



The World Bank



Final Report

GLOBAL STUDY FOR PURPOSE OF
GLOBAL WORLD BANK GUIDANCE DEVELOPMENT



SOLID WASTE MANAGEMENT HOLISTIC DECISION MODELING



Japan Country-Tied Fund



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NIPPON KOEI CO.,LTD.



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ABBREVIATIONS

GENERAL

BHC:	Biweekly High Capture
BLC:	Biweekly Low Capture
BOD:	Biochemical Oxygen Demand
BTU:	British Thermal Unit
CH ₄ :	Methane
CO:	Carbon Monoxide
CO ₂ :	Carbon Dioxide
DHC:	Daily High Capture
DLC:	Daily Low Capture
DST:	Decision Support Tool
D/S:	Dumping Site
ER:	Energy Recovery
FCA:	Full Cost Accounting
GHG:	Greenhouse Gas
GNI:	Gross Nation Income
GNP:	Gross Nation Product
HDPE:	High Density Polyethylene
LCA:	Life Cycle Assessment
LCI:	Life Cycle Inventory
LDPE:	Low Density Polyethylene
LF:	Landfill
MRF:	Material Recovery Facility
MSW:	Municipal Solid Waste
MSW DST:	Municipal Solid Waste Decision Support Tool
MTCE:	Metric Tons of Carbon Equivalents
NO _x :	Nitrogen Oxides
O & M:	Operation and Management
PDU3:	3 rd Urban Development Project
PET:	Polyethylene Terephthalate
PM:	Particulate Material
SO _x :	Sulfur Oxides
SPTD:	Service Public de Tranfert des Dechets

SWM:	Solid Waste Management
SWM HDM:	Solid Waste Management Holistic Decision Modeling
T/S:	Transfer Station
WDI:	World Development Indicator
WTE:	Waste to Energy

ORGANIZATION

EPA:	United States Environmental Protection Agency
NK:	Nippon Koei Co., Ltd.
NK-UK:	Nippon Koei UK Co., Ltd.
RTI:	Research Triangle Institute
WB:	The World Bank

(Amman)

GAM:	Greater Amman Municipality
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(Buenos Aires)

AIDIS:	Inter-American Association of Sanitary Engineers
ARS:	Solid Waste Association
CBA:	City of Buenos Aires
CEAMSE:	Metropolitan Area Ecologic Coordination Society
GBA:	Government of Province of Buenos Aires
IATASA:	Engineering Technical Support Argentina Co.
UBA:	University of Buenos Aires

(Conakry)

SME:	Guinéenne d'Assainissement
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(Kathmandu)

BKM:	Bhaktapur Municipality
KMC:	Kathmandu Metropolitan City
KRM:	Kirtipur Municipality
LSMC:	Lalitpur Sub-Metropolitan City
MTM:	Madhyapur Thimi Municipality
SchEMS:	School of Environmental Management and Sustainable Development
SWM RMC:	Solid Waste Management & Resource Mobilization Center

(Lahore)

CDGL:	City District Government of Lahore
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(Shanghai)

SCAESAB: Shanghai City Appearance Environmental Sanitation Administrative Bureau

SCEID: Shanghai Chengtou Environment Industry Development Co., Ltd.

SIDREE: Shanghai Institute for Design and Research in Environmental Engineering

GLOSSARY

Collection: The process of picking up wastes from residences, businesses, or a collection point, loading them into a vehicle, and transporting them to a processing site, transfer station or landfill.

Collection Frequency: The number of MSW collections made from a specific location within a given time period. **Collection Timing.** The pre-determined time period when MSW is collected from a location or pick-up point.

Combustion Process Energy: the electricity consumed in producing the product and the energy associated with the amount of fuel combusted in the production process. An example of this type of fuel combustion is the use of coal in process boilers to produce process steam.

Combustion Transportation Energy: the energy consumed to transport the various intermediate products or materials to the next unit process in the system.

Commercial Waste: All municipal solid waste emanating from business establishments such as stores, markets, office buildings, restaurants, shopping centers, and entertainment centers.

Commingled MRF: it is a material recovery facility that receives recyclables from a commingled recyclables (i.e., segregated collection) collection program. All fiber recyclables are collected in one compartment and non-fiber recyclables are collected in a separate compartment on the collection vehicle.

Commingled Recyclables: Mixed recyclables that are collected together.

Compost: The relatively stable humus material that is produced from a composting process of putrescible fraction of MSW in which bacteria in soil mixed with it break down the mixture into organic fertilizer.

Energy Recovery: Obtaining energy from MSW through a variety of processes (eg combustion).

Greenhouse Gases: Components of the atmosphere that contribute to greenhouse effect which is the process in which the emission of infrared radiation by the atmosphere warms a planet's surface. The name comes from an incorrect analogy with the warming of air inside a greenhouse compared to the air outside the greenhouse.

Gross National Income : Economic indicator that comprises the total value of goods and services produced within a country (i.e. its Gross Domestic Product), together with its income received from other countries (notably interest and dividends), less similar payments made to other countries.

Landfill: Generally used to mean the same as sanitary landfill, though it may be used to indicate any disposal site where waste is deposited on land, rather than specifying the standard of the operation.

Landfill Gas: Gases arising from the decomposition of the organic (putrescible) fraction of MSW; principally methane, carbon dioxide, and hydrogen sulfide. Such gases may cause explosions at landfills if not properly managed.

Leachate: Wastewater that collects contaminants as it trickles through MSW disposed in a landfill. Leaching may result in hazardous substances entering surface water, ground water or soil.

LCI: Life Cycle Inventory: “Life Cycle Inventory” involves model of the product system, data collection, as well as description and verification of data for life cycle assessment which is the assessment of environmental impact of a given product or service throughout its lifespan. This implies data for inputs and outputs for all affected unit processes that compose the product system.

Manufacturing Emissions: the total air, water, and solid waste emissions associated with both the production process and transportation energy consumption. This includes emissions from process, transportation, and pre-combustion activities.

Manufacturing Energy Consumption: the total energy consumed in the manufacturing process, including combustion and pre-combustion, as well as process and transportation related energy consumption.

Materials Recovery Facility (MRF): Facility that processes residentially collected mixed recyclables into new products.

Metric Tons of Carbon Equivalent: CO₂eq or CO₂e, is an internationally accepted measure that expresses the amount of global warming of greenhouse gases (GHGs) in terms of the amount of carbon dioxide (CO₂) that would have the same global warming potential.

Mixed Waste MRF: material recovery facilities (MRF) are used to recover recyclables from the municipal waste stream. The process flow in a MRF depends

on the recyclables processed and the manner in which they are collected (e.g., segregated vs. non-segregated collection). A mixed waste MRF processes mixed municipal solid waste from non-segregated collection.

Non-segregated Collection: Collection of mixed refuse in a single compartment truck.

Open Burning: Uncontrolled fires in a dump.

Open Dump: A site used for disposal of waste without any management and/or environmental controls (see also dump).

Pre-combustion Process Energy: the energy consumed in mining and transportation steps required to produce fuels used in the manufacturing process. Examples of this type of energy are the use of energy to extract petroleum, transport it to a refinery, and produce natural gas that is combusted at a manufacturing facility for process steam.

Pre-combustion Transportation Energy: the energy consumed in mining and transportation steps required to produce fuels for transportation. Examples of this type of energy are the use of energy to extract petroleum, transport it to a refinery, and produce diesel fuel for truck, ocean freighters, locomotives, etc.

Primary Collection: The means by which municipal solid waste is collected from its source (domestic and commercial premises) and transported to communal stations, transfer points or disposal sites. Usually primary collection is characterized in developing countries by hand carts, bicycles or small vehicles.

Recycle/Reuse: Recovering and re-processing useable MSW that might otherwise end disposed in landfills (ie, recycling of aluminium cans, paper, and bottles, etc.).

Residuals: Unintended outputs of production processes. These include municipal solid waste and wastewater.

Sanitary Landfill: A US term for land MSW disposal site that is located to minimize water pollution from runoff and leaching. MSW is spread in thin layers, compacted, and covered with a fresh layer of soil each day to minimize pest, aesthetic, disease, air pollution, and water pollution problems (see also: landfill).

Segregated Collection: collection of commingled recyclables in a vehicle with two compartments.

Tonnage: The amount of waste that a landfill accepts, usually expressed in tons per month. The rate at which a landfill accepts waste is limited by the landfill's permit.

Transfer Station: A facility at which municipal solid waste from collection vehicles is consolidated into loads that are transported by larger trucks or other means to more distant landfill sites.

Waste Stream: The total flow of MSW from homes, businesses, institutions, and manufacturing plants that are recycled, burned, or disposed of in landfills, or segments thereof such as the 'residential waste stream' or the 'recyclable waste stream'.

Yard Waste (Yard Trimmings): The part of MSW composed of grass clippings, leaves, twigs, branches and garden refuse.

CHAPTER 1 INTRODUCTION

1.1 Background of the Project

Solid waste management is the most labor intensive service in the cities of developing countries and its costs comprise the largest expenditure in most cities. Optimizing costs by helping cities choose correct technologies is critically important. Everyday cities are besieged by private vendors selling inappropriate technologies and they have limited technical capacity and analytical tools for assessing their claims and viability. Many times inappropriate systems have been built, only to close within months of costly start up operations.

The variables affecting Local Government's decision-making on solid waste technology and management choices have become more complicated, especially when we take into consideration carbon finance for green house gas reduction and avoidance, economic instruments that provide incentives for energy-reduction, power grid use of renewable energy, and landfill-minimization, emissions trading, recycling targets, land reclamation and irrigation water reduction needs, and both fuel and emission impacts for transporting recyclables and by-products. As waste characteristics, costing factors, economic incentives, and local environmental conditions vary by region and income level, it is useful for the Bank's policy dialogue with client countries to have explicit analytical information to discuss the technology choices.

The US Environmental Protection Agency (US EPA) worked for 10 years with the Research Triangle Institute (RTI), a non-profit organization, in a public/private partnership to develop a comprehensive holistic model that is able to compare technologies holistically regarding all of these issues. Dozens of organizations were involved in peer review and the model has been extensively tested, calibrated, and used in over [] cities.

The model, officially known as the Municipal Solid Waste Decision Support Tool (MSW DST), uses a materials balance flow logical framework to evaluate all waste management processes and systems, including collection, transfer, recycling, source segregation, composting, waste-to-energy, anaerobic digestion, and sanitary landfill. The model also assesses the use of these technologies at different levels of environmental control and emission standards. The model provides a comprehensive and standard method to screen solid waste management alternatives, and ultimately bridge the gap between cost and environmental objectives. The main categories of cost and environmental parameters presented in the model results include annual estimates of cost, energy consumption, air emissions, water pollutants, and solid waste residuals. The model evaluates life-cycle environmental tradeoffs from start-up operations through post-closure emissions, including all air and water emissions, energy requirements, and impacts to the environment, including land use and climate change impacts. The model provides full cost accounting of life-cycle capital, debt, and recurrent expenditures.

The type of data entered to the model is site-specific for each country, and often site-specific for individual cities in each country. The data includes: waste generation for each sector of activity, including households; waste composition for each sector; process specific operation and consumption data for each technology; emission data for each technology, local conditions affecting operations. All mass flows are then identified and quantified. All analysis conducted on a life-cycle basis is translated to present worth, with capacity for sensitivity analysis.

This study provides support to the Bank's ability to conduct client dialogue on solid waste management technology selection, and will contribute to client decision-making. The study was financed by Japanese Country-Tied Trust Funds and was conducted by a combined team of Japanese and US consultants. The Japanese firm of NIPPON KOEI Co., Ltd., was the prime contractor. RTI and the individual consultant, Nancy Cunningham Wilson, were the subcontractors.

1.2 Goals and Scope of the Study

The goal of the study was to fully explore the use of the EPA/RTI holistic decision model to study alternative solid waste systems in a wide array of waste management conditions using data collected from cities selected in each region of the world. Alternative scenarios included different arrangements of technical systems, and also included scenarios that optimized energy, global warming emission reduction, and global dimming emission reduction.

Target waste was the combined mixture of municipal solid waste identified in each of the selected cities. Target technologies were landfill, composting, materials recovery, and incineration. Collection and transportation systems were included in each scenario analyzed, and different scenarios of separate or mixed collection of various recyclable, combustible or compostable materials were additionally analyzed.

1.3 Consulting Team Formation

The following organization chart shows the consulting team formation for this study.

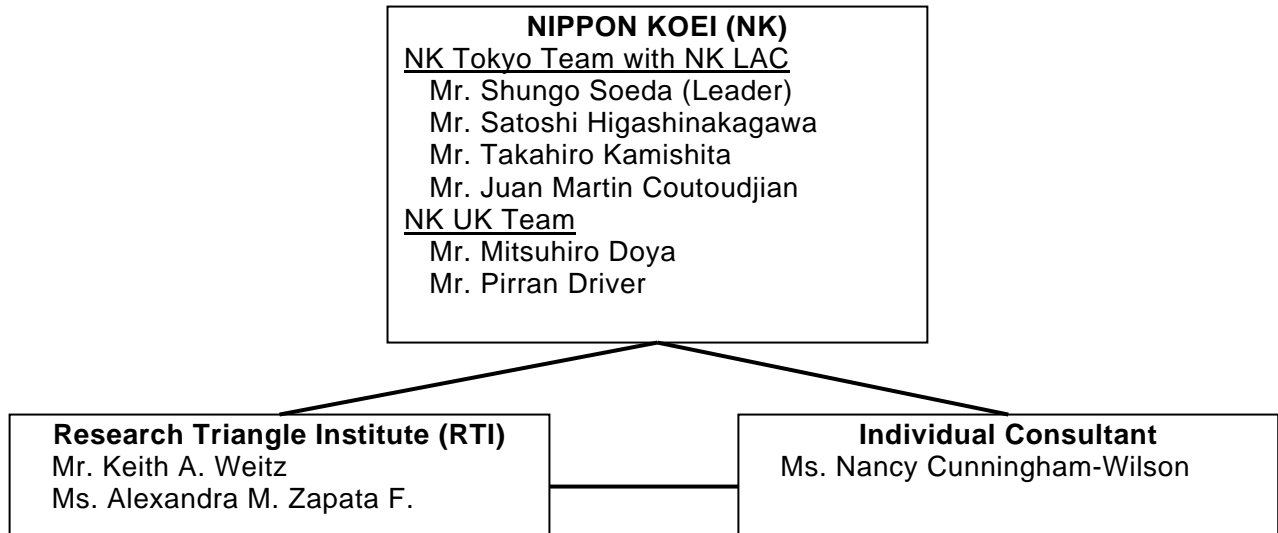


Figure 1.3-1 Consulting Team Formation

As the prime contractor, NIPPON KOEI (NK) was responsible for fully addressing the Terms of Reference for the study including reconnaissance of solid waste conditions in each of the target cities and collection of all data to be used in the modeling effort. Nancy Cunningham-Wilson worked with various operations staff of the World Bank to facilitate country visits and data access, and she obtained the available pre-reconnaissance background information for the target cities. RTI was responsible for all modeling activities, and for adequately training NK Team on the data requirements of the model. RTI was responsible to provide in-depth output from the model, together with analysis in figures, charts and text, to enable NK to provide a comprehensive analysis of each city investigated. The full team worked together to develop the framework of the scenarios to be modeled and dealt with inconsistencies and calibration of the data, including additional research of literature, including master plans from various cities, to address data gaps or questions. The full team jointly developed the reports to the Bank.

All study travel was conducted by two NK field teams that utilized staff from NK Tokyo Headquarters, NK UK and NK LAC (Latin America-Caribbean). Table 1.3-1 shows the demarcation of field visits by various NK staff on the field teams

Table 1.3-1 Responsibility of Field Visit by NK and NK UK Team

		Kawasaki (Japan)							
		Kathmandu				Shanghai			
		Lahore		Buenos Aires		Sarajevo		Conakry	
								Amman	
NK	S. Soeda	X	X	X	X	X			
	S. Higashinakagawa	X	X	X	X				
	T. Kamishita	X		X					
NK-LAC	J. Koutoudjian					X			
NK-UK	M. Doya						X	X	X
	P. Driver						X	X	X

The consulting team worked under the World Bank direction of Ms. Sandra Cointreau, Solid Waste Management Advisor. The team was regularly supported by technical guidance from Dr. Susan Thorneloe, the US EPA Project Manager who conceived development of the holistic decision support tool and continues to manage its use and continuous improvement, as well as . and continues to manage the public/private partnership use of the holistic decision support tool, as well as Ms. Ozge Kaplan, both from the US EPA Office of Research and Development in Raleigh-Durham, North Carolina.

1.4 Selection of Target Cities

Seven cities were selected from the different regions of development countries served by the World Bank. They were: (1) Buenos Aires, Argentina; (2) Conakry Guinea; (3) Shanghai, China; (4) Kathmandu, Nepal; (5) Lahore, Pakistan; (6) Amman, Jordan; and (7) Sarajevo, Bosnia and Herzegovina. These cities presented study conditions where data was expected to be reasonably competent and complete, and where cooperation with the team’s field reconnaissance and data collection efforts were confirmed. They represented a wide array of economic development conditions and costing factors, in addition to their different physical settings and conditions. Some were very low-income and with minimal industrial and commercial activity, while others were on the other end of the spectrum of upper middle income and significant industrial and commercial activity. Some were in cool wet climates; others were from hot dry climates. The diversity of conditions were selected to determine whether and, if so, how these conditions would effect the outcome of the modeling analysis

Each of the selected cities is one of the largest within its country. However, a city that is large in Nepal and Guinea, is comparatively small when compared to Argentina and China. Despite the wide range in city size of these selected cities, it is important to note that most cities in developing

countries fall into the category of secondary cities, and are much smaller than these cities. Such secondary cities commonly would have much less industrial and commercial activity than primary cities, and therefore market prices for recyclables could be lower and transport distances to markets could be longer. This aspect of the modeling needs to be weighed when the reader attempts to extrapolate from analysis for these primary cities to secondary cities.

In addition to the 7 target cities from developing countries, Kawasaki, Japan and Atlanta, Georgia were selected for comparative purposes. The following table provides some comparative information on the countries wherein the 9 cities are located. For perspective of these countries relative to all other countries in the world, the reader is referred to the annual World Development Reports published by the World Bank, and available at <http://www.worldbank.org/>.

Table 1.4-1 Comparative Information on the Countries of the 9 Target Cities

City, Country, Region	Country GDP, \$ millions, 2006 ^{*1}	Country Population, Billions, 2006 ^{*1}	%Urban Population in Country, 2004 ^{*2}	GNI, \$ per capita, 2006	%Below Poverty Level, below \$1 a day ^{*1}	%Literacy, ages 15 and older, 2000-05 ^{*1}	Average Life Expectancy, 2005 ^{*1}	
							Male	Female
Buenos Aires, Argentina	214,058	39	90	5,150	6.6 (2004)	97	71	79
Conakry, Guinea	3,317	9	36	410	--	29	54	54
Shanghai, China	2,668,071	1,312	40	2,010	9.9 (2004)	91	70	74
Kathmandu, Nepal	8,052	28	15	290	24.1 (2003-04)	49	62	63
Lahore, Pakistan	128,830	159	34	770	17.0 (1998-99)	50	64	65
Amman, Jordan	14,176	6	79	2,660	<2.0 (2002-03)	91	71	74
Sarajevo, Bosnia and Herzegovina	11,296	4	45	2,980	--	97	72	77
Kawasaki, Japan	4,340,133	128	66	38,410	--	--	79	86
Atlanta, United States	13,201,819	299	80	44,970	--	--	75	81

Data Source: ^{*1}: World Development Report 2008, Agriculture for Development: http://siteresources.worldbank.org/INTWDR2008/Resources/WDR_00_book.pdf

^{*2}: 2006 World Development Indicators: <http://siteresources.worldbank.org/DATASTATISTICS/Resources/table3-10.pdf>

CHAPTER 2 DATA AND METHODOLOGY

2.1 General Approach

Total annual cost, energy consumption, and emissions (air, water) were calculated using the US EPA/RTI Municipal Solid Waste Decision Support Tool (MSW DST). The MSW DST is populated with average facility default data, which has been modified for this study to include site-specific data collected by Nippon Koei for each of the nine cities. Numerous MSW management options were evaluated to identify the options that appear economically and environmentally efficient.

The MSW DST employs the principles of Full Cost Accounting (FCA) and Life Cycle Assessment (LCA). FCA is a systematic approach for identifying, quantifying, and reporting the costs of all stages of MSW management from the point of waste collection to its final disposition. It also takes into account past and future outlays, overhead (oversight and support services) costs, and operating costs by process. The cost of some activities is shared between waste management processes. For example, the cost of recycling can be shared by a source-segregated collection system and materials recovery facility (MRF). Understanding the costs of the individual MSW management processes enables understanding the costs of the entire solid waste system, and the relationship between processes.

LCA is a type of systems analysis that accounts for the complete set of upstream and downstream (cradle-to-grave) energy and environmental aspects associated with industrial systems. The technique examines the inputs and outputs from every stage of the life cycle from the extraction of raw materials, through manufacturing, distribution, use/reuse, and waste management. In the context of integrated waste management systems, an LCA tracks the energy and environmental aspects associated with all stages of waste management from waste collection, transfer, materials recovery, treatment, and final disposal or reuse. For each waste management process, energy and material inputs and emissions and energy/material outputs are calculated (see Figure 2.1.1). In addition, energy and emissions associated with the manufacturing of the fuels, energy, and material inputs are captured. Likewise, the potential benefits associated with energy and/or materials recovery displacing energy and/or materials production from virgin resources are captured in the life cycle results. Additional information about the MSW DST can be found at:

<https://webdstmsw.rti.org/resources.htm>.

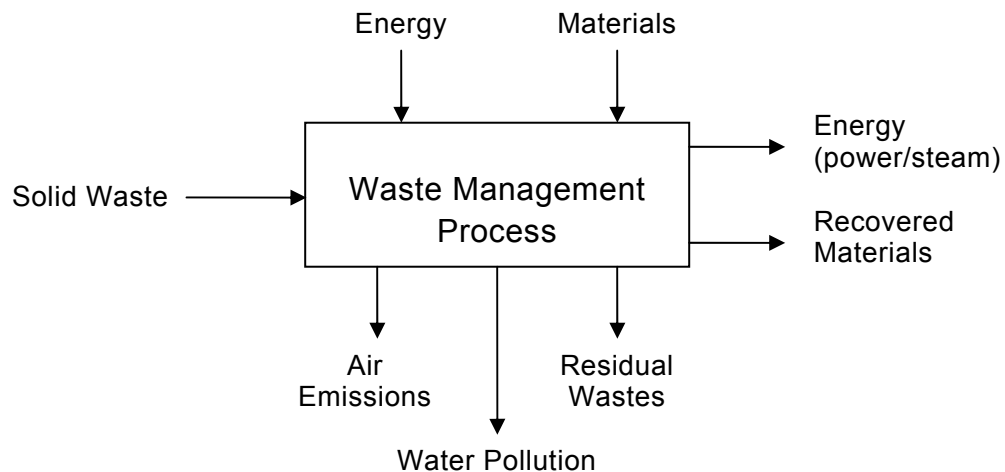


Figure 2.1-1 Life Cycle Inputs and Outputs of a Waste Management Process (Note: Some materials leaving a waste management process may loop back into the process.)

Taking a life-cycle perspective encourages waste management planners to consider the environmental aspects of the entire system including activities that occur outside of the traditional framework of activities from the point of waste collection to final disposal.

With these considerations in mind, the MSW DST generates cost, energy consumption, and multimedia (e.g., air and water) emission results that a waste management planner can use to evaluate a given system. The MSW DST can be used in two basic modes: simulation and optimization. Simulation refers to the ability of the MSW DST to model predefined (e.g., current or future planned) waste management systems. Optimization refers to the ability of the MSW DST to identify the “best” waste management system based on a defined objective, such as minimizing cost or minimizing greenhouse gas (GHG) emissions.

Cost

The cost modeled by the MSW DST is consistent with “full cost accounting” principles. It includes the capital, operating and maintenance, and labor costs over the life of the facilities included in each strategy. Therefore, the cost is not necessarily representative of the price or tip fee charged by any facility. The cost values include all waste management activities from collection through final disposition. For facilities that recover energy and/or materials and sell them to create revenue, this revenue stream is netted out of the total cost. The cost results therefore represent a net annual total cost. It should be noted that for the recycling scenarios, the revenue obtained from the sale of recyclables is dependent on available markets for recyclables. This is important because the revenue stream from the sale of recyclables can significantly lower the net cost of the recycling scenarios.

Energy Consumption

Energy is consumed by all waste management activities (e.g., landfill operations), as well as by the processes to produce energy and material inputs (e.g., diesel fuel, landfill liner) that are included in the analysis. Energy can also be produced by some waste management activities (e.g., landfill gas-to-energy, waste-to-energy technologies) and can be offset or avoided by other activities (e.g., recycling). An additional activity in the holistic model analysis involves assessing the energy required for collection and transport of mixed or source segregated materials. If the energy produced and/or offset by the waste management system is greater than the energy consumed, then there is a net energy savings. Energy consumption is an important parameter in life-cycle studies, because it often drives the results of the study due to the significant amounts of air and water emissions associated with energy production. Therefore, energy consumption is also a good indicator of the emissions of key air pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), particulate material (PM), and sulfur oxides (SO_x).

Carbon Emissions

- Recycling of materials offsets carbon emissions by avoiding the consumption of energy that otherwise would be used in materials production processes.
- Production of electrical energy offsets carbon emissions from the generation of electrical energy using fossil fuels in the utility sector.
- Diversion of organics from landfills avoids methane gas generation.

In this study carbon emissions are reported in units of metric tons of carbon equivalent (MTCE), derived as follows:

$$\text{MTCE} = [(\text{Fossil CO}_2 \times 1 + \text{CH}_4 \times 21) \times 12/44] / 2200$$

2.2 Waste Management Scenarios Analyzed

In this study, simulation and optimization scenarios were defined and analyzed. The same scenarios were applied to all cities to aid in the identification and understanding of how city-specific factors affect scenario results. It should be noted that all scenarios are hypothetical, meaning that they are not a representation of the actual waste management situation in any of the cities included in the study. The scenarios modeled in this study include the following:

Simulation Scenarios:

- **Group 1** includes base case simulation scenarios consist of 2 scenarios, one sending all the waste to an open dump and the other open burning.
- **Group 2** includes nine different scenarios, each sending all the waste to one primary technology/waste management process.

Optimization Scenarios:

- **Group 3** optimization scenarios are set to maximize the amount of material recovered (or diverted from landfill disposal) using non-incineration processes.
- **Group 4** consists of maximizing the energy recovered.
- **Group 5** seeks to minimize climate change related emissions including carbon (global warming) and PM (global dimming) emissions.

For the optimization scenarios, variations in the type of MRF and Composting facility (manual sorting and pile turning vs. mechanical sorting and pile turning), the frequency of waste collection (daily vs. biweekly), and the percent of recyclables recovered (high capture vs. low capture) were considered for each of the optimization scenarios to gauge their impact on the LCI results.

Table 2.2.1 presents additional detail about the selected scenarios and each of the waste management processes (collection, recycling, composting, incineration with and without energy recovery, and landfill disposal) considered in each scenario. The waste management scenarios assume that the processes employ modern designed facilities and equipment that meet U.S. and EU design and operation requirements. Other key assumptions include:

- Unless otherwise specified, all residual waste is disposed of in a landfill with gas flaring and 70% gas collection efficiency.
- Both segregated and non-segregated collection systems were considered in the optimization scenarios.

Table 2.2-1 Waste Management Scenarios Analyzed

Scenario	Scenario Variations	Non Segregated Collection*	Segregated Collection**	Recycling	Composting	Incineration	Landfill Disposal
SIMULATION SCENARIOS							
Group 1: Base Case	Open dumping		X				X
	Open burning		X			X	
Group 2: Mixed Waste Collection And Management Using One Primary Technology	Recycling - manual sort		X	X			
	Recycling - mechanical sort		X	X			
	Composting - manual turning		X		X		
	Composting – mechanical windrow turner		X		X		
	Incineration		X			X	
	Incineration with energy recovery		X			X	
	Landfill - vent		X				X
	Landfill - flare		X				X
Landfill- energy recovery		X				X	
OPTIMIZATION SCENARIOS							
Group 3: Maximize Materials Recovery (via recycling and composting)	Manual MRF and Compost	Daily - High Capture		X	X	X	X
		Daily - Low Capture		X	X	X	X
		Biweekly Collection - High Capture		X	X	X	X
		Biweekly Collection - Low Capture		X	X	X	X
	Mechanical MRF and Compost	Daily - High Capture		X	X	X	X
		Daily - Low Capture		X	X	X	X
		Biweekly Collection - High Capture		X	X	X	X

Scenario		Scenario Variations	Non Segregated Collection*	Segregated Collection**	Recycling	Composting	Incineration	Landfill Disposal	
		Biweekly Collection- Low Capture		X	X	X		X	
Group 4: Maximize Energy Recovery	Run DST in Optimization Mode to Minimize Energy Consumption (non-incineration options only)	Daily - High Capture	X	X	X		X	X	
		Daily - Low Capture	X	X	X		X	X	
		Biweekly Collection - High Capture	X	X	X		X	X	
		Biweekly Collection - Low Capture	X	X	X		X	X	
Group 5: Optimize Reduction of Global Warming and Dimming Emissions	Minimize Carbon (Global Warming) Emissions	Daily - High Capture	X	X	X		X	X	
		Daily - Low Capture	X	X	X		X	X	
		Biweekly Collection - High Capture	X	X	X		X	X	
		Biweekly Collection - Low Capture	X	X	X		X	X	
	Minimize PM (Global Dimming) Emissions	Daily - High Capture			X	X		X	X
		Daily - Low Capture			X	X		X	X
		Biweekly Collection - High Capture			X	X		X	X
		Biweekly Collection - Low Capture			X	X		X	X

*Non- segregated collection: mixed waste collection only

**Segregatedcollection:separaterecyclables,organics,andresidualscollection.

- Both yard waste and mixed MSW composting were considered.
- The incineration facility modeled is assumed to be a modern mass burn type of facility with 17,500 BTU/kWh heat rate and 70% ferrous recovery rate from ash. EU Incinerator emissions standards were used to estimate facility emissions.
- The landfill facility modeled is a modern U.S.EPA Subtitle D type landfill with 100-year as the time period for calculating emissions. For scenarios that included gas collection, an assumed gas collection efficiency of 70% was used.
- Daily waste collection is assumed to be 6 times/week.
- Biweekly waste collection is assumed to be 2 times/week.
- High capture is defined by 75% participation factor¹, 75% capture rate², and 75% separation efficiency of mixed waste at the MRF. Low capture is defined by 50% participation factor, 50% capture rate, and 55% separation efficiency. Unless otherwise specified low capture settings were used.

Scenario Analysis Boundaries

The boundaries of the scenarios included in this study are largely defined by the waste management processes included under each scenario and the mass flow among processes (see Figures 2.2.1 to 2.2.4). In addition, the boundaries considered for the cost analysis are different from those of the life cycle environmental (energy and emissions) assessment as mentioned below.

Boundaries for Cost Analysis

Costs have also included in this study because they play such a crucial role in making decisions about MSW management strategies. The system boundaries for the cost analysis differ from that of the life cycle environmental assessment because they are designed to provide a relative comparison of annual cost among alternative MSW management strategies as incurred by the public sector (e.g., municipal government). These costs are intended to provide a relative ranking of the different alternatives as part of a screening tool to narrow the range of options associated with integrated MSW management. No distinction is made between public and private sector costs. All MSW management activities are assumed to occur in the public sector and therefore costs are calculated as though they are accruing to the public sector. The cost analysis is intended to reflect the full costs associated with waste management alternatives based on U.S. EPA guidance from Full Cost Accounting for Municipal Solid Waste Management: A Handbook (U.S. EPA, 1997).

1 The participation factor indicates the average percentage of households that set out recycling bins for each collection cycle within a region in a source-segregated recyclables collection program.

2 The capture rate is the fraction of recyclable material removed by households from the waste and put in the recyclables collection bin.

In focusing the cost analysis on publicly accrued costs, the costs associated with electricity production, for instance, are not included in the study because the public sector only pays the price for electricity consumed. In cases where recyclables are shipped from a MRF, the cost analysis ends where the public sector receives revenue (or incurs a cost) in exchange for the recyclables. The cost analysis does not include the costs associated with the remanufacturing processes for different materials (e.g., recycled office paper). These costs are borne by the manufacturing sector and not by municipal or county governments. The same procedure is applied to the generation and sale of electricity derived from incineration facilities or landfills. Where waste is produced as part of a waste management facility, the cost of waste disposal or treatment is included in the cost analysis of that facility. For example, we include the cost of leachate treatment in our cost analysis of landfills. We also include the cost of training, educational, or other materials associated with source reduction or other aspects of MSW management.

In addition, we compare the landfill cost with and without the land price in the cost analysis because usually the government does not pay for land in case the land is the government land.

Cost parameters and results are allocated to individual MSW components. Thus, the result of the cost analysis can illustrate, for example, the capital and operating costs attributed to a MRF versus a composting facility.

Boundaries for Environmental Assessment

The boundaries for life cycle environmental assessment include all activities that have a bearing on the management of MSW, from collection through transportation, recovery and separation of materials, treatment, and disposal. Collection begins whenever and wherever waste is put outside the generation source for removal by the municipality or private collectors. As observed in Figures 2.2.1 to 2.2.4, we assume that MSW enters the system boundaries when it is set out for collection; thus, the production of garbage bags, garbage cans, and recycling bins were not included in the study. Similarly, the transport of waste by residents to a collection point (for example, drop-off facility) was not included.

The functional elements of MSW management include numerous pieces of capital equipment, from refuse collection vehicles to balers for recycled materials to major equipment at combustion facilities. Resource and energy consumption and environmental releases associated with the operation of equipment and facilities were included in the study. For example, energy (fuel) consumed during the operation of waste collection vehicles was included in the study. We included in the study electricity consumed for operation of the office through which the vehicle routes are developed and the collection workers are supervised. Activities associated with the fabrication of capital equipment, however, were not included.

For material and energy inputs to various processes, the resource and energy consumption and environmental releases associated with producing the material and energy inputs were

included in the study. For example, the resources and environmental releases associated with the production of diesel fuel consumed by collection vehicles were included.

Where a material was recovered and recycled, the resource and energy consumption and environmental releases associated with the manufacture of a new product were calculated and included in the study. We assumed closed-loop recycling processes. These parameters were then compared against parameters for manufacturing the product using virgin resources to estimate net resource and energy consumption and environmental releases. This procedure was also applied to energy recovery from other unit processes, including incineration with energy recovery and landfill gas recovery projects.

Another system boundary was set at the waste treatment and disposal. Where liquid wastes are generated and require treatment (usually in a publicly owned treatment works), the resource and energy consumption and environmental releases associated with the treatment process were included. For example, if BOD is treated in an aerobic biological wastewater treatment facility, then energy is consumed to supply adequate oxygen for waste treatment. If a solid waste is produced that requires burial, energy is consumed in the transport of that waste to a landfill during its burial (for example, bulldozer) and after its burial (for example, gas collection and leachate treatment systems) in the landfill. Also, where compost was applied to the land, volatile and leachate emissions were included in the study.

Similar to the cost analysis, environmental parameters such as carbon, PM and other air emissions as well as water emissions are also allocated to individual MSW components. Thus, the result of the life cycle environmental assessment can illustrate, for example, the environmental aspects of recycling versus composting of paper waste.

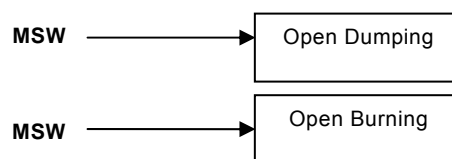


Figure 2.2-1 Boundaries for Group 1- Base Case

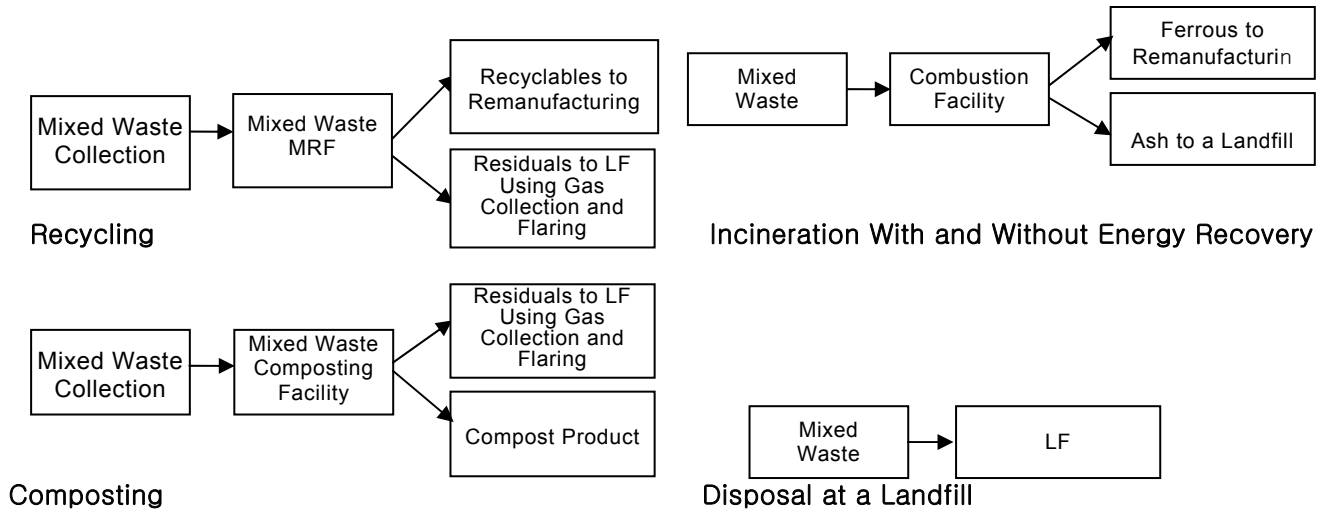


Figure 2.2-2 Boundaries for Group 2 Scenarios

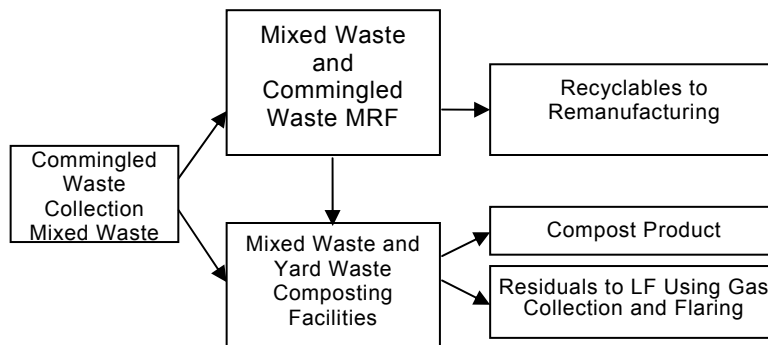


Figure 2.2-3 Boundaries for Group 3 Scenarios

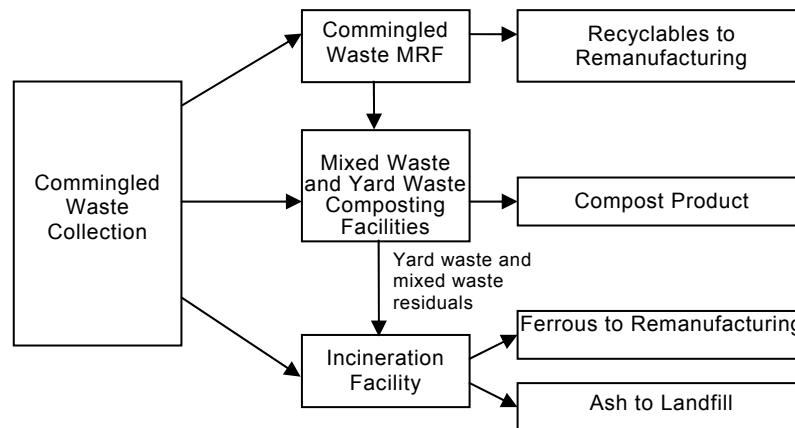


Figure 2.2-4 Boundaries for Groups 4 and 5 Scenarios

2.3 Data Collection and Key City Characteristics

2.3.1 Data Requirements

To conduct Solid Waste Management Holistic Decision Modelling (SWM HDM) calculation reflecting the actual conditions of SWM in target cities of this study, it was required to collect city-specific data, as well as some regional contextual data on economic, social and natural environmental conditions. This supplemented the model's extensive default data (e.g., defaults on calorific values for each type of waste constituent, and defaults on the emissions from processing of each type of waste constituent). As emissions data is continuously developed through the monitoring and research of the US EPA, the defaults on emissions are routinely updated. In addition to the city-specific input data, the SWM system within each country was fully described through actual field reconnaissance and interviews conducted in each city by the Nippon Koei team.

As needed, the SWM HDM data input sheets needed to be modified to address unique solid waste system situations in the target cities. For example, barge transfer needed to be added to address the unique transfer system used in Shanghai, China. Additionally, systems of informal sector recycling and use of carts for primary collection are unique to many cities in developing countries.

2.3.2 Site Visits to Collect Data

For the requirement of data collection and reconnaissance of the solid waste systems in the target cities, as described in 2.3.1, the consultant team visited in each target city on the following schedule.

	Schedule	Visited organization and facility
Amman, Jordan	Nov. 14 – Nov. 26, 2006	(1) Organization GAM (Greater Amman Municipality), Jordan Biogas Co, Arab Paper Converting & Trading Co, Jordan Paper and Cardboard Factories Co, Friends of Environment Society, Ministry of Environment, Ministry of Municipal Affairs, Ministry of Health, Ministry of Planning and International Cooperation, UNHABITAT (2) Facilities Al Ghabawy Landfill, Al Rusaifah Landfill and Biogas facility, Al Sha'er TS, Al Yarmook TS, Ain Gazal TS, Slaughterhouse,
Atlanta, Georgia, USA	-	-

	Schedule	Visited organization and facility
Buenos Aires, Argentina	Sep. 24 – Oct. 6, 2006	(1) Organization CBA, WB, ARS (Solid Waste Association), CEAMSE (Metropolitan Area Ecologic Coordination Society), AIDIS (Inter-american Association of Sanitary Engineers), UBA, Cliba, IATASA, El Ceibo (2) Facilities Pompeya T/S, Relleno Sanitario Norte III, Relleno Sanitario Villa Dominico
Conakry, Guinea	Dec. 6 – Dec. 18, 2006	(1) Organization SPTD (Service Public de Transfert des Dechets), PDU3 (3rd Urban development Project), Guinéenne d'Assainissement (SME), Electricité de Guinée, Ministry of Public Health (2) Facilities La Minière Landfill, Transfer points, Pilot compost, Slaughterhouse
Kathmandu, Nepal	Dec. 11 – Dec. 23, 2006	(1) Organization SWMRMC, KMC, LSMC, BKM, MTM, KRM, SchEMS, Watsan (2) Facilities Teku T/S, Sisdol Landfill, BKM's Segregated Collection and Compost
Kawasaki, Japan	Oct 2006 – Feb 2007	(1) Organization Environmental Dept. of Kawasaki City (2) Facilities Kase Transfer Station, Sikine Incinerator, Ukisima Final Disposal Site (sea reclamation), Ukisima Incinerator, Nanbu MRF, Shikine MRF
Lahore, Pakistan	Nov. 25 – Dec. 10, 2006	(1) Organization The Urban Unit, CDGL, University of Engineering and Technology (2) Facilities Mahamood Booti LF, Saggian D/S, Nashitar D/S, CDGL's workshops, Lahore Composting, Waste Busters, Children Hospital
Sarajevo, Bosnia And Herzegovina	Sep. 26 – Oct. 9, 2006	(1) Organization Cantonal Public Utility Rad, Cantonal Public Utility Park, Papir Servis, Ministry of Environment and urban development (2) Facilities Smiljevići Landfill (& MRF), Papir Servis, Hospital, Slaughterhouse

	Schedule	Visited organization and facility
Shanghai, China	Oct. 26 – Nov. 13, Dec. 18 – 22. 2006	(1) Organization SCEID, SIDREE, SCAESAB, Shanghai Electric Power Design Institute, Tongji University (2) Facilities Huangpu Transfer Station, Jiangqiao incinerator, Yangpu Transfer Station, Huling Dock, Gacu dumping site, Minghan dumping site, Laogang Landfill Site

Each consultant field reconnaissance team consisted of 2 members and spent at last two weeks in each target city. The site visit were successfully implemented with the support of relevant government organizations, facilitated by the World Bank.

2.3.3 Key City Characteristics

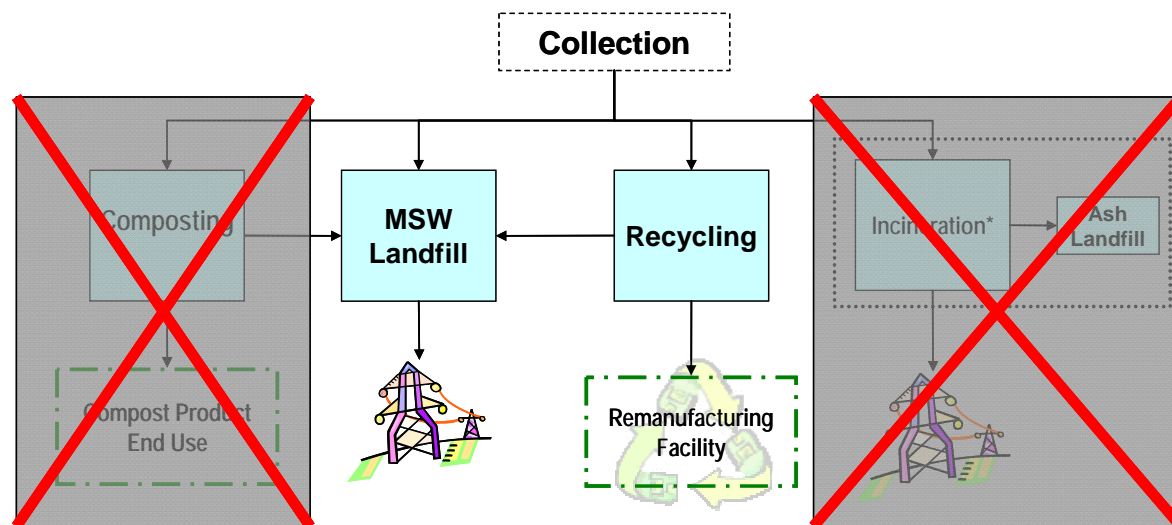
The key city characteristics of the selected cities are summarized as follows. Basic size, population and economic information is provided, as well as a description of the solid waste system in each city. Annex [] provides a summary of solid waste systems, together with illustrative photos.

Amman, Jordan

Amman is the capital city of Jordan and its area is 688 km², located in the northern part of Jordan. Amman's population is approximately 2,125,000 and rapidly has been increasing over the past years, partly due to the large influx of refugees that have arrived from the surrounding countries. The GNI per capita is approximately US\$2,500 in 2005. The climate of Amman is characterized by sharp seasonal variations in both precipitation and temperature. Its rainy season is in winter and the annual precipitation is about 230 mm. the average winter temperature is above 7°C and the average summer temperature is 26°C.

Its unit generation rate of MSW is 1.02 kg/person/day, means about 2,174 tonnes of MSW are generated every day from the city. The hilly nature of the city makes collection of MSW a difficult task, as many areas of town have roads that are too steep, narrow or winding for conventional collection vehicles to use. The majority of Amman's MSW is disposed at Al Rusaifah landfill site which has landfill gas collection as shown in Figure 2.3-1.

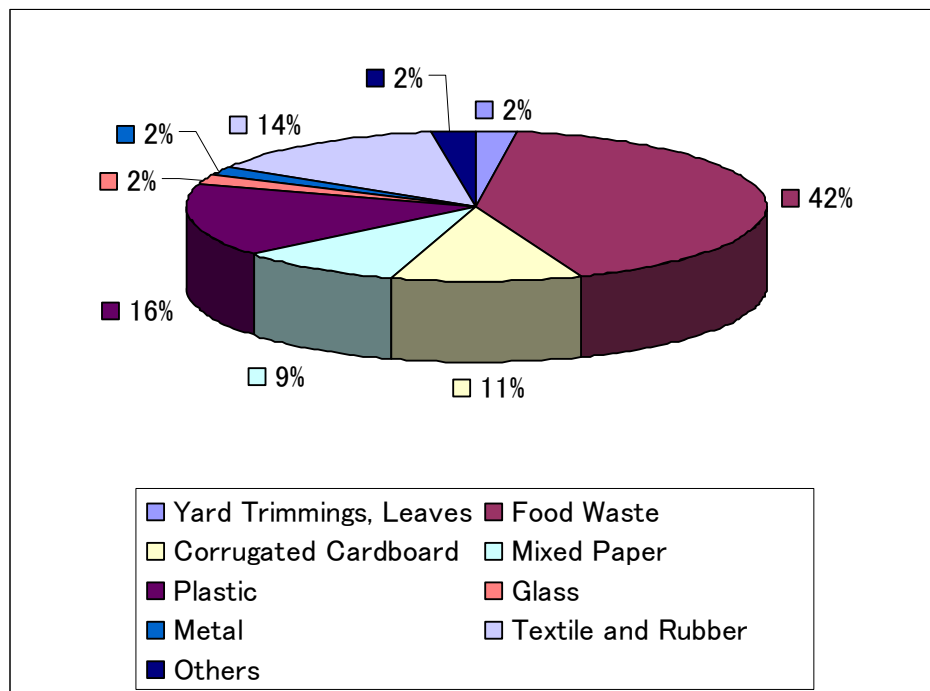
Figure 2.3-1 Simplified Waste Flow in Amman



* Incineration can be with or without energy recovery.

Figure 2.3-2 shows typical composition of municipal solid waste in Amman that includes 42% of food waste, 11% of corrugated cardboard, 9% of paper and 16% of plastic waste.

Figure 2.3-2 Waste Composition in Amman

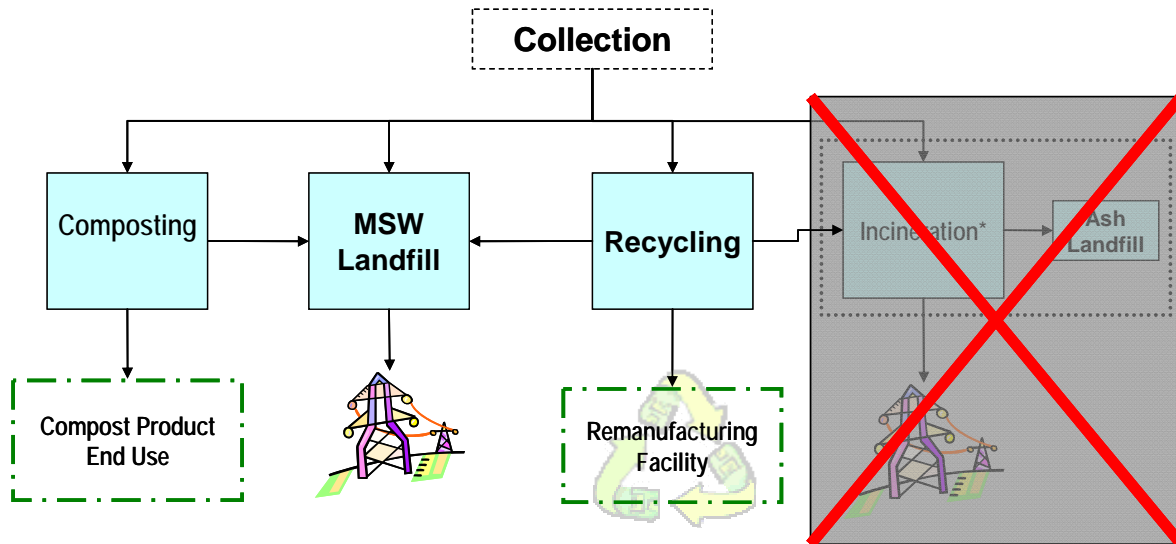


Atlanta, Georgia, USA

Atlanta city which was selected as a representative US city has the area of 343 km², located in the southern part of America. The population of the city roughly is 442,000 and is rapidly increasing in the northern portions in Metro Atlanta. A large number of residents commute to this area and commercial and industry activity is concentrating in this area and GNPper capita is approximately US\$43,740. Atlanta has a humid subtropical climate, with hot, humid summers and mild winters by the standards of the United States. The annual precipitation is about 1,270 mm and the average temperature is approximately 16°C.

Rear-loading compactor trucks are utilized for single family waste collection and front-loading compactor trucks are utilized for the collection from multi-family, commercial and institutional sectors. The average unit generation rate of MSW is 1.72 kg/person/day, which means that about 2,174 tonnes of MSW are generated every day. The landfill site in Metro Atlanta was closed in 2004 and the city began taking the waste to two existing transfer stations in metro Atlanta. Transfer stations accept the waste from primary collection vehicles and then load it on to secondary transportation vehicles that take it to landfills outside of metro Atlanta. Figure 2.3-3 shows simplified waste flow in which people can understand no incinerator operated in Atlanta.

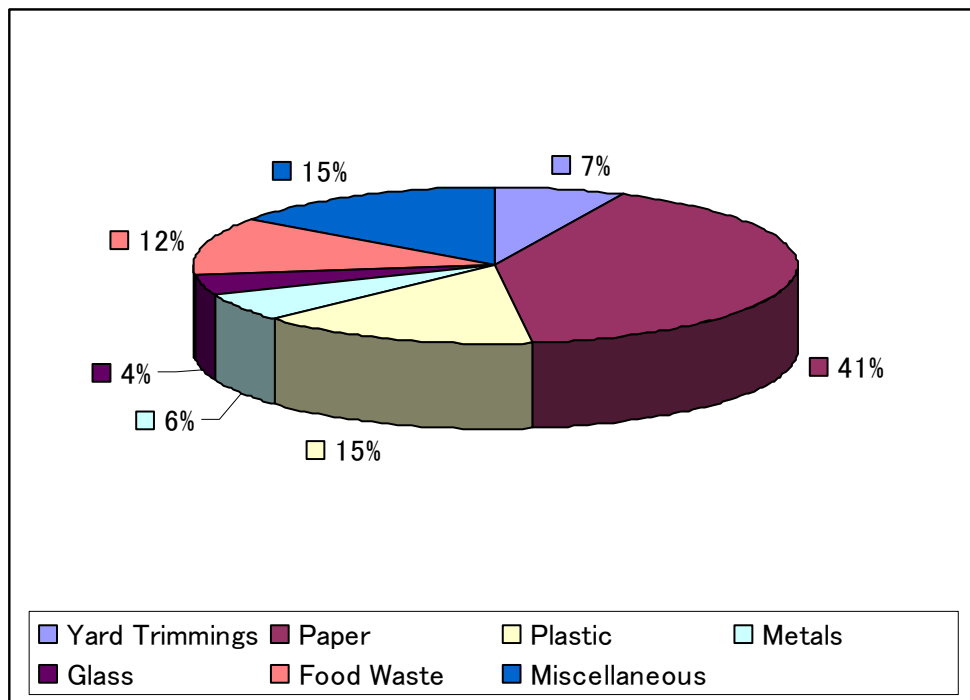
Figure 2.3-3 Simplified Waste Flow in Atlanta



* Incineration can be with or without energy recovery.

Figure 2.3-4 shows typical composition of municipal solid waste in Atlanta that includes 41% of food waste, 7% of yard trimmings, 4% of paper, 6% of metals and 15% of plastic waste.

Figure 2.3-4 Waste Composition in Atlanta

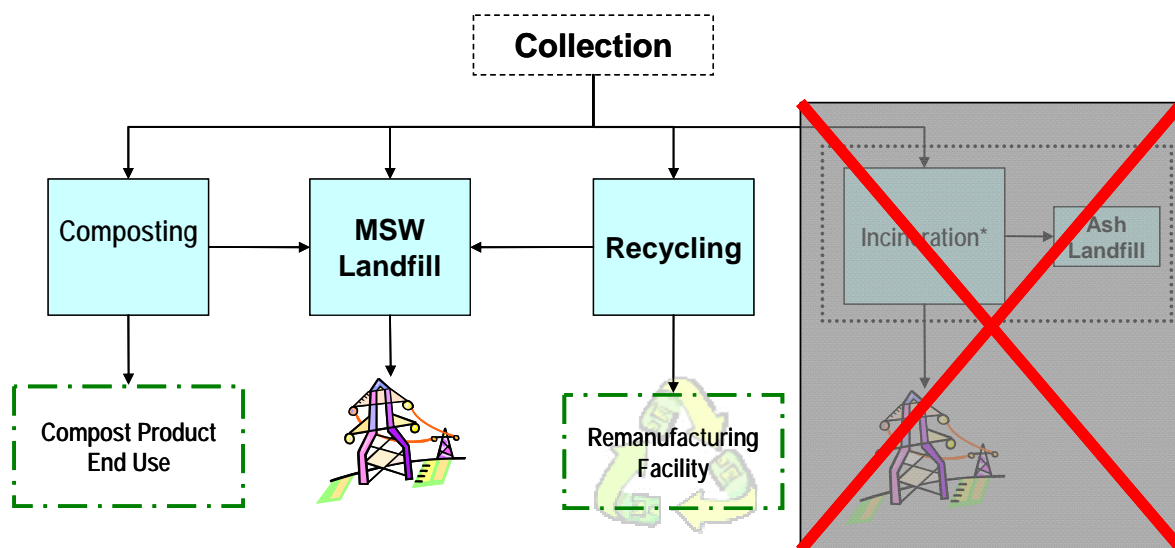


Buenos Aires, Argentina

The City of Buenos Aires (CBA) is the capital city of Argentina and its area is 203 km². It is located on the southern shore of the Río de la Plata, on the southeastern coast of the South American continent. The population in 2001 was 2,776,138 and has been increased around 3 millions. GNP per capita in Argentina was US\$4,470 in 2005, and income level in Buenos Aires would be higher. The climate of Buenos Aires is characterized by South Temperate Zone, "Humid Subtropical", with average temperatures ranging from 35°C in January to 10°C in July, 17°C annually. Annual precipitation is about 1,200 mm and the heaviest rain falls during the winter months, though rain can be expected at any time of year.

The unit generation rate of MSW is 0.979 kg/person/day, means about 4,300 tonnes of MSW are generated every day from the city. Almost all MSW is collected and transported to a designated landfill via three transfer stations or directly. Buenos Aires is divided into 6 zones for waste management and three private haulers are contracted for the primary collection at 5 of those zones. Small scale composting and MRFs are operated in or around the landfill site. Figure 2.3-5 shows simplified waste flow. There is no incinerator operated in Buenos Aires.

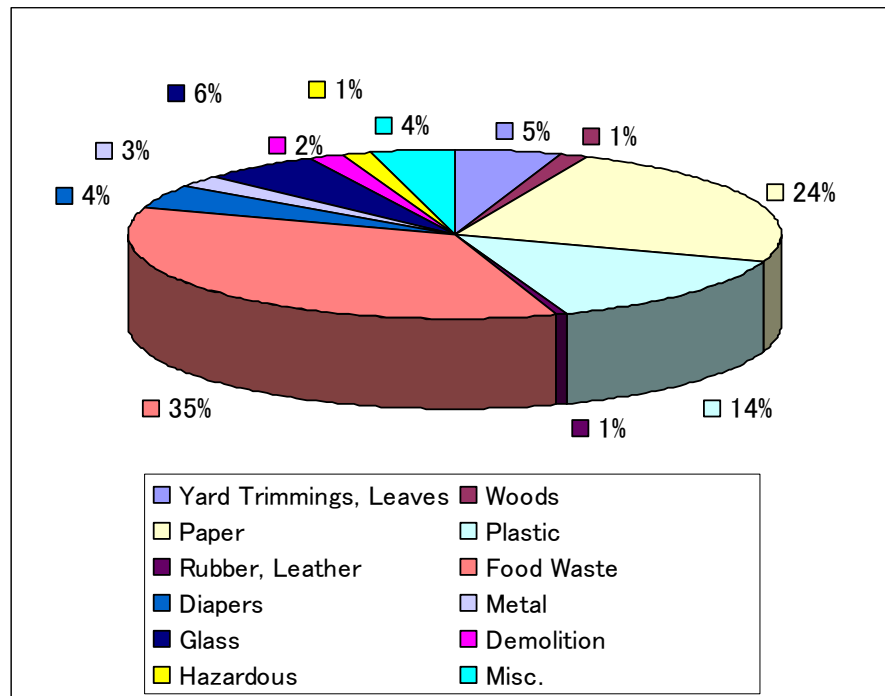
Figure 2.3-5 Simplified Waste Flow in Buenos Aires



* Incineration can be with or without energy recovery.

Figure 2.3-6 shows typical composition of municipal solid waste in Buenos Aires that includes 35% of food waste, 24% of paper, and 14% of plastic waste.

Figure 2.3-6 Waste Composition in Buenos Aires



Conakry, Guinea

The Conakry is the capital of Guinea and includes five municipalities and is located on a peninsular of 308 km². The population is estimated at over 2 million in 2006. The population has risen to its present level extremely rapidly; in 1958 the city had only 120,000. The rapid rise in population in such a physically restricted area has resulted in extreme pressure on the city’s infrastructure and housing. Most people live in very poor and overcrowded makeshift housing, few have access to safe water and power (around 60% and 20% respectively). There is significant evidence of inadequate solid waste collection, with uncollected waste throughout the city. Guinea’s GNP per capita is US\$370, evidence that it is one of the poorest countries in Africa. The climate of Conakry is tropical with the an annual average temperature of 27°C. The rainy season usually lasts from April or May to October or November.

The total generation of MSW is approximately 800 tonnes/day and the unit generation rate is approximately 0.4 kg/person/day. The generated waste is transported to La Miniere disposal site through transfer stations or by direct haul. Much of the uncollected waste is burned openly or dumped illegally. Figure 2.3-7 shows simplified waste flow in Conakry. Informal sector involves collecting recyclables from the waste. Pilot scale composting plant is operated to produce the compost from the kitchen waste.

Figure 2.3-7 Simplified Waste Flow in Conakry

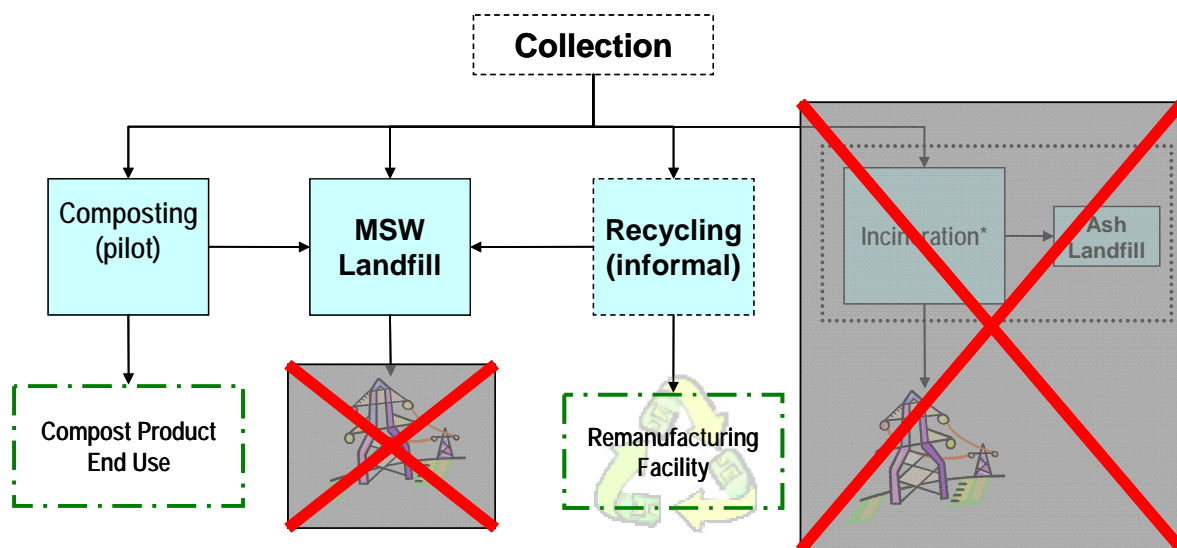
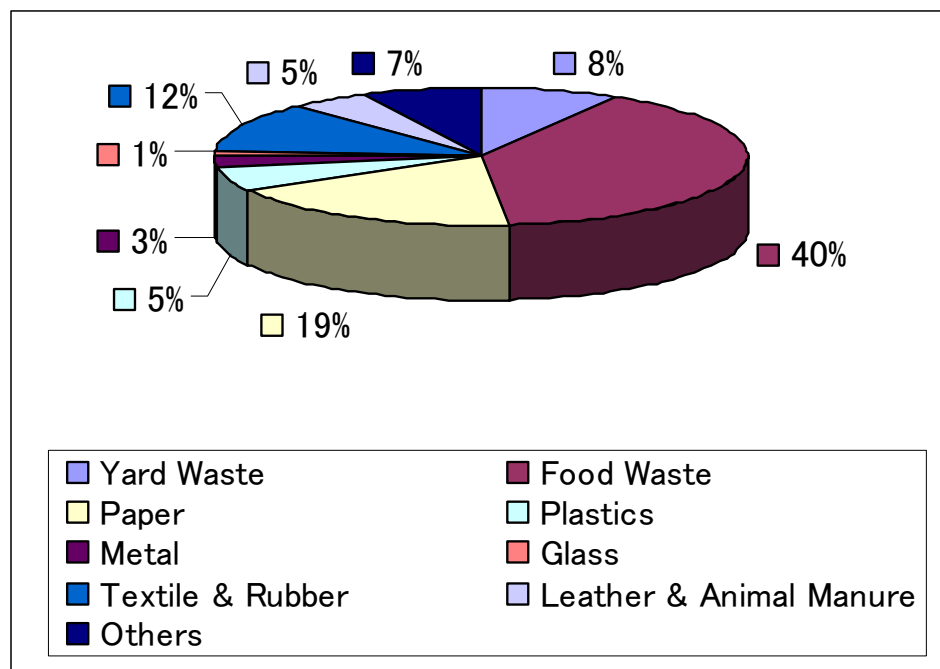


Figure 2.3-8 shows typical composition of municipal solid waste in Conakry that includes 40% of food waste, 19% of paper, 12% of textile/Rubber 8% of yard waste and 5% of plastic waste.

Figure 2.3-8 Waste Composition in Conakry



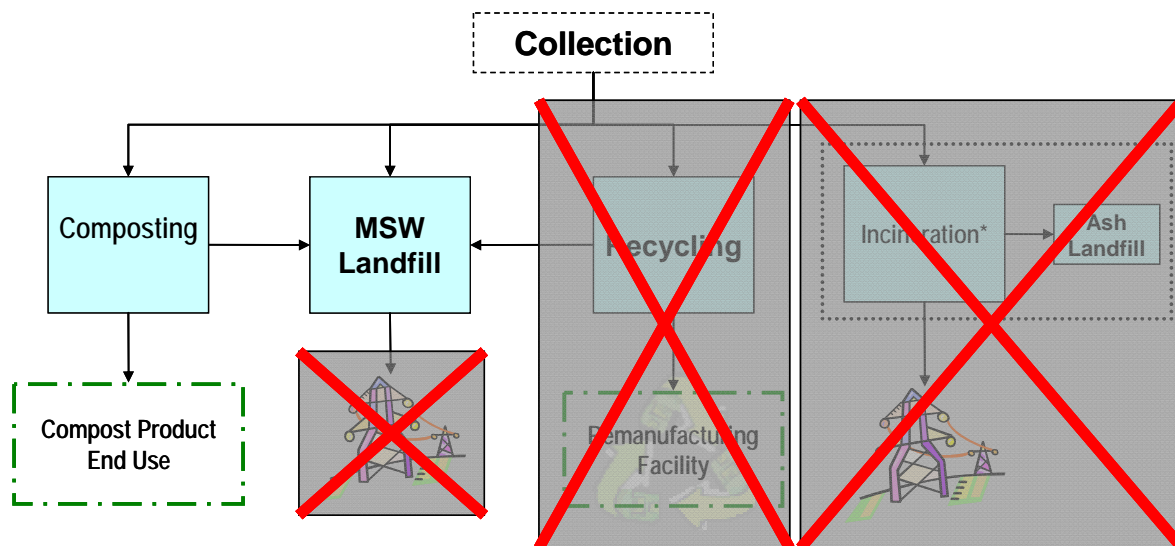
Kathmandu, Nepal

Kathmandu Valley has five municipalities including Kathmandu Municipality, which is the capital of Nepal. The area of the valley is 580km². The Kathmandu Valley is located at an average attitude of 1,350m above sea level and surrounded by mountains. The total population of five municipalities is 1,099,158 in 2004. The economy in Kathmandu depends on the tourism and the GNI per capita is US\$270 in 2005. The climate of Kathmandu Valley is temperature monsoon type with rainy season lasting from June to September. The annual precipitation is 2,000 mm. The temperature is 1°C in winter to 25°C in summer on average and approximately 13°C on average.

The total waste generation of Kathmandu's five municipalities is 435 tonnes/day and the generation ratio is approximately 0.4 kg/person/day in five municipalities on average. Traditionally, much of the generated waste has been dumped on the bank's of Bagmati River. Sisdol sanitary landfill site commenced operation in 2006 and waste is transported there through the Teku transfer station. Because of the relatively high composition of organic materials in the waste, a variety of small scale composting activities have been tried in the Kathmandu Valley. There are also a number of small scale recycling activities.

Figure 2.3-9 shows simplified waste flow in Kathmandu. Small scale composting plant is operated to produce the compost from the kitchen waste.

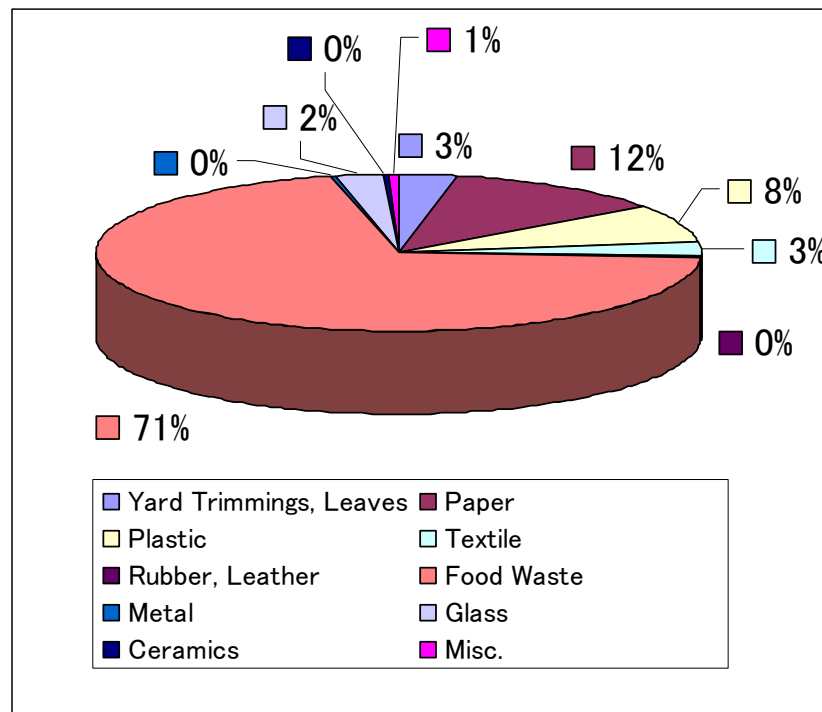
Figure 2.3-9 Simplified Waste Flow in Kathmandu



* Incineration can be with or without energy recovery.

Figure 2.3-10 shows typical composition of municipal solid waste in kahtmandu that includes 71% of food waste, 12% of paper and 8% of plastic waste.

Figure 2.3-10 Waste Composition in Kathmandu



Kawasaki, Japan

Kawasaki city in Kanagawa prefecture, Japan, is located between the Capital Tokyo and Yokohama that is the biggest population city in Japan. The reclaimed land beside Tokyo bay is occupied by heavy chemical industry complexes at the centre of the Keihin Industrial Area. The eastern end of the area is flat, and much of it consists of heavily industrialized and densely built working-class areas. In contrast, its western suburbs occupy an area of hills known as Tama hills and are mostly pleasant, often newly developed residential areas for people commuting to metropolis Tokyo area. As of 2006, the population of the city is 1,330,309 and the density is 9,216 persons/ km² and the total area is 144.35 km². Kawasaki city is located in the temperate humid climate area. Climate monitoring at Yokohama local observing station located close to Kawasaki city shows that precipitation was 1,932 mm/year in 2005, and average temperature was around 17°C. Residential waste generation was 0.7 kg/person/day in 2005. Waste generation rate of MSW including commercial waste was 1.01 kg/person/day in 2005, and the total generation amount is 1,399 tonnes/day. A part of municipal waste is transported by train, general and bulky waste, resource material and residual ash from incinerators which is generated in the northern part of Kawasaki city. The difficulty of suitable site for landfill causes the historical promotion of incineration as well as other cities in Japan as shown in Figure 2.3-11.

Figure 2.3-11 Simplified Waste Flow in Kawasaki

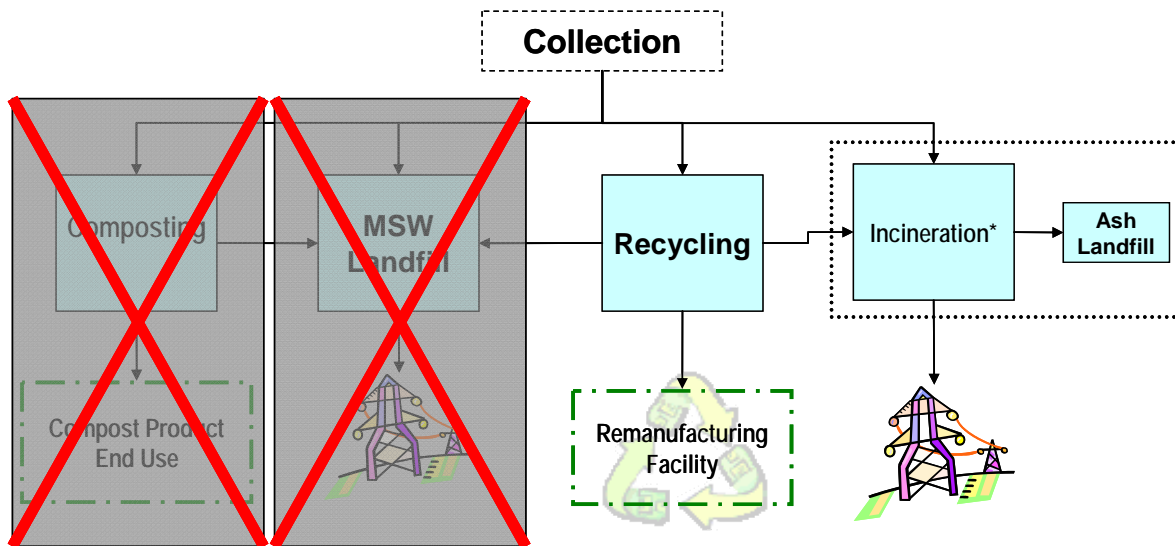
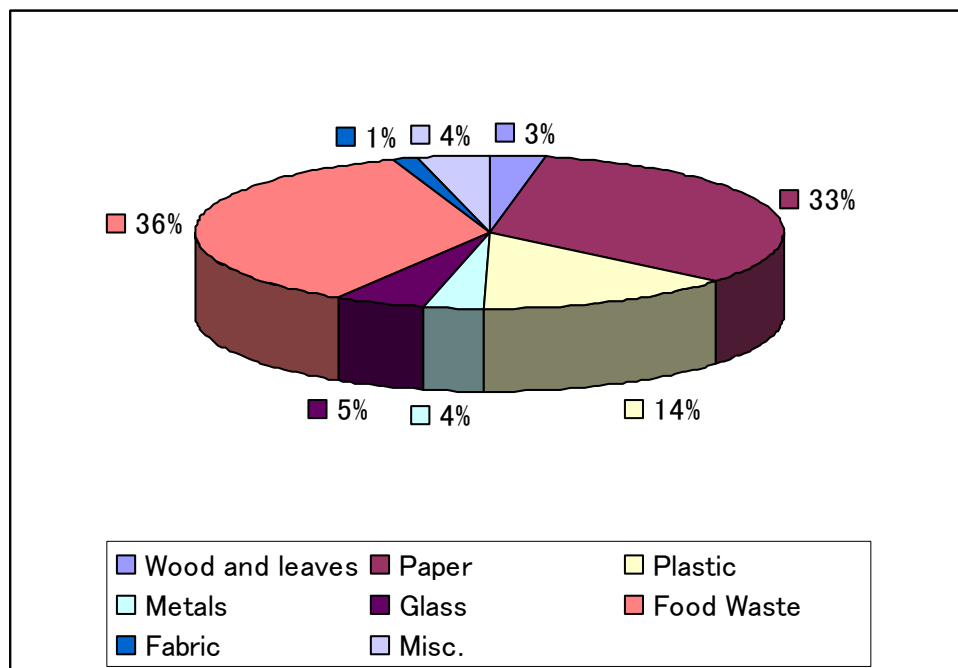


Figure 2.3-12 shows typical composition of municipal solid waste in Kawasaki that includes 36% of food waste, 33% of paper and 14% of plastic waste.

Figure 2.3-12 Waste Composition in Kawasaki

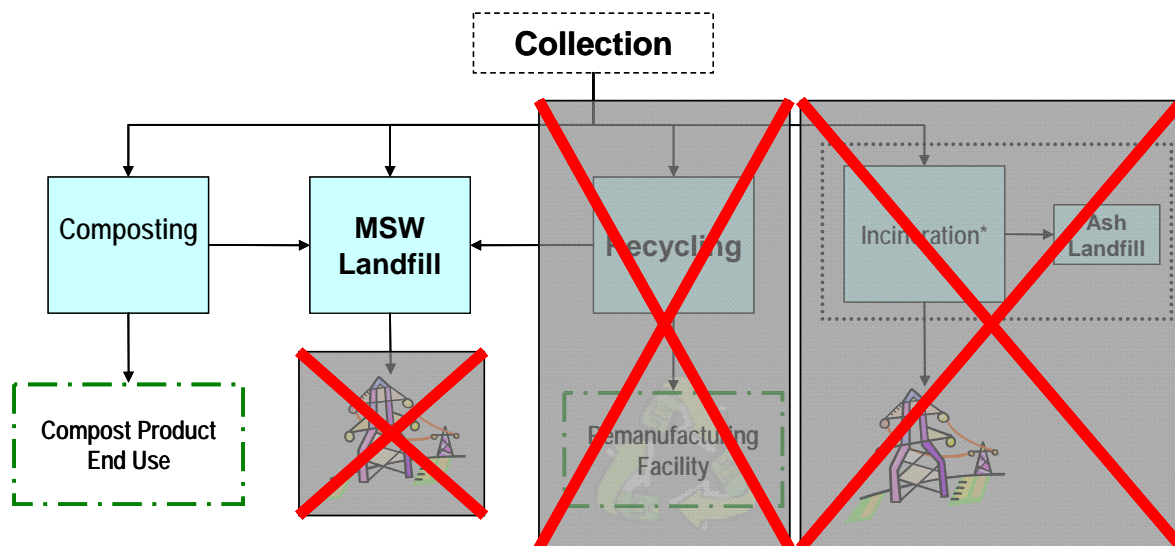


Lahore, Pakistan

The Republic of Pakistan is in the South Asia region and is bordered by India to the east, China to the north east, and Iraq to the west. Lahore is a historical city, is the second largest city in the country, and is capital of the province of Punjab, located in the north-east of Pakistan. The total area is 1,772 km². The total population of the city including 9 districts is approximately 8,000,000 in 2006. Lahore city and near the area is the most fertile area of Pakistan and chief producer of agricultural products for the country as well as software producing, tourism and handmade manufacturing. The climate of Lahore is semi arid and the temperature is approximately 20°C on average and annual precipitation is around 500 mm/year. The GNI of the Republic of Pakistan in 2005 was roughly US\$690/person.

The total amount of generation is 5,200 tonnes/day and the unit generation ratio of solid waste is approximately 0.65 kg/person/day on average in Lahore city. In the collection and transportation system, arm roll vehicle, tipper and dump truck is utilized as well as handcarts for primary collection. The main treatment and disposal method is landfilling; and there is composting by the city near existing landfill site, as well as composting plant by NGO combined with materials recovery. Figure 2.3-13 shows waste flow in Lahore.

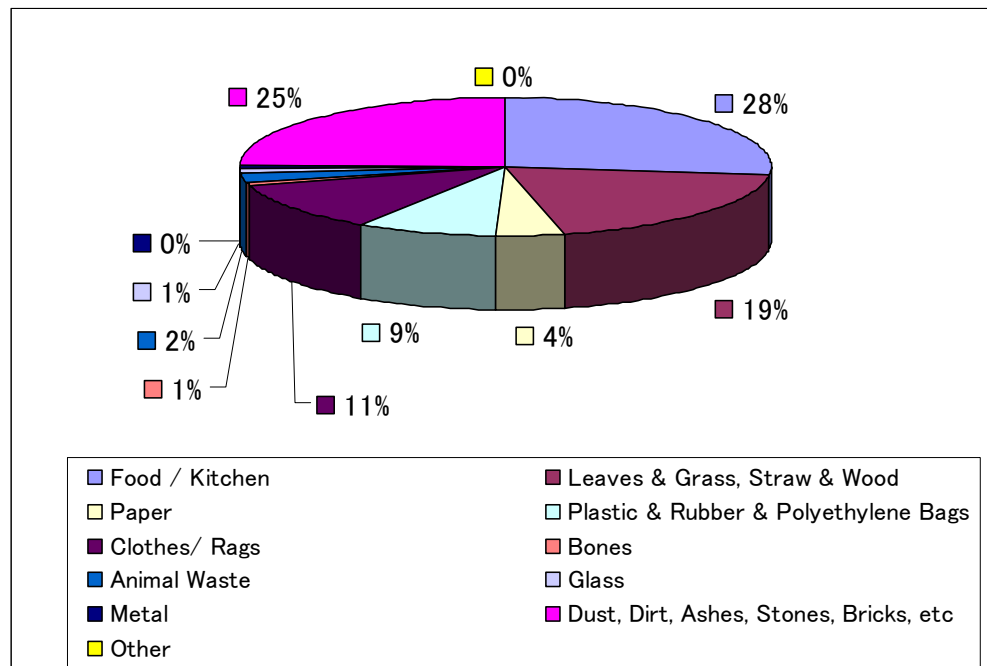
Figure 2.3-13 Simplified Waste Flow in Lahore



* Incineration can be with or without energy recovery.

Figure 2.3-14 shows typical composition of municipal solid waste in Lahore that includes 28% of food waste, 19% of yard wastes, 4% of paper, 9% of plastic waste and 25% of dust, dirt and others.

Figure 2.3-14 Waste Composition in Lahore

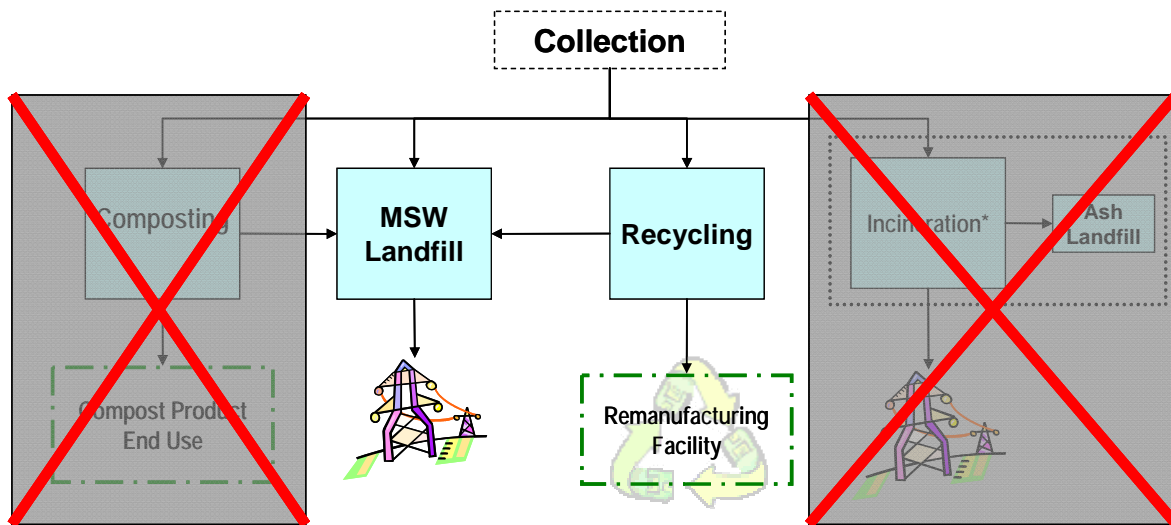


Sarajevo, Bosnia And Herzegovina

Sarajevo Canton is the capital of Bosnia and Herzegovina, which constitutes 9 municipalities, located between the surrounding mountains and the area is 1,227 km². The Center Sarajevo Municipality, the oldest part of Sarajevo, has a population of about 410,000. Sarajevo's economy is largely based on secondary and tertiary industries. Its manufacturing activities include production of foods, beverages, tobacco, textiles furniture, automobiles, pharmaceuticals and metal working. The service sectors include tourism, communications, banking and public administrations. The GNP per capita is approximately US\$2,440. The climate of Sarajevo is continental climate and the average year-round temperature is 10°C. Summers are warm, with temperatures of over 30°C not being uncommon. The temperatures in winter go down to below minus 10°C and the annual precipitation is around 900 mm.

Despite this common trend for the capital city to produce, on average, more waste per capita than in rural areas, it was noticed during the fieldwork that per capita generation rates calculated on the basis of the amount of waste landfilled were higher than expected, and were far higher than other comparable capital cities in the region, equaling the US average of 1.2 kg/person/day, which is rough estimation based on population data and on total mass of waste delivered to the landfill. The total generation amount is 492 tonnes/day. The vast majority of Sarajevo's municipal and commercial solid waste ends up at landfill site as shown in Figure 2.3-15.

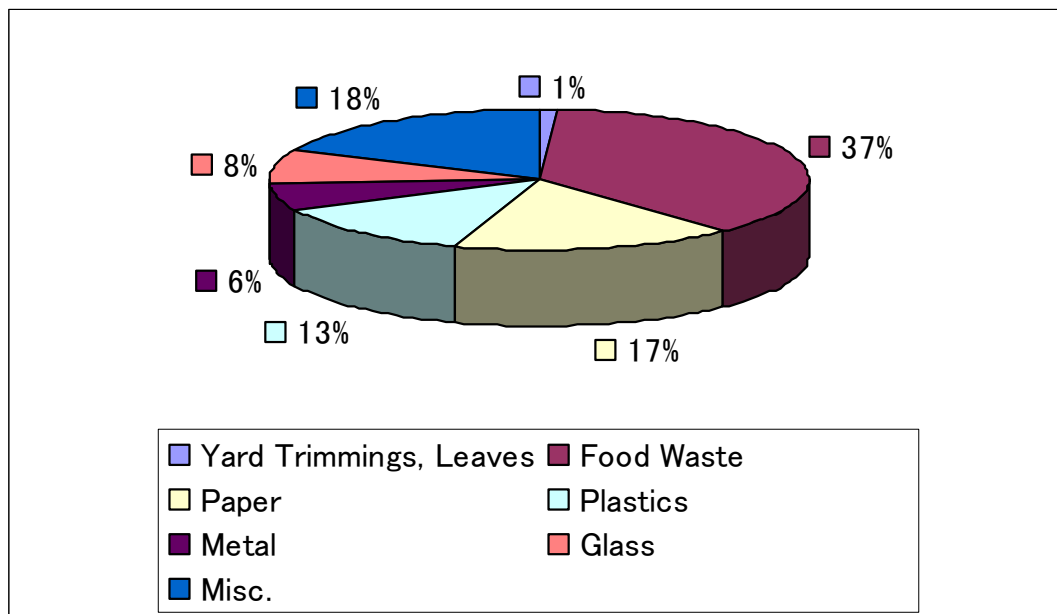
Figure 2.3-15 Simplified Waste Flow in Sarajevo



* Incineration can be with or without energy recovery.

Figure 2.3-16 shows typical composition of municipal solid waste in Sarajevo that includes 37% of food waste, 17% of paper, 13% of plastic waste and 18% of miscellaneous waste such as dust and sand.

Figure 2.3-16 Waste Composition in Sarajevo

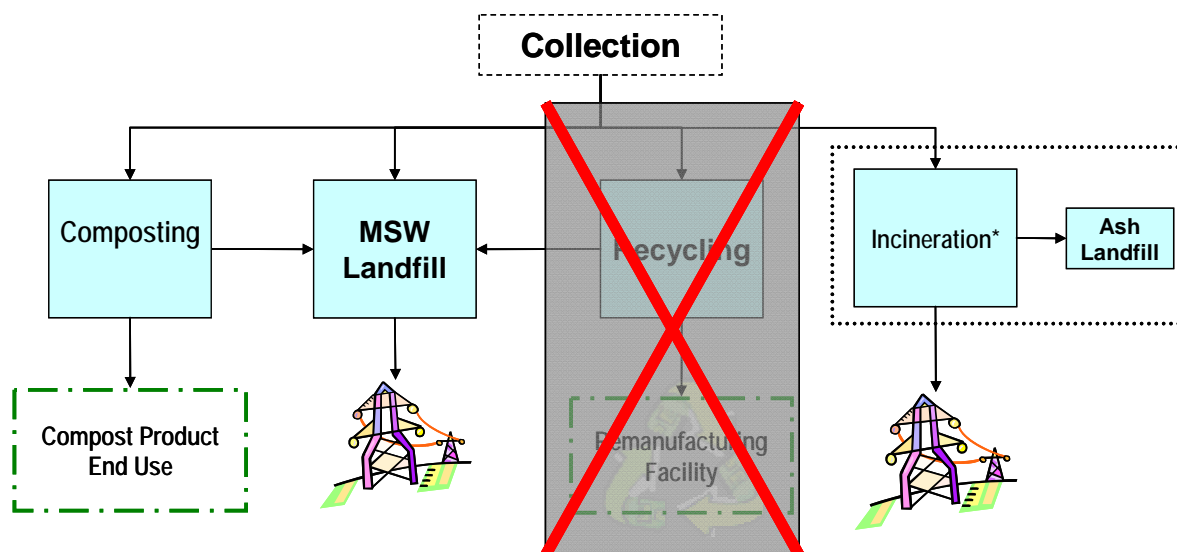


Shanghai, China

Shanghai city is located in east coast of China and is one of most urbanized cities in China. The area is 6,340km². It has 19 districts which are divided into three categories which are urban including Pu Dong district, suburban and outskirt area. Geographically, the area is flat and there are some water courses such as canals or Huang Pu River, which is a tributary of Yangtze River. The total population is approximately 17,800,000 not including up to three million visitors commonly present in the city. The GDP of Shanghai alone grew 11.1 percent to over US\$109 billion in 2005, accounting for over five percent of China's total output. GNI per capita in Shanghai is US\$1,740. Shanghai city belongs to typical subtropical monsoon climate. The temperature is from 5°C in winter to 25°C in summer and the average is about 15°C. The rainfall is 1,440 mm/year on average. Shanghai is the industrial, financial, and commercial center of China. It hosts a concentration of manufacturing activities as well as commercial or tourism sectors.

The total amount of generation is 17,000 tonnes/day and the unit generation ratio of solid waste is approximately 0.96 kg/person/day on average in Shanghai city. The collection and transportation is variously based on the areas. The area far from existing landfill site, the collected waste is transported by a barge or secondary transfer vehicles through a transfer station. As shown in Figure 2.3-17, the treatment and disposal method is mainly landfilling but incinerators have been introduced as well as composting facilities including separating system.

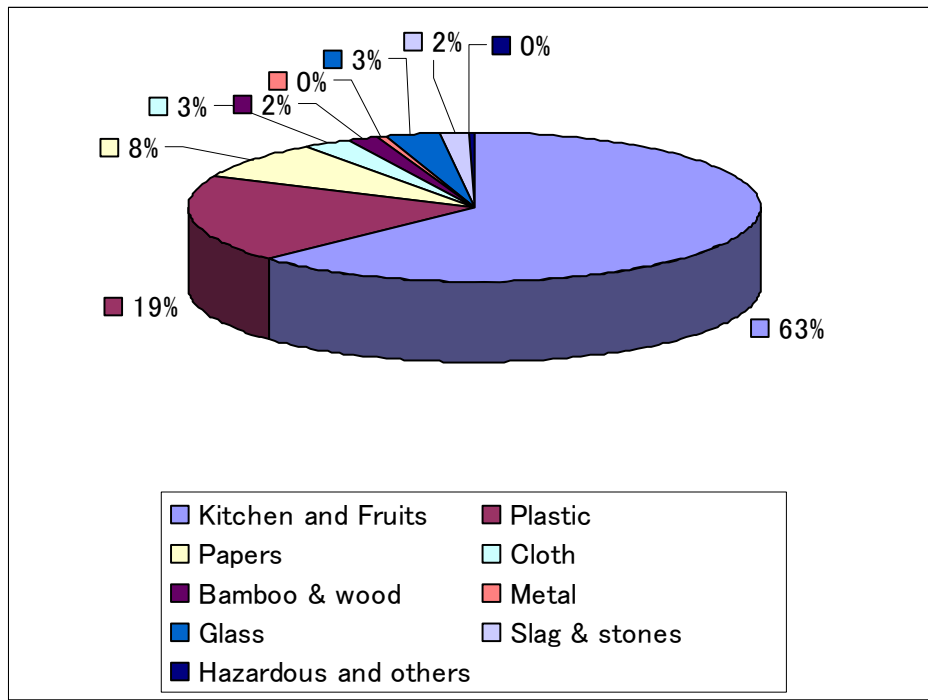
Figure 2.3-17 Simplified Waste Flow in Shanghai



* Incineration can be with or without energy recovery.

Figure 2.3-18 shows typical composition of municipal solid waste in Shanghai that includes 63% of food waste, 8% of paper and 19% of plastic waste.

Figure 2.3-18 Waste Composition in Shanghai



2.4 Data Analysis

2.4.1 Review of Other Sources of Existing Solid Waste Data

MSW DST was originally developed based on the waste compositions, solid waste management systems and operating conditions in the US. While solid waste compositions in developing countries are different, each separate constituent (paper, plastic, metal, glass, etc.) behaves the same way when processed developing countries as it does in the US. Reliable waste composition data is not well available in developing countries, and most cities do not have complete weight records of all wastes being handled. Some of the target cities had good data, from actual weighbridge recordings or from recent surveys done in master plans. But, overall, data was poor.

In order to fill data gaps and determine whether the actual data collected was reasonable, the published literature was examined for regional data and also data from cities of comparable economic levels. The studies that were reviewed for the most comprehensive waste quantity and composition data were prepared by:

- JICA: Japan International Cooperation Agency
- METAP: Mediterranean Environmental Technical Assistance Program
- PAHO: Pan American Health Organization

2.4.2 Review of JICA Study Reports

The government of Japan has carried out many major planning efforts for cities in developing countries. Most of these were city-wide master plans. These studies typically lasted 18-24 months and included extensive field efforts to survey, sample, and analyze waste quantity and composition in a wide range of neighborhoods of various income levels and economic activities. In addition to JICA master planning studies, other studies named “basic design study” also conducted by JICA were also reviewed. Most of these various studies are available in the JICA library, and many are posted on the JICA website at : []

As Table 2.4.1 shows, more than 20 JICA studies were completed after 1995 over the world. While there were other studies in the previous two decades, it was decided to focus on those done since 1995.

Table 2.4-1 List of JICA Development Study for Solid Waste Management

	Project Name	Year	Target of Solid Waste	
1	The Study on the Improvement of the Solid Waste Management System for the City of Managua in Nicaragua	1995.05	domestic waste, market waste, commercial waste, road cleaning waste and public institution waste	X
2	The Study on the Solid Waste Management System for Bucharest Municipality in Rumania	1995.12	municipal waste, medical waste, and construction waste	X
3	The Study on Wastewater and Solid Waste Management for the City of Ujung Pandang in the Republic of Indonesia	1996.03	Domestic waste, commercial waste, factory waste, hospital waste, road and drain waste	X
4	The study on the National Guidelines for Solid Waste Management for the Kingdom of Morocco	1996.08	Municipal waste, industrial waste and medical waste	X
5	The Study on the Solid Waste Management for Dar es Salaam City in Tanzania	1997.09	Domestic waste, commercial waste, market waste and road cleaning waste	X
6	The Study on Solid Waste Management in Nairobi City in the Republic of Kenya	1998.08	Domestic waste, market waste, commercial waste and road waste	X
7	The study on Solid Waste Management for Metro Manila in the Republic of Philippines	1999.03	Domestic waste, commercial waste, market waste, road cleaning waste medical waste and industrial waste	X
8	The Study on Solid Waste Management of the Urban Area of Tegucigalpa's Central District in Honduras	1999.03	Domestic waste, commercial waste, market waste and road cleaning waste	
9	The Study on Solid Waste Management for Mexico City in the United Mexican States	1999.05	Domestic waste, commercial waste, market waste, road cleaning waste and medical waste	X
10	The Study on Solid Waste Management for Male' City in the Republic of Maldives	1999.05	Domestic waste, commercial waste, market waste, public area waste, industrial and medical waste	
11	The Study on Regional Solid Waste Management for Adana-Mersin in the Republic of Turkey	2000.01	Domestic waste, commercial waste, market waste, road cleaning waste and medical waste	X
12	The Study on solid Waste Management for Almaty City in the Republic of Kazakhstan	2000.01		X
13	The study on environmental improvement for Hanoi City in the Socialist Republic of Vietnam	2000,7	Domestic Waste, Medical Waste, Industrial Waste	X
14	The Study on Regional Solid Waste Management for San Salvador Metropolitan Area in the Republic of El Salvador	2000.11	Domestic waste, commercial waste, institution waste, road cleaning waste and medical waste	

	Project Name	Year	Target of Solid Waste	
15	The Study on sanitation Improvement for the Niamey City in the Republic of Niger	2001.12	Domestic waste, industrial waste and medical waste	X
16	The Study on Solid Waste Management at Local Cities in the Syrian Arab Republic	2002.01	Domestic waste, commercial waste, park and road waste, medical waste and industrial waste	X
17	The Study on Solid Waste Management Plan for Municipality of Panama in the Republic of Panama	2003.03	Domestic waste, commercial waste, market waste, road cleaning waste and public institution waste	X
18	The Study on Improvement of Solid Waste Management in Secondary Cities in Sri Lanka	2003.11	domestic waste, commercial waste, and public institution waste	X
19	The Study on the Solid Waste Management for the Phnom Penh in Cambodia	2005.03	Municipal waste (sludge, industrial and medical waste)	
20	The study on the solid waste management in Dhaka City in Bangladesh	2005.03	Domestic waste, industrial and medical waste	
21	The Study on Solid Waste Management for Kathmandu Valley in the Kingdom of Nepal	2005.09	Domestic waste	
22	The Study on Integrated Management Plan of Municipal Solid Waste in Havana City in the Republic of Cuba	2006.09	Domestic waste	

The result of comparison between the data of JICA past studies and data collected from the target cities for MSW HDM are summarized as follows;

- Unit Generation Rate (kg/person/day) vs. Economic Indicator (GDP or GNI)
- Ditto, by regional areas
- Composition Rate for Compostable materials* vs. Economic Indicator (GDP or GNI)
* Compostable: kitchen waste and yard waste (wood and grass)
- Ditto, by regional areas
- Composition Rate for Combustible materials** vs. Economic Indicator (GDP or GNI)
** Combustible: compostable waste, paper and plastics
- Ditto, by regional areas
- Composition Rate for Recyclable materials*** vs. Economic Indicator (GDP or GNI)
*** Recyclable: paper, plastic, metals and glass
- Ditto, by regional areas

Comparisons between the unit generation rate and economic indicator are shown in Figure 2.4.1 and 2.4.2 and other results are shown in Appendix 2.4.1 to 6.

Comparing those data, it could be said the data obtained from the field survey at each target city for MSW HDM was within the range representing the regions with similar geographical, metrological and economic conditions.

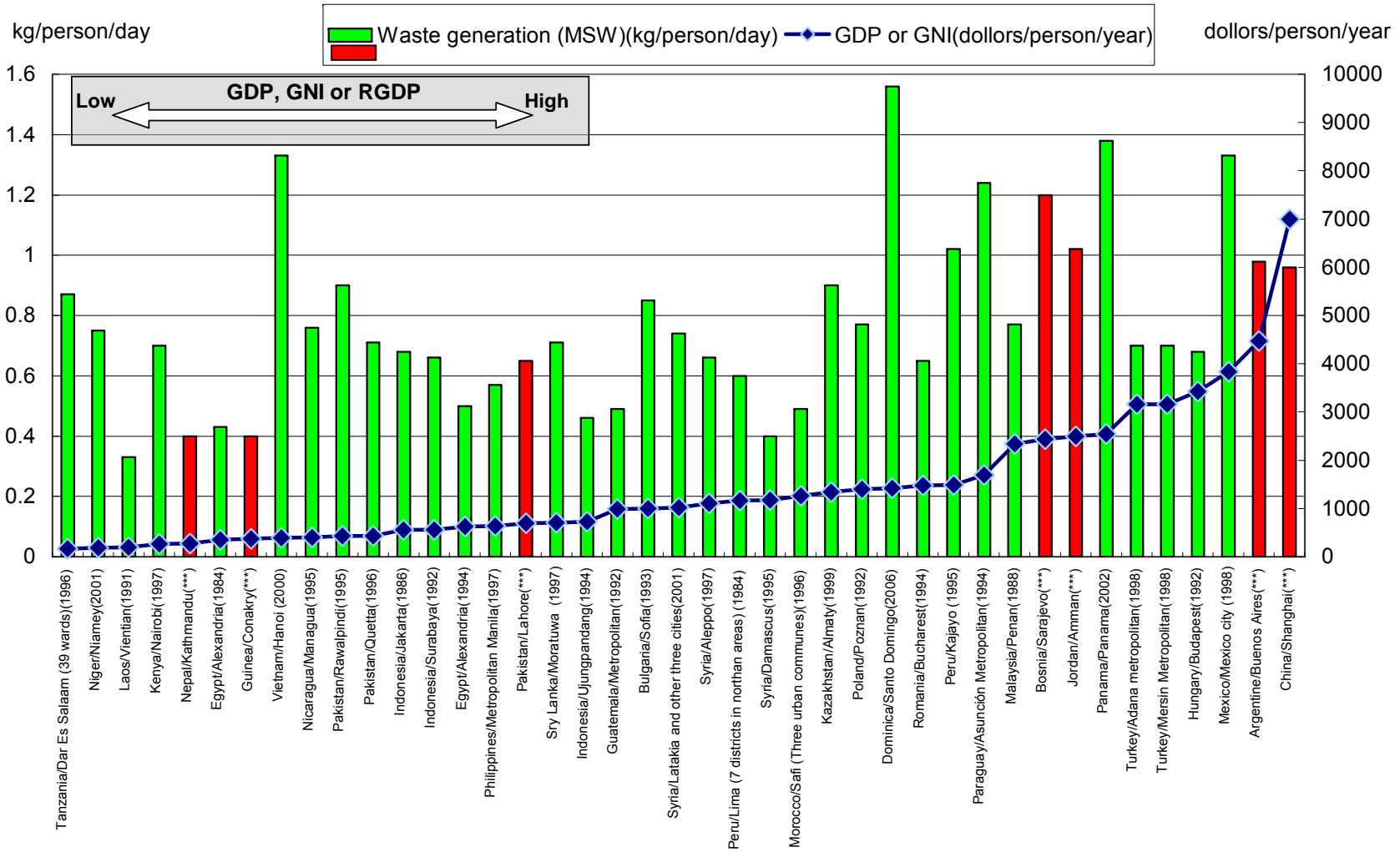


Figure 2.4-1 Unit Generation Rate vs. Economic Indicator of Cities of JICA Study and this MSW HDM Study (Sorted by Economic Indicator)

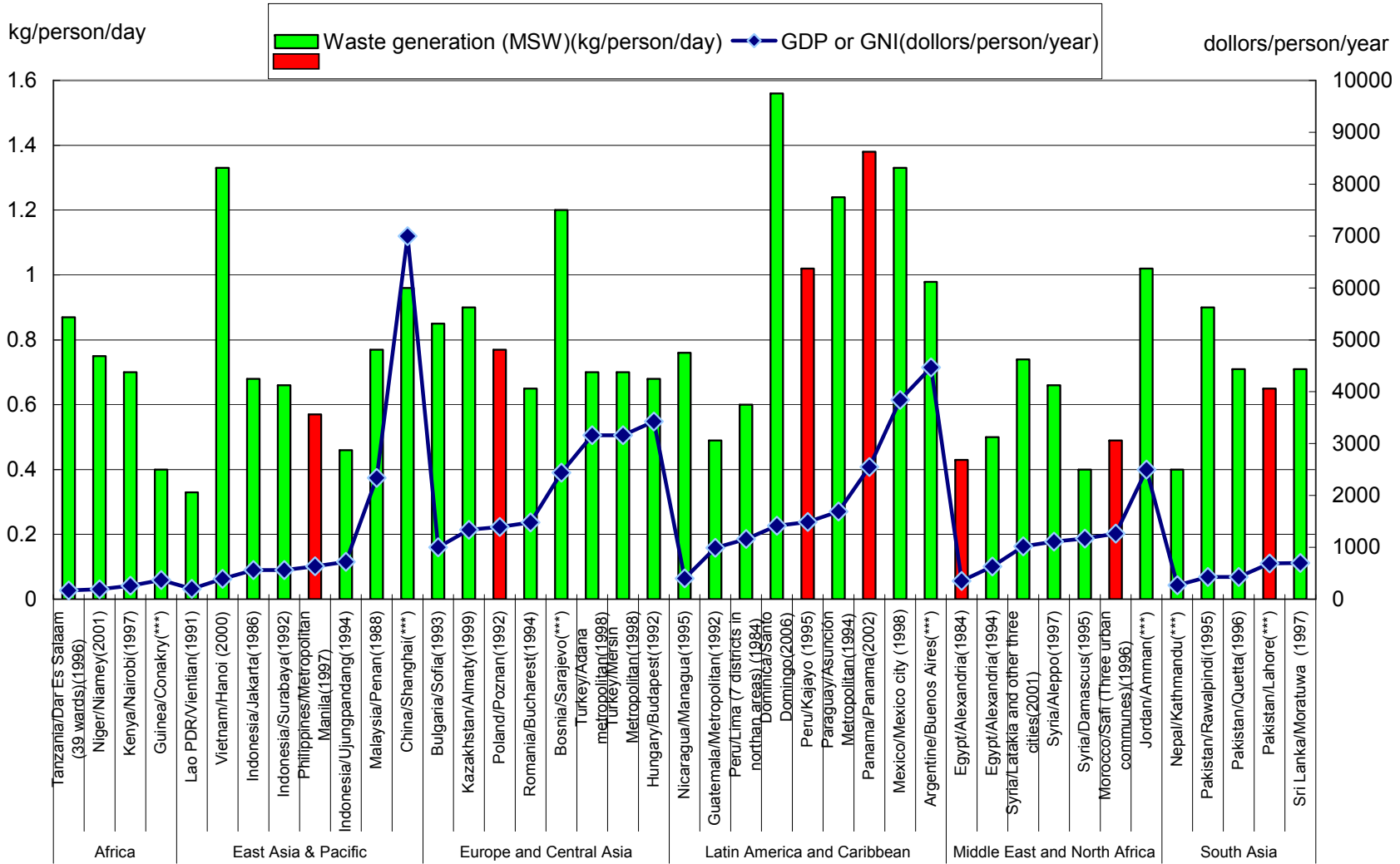


Figure 2.4-2 Unit Generation Rate vs. Economic Indicator of Cities of JICA Study and this MSW HDM Study (Sorted by Regional Area)

2.5 Summary of Key Input Parameters, Default Model Data, Assumptions, and Limitations

Key Input Parameters and Assumed Data for the Model

In any complex modeling exercise, there is a considerable amount of data and assumptions that can significantly affect model outcomes. In this study, the key data and assumptions used include a mixture of city-specific data that was collected through site visits and default data and assumptions that are built into the MSW DST. In this section, key data inputs, default MSW DST data, and assumptions are presented and discussed.

The full consulting team met to work together at RTI after the completion of data collection, and the analysis assumptions were discussed and developed as per attached in Appendix 2.5. The World Bank and US EPA participated in this phase of the work, wherein there was agreement on assumptions and how to handle data gaps and the design of scenarios. From RTI, the full team went to the World Bank headquarters and held a workshop with various Bank staff, including many of those who were involved with projects in the target cities.

Table 2.5-1 presents a summary of the most important input parameters from those described in Sections 2.3 and 2.4 based on their impact on the cost, energy consumption, and environmental emission results. This table also characterizes the input parameters according to their data sources (i.e., field data or based on assumptions) and provides references to the tables where the specific data can be found. Key assumptions and limitations common to all data are subsequently described.

Table 2.5-1 shows how the data inputs were a mix of city specific values and assumptions. For some parameters city specific data were not found and the model used default values to cover the data gaps. Cost data in particular were difficult to obtain. Therefore, cost results may not be an accurate reflection of actual practice in a given city. Table 2.5-2 shows the available cost data for all cities and waste management processes including energy cost data. The blanks in the table indicate lack of data and the zeroes indicate values that were set to zero. Available cost data are carefully reviewed and some of them are modified for the model run. For example, cost for equipment and maintenance for the landfill in Conakry is omitted and operation cost of incinerator in Shanghai is replaced to the US default data.

Calculated costs represent average costs for these types of processes and not are specific facility costs.

For facilities that recover energy and/or materials and sell them for revenue, as mentioned in Section 2.1, this revenue is netted out of the cost. The cost results therefore represent a net annual total cost. It should be noted that for the recycling scenarios, the revenue obtained from the sale of recyclables is dependent on available markets for recyclables.

In addition, as previously mentioned, we prepare two input data, one is with land prices for landfill cost and the other is without those to see how the land price affect the net total cost.

Table 2.5-1 Summary of Key Input Parameters, Assumptions and Data Sources by Process.

Input Parameter	Data Sources and Assumptions
Common	
Energy sources breakdown	City specific (utility grid mix of fuels)—See Appendix 2.5.8 Energy Data Inputs.
Electrical Energy Offset	
Electricity Cost- purchase	
Electricity Price- sale	
Diesel Fuel	
Generation	
Waste Generation	City specific—See Appendix 2.5.2 MSW Generation Data Inputs.
Waste Composition	
Fraction of residential waste that is single family	Assumed 10% for all cities except Kawasaki and Atlanta (50%)—See Appendix 2.5.9 Constants Data.
Fraction of residential waste that multi family	Assumed 90% for all cities except Kawasaki and Atlanta (50%)—See Appendix 2.5.9 Constants Data.
Collection	
Sectors	Residential and Multifamily
Collection cost	Set to be the same value per income category—See Appendix 2.5.3 Collection Data Inputs.
Low participation factor*	50%—See Appendix 2.5.9 Constants Data.
High participation factor*	75%—See Appendix 2.5.9 Constants Data.
Low capture rate**	50%—See Appendix 2.5.9 Constants Data.
High capture rate**	75%—See Appendix 2.5.9 Constants Data.
Collection frequency	Daily: 6 times/week, Biweekly: 2 times/week—See Appendix 2.5.9 Constants Data.
Houses per stop in the residential sector	Assumed the same for all cities—See Appendix 2.5.9 Constants Data.
Household size in the residential sector	
Usable capacity in open trucks	
Vehicle travel speeds	
Vehicle travel distances	30 km one way—See Appendix 2.5.9 Constants Data.
Families per stop in the multifamily sector	Income category- specific—See Appendix 2.5.3 Collection Data Inputs.
Household size in the multifamily sector	
Number of multifamily collection locations	
Fraction of compactor vehicles	
Fraction of open trucks	
Usable capacity of compactor vehicles	
Waste density in compactor vehicles- compacted	
Waste density in compactor vehicles- uncompact	

**Table 2.5-1 Summary of Key Input Parameters, Assumptions and Data Sources by Process.
 (continued)**

MRF	
Basic design	Accepts mixed MSW, manual/ mechanical designs
Low separation efficiency	55%—See Appendix 2.5.9 Constants Data.
High separation efficiency	75%—See Appendix 2.5.9 Constants Data.
Recyclables prices	City specific—See Appendix 2.5.4 MRF Data Inputs.
Separation efficiencies	
Working day length	
Driver and operator requirement	
Capacity of manual bag opener	
Labor overhead rate	
Management wages	
Picker wage rate	
Driver and operator wage rate	
Bin cost rate	
Rolling stock cost rate	
Baler cost rate	
Vehicle travel distances to remanufacturing	
Residuals management	Landfill with gas collection flaring
Compost	
Basic design	Accepts mixed MSW, manual/mechanical designs
Number of operating hours	City specific—See Appendix 2.5.5 Compost Data Inputs.
Number of days per week	
Operating days per year	
Wage for operator	
Wage for manager	
Compost residence time	
Curing stage residence time	
Compost pile turning frequency	
Compost product prices	
Residuals management	
Incineration	
Basic design	Modern Mass Burn
Plant heat rate	17,500 BTU/kWh
Ferrous recovery rate	70%
Unit WTE capital cost	City specific—See Appendix 2.5.6 Incineration Data Inputs.
Unit WTE O & M cost	

**Table 2.5-1 Summary of Key Input Parameters, Assumptions and Data Sources by Process.
 (continued)**

Landfill	
Basic design	Modern (U.S.EPA Subtitle D type)
Time period for calculating emissions	100 years
Gas collection efficiency	0% for venting; 70% for gas control—See Appendix 2.5.9 Constants Data.
Landfill gas management	Vent, flare, and energy recovery
Active life of facility	City-specific—See Appendix 2.5.7 Landfill Data Inputs. Both cases with and without land prices are analyzed.
Number of cells	
Type of liner	
LF gas composition	
Precipitation	
Minimum labor cost	
Maximum daily waste handled by minimum labor costs	
Utility rate	
Overhead costs	
Equipment and maintenance	
Capital cost of internal combustion engine	
Land prices	
Landfill depth	
Landfill slope	

*Participation factor: percent of population that participates in recycling

**Capture rate: percent of recyclables placed in bins by those participating

Table 2.5-2 Cost Data Availability by City.

Cost Input Parameters		Katmandu	Conakry	Lahore	Sarajevo	Amman	Buenos Aires	Shanghai	Kawasaki	Atlanta
Energy Data										
Electricity Cost- purchase			X		X	X	X	X	X	X
Electricity Price- sale			X		X	X	X	X	X	X
Diesel Fuel		X	X	X	X	X	X	X	X	X
MRF Data										
Recyclables prices	Old News Print							X	X	X
	Corrugated Cardboard	X					X	X	X	X
	Office Paper					X	X	X	X	X
	Phone Books							X	X	X
	Books							X	X	X
	Old Magazines							X	X	X
	3rd Class Mail							X	X	X
	Mixed paper	X		X	X	X		X	X	X
	HDPE - Translucent	X					X	X		X
	HDPE - Pigmented	X				X		X		X
	PET			X	X		X	X	X	X
	Mixed plastics		X	X		X	X			X
	Ferrous Cans		X			X	X		X	X
	Ferrous Metal - Other	X	X	X					X	X
	Aluminum Cans		X			X	X	X	X	X
	Aluminum Other #1									0
Aluminum Other #2									0	
Glass - Clear	X	X	X				X	X	X	
Glass - Brown	X	X						X	X	
Glass - Green	X	X						X	X	

Cost Input Parameters	Katmandu	Conakry	Lahore	Sarajevo	Amman	Buenos Aires	Shanghai	Kawasaki	Atlanta
Energy Data									
Mixed Glass		X				X	X	X	X
Picker wage rate		X		X	X	X		X	X
Driver and operator wage rate		X		X	X	X		X	X
Bin cost rate				X					X
Rolling stock cost rate				X					X
Baler cost rate				X					X
Composting Data									
Wage for operator	X	X	X			X			X
Wage for manager	X					X			X
Value of compost product	X	X	X	X	X	X	X	X	X
Incineration Data									
Unit combustor capital cost							X	X	X
Unit combustor O & M cost							X	X	X
Landfill Disposal Data									
Labor cost	X	X							X
Overhead costs	X			X					X
Equipment and maintenance		X		X			X		X
Capital cost of internal combustion engine				X	X				X
Land Prices	X	X	X	X	X	X	X	X	X

Note x: City specific data were found for that parameter by field survey or on the web site.
Some of them are not used for the model input because of their data reliability.

0: The value was set to zero as for the recyclables prices.

Blank cells mean no data available by the field survey, therefore defaults or other related values are applied.
Zeroes are also set for the recyclables prices in case of no market for those recyclables.

Key MSW DST Default Data Employed

In addition to the key input parameters presented in Tables 2.5.1 and 2.5.2, there are key default data used in the MSW DST that can significantly affect scenario results and are key to understanding the behavior of the results for each city. In particular, energy production, materials production, and landfill gas production data are highly sensitive parameters. In the context of their significance on the scenario results presented in Section 3 of this report, the following default data are highlighted:

- Electrical energy production total energy consumption factors
- Electrical energy production fuel-specific emission factors
- Energy savings factors associated with materials recycling
- Emission savings (or burdens) factors associated with materials recycling
- Landfill gas production parameters by waste item.

Defaults used in the MSW DST for each of these items are presented in Tables 2.5.3 to 2.5.7 below. It should be noted that each table is sorted in descending order according to the values highlighted in bold to aid illustrating the impact of these values in the results. Carbon dioxide and methane emission factors are presented as these pollutants are the main contributors to the total carbon emissions from the waste management processes.

**Table 2.5-3 MSW DST Default Pre/Combustion Energy Factors
(Fuel Type Used to Produce Electricity)**

Fuel Type (fuel units)	Pre-combustion* Energy Factor (BTU/fuel unit)	Combustion** Energy Factor (BTU/fuel unit)	Total Energy Factor (BTU/fuel unit consumed)	Fuel Units Consumed per Electric kWh delivered (fuel unit/kWh)	Total Energy Factor (BTU/kWh)
Natural Gas (ft3)	129	1,022	1,151	13.535	15,578
Distillate Oil (gal)	19,300	138,700	158,000	0.090	14,181
Residual Oil (gal)	21,000	149,700	170,700	0.075	12,781
Uranium (lb)	50,600,000	985,321,000	1,035,921,000	0.000	11,585
Wood (lb)	0	10,350	10,350	1.015	10,504
Other	0	10,350	10,350	1.015	10,504
Coal (lb)	264	10,402	10,666	0.979	10,438
Hydro	0	3,413	3,413	1.000	3,413

*Pre-combustion energy is the energy used to mine and process a unit of fuel.

**Combustion energy is the energy value of the fuel as combusted in a utility boiler.

Table 2.5-4 MSW DST Default Emission Factors (Fuel Type Used to Produce Electricity)

Fuel Type (fuel units)	Emission Factors (lb/kWh)		
	Carbon Dioxide	Methane	PM
Residual Oil	2.75E+00	4.09E-04	4.21E-04
Coal	2.18E+00	4.76E-03	2.90E-03
Distillate Oil	1.98E+00	3.28E-04	2.66E-04
Natural Gas	1.47E+00	4.07E-03	4.79E-05
Uranium	7.51E-02	1.66E-04	4.86E-04
Hydro	0.00E+00	0.00E+00	0.00E+00
Wood	0.00E+00	0.00E+00	8.63E-05

Table 2.5-5 MSW DST Default Energy Savings (Recycling Individual Materials)

Recyclables Category	Energy Savings Factors (BTU/ ton of remanufactured material)
Aluminum	201,882,712
STEEL	171,726,050
LDPE	25,978,843
PET	23,785,635
HDPE	20,233,296
Newspaper	17,353,633
Corrugated Boxes	13,001,578
Phone Books	12,341,360
OFFICE PAPER	11,184,559
Glass	2,361,566
Text Books	1,082,049
Magazines/3rd Class Mail	711,964

Table 2.5-6 MSW DST Default Emission Savings (Recycling Individual Materials*)

Recyclables Category	Emission Factors (lb/ ton of remanufactured material)		
	Carbon Dioxide	Methane	PM
Aluminum	2.12E+04	3.26E+01	5.92E+01
LDPE	3.70E+03	1.60E-01	4.31E+00
PET	3.58E+03	4.84E-02	5.69E+00
HDPE	2.82E+03	-1.67E-01	2.59E+00
Steel	2.06E+03	1.71E+00	1.00E+01
Newspaper	1.90E+03	4.15E+00	2.82E+00
Glass	6.94E+02	4.49E+00	6.92E+00
Phone Books	3.36E+02	1.88E+00	5.09E+00
Text Books	1.18E+02	-1.65E+00	-3.48E-01
Magazines/3rd Class Mail	3.70E+01	4.27E-02	2.99E-01
Corrugated Boxes	-2.27E+02	-7.20E-01	2.34E+01
Office Paper	-5.80E+02	-6.74E-01	4.94E+00

* These values are calculated based on production of materials using recycled vs. virgin resources. Waste collection, separation, and transport are not included. A negative value denotes a net positive emission, or additional burden.

Table 2.5-7 MSW DST Default Landfill Gas Generation (Individual Waste Items*)

Waste Category	% moisture	CH₄ Yield (L CH₄/ dry kg)	Gas Production Rate (yr-1)
Food Waste	0.70	300.70	0.11
Office Paper	0.06	217.30	0.02
Books (used Office Paper)	0.06	217.30	0.02
Corr. Cardboard	0.05	152.30	0.03
3rd Class Mail	0.06	150.85	0.06
Yard Trimmings, Grass	0.60	136.00	0.31
Mixed Paper	0.06	103.67	0.06
Paper - Non-recyclable	0.06	103.67	0.06
Magazines	0.06	84.40	0.16
Newsprint	0.06	74.30	0.04
Phone Books	0.06	74.30	0.04
Yard Trimmings, Branches	0.60	62.60	0.12
Yard Trimmings, Leaves	0.60	30.60	0.25

* These values were selected to represent typical waste from the cities under analysis according to personal communications with Professor Morton A. Barlaz, North Carolina State University and Susan Thorneloe, US EPA.

CHAPTER 3 SCENARIO RESULTS

3.1 Open Dumping and Open Burning (Base Case)

This section of the report presents and explains the results of base case waste management simulation including open dumping and open burning. The MSW DST originally developed based on SWM experiences in the US does not contain open dumping and open burning models per se. The conventional landfill and incineration models were tailored to represent unmanaged landfill disposal and incineration, respectively.

It is assumed that there is no collection, transportation, or open dump/burn related cost or energy consumption. Waste is either taken by households to an open dump site or burned on-site or at a common burn site. Emissions have been estimated using a combination of the MSW DST landfill and incineration models and additional emission factors data for open burning of solid waste available from the U.S. EPA.

Due to the difficulty in characterizing open dumping and burning practices and emissions, results should be taken as rough approximations and used as a relative guide to compare against the more conventional MSW management practices and scenarios analyzed in Sections 3.2 and 3.3. These MSW management scenarios are also hypothetical, meaning that they are not a representation of the waste management situation in any of the cities included in this study, but are tailored to meet the objectives of this study.

Open Dumping

In many locations, waste is disposed of in unmanaged dumps or piles. To approximate an open dumping scenario, the following modifications were implemented to the MSW DST's landfill model:

- Energy consumption factors were zeroed out.
- Liner system removed
- Daily and final covers removed
- Leachate collection and treatment systems removed
- Assumed zero oxidation of methane through cover soil (i.e., there is no cover soil)
- Assumed all gas produced is released to the atmosphere (i.e., vented).

Estimates for unit and annual gas emissions associated with open dumping of waste are shown in Table 3.1.1 and Table 3.1.2. Table 3.1.3 and Table 3.1.4 contains estimates for selected key emissions of water pollutants (i.e., leachate) associated with open dumping of waste.

Table 3.1-1 Unit Gas Emissions from Open Dumping of Waste

City	Total Gas Emissions (kg/ton)		Total Carbon Emissions (kg/ton)
	CO ₂	CH ₄	C-eq
Kathmandu	156.77	53.11	0.15
Conakry	188.28	41.23	0.12
Lahore	69.96	25.06	0.07
Sarajevo	180.50	38.41	0.11
Amman	214.16	43.54	0.13
Buenos Aires	177.00	38.97	0.11
Shanghai	113.66	43.80	0.13
Kawasaki	308.48	51.40	0.15
Atlanta	479.30	50.69	0.15

Table 3.1-2 Annual Gas Emissions from Open Dumping of Waste

City	Total Gas Emissions (kg/year)		Total Carbon Emissions (kg/year)
	CO ₂	CH ₄	C-eq
Kathmandu	25,131,710	8,513,320	24,423
Conakry	17,675,735	3,870,470	11,113
Lahore	92,950,012	33,294,527	95,750
Sarajevo	31,247,946	6,649,108	19,096
Amman	167,749,561	34,105,656	97,915
Buenos Aires	662,330,435	145,844,940	418,864
Shanghai	684,101,219	263,611,212	756,667
Kawasaki	161,212,661	26,860,029	77,091
Atlanta	380,333,797	40,219,898	115,464

Table 3.1-3 Unit Emissions of Key Water Pollutants from Open Dumping of Waste

City	Unit Emissions (kg/ton)					
	TDS	TSS	BOD	COD	Ammonia	Phosphate
Kathmandu	2.49E-03	2.87E-03	3.79E+00	4.99E+00	1.61E-02	4.71E-04
Conakry	2.77E-03	2.22E-03	2.84E+00	3.74E+00	1.21E-02	3.53E-04
Lahore	2.75E-03	1.49E-03	1.81E+00	2.38E+00	7.72E-03	2.25E-04
Sarajevo	2.90E-03	2.12E-03	2.68E+00	3.52E+00	1.14E-02	3.33E-04
Amman	2.85E-03	2.39E-03	3.06E+00	4.03E+00	1.31E-02	3.81E-04
Buenos Aires	2.93E-03	2.02E-03	2.54E+00	3.34E+00	1.08E-02	3.15E-04
Shanghai	2.66E-03	2.43E-03	3.14E+00	4.13E+00	1.34E-02	3.90E-04
Kawasaki	2.98E-03	2.64E-03	3.40E+00	4.48E+00	1.45E-02	4.23E-04
Atlanta	3.28E-03	2.86E-03	3.69E+00	4.85E+00	1.57E-02	4.58E-04

Table 3.1-4 Annual Emissions of Key Water Pollutants from Open Dumping of Waste

City	Unit Emissions (kg/year)					
	TDS	TSS	BOD	COD	Ammonia	Phosphate
Kathmandu	399	461	607,357	799,533	2,588	75
Conakry	260	209	266,574	350,930	1,136	33
Lahore	3,659	1,986	2,404,820	3,165,949	10,252	299
Sarajevo	502	367	463,196	609,778	1,974	58
Amman	2,234	1,872	2,400,433	3,160,028	10,230	298
Buenos Aires	10,948	7,565	9,488,471	12,491,228	40,443	1,180
Shanghai	16,009	14,620	18,903,639	24,885,359	80,561	2,350
Kawasaki	1,558	1,379	1,777,544	2,340,022	7,575	221
Atlanta	2,599	2,272	2,926,014	3,851,912	12,470	364

Open Burning

In addition to open dumping of waste, in many locations waste is also burned in open piles or barrels. To approximate an open burning scenario, the following modifications were implemented to the MSW DST's incineration model:

- Energy consumption and production zeroed out.
- Air pollution controls were zeroed out.
- Environmental burdens associated with the production of air pollution control agents (e.g., lime) were removed.
- For metal air emissions, emission removal efficiencies were zeroed out.
- For non-metal air emissions, emissions factors for uncontrolled solid waste combustion were taken from the U.S. EPA's AP-42 Emission Factors for Open Burning and PCDD/F Emissions From Uncontrolled, Domestic Waste Burning¹. The emission factors used are shown in Table 3.1.5.

Estimates for total non-metal gas emissions associated with open burning of waste are shown in Table 3.1.6. Table 3.1.7 contains estimates for emissions of dioxins/furans associated with open burning of waste. There likely are water pollutants associated with the ash residues from open burning. However, no emission factors were found to characterize these potential emissions.

Table 3.1-5 Open Burning Non-Metal Emissions Factors Applied

Pollutant	Emission Factors	Units
PM	7.3	kg/ton
SO _x	0.5	kg/ton
NO _x	2.7	kg/ton
CO	38.6	kg/ton
CH ₄	5.9	kg/ton
Dioxin/Furans	35,196	Ng/kg

¹ Gullett, B. K. , P. Lemieux, C . Winterrowd, D . Winters. 2000. PC DD/F Emissions from Uncontrolled, Domestic Waste Burning. Presented at Dioxin '00, 20th International Symposium on Halogenated and Environmental Organic Pollutants & POPs, held Aug 13-17 at Monterey, CA. Corrected revision of short paper in Organohalogen Compounds 46: 193-196.

Table 3.1-6 Unit Non-Metal Emissions from Open Burning of Waste

City	Unit Non-Metal Emissions (kg/ton)						Total Carbon Emissions (MTCE/yr)
	PM	SO _x	NO _x	CO	CO ₂	CH ₄	Carbon
Kathmandu	7.94	0.50	2.98	42.16	184.76	6.45	0.09
Conakry	7.92	0.50	2.97	42.08	127.80	6.44	0.08
Lahore	7.92	0.50	2.97	42.08	207.38	6.44	0.10
Sarajevo	7.95	0.50	2.98	42.23	121.84	6.46	0.07
Amman	7.94	0.50	2.98	42.19	374.95	6.45	0.14
Buenos Aires	7.94	0.50	2.98	42.20	318.40	6.45	0.13
Shanghai	7.92	0.49	2.97	42.06	455.06	6.43	0.17
Kawasaki	7.93	0.50	2.97	42.12	240.99	6.44	0.11
Atlanta	7.88	0.49	2.96	41.89	406.05	6.41	0.15

Table 3.1-7 Annual Non-Metal Emissions from Open Burning of Waste

City	Unit Non-Metal Emissions (lb pollutant/year)						Total Carbon Emissions (MTCE/yr)
	PM	SO _x	NO _x	CO	CO ₂	CH ₄	Carbon
Kathmandu	1,272,306	79,519	477,115	6,759,124	29,618,537	1,033,748	14,709
Conakry	743,515	46,470	278,818	3,949,925	11,997,781	604,106	7,133
Lahore	10,522,512	657,657	3,945,942	55,900,845	275,531,539	8,549,541	130,075
Sarajevo	1,376,330	86,021	516,124	7,311,755	21,093,032	1,118,268	12,896
Amman	6,220,246	388,765	2,332,592	33,045,055	293,694,361	5,053,950	112,930
Buenos Aires	29,722,406	1,857,650	11,145,902	157,900,284	1,191,484,239	24,149,455	481,246
Shanghai	47,645,928	2,977,871	17,867,223	253,118,993	2,738,875,886	38,712,317	999,796
Kawasaki	4,143,514	258,970	1,553,818	22,012,416	125,944,770	3,366,605	56,027
Atlanta	6,256,433	391,027	2,346,162	33,237,299	322,206,706	5,083,352	120,971

Table 3.1-8 Dioxin/Furan Emissions from Open Burning of Waste

City	Unit Dioxin/Furan Emissions (kg/ton)	Annual Dioxin/Furan Emissions (kg/year)
Kathmandu	3.93E	6
Conakry	3.83E	4
Lahore	3.83E	51
Sarajevo	3.90E	7
Amman	3.85E	30
Buenos Aires	3.85E	144
Shanghai	3.83E	230
Kawasaki	3.87E	20
Atlanta	3.80E	30

3.2 Mixed Waste Collection and Management Using One Primary Technology

3.2.1 Simulation Scenario Results Using One Primary Technology

This section of the report presents and explains the results of the waste management simulation scenarios introduced in Section 2.2. These simulation scenarios correspond to the Group 2 scenarios under Table 2.2.1 and Figure 2.2.2. They are hypothetical, meaning that they are not a representation of the waste management situation in any of the cities in this analysis, but are tailored to meet the objectives of this study. Special emphasis is made on detailing these results since they will aid understanding the optimization scenario results in Section 3.3. Each simulation scenario entails collecting and sending all MSW to one waste management process:

- Recycling Using Manual Sorting
- Recycling Using Mechanical Sorting
- Mixed Waste Composting Using Manual Turning
- Mixed Waste Composting Using Mechanical Windrow Turner
- Incineration Without Energy Recovery
- Incineration With Energy Recovery
- Landfill With Gas Venting
- Landfill With Gas Collection And Flaring
- Landfill With Gas Collection And Energy Recovery

To the extent possible, the results are presented in graphical format with the cities organized according to their present income level from lowest to highest. As discussed in Section 2, energy consumption is used as a general indicator for key air pollutants including CO, NO_x, PM, and SO_x. Carbon emissions are also presented due to their contribution to the greenhouse effect.

When comparing the behavior of the simulation results across cities, it is usually helpful to determine the process having the largest impact on the net total results and the parameters governing the results for that process. For this purpose, Table 3.2.1 presents the key data inputs by waste management process and summarizes their effects on the cost, energy and emissions results. For example, according to Table 3.2.1 a recyclable price is a key input parameter for its impact in the cost results. This parameter does not affect the cost results from collection, composting, or landfill disposal, but it does play an important role in the

recycling and incineration results. High recyclable prices usually result in low net total costs from recycling and incineration (ferrous material is recovered from incineration).

Table 3.2-1 Summary of the Significance of Key Input Parameters to the Scenario Results by Process*

Key Data Inputs	Collection	Recycling Using Manual and Mechanical Sorting	Composting Using Manual and Mechanical Windrow Turning		Incineration		Landfill Disposal		
			Manual	Mechanical Windrow	Without Energy Recovery	With Energy Recovery	With Gas Venting	With Gas Collection and Flaring	With Gas Collection and Energy Recovery
Net Total Cost									
Recyclables prices	no	yes, High→Low	no		yes (ferrous), High→Low		no		
Compost prices	no	no	yes, High→Low		no		no		
Electricity price	no	no	no		no		no	yes, High→Low	
Electricity cost	no	yes, High→High	yes, High→High		yes, High→High		yes, High→High	yes, High→High	
Diesel fuel cost	yes, High→High	no	no	yes, High→High	no		no		
Wage rates for labor	yes, High→High	yes, High→High	yes, High→High		Model default values were used for all cities		yes, High→High		
Collection vehicle usable capacity	yes, High→Low	no	no		no		no		
Multifamily collection locations	yes, High→High	no	no		no		no		
Incineration facility capital and O & M cost	no	no	no		yes, High→High		no		
Ash/LF capital and O & M cost	no	no	no		no		yes, High→High		
Net Total Energy Consumption									
Percentage of natural gas and distillate oil in electricity grid mix	no	yes, High→High	yes, High→High		yes, High→High	yes, High→Low	yes, High→High		yes, High→Low
Collection vehicle usable capacity	yes, High→Low	no	no		no		no		
Multifamily collection locations	yes, High→High	no	no		no		no		
Percentage of remanufactured aluminum and ferrous materials	no	yes, High→Low	no		yes, High ferrous→High		no		
Waste heating value	no	no	no		no	yes, High→Low	no	yes, High→Low	

Key Data Inputs	Collection	Recycling Using Manual and Mechanical Sorting	Composting Using Manual and Mechanical Windrow Turning		Incineration		Landfill Disposal		
			Manual	Mechanical Windrow	Without Energy Recovery	With Energy Recovery	With Gas Venting	With Gas Collection and Flaring	With Gas Collection and Energy Recovery
Net Total Emissions									
Percentage of residual oil and coal in electricity grid mix	no	yes, High→High	yes, High→High		yes, High→High	yes, High→Low	yes, High→High		yes, High→Low
Collection vehicle usable capacity	yes, High→Low	no	no		no		no		
Multifamily collection locations	yes, High→High	no	no		no		no		
Percentage of remanufactured metals and plastics	no	yes, High→Low	no		yes, High ferrous→Low		no		
Compost residence time and turning frequency	no	no	yes, High→High		no		no		
Percentage of landfill disposed food waste and grass	no	no	no		no		yes, High→High		
Percentage of incinerated and metals	no	no	no		yes, High→High		no		

*yes/no: whether the input parameter contributes to the LCI Results (cost, energy, or emissions) from the corresponding process, High/Low: refers to the relative magnitude of the input parameter, →High/Low: refers to the relative magnitude of the LCI result as a results of the relative magnitude of the input parameter.

3.2.2 Recycling Using Manual and Mechanical Sorting

There are a wide range of designs for MRFs. In this study, we focus on two basis design variations: manual and mechanical sorting. The scenarios modeled assume mixed waste is collected in a single-compartment vehicle and sent to a mixed waste MRF that uses either manual sorting or one that uses mechanical sorting. Both the manual and mechanical sort design options assume a materials separation efficiency² of 55%. Results from these scenarios are recorded in Figure 3.2-1 Net Total Cost by City (with Land Price) Figure 3.2-4 Net Total Cost by City (without Land Price), Figure 3.2-7 Net Total Energy Consumption by City, and Figure 3.2-10 Net Total Carbon Emissions by City. Each figure shows the results for the nine cities under analysis on a per ton basis (i.e., the net total cost/energy/emissions divided by the amount of waste generated in each city).

To aid the analysis, the recycling results were further broken down by processes (i.e., collection, MRF, remanufacturing, landfill disposal, and transportation) dividing the net totals from each process by the amount of waste managed by that process as shown in Figures 3.2-2, 3.2-3, 3.2-5, 3.2-6, 3.2-8, 3.2-9, 3.2-11 and 3.2-12. It should be noted that the values in the last figures cannot be summed to obtain the Net Totals by City in Figures 3.2-1, 3.2-4, 3.2-7 and 3.2-10, since the result of this sum will be on a per ton of waste as generated and not as managed by a mix of different processes.

Table 3.2-2 indicates how much waste is available for recycling and how much waste goes to each of the management processes. This table is sorted in descending order by percentage of material sent to the remanufacturing process. Having a low recyclables recovery rate most of the waste in the cities goes to the landfill rather than remanufacturing. The same recovery rate applies to the manual and the mechanical MRFs. Therefore, there are not differences in the percentage of waste going to the different processes between the manual and the mechanical designs.

Table 3.2-2 Percentage of Available Recyclables* and Flow to the Different Processes

Cities	Percentage of Available Recyclables (a)	Waste Flow	
		Material Recovered (a x 55%)	Residuals Disposed
Kawasaki	36.55%	20.10%	79.90%
Atlanta	32.39%	17.81%	82.19%
Buenos Aires	31.07%	17.08%	82.92%
Amman	29.17%	16.03%	83.97%
Shanghai	22.84%	12.56%	87.44%
Conakry	19.80%	10.89%	89.11%
Kathmandu	15.72%	8.65%	91.35%
Sarajevo	12.76%	7.02%	92.98%
Lahore	12.38%	6.80%	93.20%

² The separation efficiency defines the amount of recyclables that get separated from the mixed waste and sent to a remanufacturing facility. At both, the manual and the mechanical sorting MRF, corrugated cardboard and newspaper are the only paper categories separated and sent to remanufacturing.

*Not including non-paper compostable items.

In general the cost results do not show a clear correlation with the cities socio-economic groups defined by their income level (e.g. Kathmandu has the lowest income level and Atlanta has the highest income level). Cost data inputs (e.g., capital, O&M, and energy costs, recyclables prices and wage rates for labor at the MRF) were not available for all the cities. Therefore, cost variations observed in the results among cities in the same socio-economic group may not accurately reflect reality. Cost data availability varies among the different cities (see Table 2.52). For example, Lahore is one a city that can be characterized as having poor data availability, while the city of Atlanta can be characterized as having good data availability.

Energy results are highly dependent on the waste composition and electricity grid mix of each city. For example, city with a higher percentage of metals available in its waste for recycling can also have large energy savings according to Table 2.5-5. Similarly, a city that relies on a fossil-fuel based electrical energy grid can have higher energy requirements than a city that relies on renewable or alternative fuel based electrical energy (see Table 2.5-3).

Similar to the energy results, carbon emission results mainly depend on the waste composition and the electricity grid mix of each city. For example, a large percentage of aluminum and plastic recyclables will produce large emission savings according to Table 2.5-6 and a mostly residual oil electricity grid mix will have the largest carbon emissions (see Table 2.5-4). The waste composition of the residuals going to a landfill is also very important and greater amounts of food waste and grass can produce greater amounts of landfill gas (see Table 2.5-7).

Cost variation by process design

Figures 3.2-1 and 3.2-4 show that there are very small differences in the cost per ton between a manual and a mechanical design and any differences are due to costs at the MRF (see the corresponding MRF values shown in Figures 3.2-2, 3.2-3, 3.2-5 and 3.2-6). MRFs using manual sorting are consistently more expensive due to additional labor requirements.

Cost variation by city

Figures 3.2-2, 3.2-3, 3.2-5 and 3.2-6 show that the key drivers behind the differences across cities are (1) the total cost per ton for landfill disposal using gas flaring, (2) the revenues obtained from recyclables sales, and (3) the costs incurred at the MRF. Kawasaki is the city with the largest collection cost and this can be attributed to having the highest wage rates for drivers and collectors along with a low usable capacity in its collection vehicles.

Kawasaki is also the city with the highest overall cost (see Figure 3.2-1) mainly from having the highest landfill capital (e.g., very high land prices) and electricity costs, very low recyclables prices, and the highest wage rates for labor at the MRF. On the other hand Buenos Aires and Atlanta are the cities with the lowest overall cost from having the highest recyclable prices. Cost variation

among the rest of the cities can be explained by looking at the total cost of landfill disposal and the revenues from recyclables sale (see Figures 3.2-2, 3.2-3, 3.2-5 and 3.2-6).

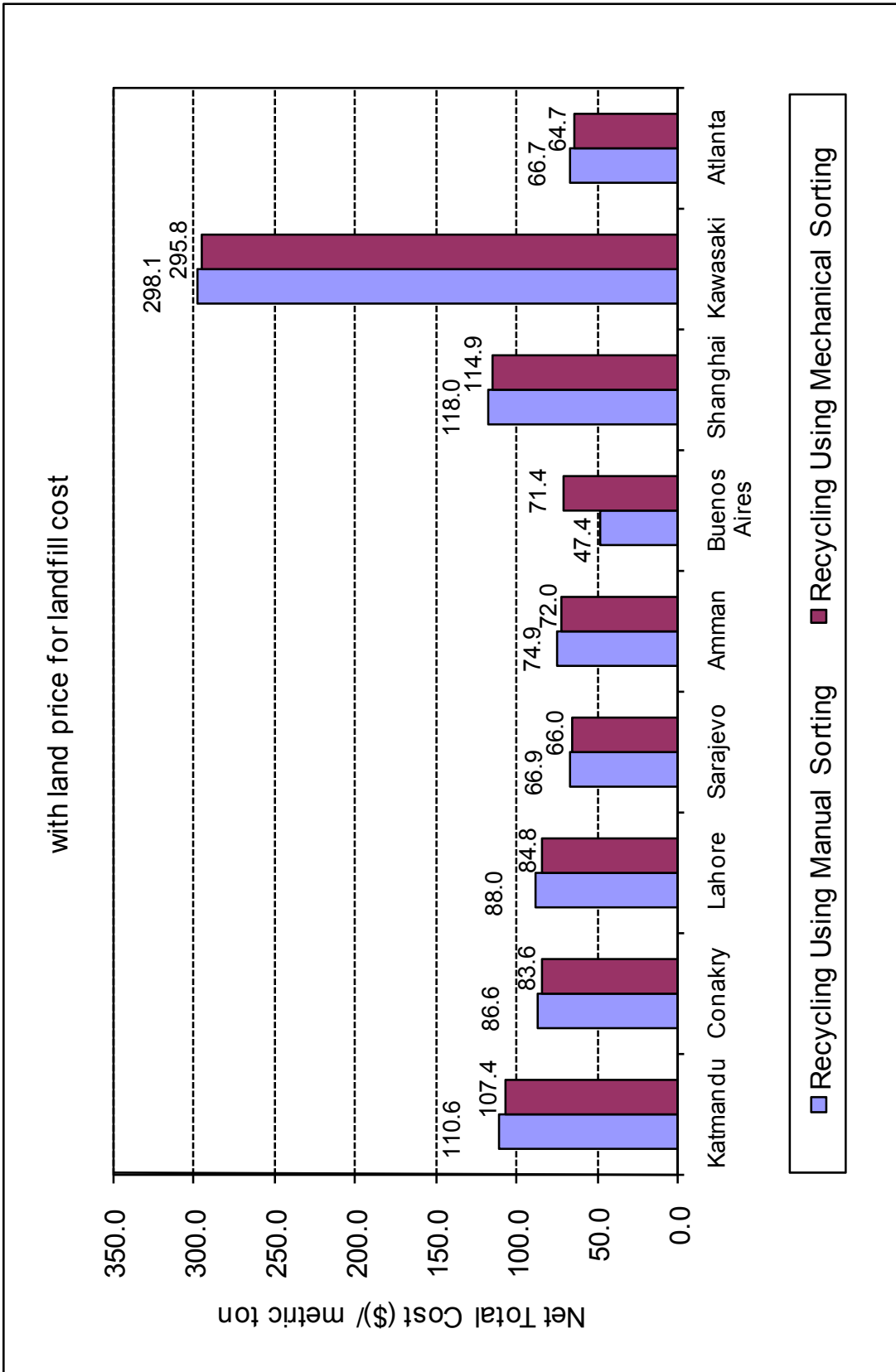


Figure 3.2-1 Net Total Cost by City (with Land Price)

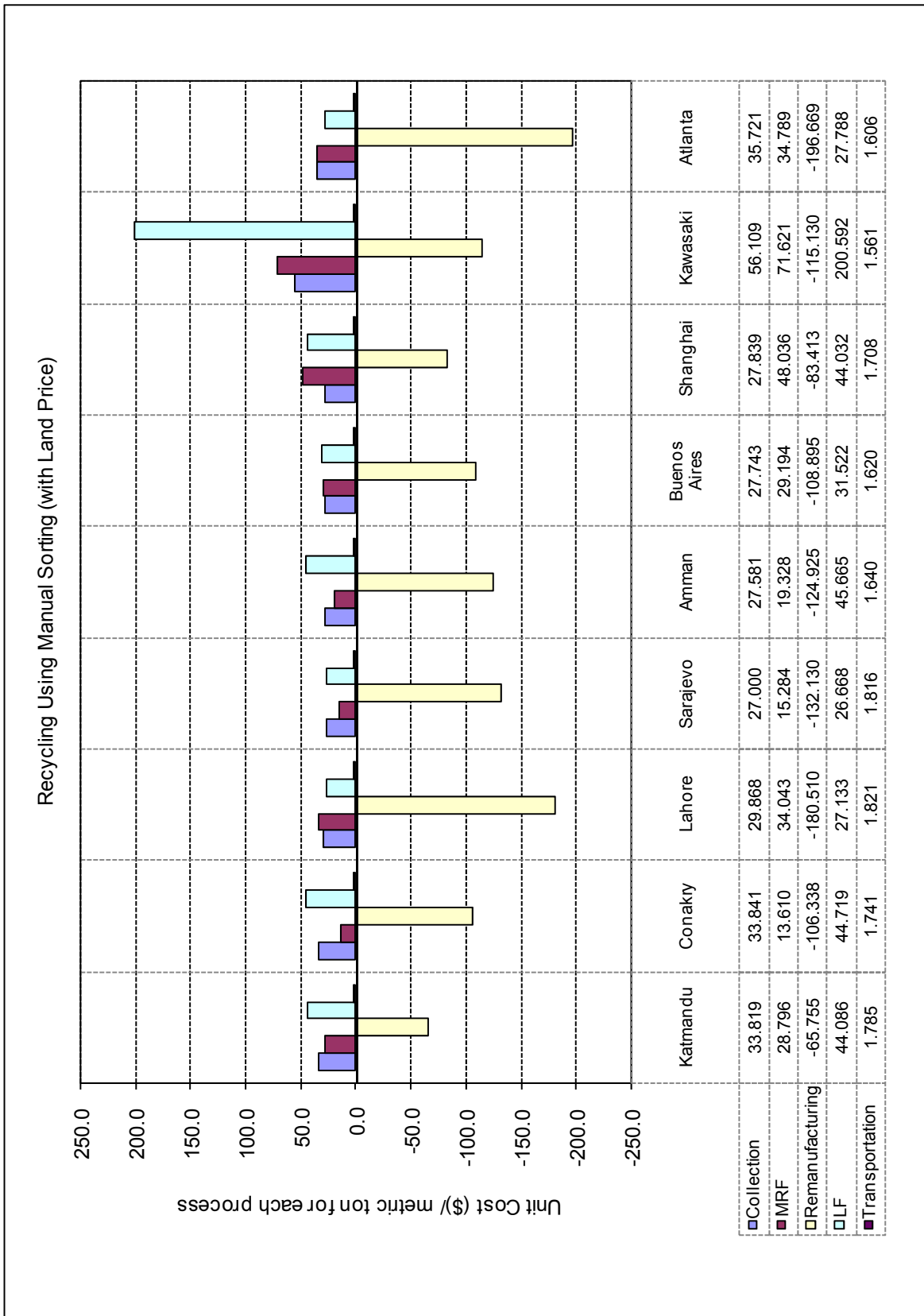


Figure 3.2-2 Unit Cost by City and Process (with Land Price: Manual MRF Design)

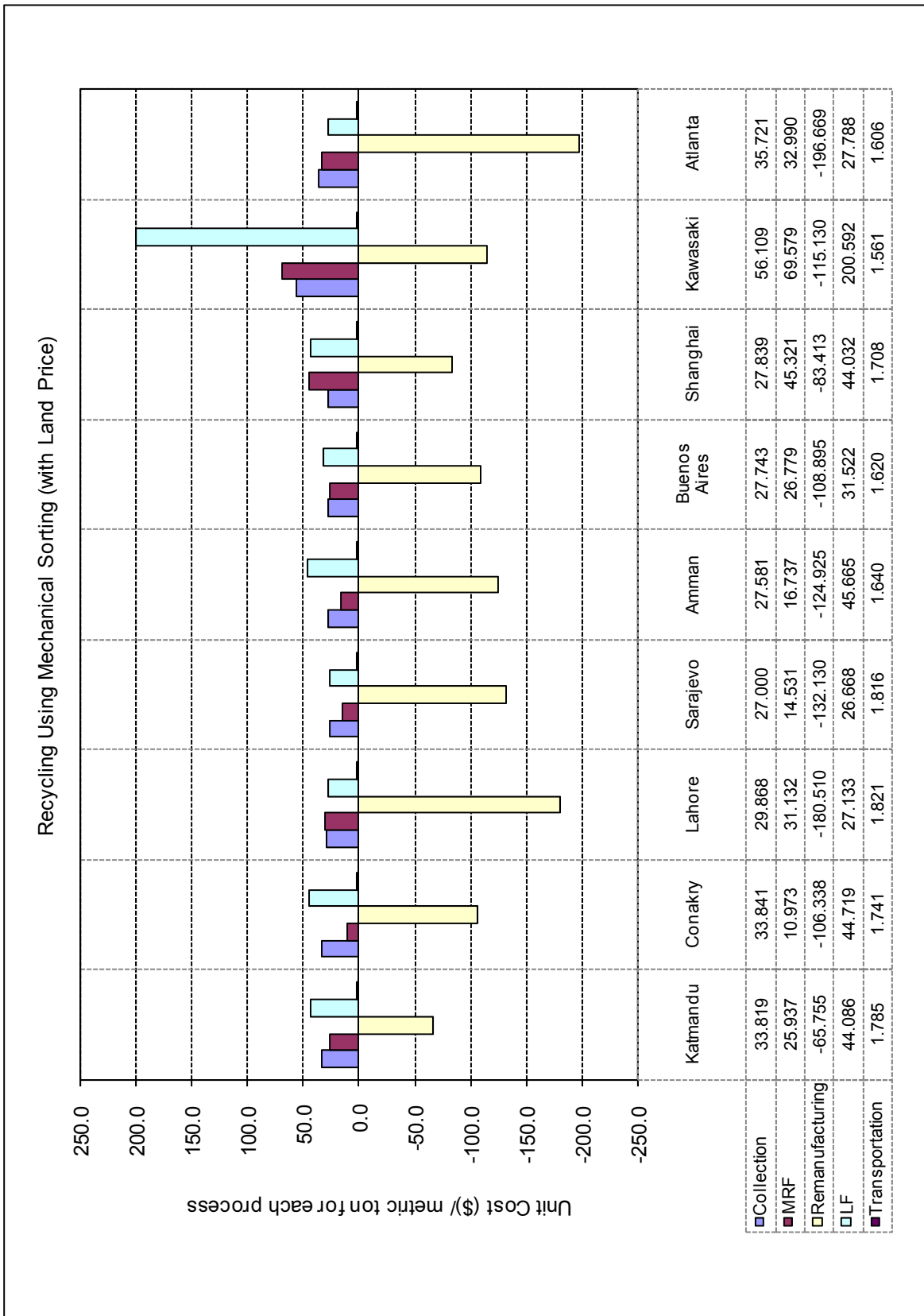


Figure 3.2-3 Unit Cost by City and Process (with Land Price: Mechanical MRF Design)

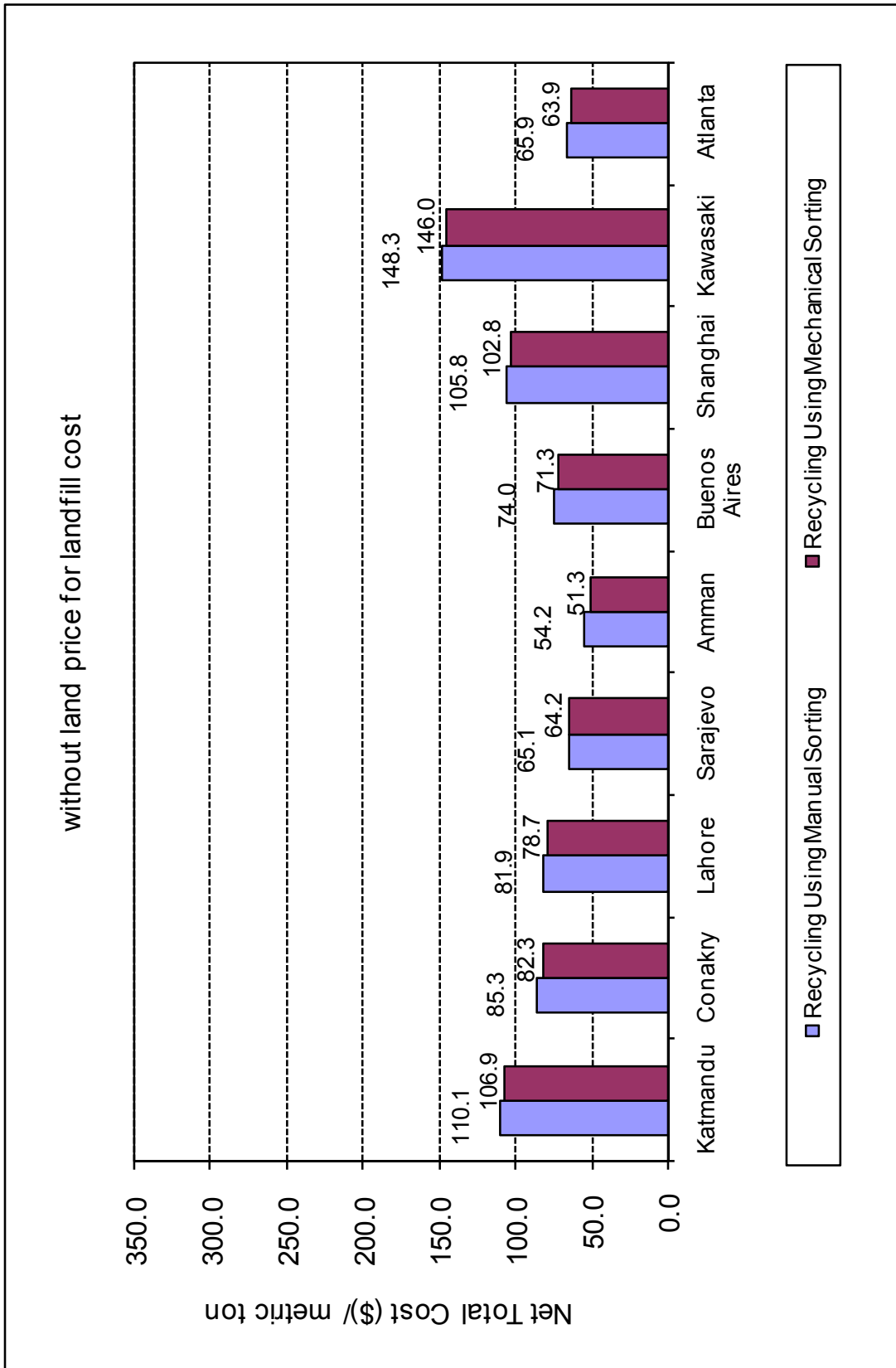


Figure 3.2-4 Net Total Cost by City (without Land Price)

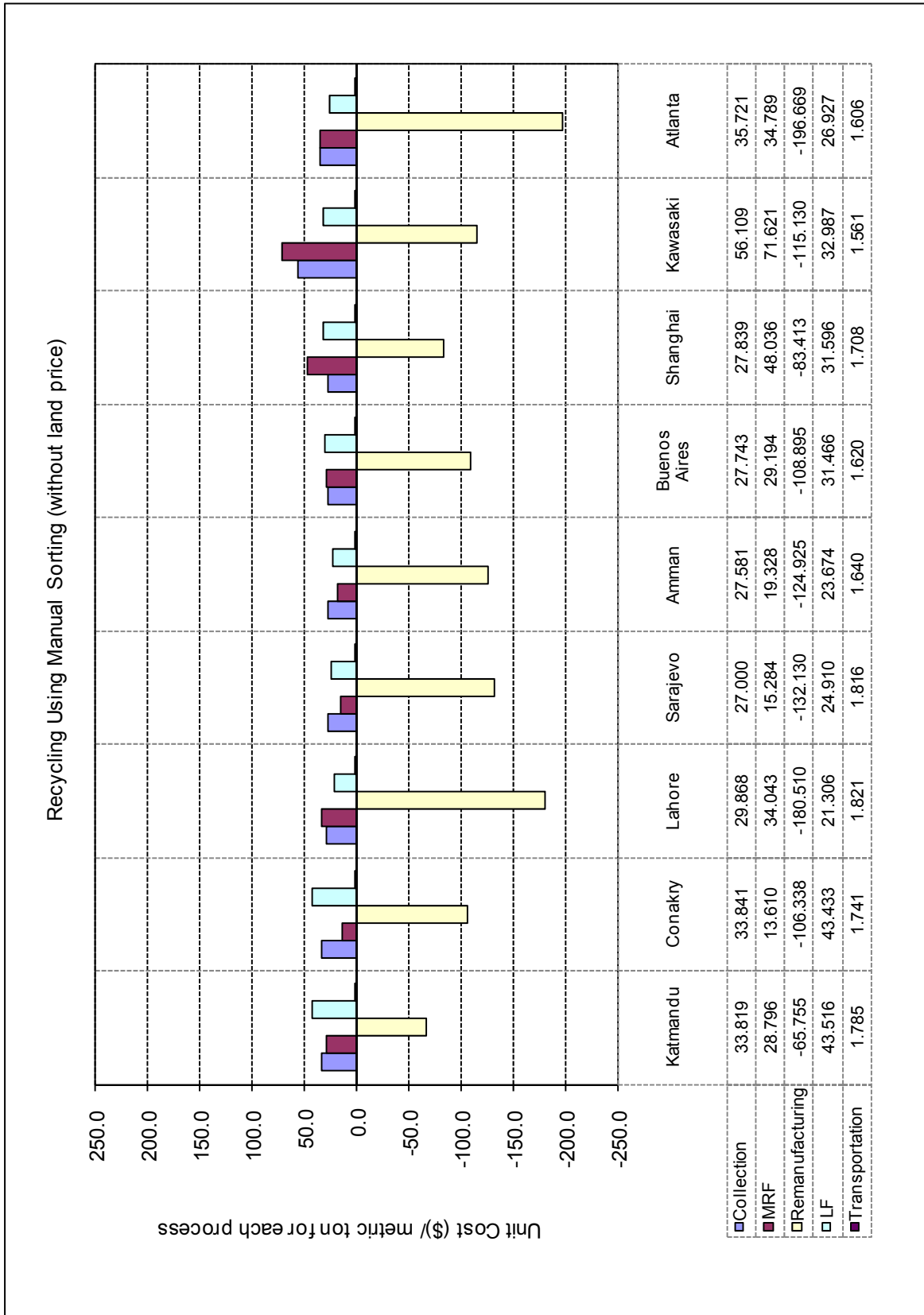


Figure 3.2-5 Unit Cost by City and Process (without Land Price: Manual MRF Design)

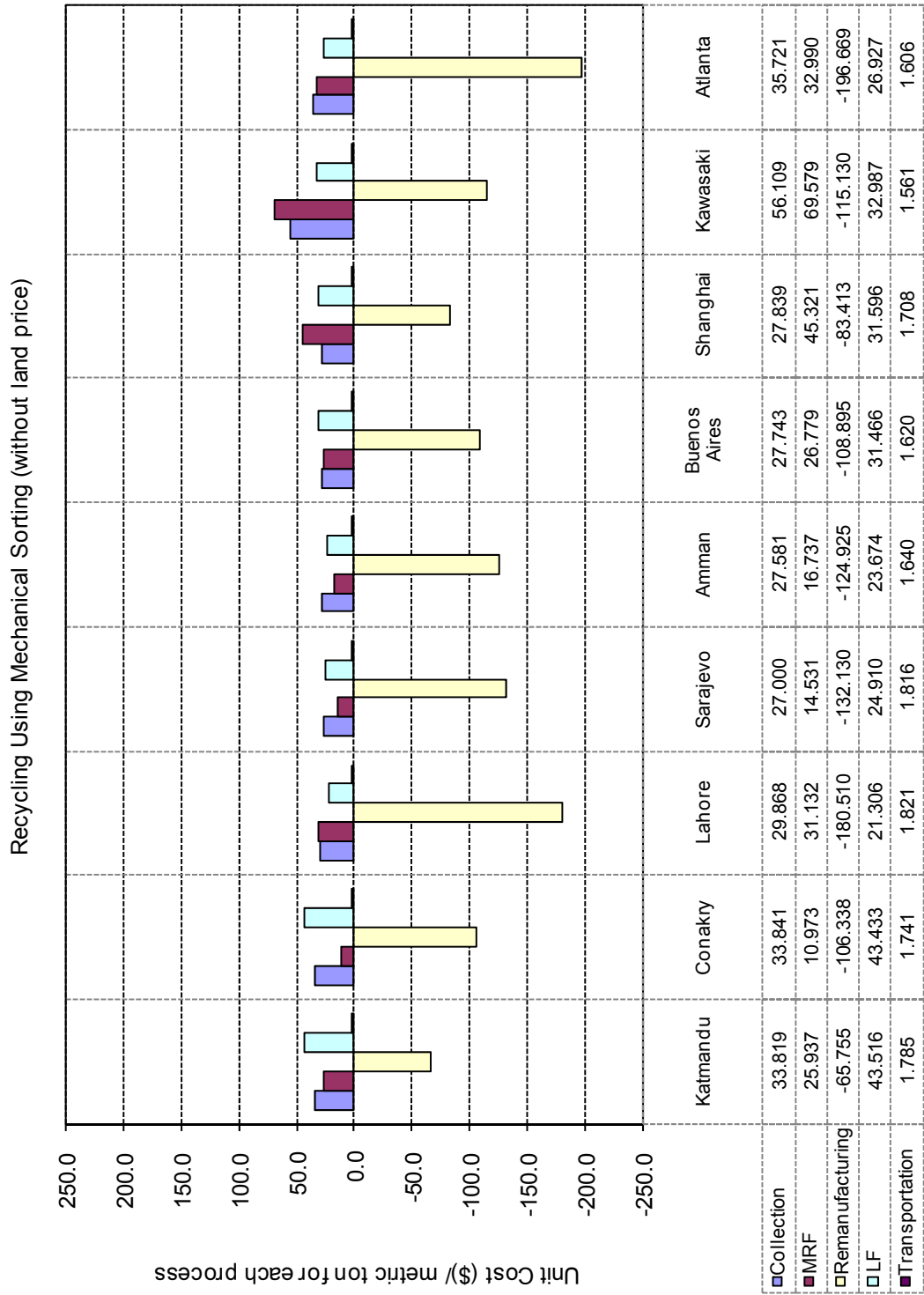


Figure 3.2-6 Unit Cost by City and Process (without Land Price: Mechanical MRF Design)

Energy variation by process design

Consistent with the cost results, Figure 3.2-7 shows that there are very small differences in the energy results between a manual and a mechanical design on a per ton basis and any differences are due to the energy requirements at the MRF (see the corresponding MRF values shown in Figures 3.2-8 and 3.2-9). As expected, MRFs using mechanical sorting have consistently higher energy requirements from the use of equipment.

Energy variation by city

Figures 3.2-8 and 3.2-9 show that the key driver behind the differences across cities is the energy savings from remanufacturing. Kawasaki is the city with the largest collection energy, mostly due to the low usable capacity (half of the usable capacity of other cities') in its collection vehicles, which increases the energy requirements associated with the vehicles fuel production.

Atlanta and Kawasaki are the cities with the highest energy savings (see Figure 3.2-7) consistent with having the highest amounts of recyclables sent to remanufacturing (see Table 3.2-2). The net energy variation among the cities is due to specific energy savings from individual recyclables. Table 3.2-3 shows the percentages of recyclables categories sent to remanufacturing in each of the cities. This table is sorted by percentage of metals since these are the recyclables that produce the highest energy savings. Then, Table 3.2-3 explains why Atlanta has higher energy savings than Kawasaki despite of having lower percentage of recyclables going to remanufacturing.

**Table 3.2-3 Percentage of Recyclable Items Recovered for Remanufacturing by City
(Sorted by Percentage of Total Metals)**

Cities	Organics		Inorganics			
	Paper	Plastics	Glass	Metals		Total
				Ferrous materials	Aluminum materials	
Atlanta	11.24%	1.37%	2.04%	2.39%	0.77%	3.16%
Kawasaki	9.45%	6.05%	2.68%	1.32%	0.60%	1.92%
Conakry	6.24%	2.62%	0.53%	1.50%	0.00%	1.50%
Buenos Aires	6.34%	6.67%	2.81%	0.73%	0.53%	1.26%
Lahore	1.30%	4.34%	0.67%	0.19%	0.29%	0.49%
Shanghai	2.29%	9.31%	0.76%	0.08%	0.12%	0.20%
Kathmandu	3.51%	3.78%	1.16%	0.19%	0.00%	0.19%
Amman	7.32%	7.65%	1.06%	0.00%	0.00%	0.00%
Sarajevo	4.11%	2.90%	0.00%	0.00%	0.00%	0.00%

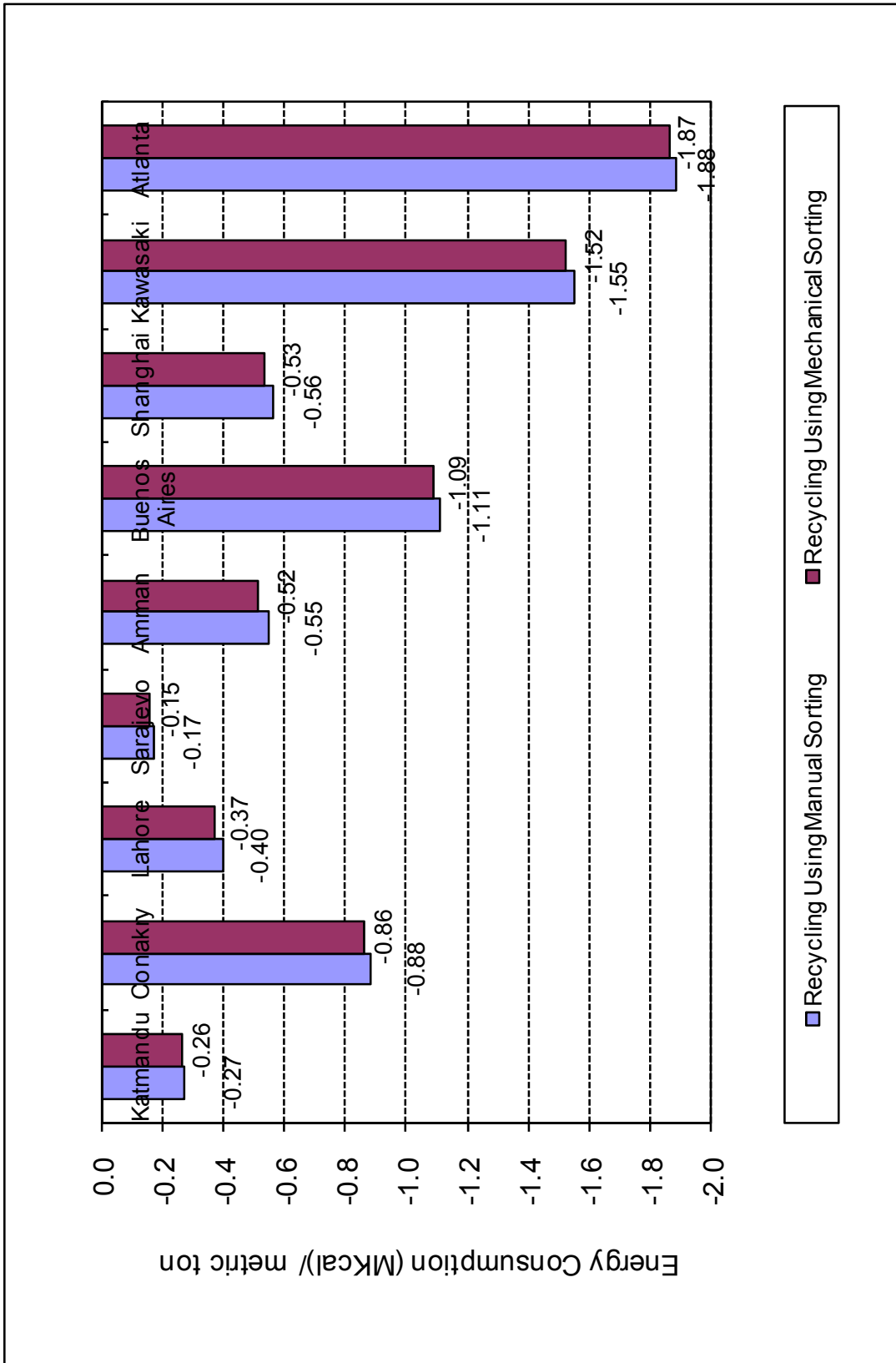


Figure 3.2-7 Net Total Energy Consumption by City

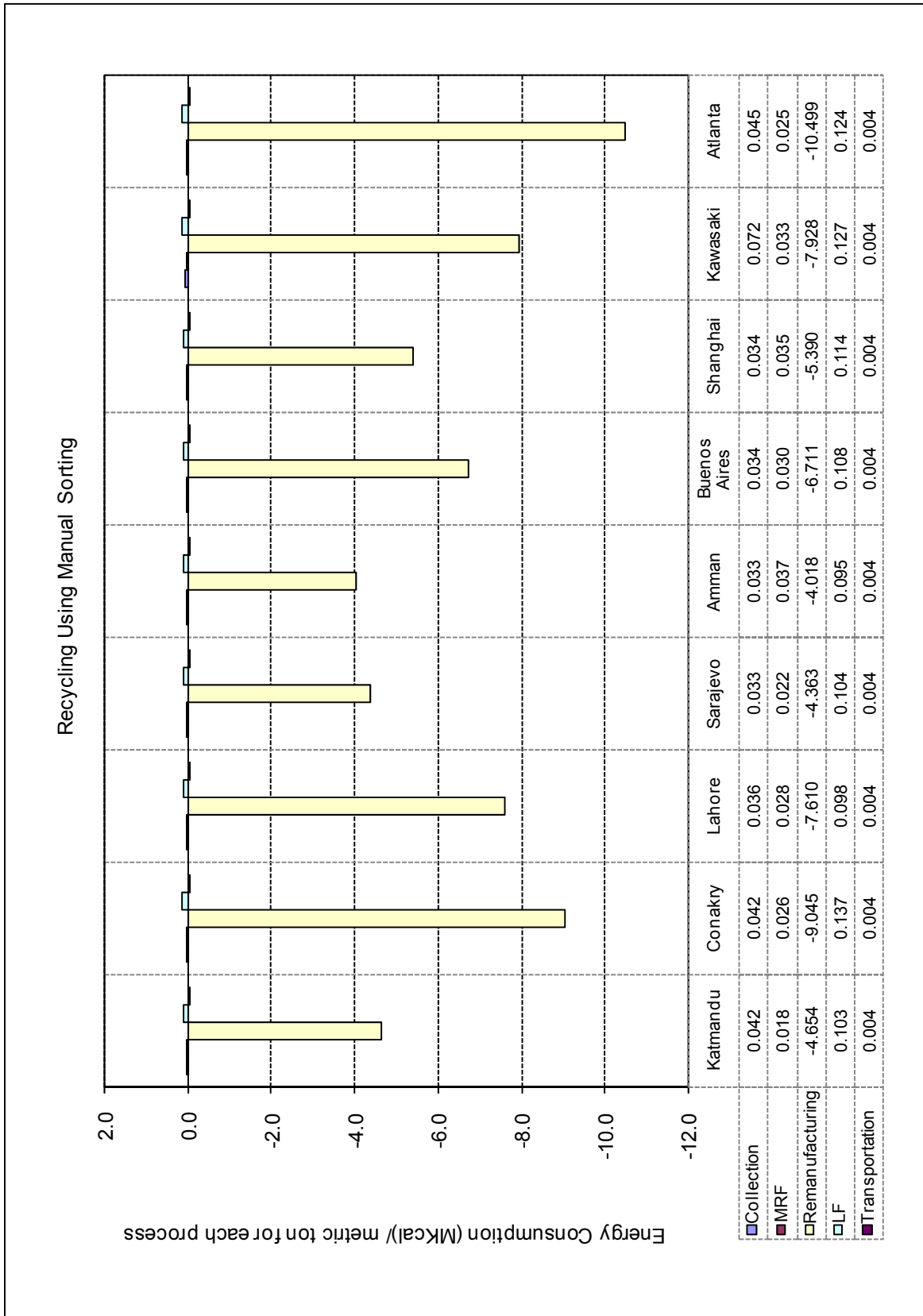


Figure 3.2-8 Energy Consumption by City and Process (Manual MRF Design)

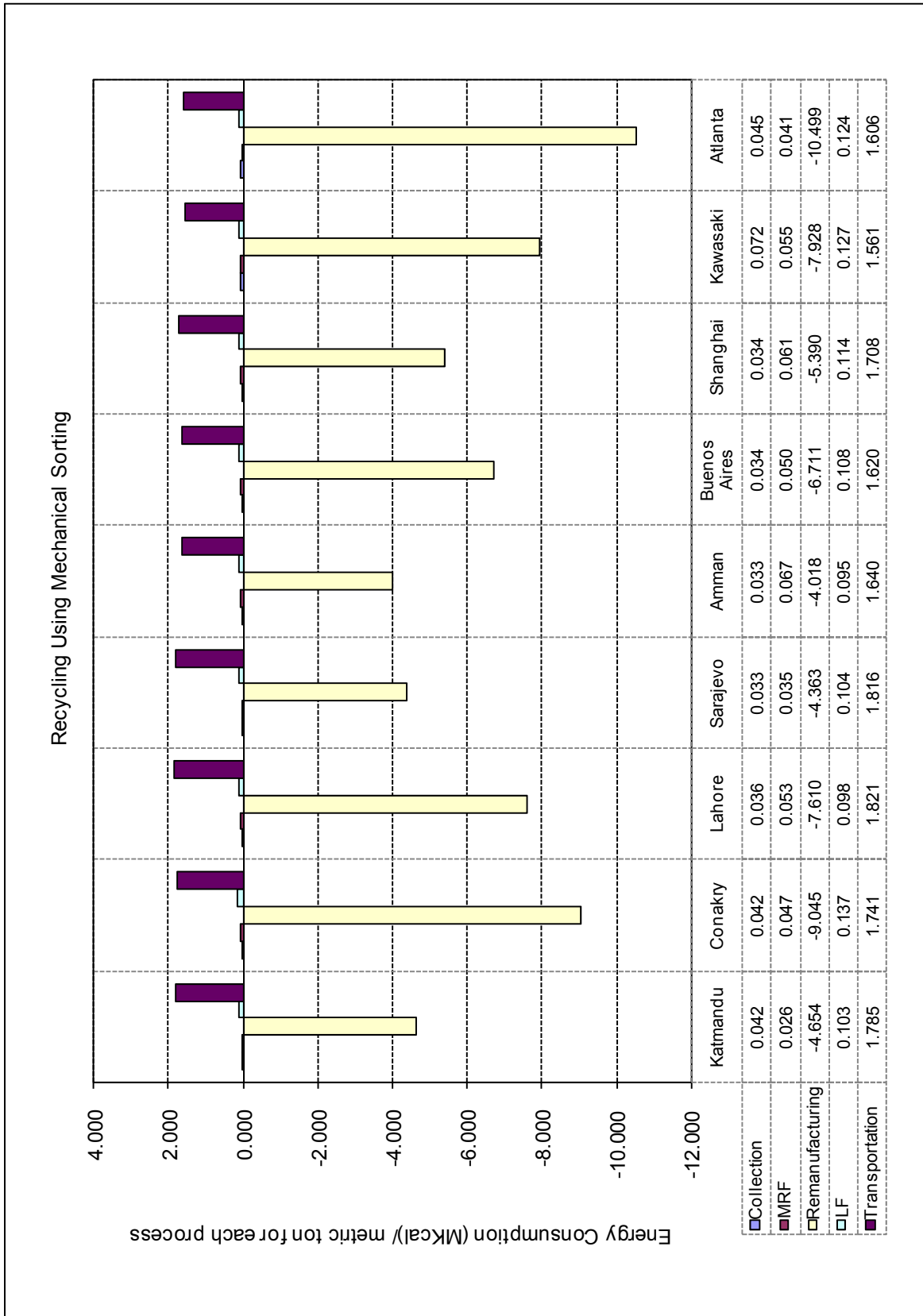


Figure 3.2-9 Energy Consumption by City and Process (Mechanical MRF Design)

Carbon emissions variation by process design

Of the three parameters reported (i.e., cost, energy, and carbon emissions), carbon emissions exhibits the largest variation between the manual and mechanical design options. Cities such Amman, Shanghai and Lahore show an order of magnitude difference between the emissions from a manual and a mechanical design (see the corresponding MRF values shown in Figures 3.2-11 and 3.2-12), with the mechanical design having consistently higher values. The magnitude of the difference can be explained by the emissions associated to the electricity grid mix in each of the cities. For example, Kathmandu exhibits an almost zero difference in the emissions since most of the electricity used at the MRF is hydro-electricity, is assumed to not have any associated GHG emissions. Cities with hydro-electricity in their grid mix exhibit a smaller variation in the emissions between the manual and the mechanical MRF than cities such Amman, Shanghai, and Lahore that rely on more fossil-fuel based electricity grids.

Carbon emissions variation by city

Figures 3.2-11 and 3.2-12 show that the key drivers behind the differences across cities are (1) the emission savings from remanufacturing and (2) the emissions at the landfill.

Buenos Aires is the city with the lowest overall emissions followed by Kawasaki, which is the city with the highest percentage of remanufactured material. This behavior is consistent with the amount of plastic and aluminum material remanufactured in each city. For example, according to Table 3.2-4 Buenos Aires has a higher percentage of plastic material than Kawasaki. In addition, Buenos Aires has a lower percentage of fossil fuels in its electricity grid mix when compared to Kawasaki, so its pre-combustion emissions at the MRF are less than Kawasaki's.

**Table 3.2-4 Percentages of Remanufactured Recyclables by City
(Sorted by Total Aluminum and Plastic)**

Cities	Organics		Inorganics			
	Paper	Plastics	Glass	Ferrous materials	Aluminum materials	Total Aluminum and Plastics
Shanghai	2.29%	9.31%	0.76%	0.08%	0.12%	9.43%
Amman	7.32%	7.65%	1.06%	0.00%	0.00%	7.65%
Buenos Aires	6.34%	6.67%	2.81%	0.73%	0.53%	7.20%
Kawasaki	9.45%	6.05%	2.68%	1.32%	0.60%	6.65%
Lahore	1.30%	4.34%	0.67%	0.19%	0.29%	4.63%
Kathmandu	3.51%	3.78%	1.16%	0.19%	0.00%	3.78%
Sarajevo	4.11%	2.90%	0.00%	0.00%	0.00%	2.90%
Conakry	6.24%	2.62%	0.53%	1.50%	0.00%	2.62%
Atlanta	11.24%	1.37%	2.04%	2.39%	0.77%	2.14%

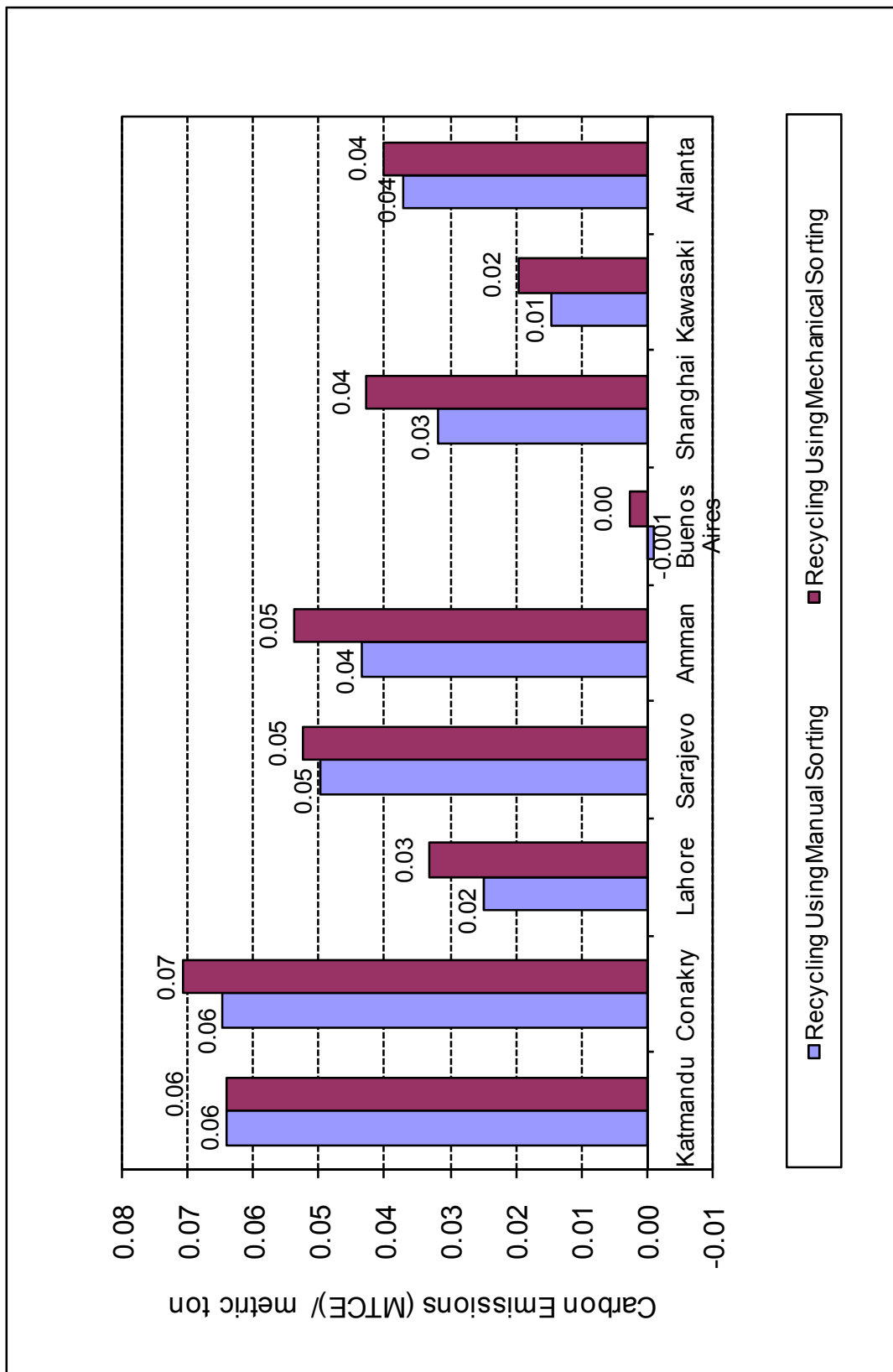


Figure 3.2-10 Net Total Carbon Emissions by City

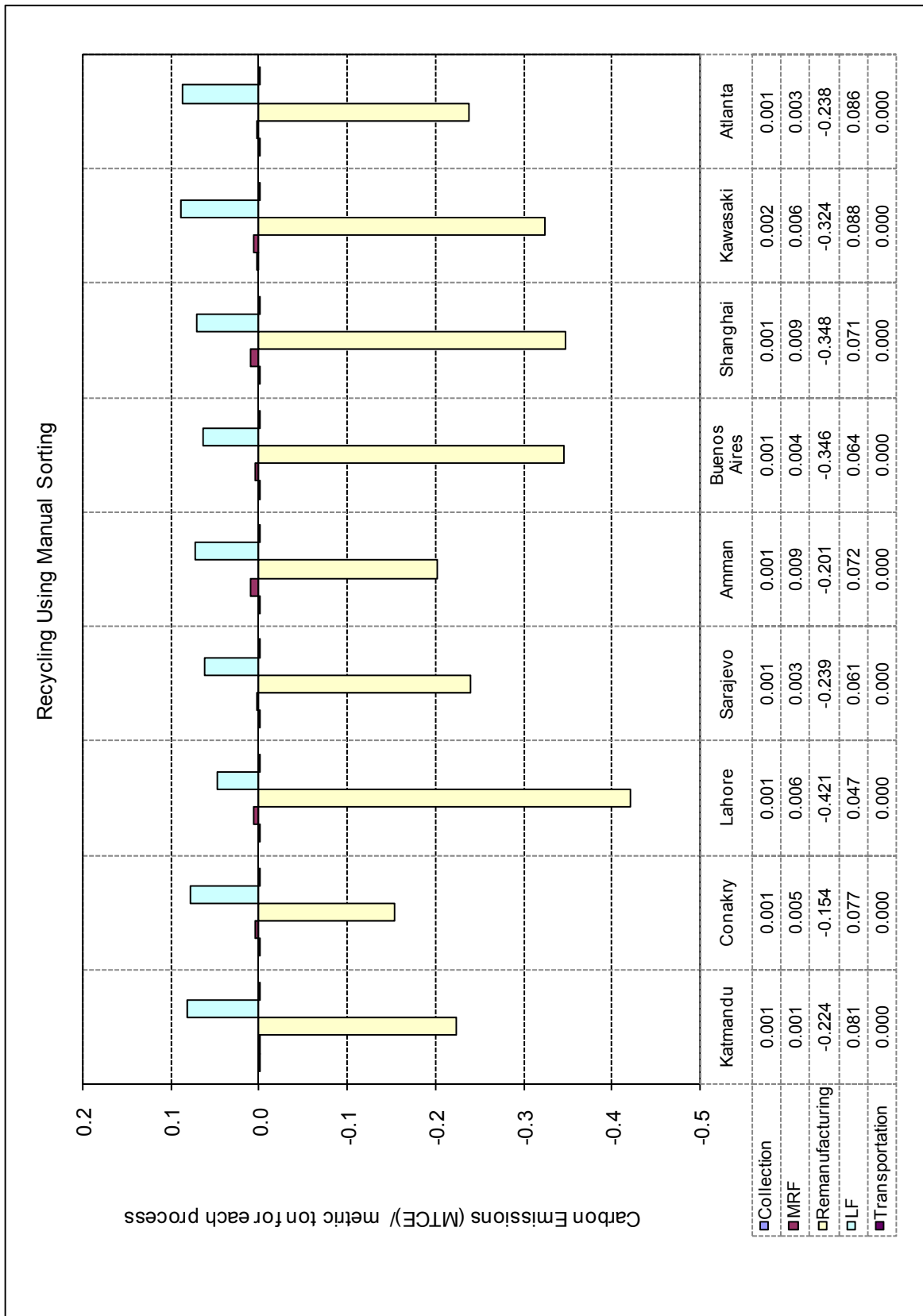


Figure 3.2-11 Carbon Emissions by City and Process (Manual MRF Design)

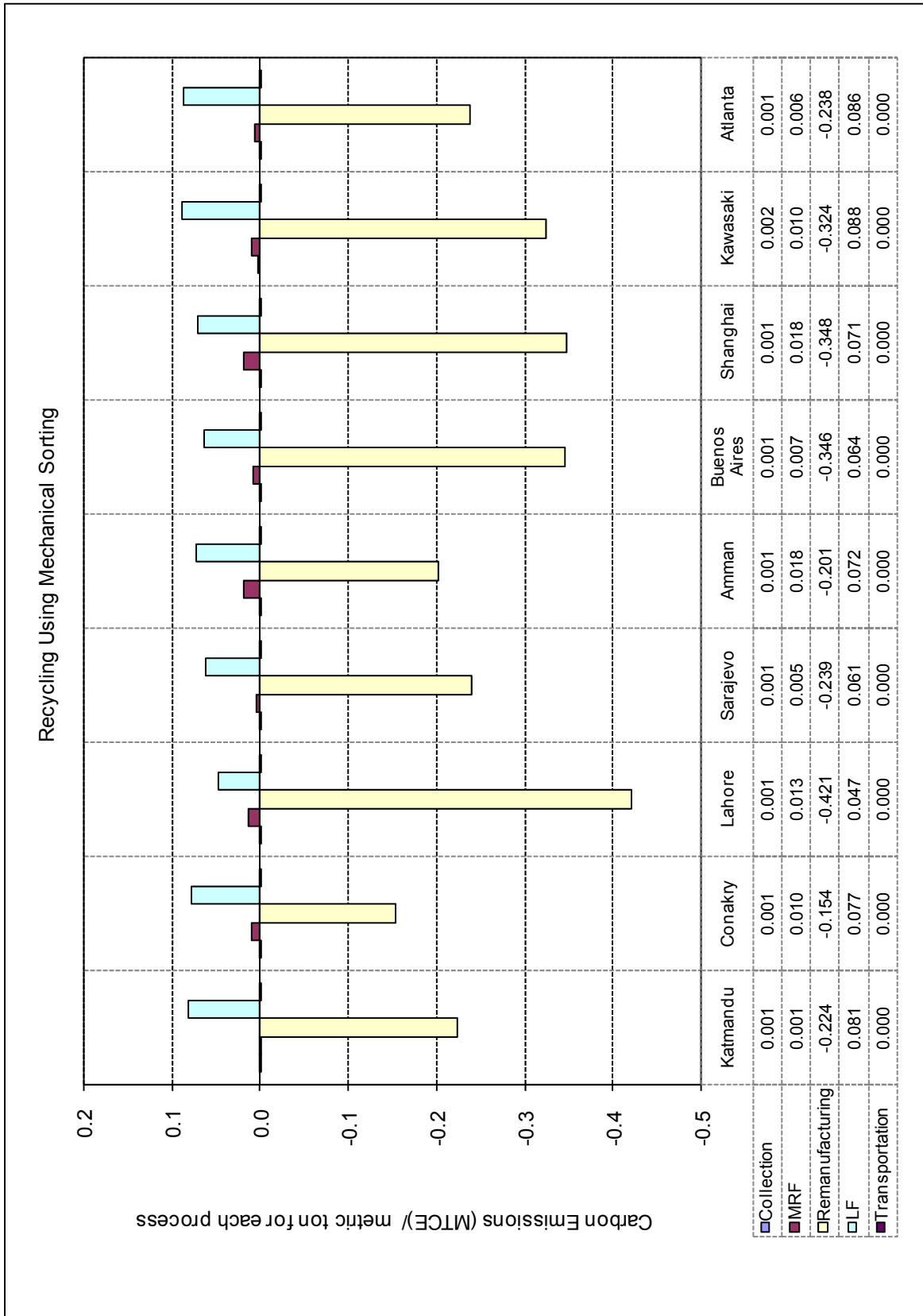


Figure 3.2-12 Carbon Emissions by City and Process (Mechanical MRF Design)

On the other hand, Conakry is the city with the highest overall emissions and even higher than Lahore, which is the city with the lowest percentage of recyclables being sent to remanufacturing. From looking at Table 3.2-4 Conakry has smaller amounts of aluminum and plastic material than Lahore, which begins to explain the differences in their overall emissions. Furthermore, Conakry has a larger percentage of fossil fuels (primarily oil) in its electricity grid mix.

Kathmandu has higher emissions than Sarajevo despite of having a higher percentage of aluminum and plastics and a hydro electricity grid mix. In this case, the emissions behavior is explained by looking at the percentage and composition of the residuals being sent to the landfill. Kathmandu has a higher percentage of landfill disposed residuals than Sarajevo and most of them are food waste, which have the highest landfill gas generation rate.

3.2.3 Mixed Waste Composting Using Manual Turning and Mechanical Windrow Turner

Two types of designs are considered for the composting scenarios: composting using manual pile turning and composting using a mechanical pile turner (i.e., a windrow turner). For these composting scenarios, mixed waste collected and sent to either a manual turning or a mechanical turner design. The overall results are recorded in Figure 3.2-13 Net Total Cost by City (with Land Price), Figure 3.2-16 Net Total Cost by City (without Land Price), Figure 3.2-19 Net Total Energy Consumption by City, and Figure 3.2-22 Net Total Carbon Emissions by City. Each figure shows the results for the nine cities under analysis on a per ton basis (i.e., the net total cost/energy/emissions divided by the amount of waste generated in each city).

To aid the analysis, the composting results were further broken down by processes (i.e., collection, composting, landfill disposal and transportation) dividing the net totals from each process by the amount of waste managed by that process as presented in Figures 3.2-14, 3.2-15, 3.2-17, 3.2-18, 3.2-20, 3.2-21 and 3.2-22. It should be noted that the values in the last figures cannot be summed to obtain the Net Totals by City in Figures 3.2-13, 3.2-16, 3.2-19 and 3.2-22, since the result of this sum will be on a per ton of waste as generated and not as managed by a mix of different processes.

For the composting scenarios, there is no product (e.g., fertilizer) that the compost product is assumed to displace because it is difficult to determine what exactly the compost product displaces, if anything. If the compost product can be shown to reduce the consumption of another product, then there would be an added environmental benefit associated with composting.

Table 3.2-5 indicates how much waste is available for composting and how much waste goes to each of the management processes. By design these scenarios aim to composting all the available organics. Therefore, the pre-screening inefficiencies of a conventional composting process were avoided by setting the pre-trommel efficiencies to 100% (i.e., all the available organics are separated and composted under these scenarios). Table 3.2-5 is sorted in descending order by percentage of material being composted. There are not differences in the percentage of waste going to the different processes between the manual and the mechanical windrow turner design.

**Table 3.2-5 Percentage of Compostable Organics and Waste Flow by City
 (Sorted by Percent of Organics Composted)**

Cities	Percentage of Organics Available for Composting (a)	Waste Flow	
		Composting (a x 100%)	Disposal
Kathmandu	81.68%	81.68%	18.32%
Kawasaki	71.70%	71.70%	28.30%
Shanghai	69.72%	69.77%	30.23%
Conakry	64.87%	64.87%	35.13%
Amman	62.06%	62.04%	37.96%
Buenos Aires	60.35%	60.35%	39.65%
Sarajevo	54.40%	54.44%	45.56%
Lahore	51.09%	51.11%	48.89%
Atlanta	47.98%	47.93%	52.07%

In general the composting cost results do not show a clear correlation with the cities socio-economic groups defined by their income level (e.g. Kathmandu has the lowest income level and Atlanta has the highest income level). Cost data inputs (e.g., landfill capital, O&M, and energy costs) were not consistently found for all the cities. Therefore, cost variations observed in the results among cities in the same socio-economic group may not accurately reflect reality.

Cost variation by process design

In Figures 3.2-14 and 3.2-15 (see the corresponding composting values) the costs for the mechanical windrow turner design are consistently 20-30% higher than those for the manual design. This range of variation mostly depends on each city’s diesel fuel price and electricity cost affecting the results of the mechanical windrow turner design.

Cost variation by city

Differences in the net total cost across cities can be explained by (1) the total cost per ton for disposal at a landfill using gas flaring and (2) net costs at the composting facility, which include the revenues from compost sale. Kawasaki is the city with the largest collection cost due to having the highest wage rates for drivers and collectors along with a low usable capacity in its collection vehicles.

When looking at costs across cities, Kawasaki, Conakry, and Sarajevo have the highest overall cost. This is primarily due to having the highest landfill capital (e.g., very high land price) and electricity costs in the case of Kawasaki and Sarajevo and having the highest equipment and maintenance costs in the case of Conakry. The overall costs for the other cities are very similar and the net costs at the composting facility play a very important role. Differences in the net costs from composting facilities across cities are due to differences in the overall cost of energy (i.e., diesel and electricity) and the revenues from compost sale.

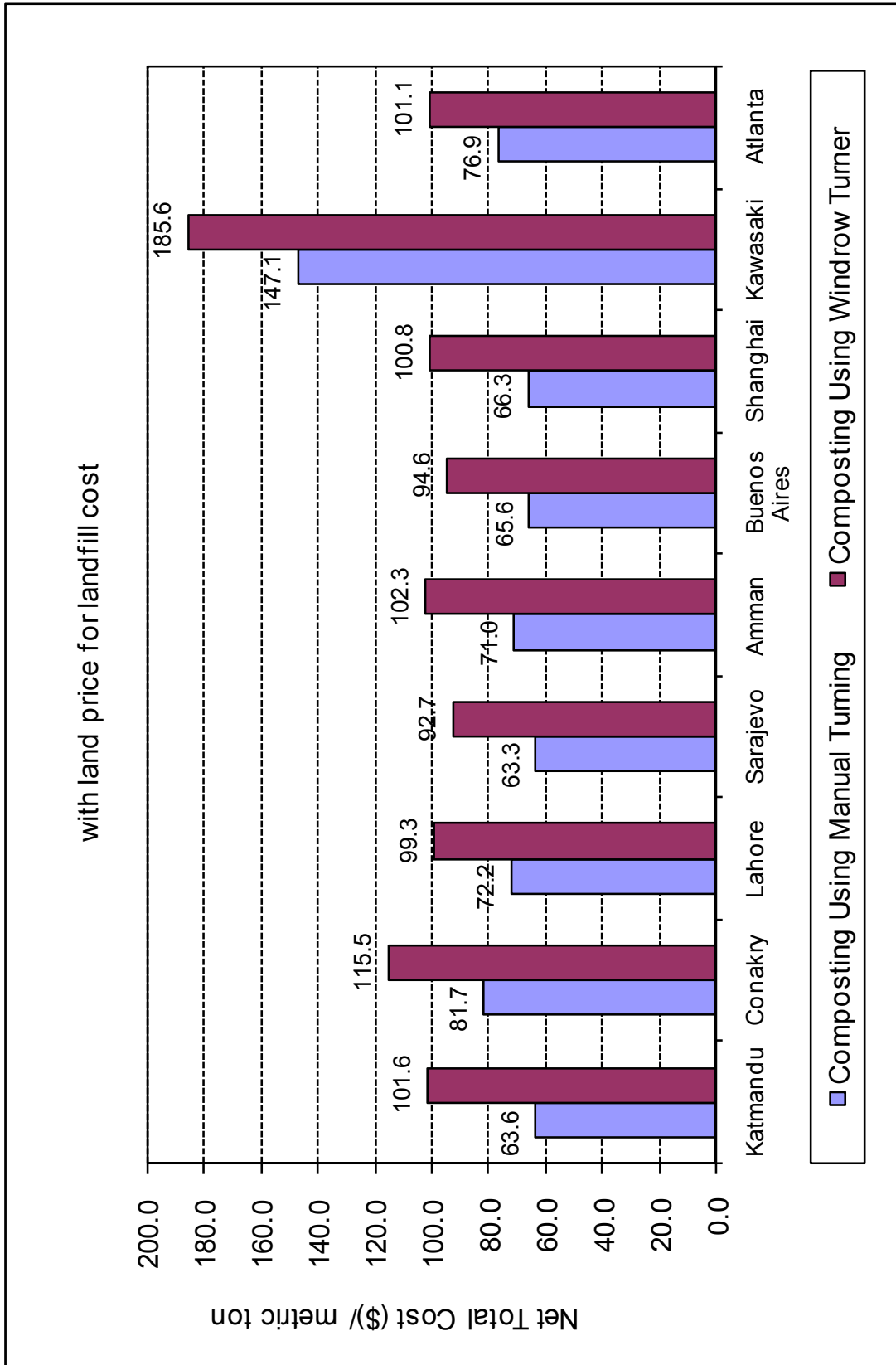


Figure 3.2-13 Net Total Cost by City (with Land Price)

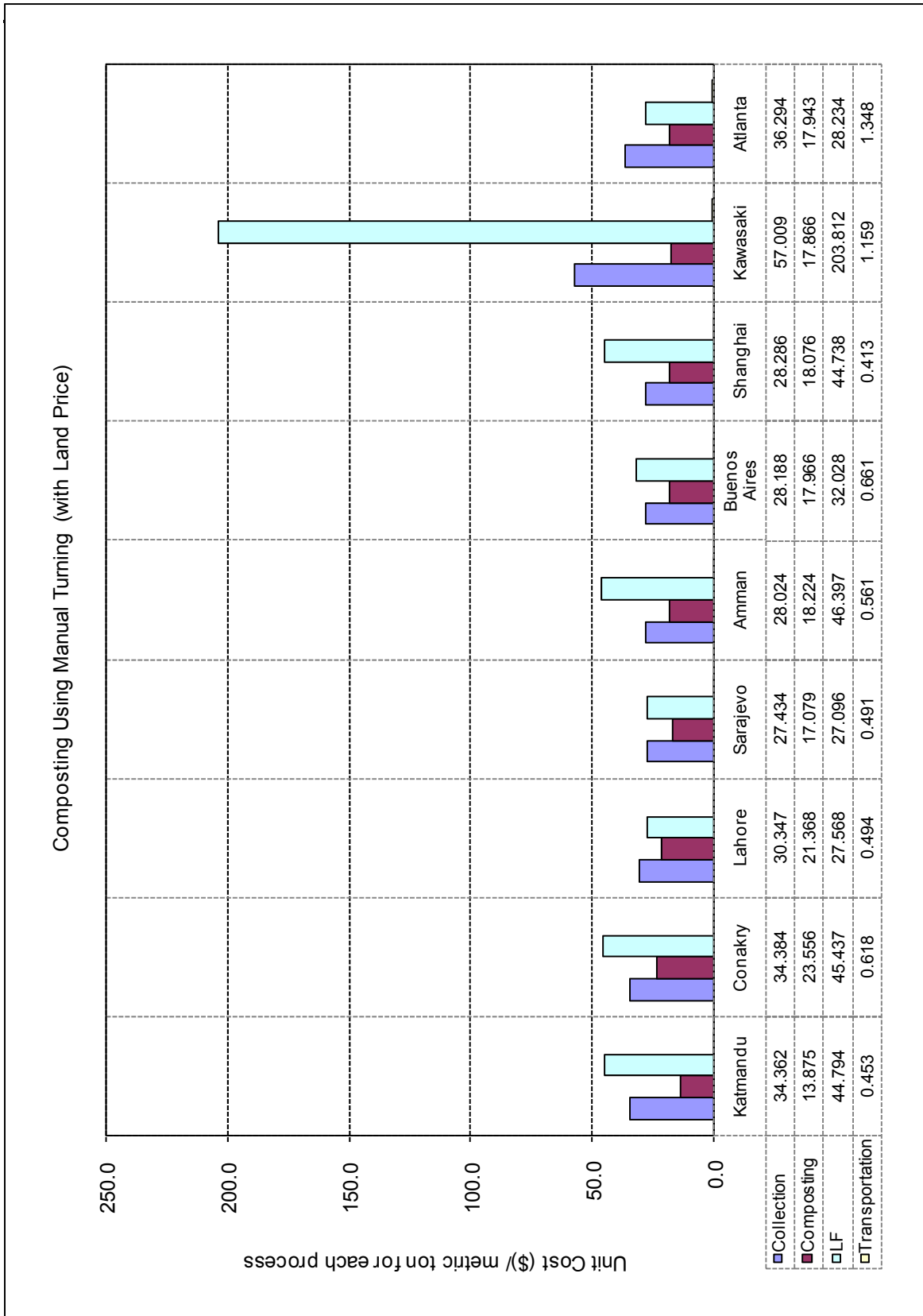


Figure 3.2-14 Unit Cost by City and Process (with Land Price: Manual Composting Design)

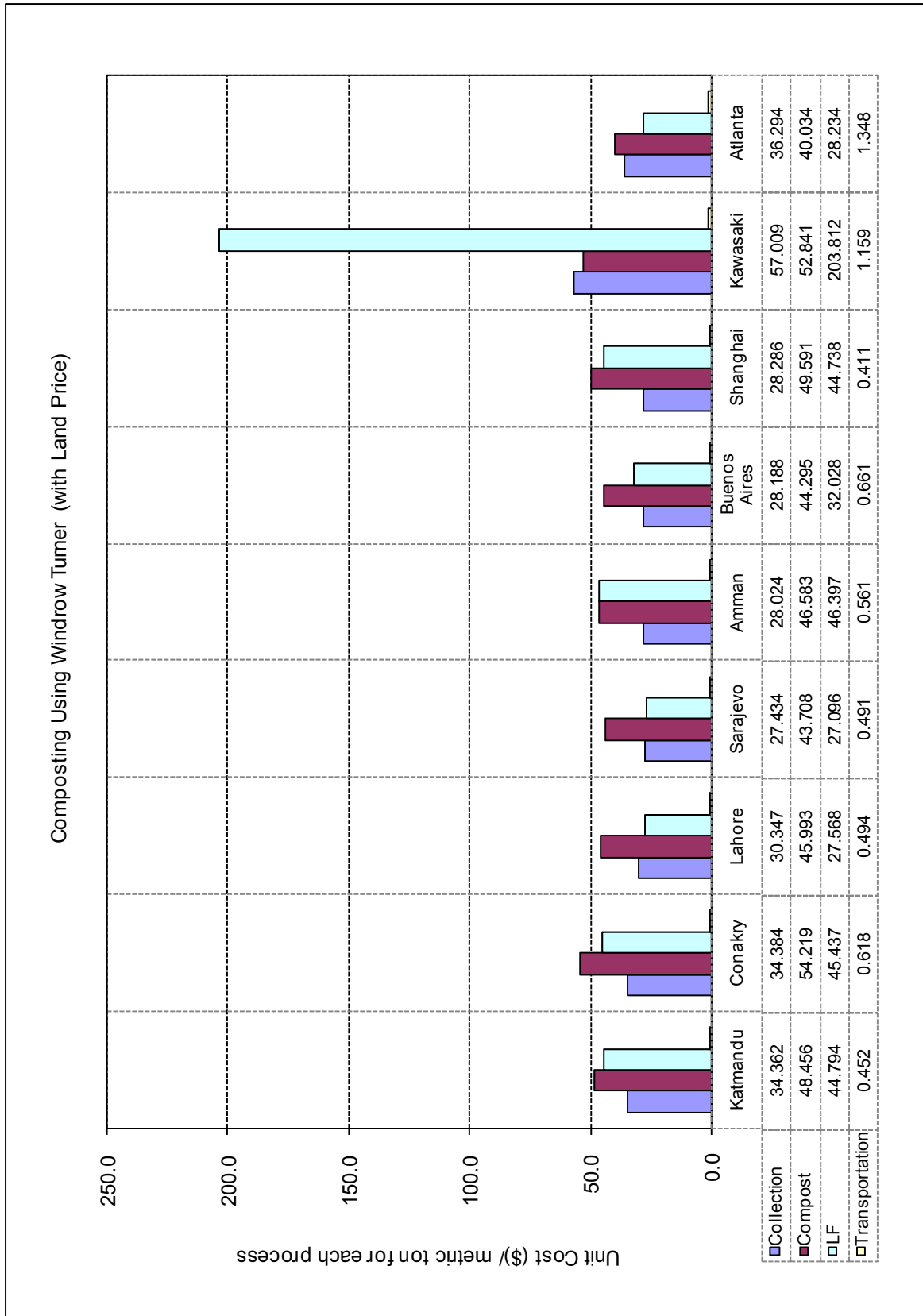


Figure 3.2-15 Unit Cost by City and Process (with Land Price: Mechanical Composting Design)

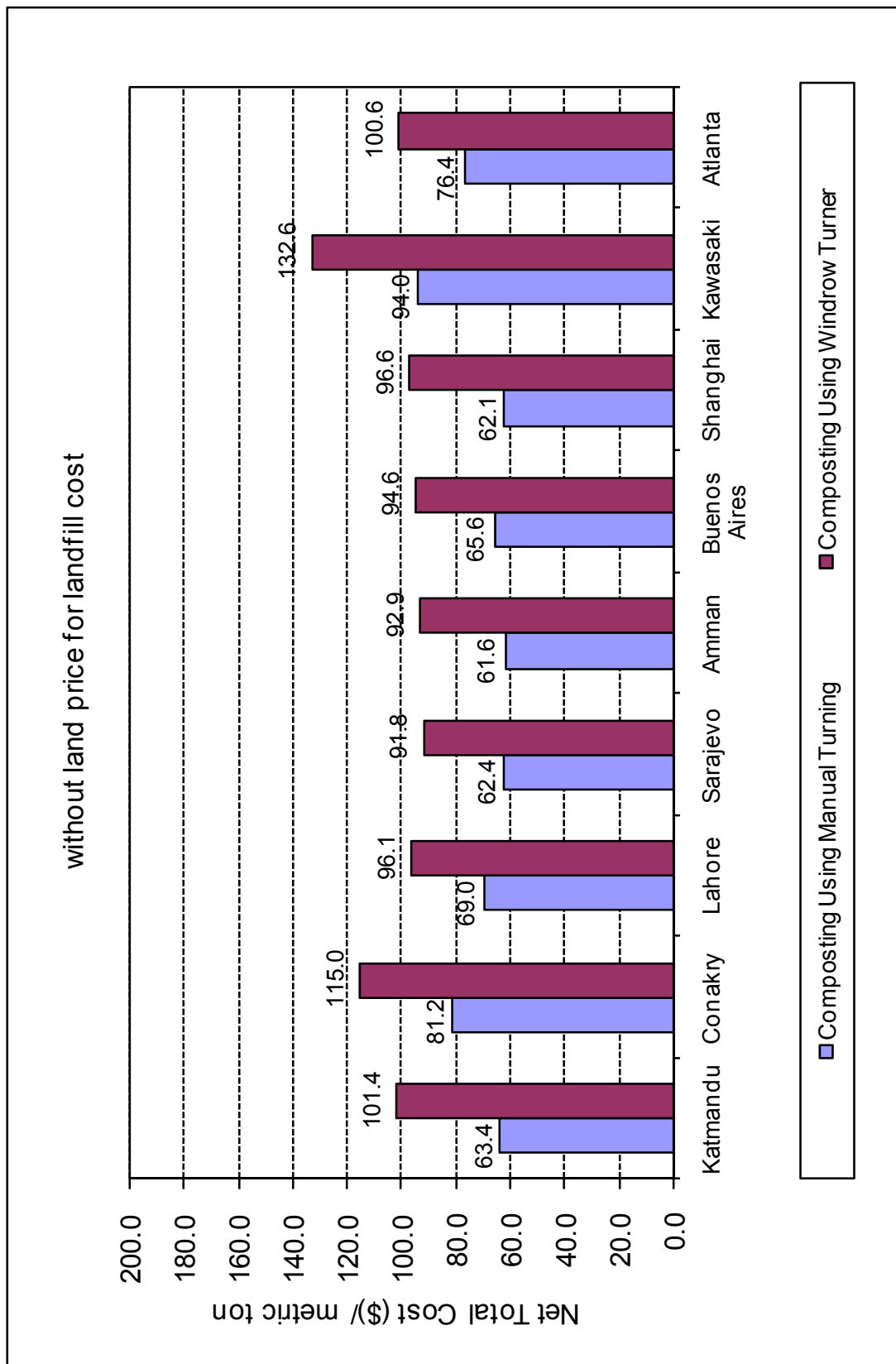


Figure 3.2-16 Net Total Cost by City (without Land Price)



Figure 3-2-17 Unit Cost by City and Process (without Land Price: Manual Composting Design)

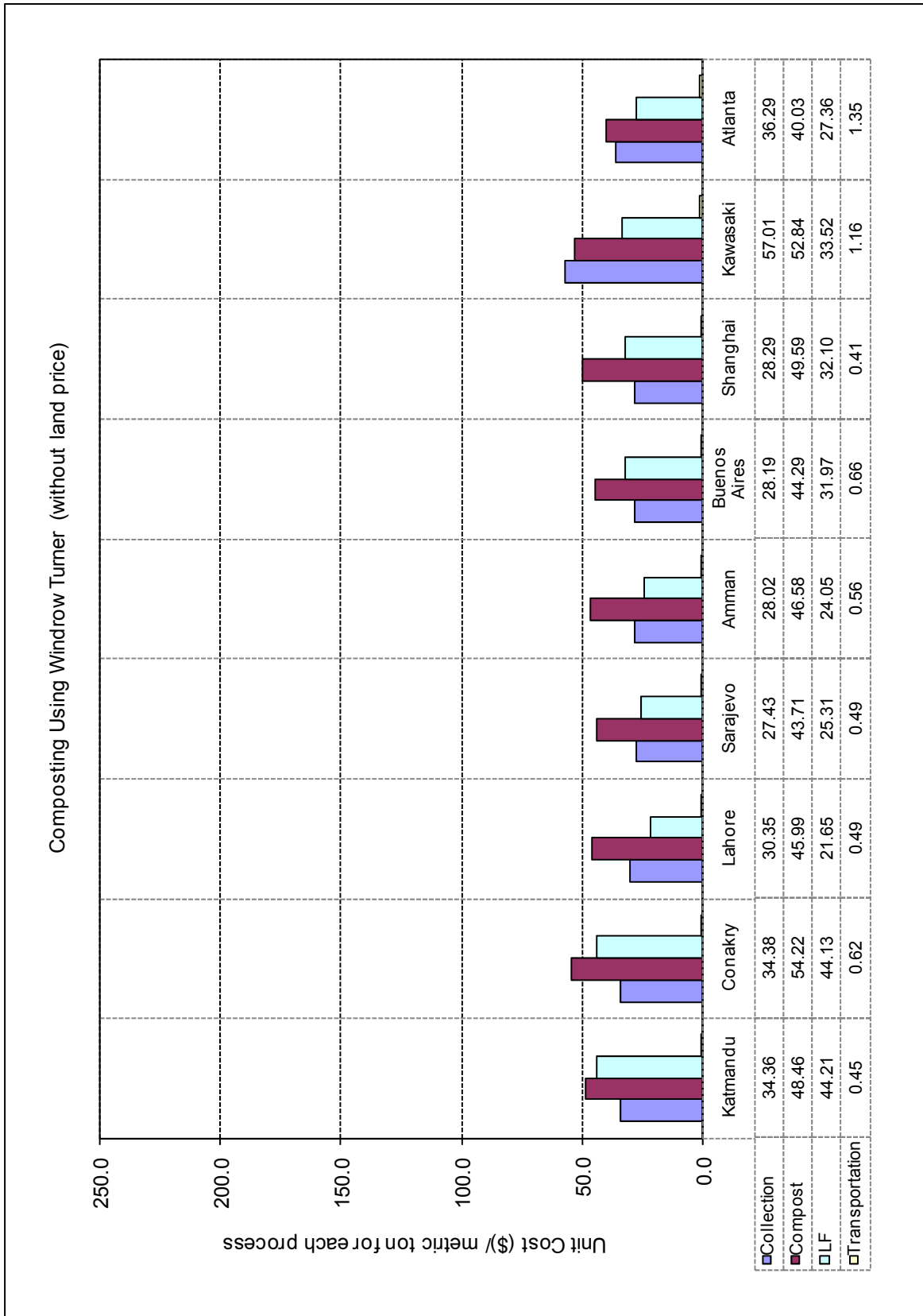


Figure 3.2-18 Unit Cost by City and Process (without Land Price: Mechanical Composting Design)

Energy variation by process design

Figures 3.2-20 and 3.2-21 (see the corresponding composting values) shows energy requirements for the mechanical windrow turner design that are consistently 6-9% higher than those for the manual design. This difference can be attributed to the avoided energy requirements from equipment fuel (i.e., mostly diesel) consumption at the manual composting facility.

Energy variation by city

Composting energy consumption among cities does not exhibit as much variation as it did for the recycling scenarios. From Figures 3.2-20 and 3.2-21, the energy requirements at the composting facility are the main drivers behind the differences across cities. Kawasaki is the city with the largest collection energy mostly due to the low usable capacity (half of the usable capacity of other cities') in its collection vehicles, which increases the energy requirements associated with vehicles fuel production.

Consistent with the cost results Kawasaki is the city with the highest overall energy consumption followed closely by Lahore and Conakry. Kawasaki's energy results can be explained by having the highest collection energy demand, a moderately high composting energy demand, and the second highest (after Atlanta) landfill energy demand. By having one of the highest percentages of organics Kawasaki's energy requirements at the composting facility will be high and the combustion and pre-combustion energy from an electricity grid mix with a large amount of natural gas will also be high (i.e., according to Table 2.5-3, natural gas is the fuel with the highest ratio BTU per kWh of electricity delivered).

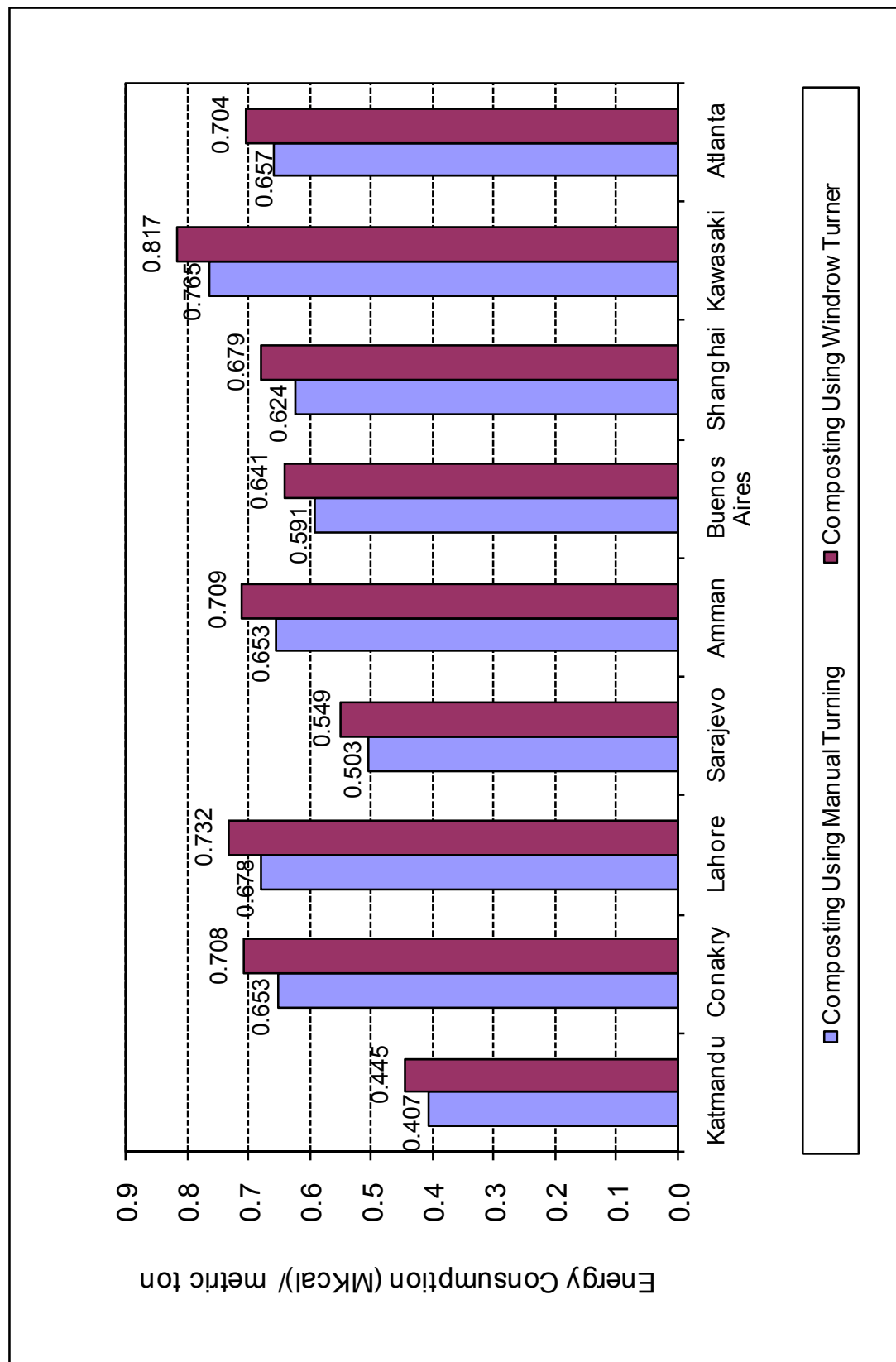


Figure 3.2-19 Net Total Energy Consumption by City

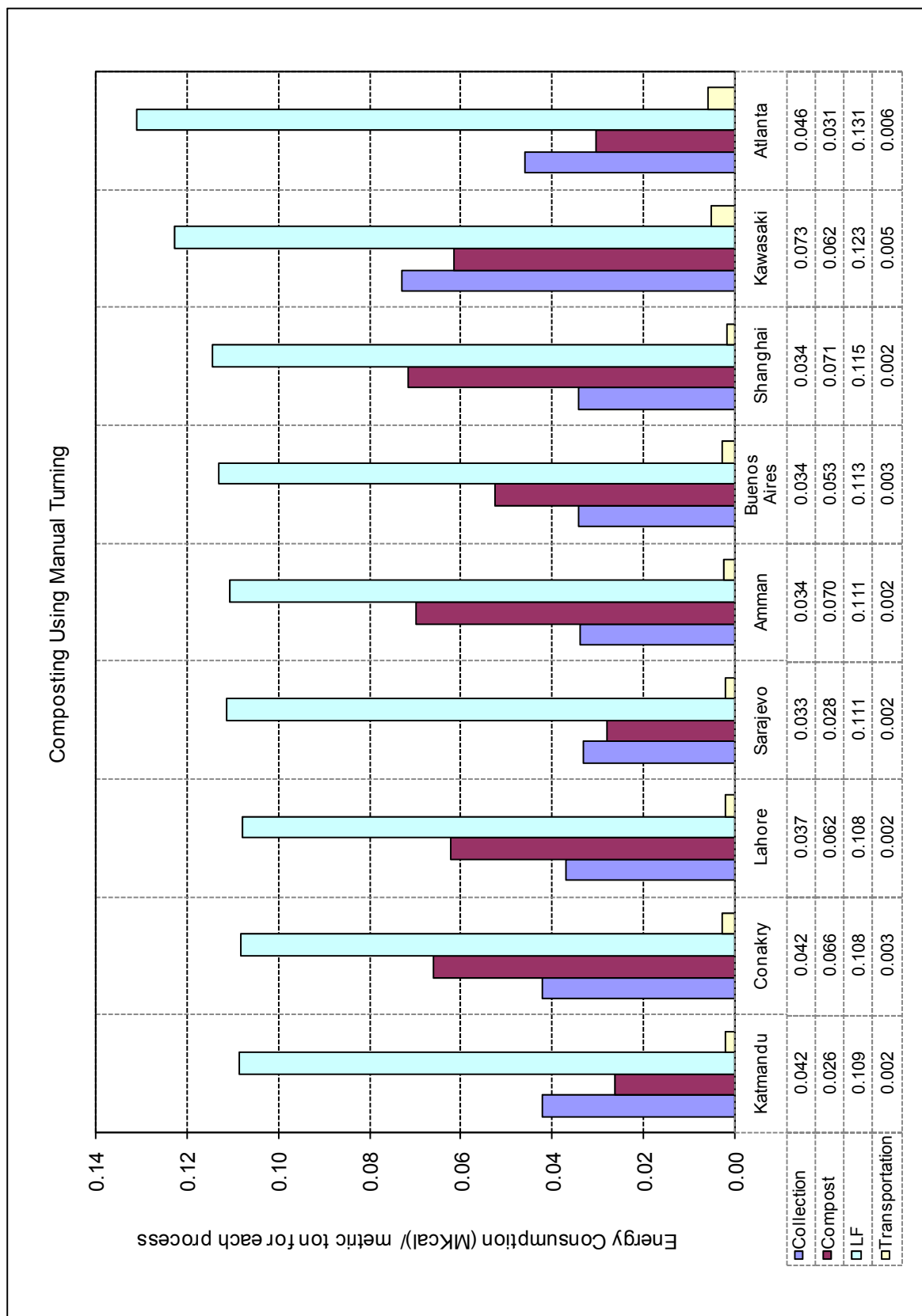


Figure 3.2-20 Energy Consumption by City and Process (Manual Composting Design)

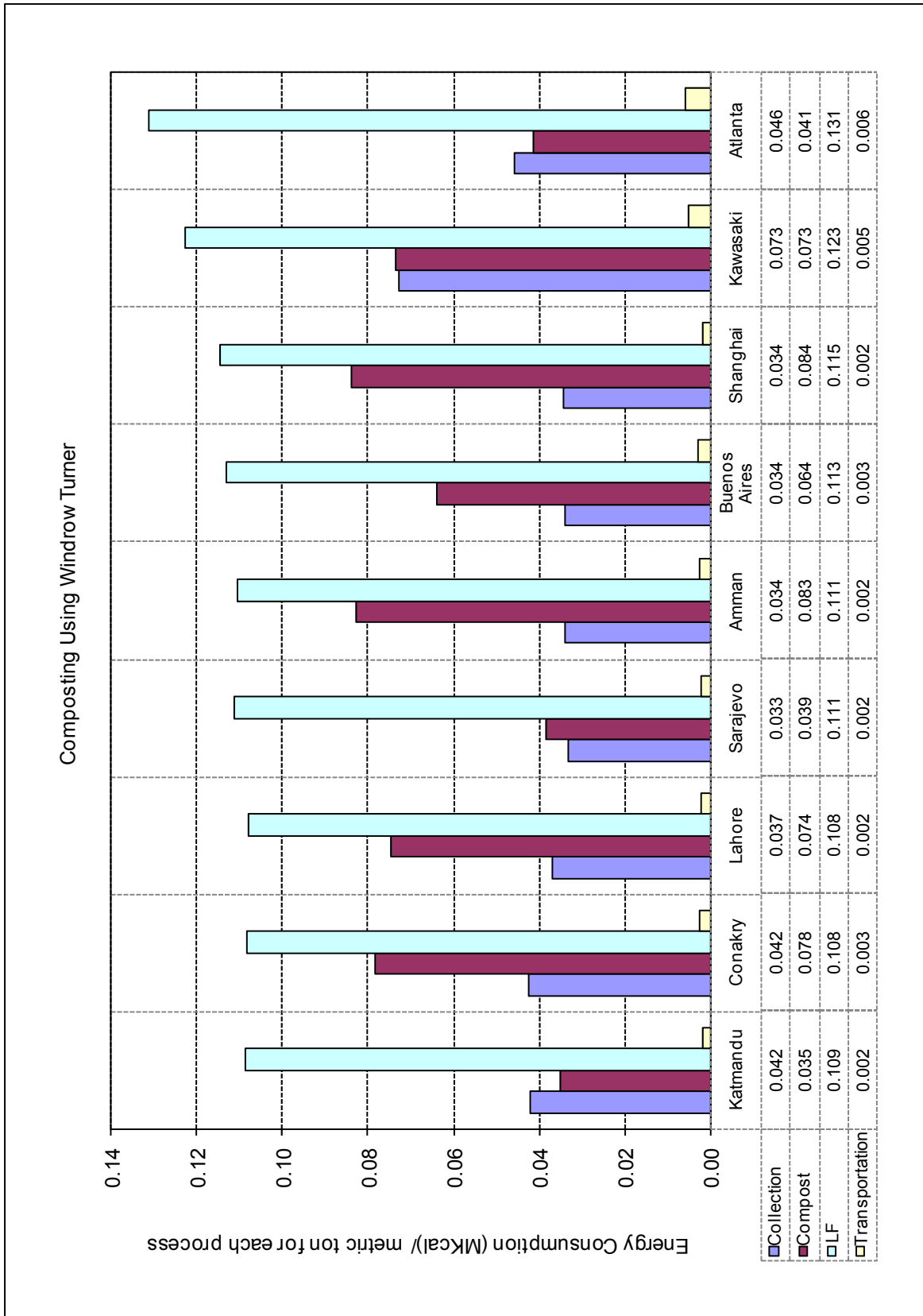


Figure 3.2-21 Energy Consumption by City and Process (Mechanical Composting Design)

Carbon emissions variation by process design

Figures 3.2-22, 3.2-23 and 3.2-24 show that in general the differences in the carbon emissions between the manual and the mechanical windrow design are very small ranging from approximately 10E-6 to 10E-3.

Carbon emissions variation by city

Figures 3.2-23 and 3.2-24 show that the key drivers behind the differences across cities are: (1) landfill emissions and (2) composting facility emissions. Atlanta has the highest overall emissions from having the highest amount of material disposed at a landfill (see Table 3.2-5) and using an electricity grid mix that includes a high percentage of fossil fuels.

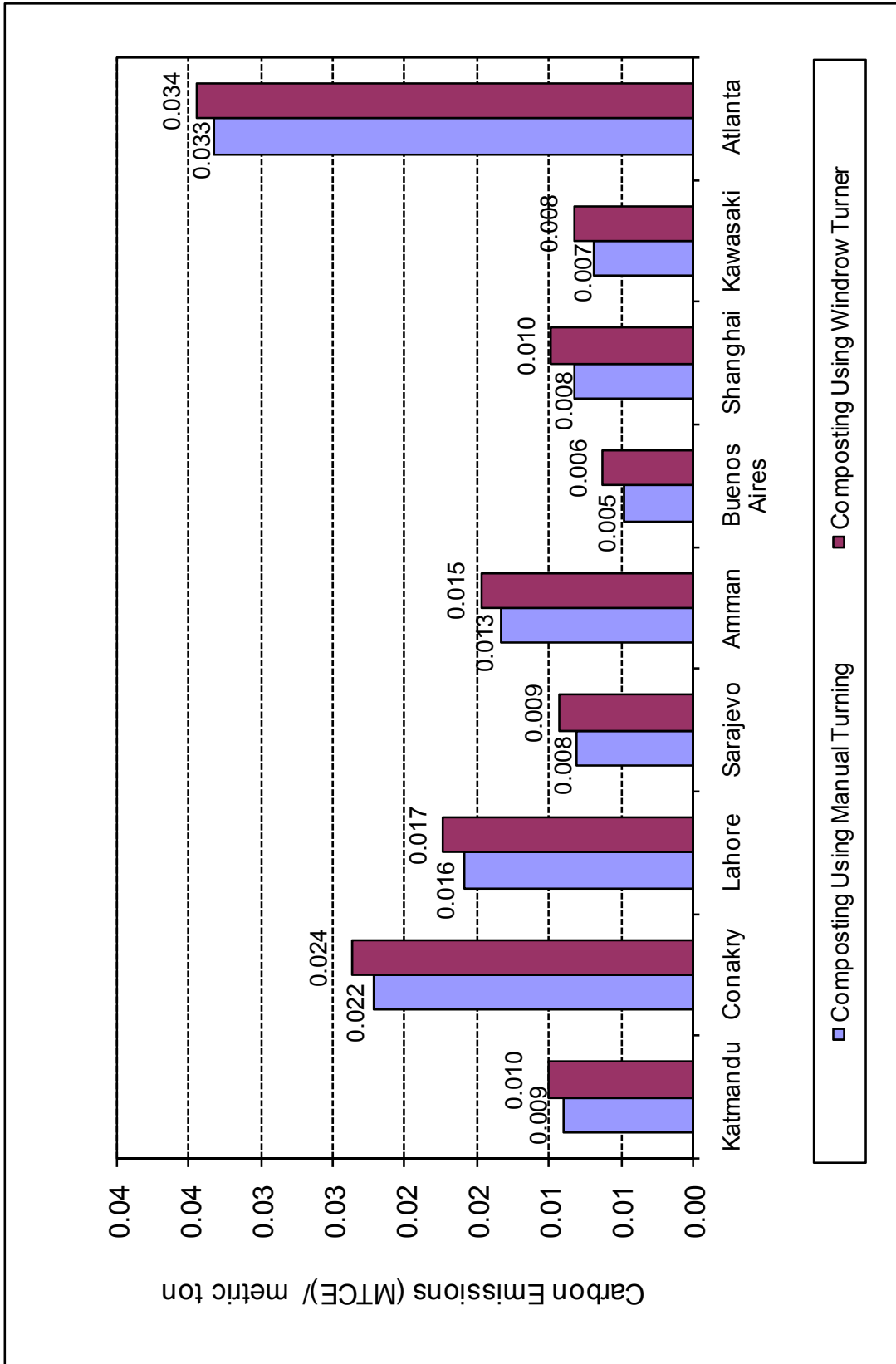


Figure 3.2-22 Net Total Carbon Emissions by City

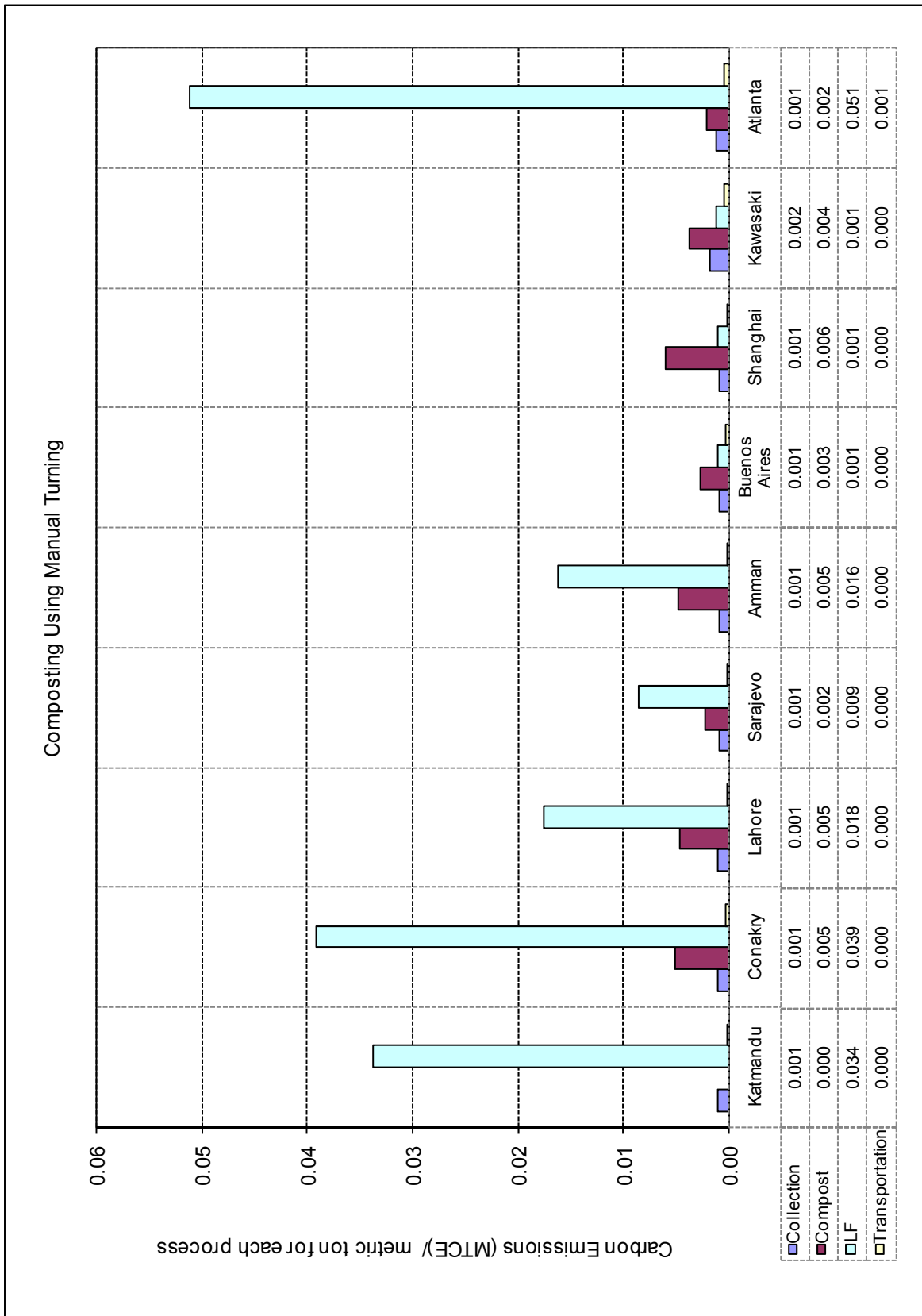


Figure 3.2-23 Carbon Emissions by City and Process (Manual Composting Design)

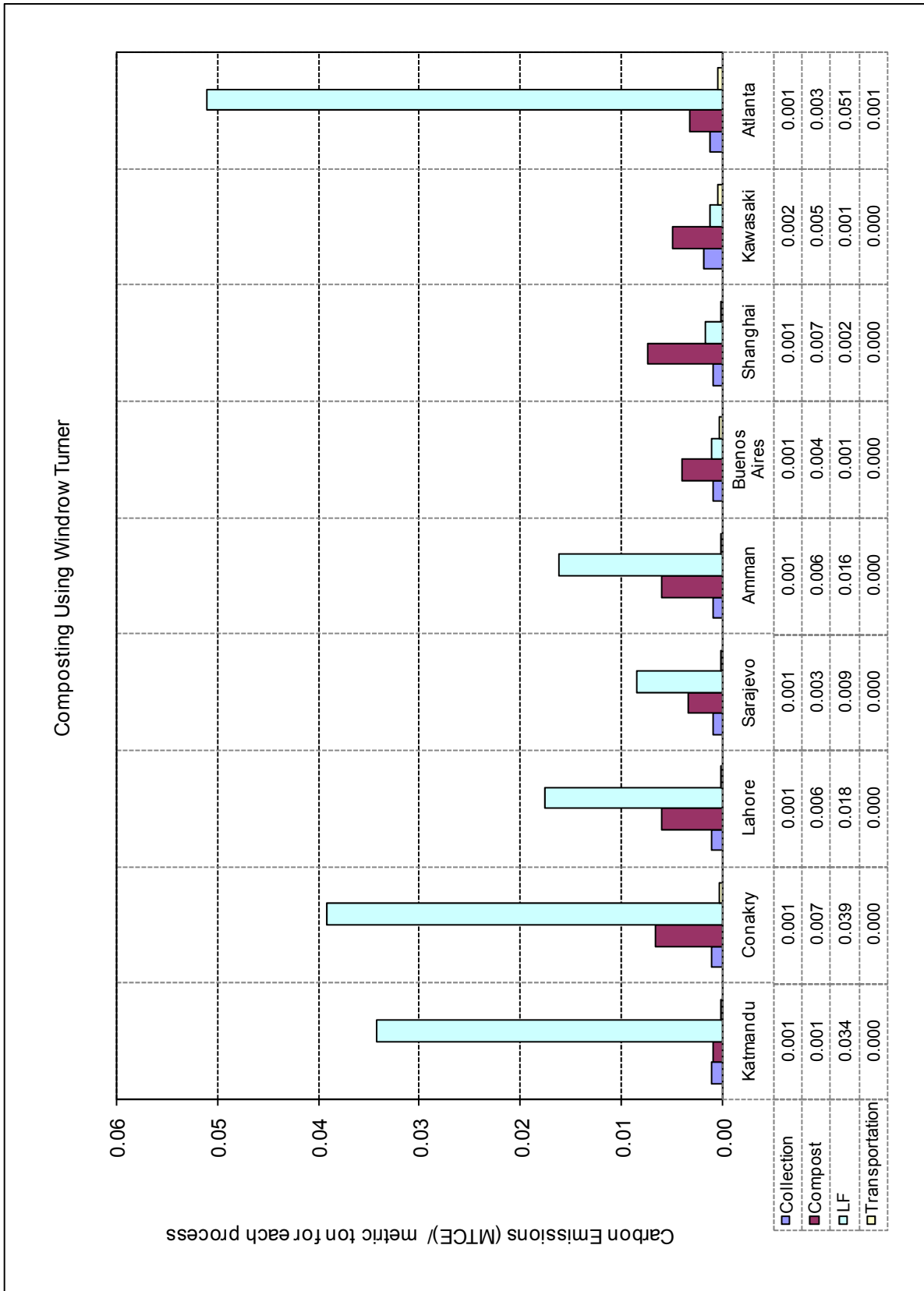


Figure 3.2-24 Carbon Emissions by City and Process (Mechanical Composting Design)

3.2.4 Incineration Without and With Energy Recovery

The modeled incineration facility is assumed to be modern mass burn combustor with an assumed plant heat rate of 17,500 BTU/kWh, 70% ferrous recovery rate from ash, and conforms to EU incinerator emission standards. The incineration scenarios consist of sending all the mixed waste collected to an incineration facility. Two variations are analyzed: (1) without energy recovery and (2) with energy recovery, both with ferrous recovery. The overall results are recorded in Figure 3.2-25 Net Total Cost by City (with Land Price), Figure 3.2-26 Net Total Cost by City (without Land Price), Figure 3.2-27 Net Total Energy Consumption by City, and Figure 3.2 Net Total Carbon Emissions by City. Because most of the cost, energy, and emissions are related to the combustion process (see percentages of waste going to the combustion process vs. other processes in Table 3.2-6), the results were not further broken down by process.

Table 3.2-6 presents the total heating value of the waste in each of the cities, which in combination with the percentage of ferrous material recovered (i.e., waste sent to remanufacturing) from the waste stream are going to define the energy life cycle assessment results.

**Table 3.2-6 Percentage of Waste Going to the Different Processes
(Sorted by Average Heat Content)**

Cities	Combustion	Remanufacturing	Disposal	Heating Content of Waste Stream (kcal/kg, dry-base)
Atlanta	79.33%	3.04%	17.63%	7,643
Kawasaki	82.22%	1.68%	16.10%	6,289
Amman	89.11%	0.00%	10.89%	6,007
Buenos Aires	85.90%	0.93%	13.17%	5,862
Shanghai	76.44%	0.10%	10.88%	5,834
Lahore	80.96%	0.25%	18.80%	5,080
Sarajevo	71.52%	0.00%	28.48%	4,787
Conakry	83.08%	1.91%	15.01%	4,356
Kathmandu	90.66%	0.25%	8.91%	874

For incineration without energy recovery the costs results will depend on the capital, O&M, and energy costs for the combustion process in each city. Because this data were not consistently found, then the costs variations observed in the results among cities may not accurately reflect reality. For incineration with energy recovery each city receives revenues from electricity sales, which will vary according to the sale price, and revenues from ferrous recovery that will depend on the percentage of ferrous in the system and the ferrous material sale price.

The energy results for incineration without energy recovery will vary according to the energy savings from ferrous recovery and in general, according to the combustion and pre-combustion energy associated with the production of the fuels in each city's electricity grid mix. For

incineration with energy recovery the initial energy requirements are offset by the energy produced and the energy savings from ferrous recovery.

The carbon emission results from the incineration scenario without energy recovery will mainly depend on (1) the fuels in electricity grid mix of each city and their associated combustion and pre-combustion emissions (e.g., fossil fuels generated energy has higher emissions than nuclear generated energy) and (2) the percentage of plastics in the waste being burned. For the scenario with energy recovery, there will be emissions offsets from the energy produced and the ferrous material recovered.

Cost variation by city

Figures 3.2-25 and 3.2-26 shows that Kawasaki is the city with the highest overall cost resulting from having the highest capital, O&M, and energy costs at the incineration facility. On the other hand Shanghai has the lowest costs from having the lowest capital and O&M costs.

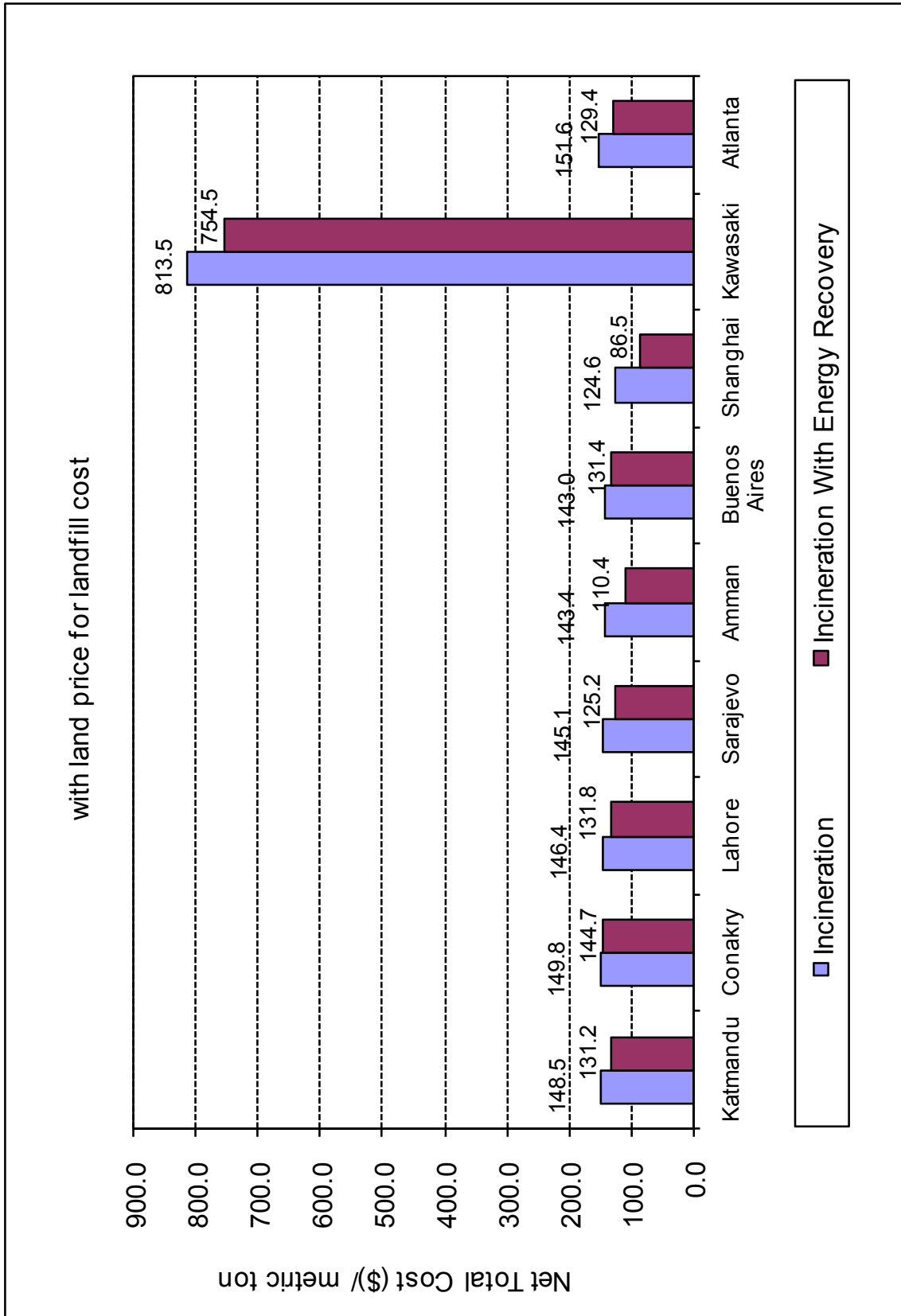


Figure 3.2-25 Net Total Cost by City (with Land price)

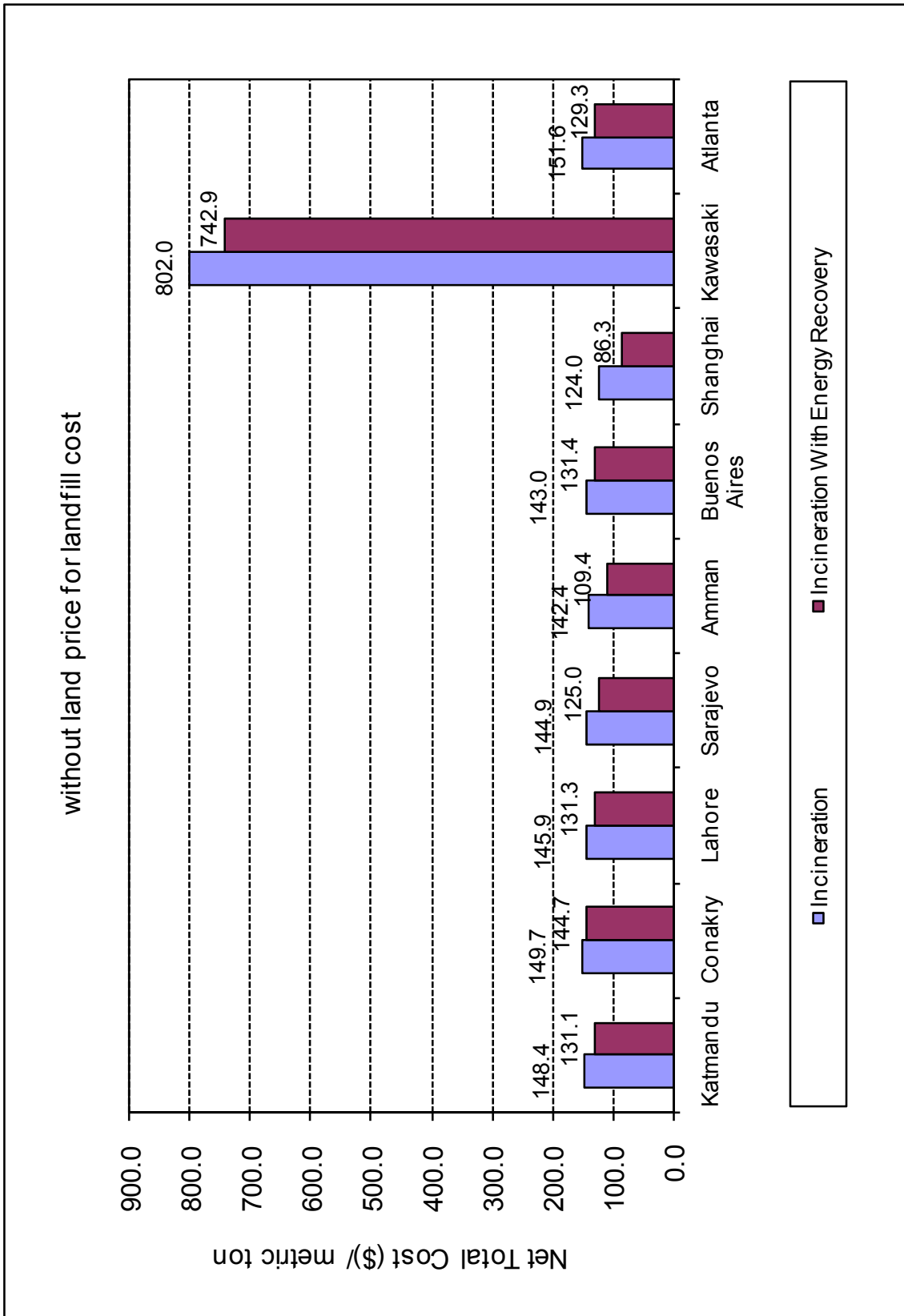


Figure 3.2-26 Net Total Cost by City (without Land price)

Energy variation by city

In Figure 3.2-27 the key drivers behind the differences among the cities are (1) the heating value of the waste in each of the cities, (2) the electricity grid mix displaced by the energy recovered and (3) the energy savings from ferrous recovery. For example, Atlanta is the city with the highest waste heating value and amount of ferrous materials in the waste stream, which explain why it has the highest energy savings from the incineration scenarios. On the other hand, Sarajevo and Amman do not have any ferrous material in their waste stream and they are not showing any energy savings from the incineration scenario without energy recovery.

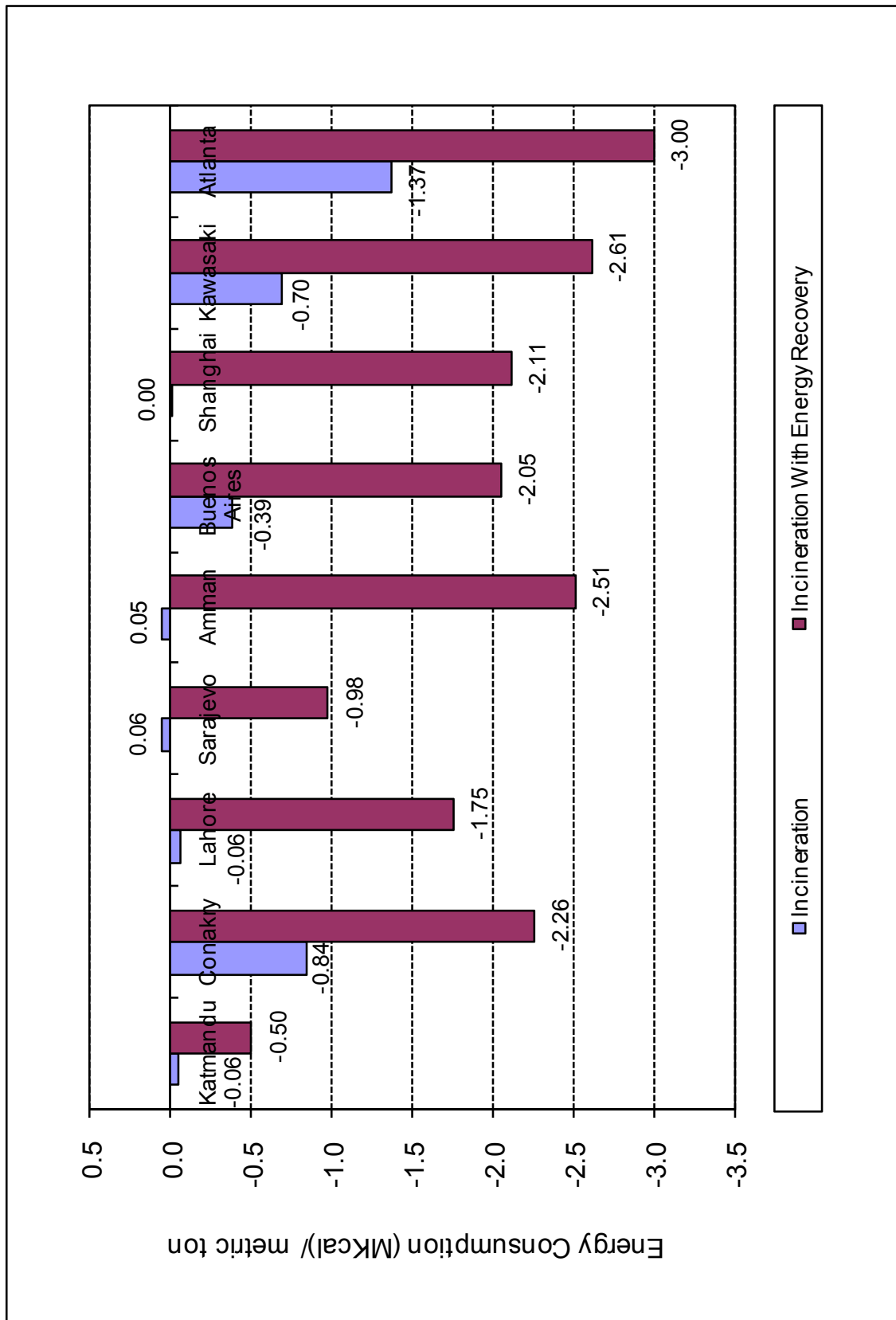


Figure 3.2-27 Net Total Energy Consumption by City

Carbon emissions variation by city

Figure 3.2-28 offers an interesting picture of the carbon emissions from the incineration scenarios in all the cities. Different from previous figures there is much more variation in the emissions across cities. In the case of incineration with energy recovery this variation depends on each city’s potential to offset electricity generation emissions from the utility sector, the amount of plastics burned, and the emission savings from ferrous material recovery and recycling.

For example, Kathmandu does not have overall carbon emission offsets from incineration with energy recovery since 90% of its electricity is hydroelectricity with assumed zero carbon emissions. Contrary, Conakry has the highest emissions savings from having the lowest amount of plastics, the highest amounts of ferrous, and offsetting energy from an electricity grid with ~75% residual oil, which has the highest combustion and pre-combustion emissions.

Shanghai, which has the highest carbon emissions from incineration without energy recovery, also has the highest amount of plastics and among the smallest amounts of ferrous material. This city’s percentage of plastics is very similar to Atlanta, which also has high carbon emissions from incineration without energy recovery. For the scenario with energy recovery Shanghai perceives higher emission offsets than Atlanta from having an electricity grid mix richer in fossil fuels. Table 3.2-7 presents the percentage of each waste category being incinerated.

**Table 3.2-7 Percentage of Each Waste Category Incinerated by City
(Sorted by Percentage of Plastics)**

Cities	Organics				Inorganics					Miscellaneous
	Yard waste	Food waste	Paper	Total	Plastics *	Glass	Ferrous materials	Aluminum materials	Total	
Shanghai	1.37%	57.49%	6.11%	64.97%	15.48%	0.03%	0.10%	0.11%	15.72%	8.43%
Atlanta	4.67%	11.16%	27.81%	43.64%	13.21%	0.08%	3.05%	0.06%	16.39%	22.34%
Amman	1.84%	41.18%	15.57%	58.59%	13.06%	0.04%	0.00%	0.00%	13.10%	17.42%
Buenos Aires	4.49%	34.16%	18.26%	56.91%	11.39%	0.11%	0.93%	0.04%	12.47%	17.46%
Kawasaki	3.13%	34.35%	29.24%	66.72%	10.33%	0.11%	1.68%	0.04%	12.16%	5.03%
Lahore	16.29%	28.77%	10.51%	55.57%	7.41%	0.03%	0.25%	0.02%	7.70%	17.93%
Kathmandu	2.50%	65.81%	7.71%	76.03%	6.45%	0.05%	0.25%	0.00%	6.74%	8.31%
Sarajevo	0.83%	37.14%	13.48%	51.46%	4.96%	0.00%	0.00%	0.00%	4.96%	15.10%
Conakry	7.35%	39.64%	14.66%	61.65%	4.47%	0.02%	1.91%	0.00%	6.40%	16.94%

*The plastics non-recyclables were added to the plastics here.

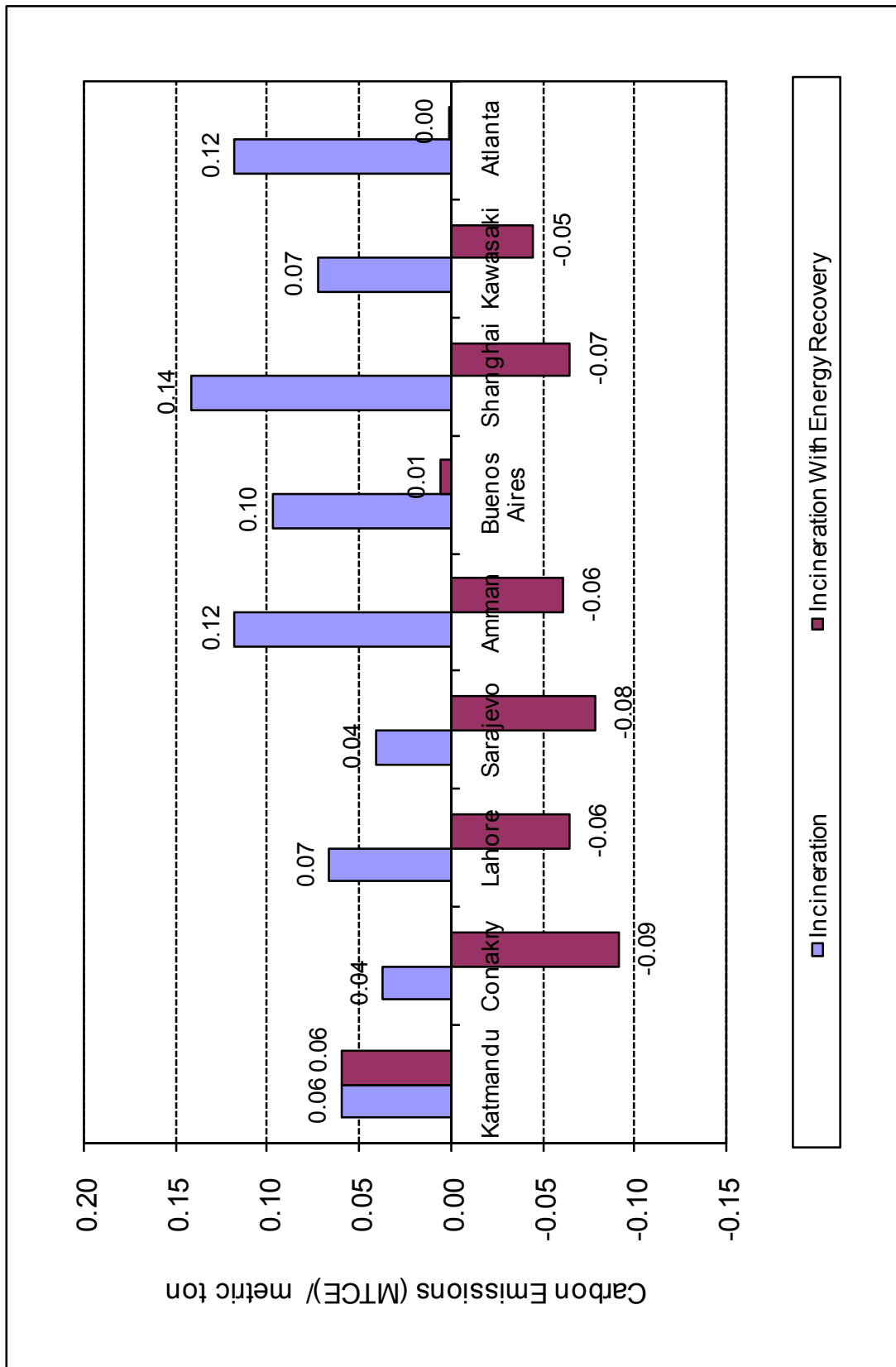


Figure 3.2-28 Net Total Carbon Emissions by City

3.2.5 Landfill with Gas Venting, Gas Collection and Flaring, and Gas Collection and Energy Recovery

The modeled landfill is assumed to be a modern U.S. EPA Subtitle D type landfill with a liner and leachate collection and treatment system. The scenarios modeled consist of collecting and sending all waste to a landfill, with three types of landfill gas management practices being analyzed: (1) venting, (2) flaring, and (3) energy recovery. For scenarios that include gas management a 70% gas collection efficiency is assumed. For all scenarios, a 100-year time period is used for calculating landfill gas generation and emissions.

The overall results were recorded in Figure 3.2-29 Net Total Cost by City (with Land Price), Figure 3.2-30 Net Total Cost by City (without Land Price), Figure 3.2-31 Net Total Energy Consumption by City, and Figure 3.2-32 Net Total Carbon Emissions by City. The same was done sending all the mixed waste to a landfill with gas collection and flaring and to one with gas collection and energy recovery.

Cost variation by landfill type and city

The cost variations across different landfills observed in Figures 3.2-29 and 3.2-30 are due to the additional equipment cost for gas collection and flaring and for gas collection and energy recovery and the revenues from energy sale in the energy recovery scenario.

Across cities the differences are due (1) the capital, O&M, and energy costs and (2) the revenues from energy sale, which are going to depend on the composition of the waste (i.e., food waste and grass have the highest decay rate- methane gas yield and consequently the highest potential for energy recovery) and the energy sale price. In some cases the collection costs play an important role (e.g., Kathmandu, Buenos Aires, Atlanta, and Lahore) and this can be observed in the cost break downs by processes presented in Table 3.2-8. It should be noted that all the three landfill types have the same cost breakdown by process.

Table 3.2-8 Percentage of Cost Attributed to the Different Landfill Scenario Processes (Sorted by Disposal Cost)

Cities	Collection	Disposal
Sarajevo	18%	82%
Conakry	19%	81%
Kawasaki	22%	78%
Amman	38%	62%
Shanghai	39%	61%
Kathmandu	44%	56%
Buenos Aires	47%	53%
Atlanta	57%	43%
Lahore	58%	42%

Kawasaki has the highest costs as a result of having the highest electricity cost and landfill land price. This city and Shanghai also present the highest revenues from energy recovery due to having the highest energy sale prices and very high percent of methane/energy generating materials (i.e., most of Shanghai's waste is food waste). Amman and Shanghai have almost the same cost for landfill venting and flaring and this is due to very similar capital, O&M, and energy costs. For example, Amman has higher land prices but a lower utility rate than Shanghai. Even though Shanghai has much more organics in its waste stream than Amman, the revenues perceived from electricity sale are very similar since Amman is offsetting a mostly natural gas electricity grid mix, which has the highest ratio BTU per kWh of electricity delivered.

Kathmandu has similar landfill venting and flaring costs to Amman and Shanghai even though its landfill capital, O&M, and energy costs are much lower than either of these two countries. However, according to Table 3.2-8 collection constitutes a much higher percentage of the net total costs and Kathmandu's diesel fuel prices are much higher than Amman and Shanghai's. On the other hand, Lahore has the lowest overall costs and most of them can be attributed to collection. Then, Lahore's low diesel fuel prices explain its low overall costs.

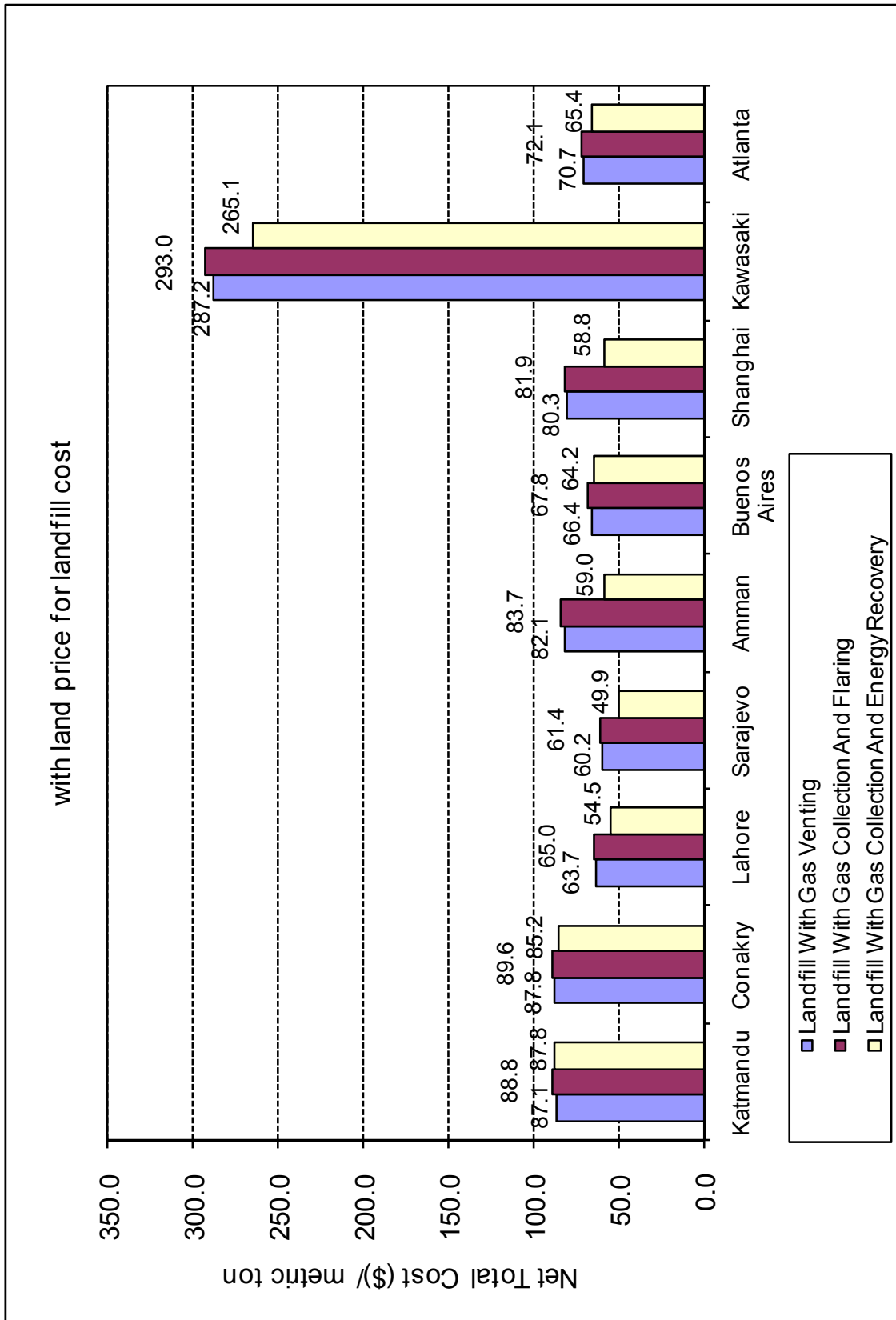


Figure 3.2-29 Net Total Cost by City (with Land Price)

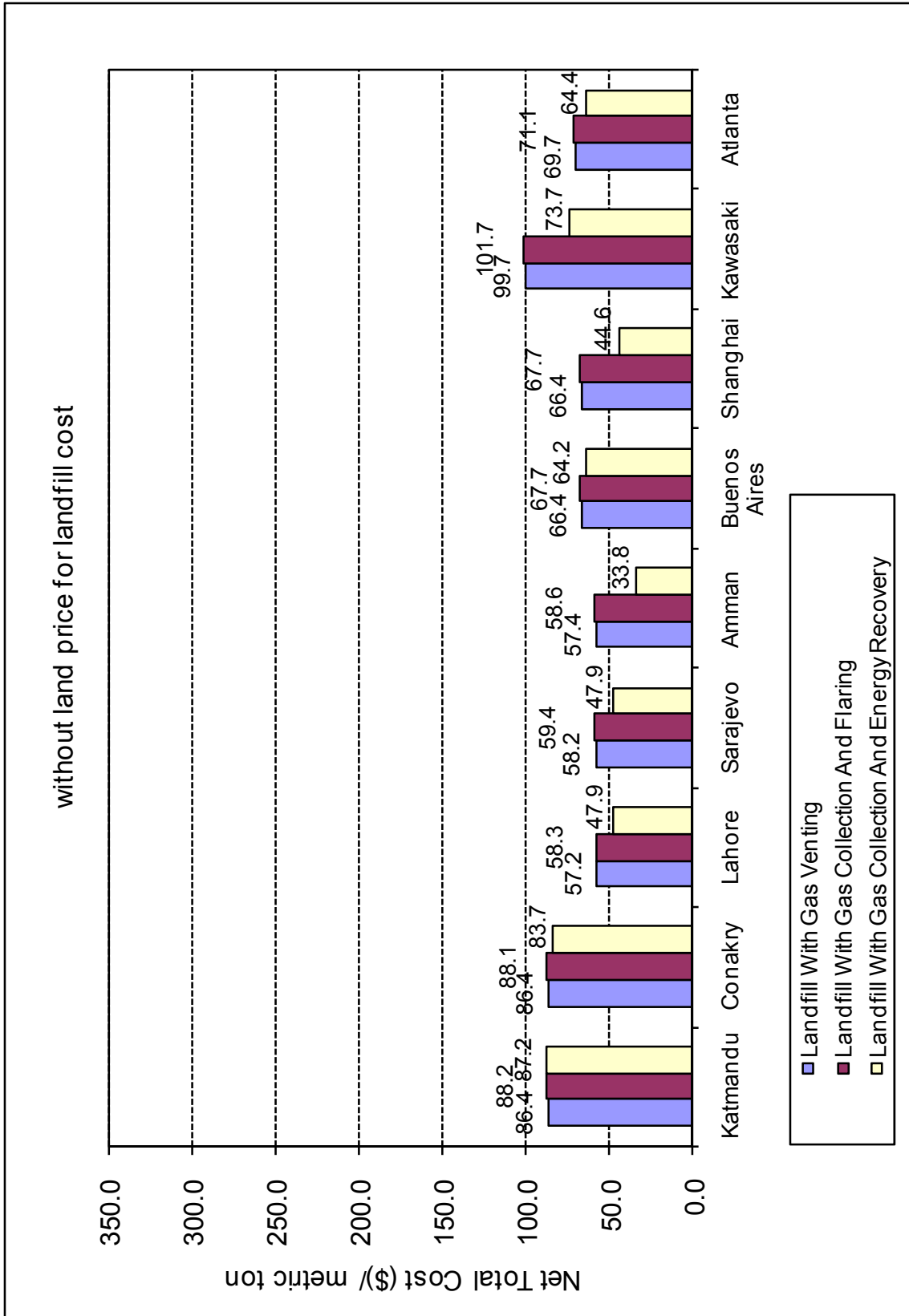


Figure 3.2-30 Net Total Cost by City (without Land Price)

Energy variation by landfill type and city

The energy requirements for the landfill with gas venting and the landfill with gas flaring exhibit very little variation across cities (see Figure 3.2-31). Kawasaki has the highest energy requirements mostly attributed to collection (see Table 3.2-9). Then, Kawasaki’s low vehicle usable capacity (half of the usable capacity of other cities’) in combination with a moderately high BTU per kWh electricity produced explains its high overall energy requirements.

Variation in the energy offsets from the landfill with energy recovery can be explained by the electricity grid mix in each city and the corresponding energy requirements that are being offset. For example, Amman, the city with the highest energy offsets, has an electricity grid mix with about 95% natural gas, which is the fuel with the highest ratio BTUs consumed per kWh of electricity produced. Therefore, for every BTU of energy recovered the energy savings from Amman’s electricity grid mix are much higher than other cities with a different grid mix. Contrary, 90% of Kathmandu’s electricity is hydro-electricity, which has the lowest ratio BTU per kWh of electricity produced.

Table 3.2-9 Percentage of Energy Attributed to the Different Landfill Scenario Processes (Sorted by Disposal Energy Consumption)

Cities	Collection	Disposal
Shanghai	22%	78%
Conakry	23%	77%
Buenos Aires	23%	77%
Sarajevo	23%	77%
Amman	25%	75%
Lahore	26%	74%
Atlanta	26%	74%
Kathmandu	28%	72%
Kawasaki	36%	64%

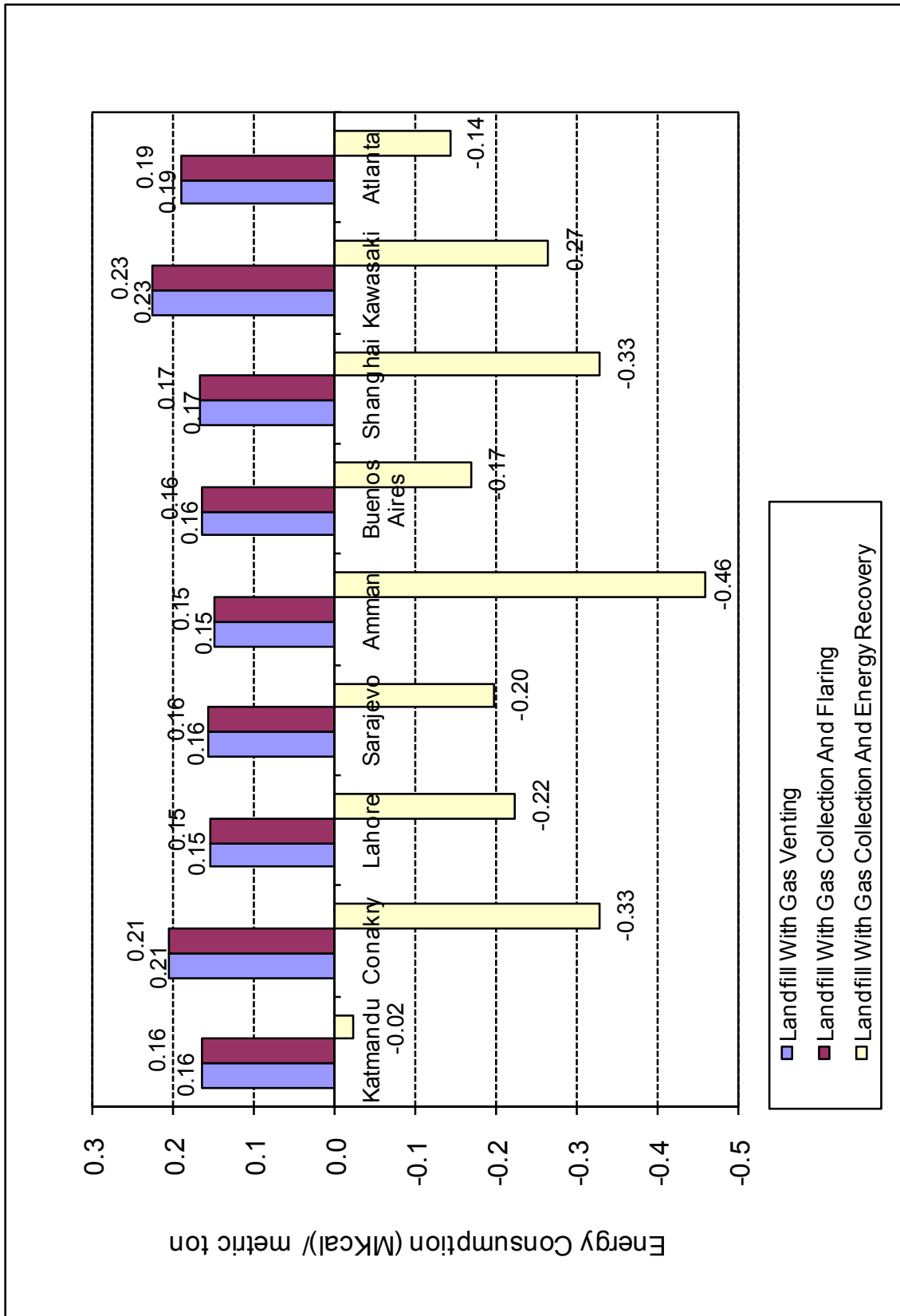


Figure 3.2-31 Net Total Energy Consumption by City

Carbon emissions variation by landfill type and city

The carbon emission variations across cities from the scenarios with gas venting and gas flaring that can be observed in Figure 3.2-32 are explained by (1) each city's waste composition which governs the methane gas production and (2) the emissions associated with each city's grid mix. For example, Kathmandu's landfill venting scenario has the highest carbon emissions explained by 60% of its MSW stream consisting of food waste (this is the waste category with the highest methane generation rate). Atlanta's landfill flaring scenario has the highest carbon emissions even though its energy requirements are lower than other cities such as Kawasaki. However, when compared with Kawasaki, Atlanta has a larger amount of fossil fuels in its electricity grid mix.

Emission variations in the results from the energy recovery scenario are due to both the waste composition governing the methane gas production and the electricity grid mix governing the emission offsets. For example, Kathmandu's has the highest emissions from this scenario because it has the largest amount of food waste and the lowest carbon offsets from a 90% hydroelectricity grid. Shanghai has the lowest emissions by having the highest carbon offsets in an electricity grid mix rich in fossil fuels.

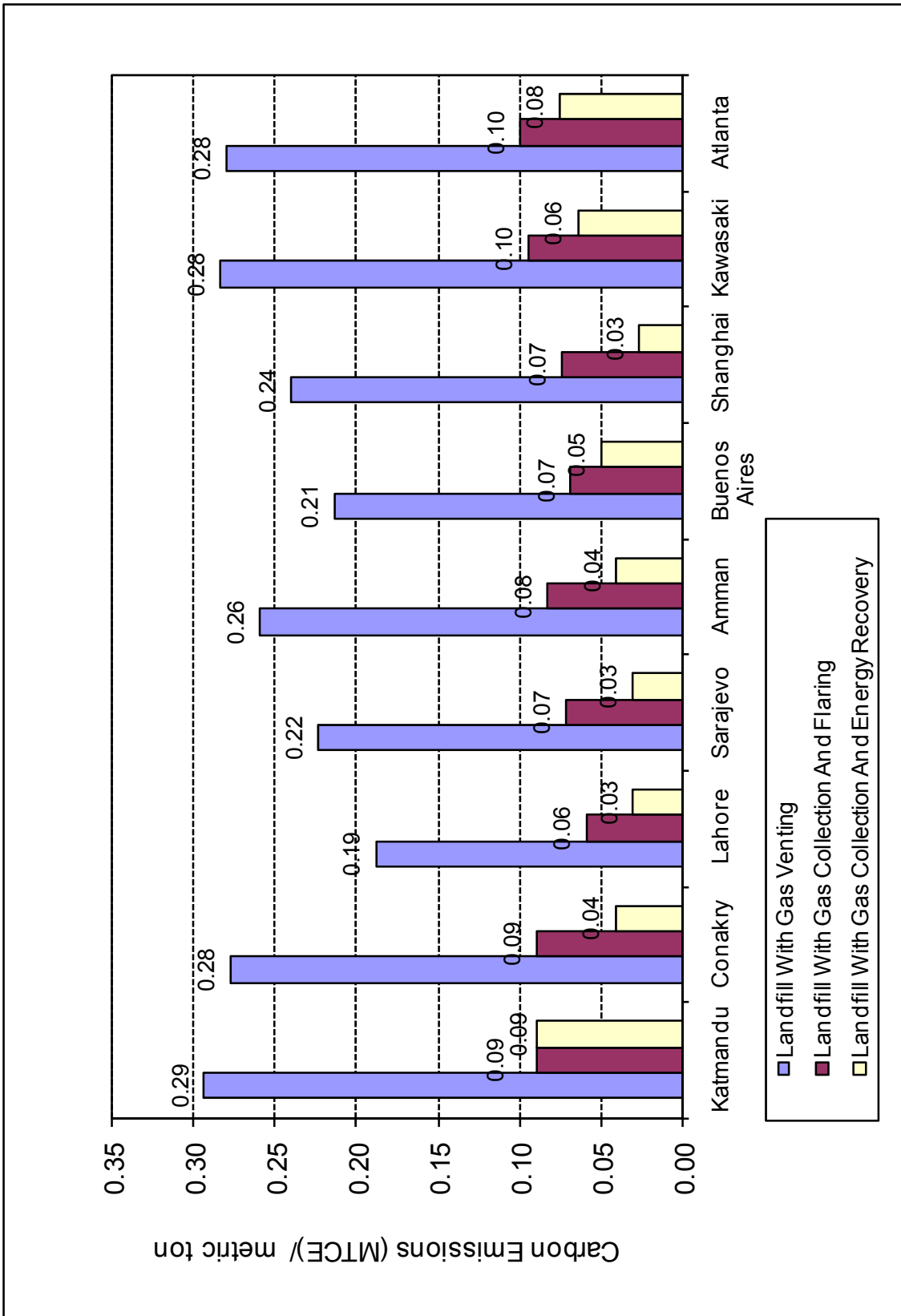


Figure 3.2-32 Net Total Carbon Emissions by City

3.3 Optimization Scenario Results

In addition to the simulation-type scenarios analyzed in Section 3.2, a number of optimization-type scenarios were analyzed. Under the optimization scenarios RTI's MSW DST identifies and selects the waste management strategy that best meets the defined optimization goal. For example, in solving for an optimization goal of minimizing energy consumption, the MSW DST will identify the waste management strategy that achieves the lowest net energy consumption, which is a function of the total process energy consumption less energy production from waste.

Four optimization scenarios are analyzed for each city including:

- Group 3—maximizing materials recovery (via recycling and composting)
- Group 4—maximizing energy recovery
- Group 5—minimize carbon (global warming) emissions and, minimize PM (global dimming) emissions.

For each optimization scenario, different variations for collection and process design and operations were considered to assess their impact on the results. The variations analyzed include:

- Daily and biweekly collection.
- Low and high percent capture of recyclables:
 - low capture is defined by 50% participation factor³ and 50% capture rate⁴
 - high capture is defined by 75% participation factor and 75% capture rate.
- Recycling and composting using manual sorting and pile turning, respectively.
- Recycling and composting using mechanical sorting and pile turning, respectively.

Table 3.3.1 presents the waste management processes that were selected according to each scenario's optimization goal. As shown in the table, similar strategies were generally selected by scenario for each city.

The lessons learned from Section 3.2 where the simulation results were presented will be very useful understanding the optimization results. For example, Table 3.2.1 Summary Contribution of Key Input Parameters to Results by Process can be used to understand the optimization results once the main (those managing most of the waste in the system) waste management processes have been identified.

³ The participation factor indicates the average percentage of households within a region in a source segregated recyclables collection program.

⁴ The capture rate is the fraction of recyclable material removed by households from the waste and put in the recyclables collection bin.

Table 3.3-1 Waste Management Processes Selected by the MSW DST for Each Optimization Scenario

Scenario		Scenario Variations	Non Segregated Collection ¹	Segregated Collection ²	Recycling ³	Composting ⁴	Incineration ⁵	Landfill Disposal ⁶
OPTIMIZATION SCENARIOS								
Group 3- maximizing materials recovery (via recycling and composting)	Manual Sorting MRF and Manual Turning Composting	Daily - High Capture		X	X	X		X
		Daily - Low Capture		X	X	X		X
		Biweekly Collection - High Capture		X	X	X		X
		Biweekly Collection - Low Capture		X	X	X		X
	Mechanical Sorting MRF and Mechanical/ Windrow Turner Composting	Daily - High Capture		X	X	X		X
		Daily - Low Capture		X	X	X		X
		Biweekly Collection - High Capture		X	X	X		X
Biweekly Collection - Low Capture			X	X	X		X	

Scenario		Scenario Variations	Non Segregated Collection ¹	Segregated Collection ²	Recycling ³	Composting ⁴	Incineration ⁵	Landfill Disposal ⁶		
Group 4- maximizing energy recovery ⁷		Daily - High Capture	X	X	X		X	X ⁸		
		Daily - Low Capture	X	X	X		X	X ⁸		
		Biweekly Collection - High Capture	X	X	X		X	X ⁸		
		Biweekly Collection - Low Capture	X	X	X		X	X ⁸		
Group 5- Optimize Reduction of Global Warming and Dimming Emissions ⁷		Minimize carbon (global warming) emissions		Daily - High Capture	X ⁹	X	X	X	X ⁸	
				Daily - Low Capture	X ⁹	X	X	X	X ⁸	
									X ⁸	
				Biweekly Collection - High Capture	X ⁹	X	X	X	X ⁸	
				Biweekly Collection - Low Capture	X ⁹	X	X	X	X ⁸	
		Minimize Particulate Material (PM- global dimming) emissions		Daily - High Capture		X	X		X	X
				Daily - Low Capture		X	X		X	X

Scenario		Scenario Variations	Non Segregated Collection ¹	Segregated Collection ²	Recycling ³	Composting ⁴	Incineration ⁵	Landfill Disposal ⁶
		Biweekly Collection - High Capture		X	X		X	X
		Biweekly Collection - Low Capture		X	X		X	X

¹ Non- segregated collection: mixed waste collection only.

² Segregated collection: separate recyclables, organics, and residuals collection.

³ Recycling: Group 3 scenarios use a commingled MRF (Material Recovery Facility) and Group 4 and 5 scenarios use a mixed waste MRF with 55% separation efficiency.

⁴ Composting: includes a mixed waste and a yard waste composting facility.

⁵ Incineration: includes a modern mass burn facility with 17,500 BTU/kWh heat rate and 70% ferrous recovery rate.

⁶ Landfill disposal: The default landfill (LF) is a conventional, modern (EPA Subtitle D type) LF, with 70% gas collection efficiency and gas flaring.

⁷ The selection of the waste management processes will vary from city to city. For example in some cities all the waste is collected through segregated collection.

⁸ Ash LF

⁹ Conakry is the only city with non-segregated collection.

3.3.1 Cost Results

Cost results are shown in Table 3.3-2 and illustrated in Figures 3.3-1 to 3.3-10. In general, we found the most significant parameters affecting the cost results to include:

- MRF/ Composting/ Incineration/Landfill disposal costs
- Recyclables revenues
- Energy prices
- Labor prices

In addition, the optimization scenario cost results were found to exhibit the following general trends:

- The combination manual MRF and composting is less expensive than mechanical MRF and composting.
- Daily waste collection is typically more expensive than biweekly waste collection.

High recyclables capture is typically more expensive than low recyclables capture (due to cost of recyclables collection being higher than mixed waste collection).

Variation by process design in the scenarios maximizing materials recovery

Figures 3.3-1, 3.3-2, 3.3-3 and 3.3-4 show the cost variation by MRF and composting process design (i.e., manual and mechanical). Consistently in all the scenarios and settings, the net cost for the manual design is lower than for the mechanical design. This is due to composting using manual turning being significantly less expensive than using a windrow turner. If labor wages at the composting facility increase, the margin of difference will decrease.

Variation by collection frequency

The waste collection frequency (daily vs. biweekly) does not change the overall amount or composition of waste managed under each of the scenarios. Therefore, it is expected that daily collection will be more costly than a biweekly collection and this is observed in the results for all the cities (see Figures 3.3-1 to 3.3-10).

Table 3.3-2 Summary of Cost Variation by Scenario and Scenario Settings

Criteria	Maximize Materials Recovery (via recycling and composting)				Maximize Energy Recovery				Minimize Carbon (Global Warming) Emissions				Minimize PM (Global Dimming) Emissions			
	Manual and Mechanical				Daily High Cap.	Daily Low Cap.	Biweekly High Cap.	Biweekly Low Cap.	Daily High Cap.	Daily Low Cap.	Biweekly High Cap.	Biweekly Low Cap.	Daily High Cap.	Daily Low Cap.	Biweekly High Cap.	Biweekly Low Cap.
	Daily High Cap.	Daily Low Cap.	Biweekly High Cap.	Biweekly Low Cap.												
Cost Variation																
By Collection Frequency (See Figures 3.3.1 to 3.3.5)	More expensive		Less expensive		More expensive		Less expensive		More expensive		Less expensive		More expensive		Less expensive	
By Percent Cap. of Recyclables (See Figures 3.3.1 to 3.3.5)	More*	Less*	More*	Less*	More*	Less*	More*	Less*	More*	Less*	More*	Less*	More*	Less*	More*	Less*
By city (See Tables 3.3.3 to 3.3.6)	Kawasaki: highest net cost due to: - Highest electricity cost - Among the lowest recycling revenues				Kawasaki: highest net cost due to: - Highest incineration cost (Highest capital and O & M costs)											
	Atlanta and Buenos Aires: lowest net cost due to: - Highest recycling revenues				Shanghai: lowest net cost due to: - Highest recycling revenues (sale prices for all recyclables)				Atlanta: lowest net cost due to: - High incineration revenues (High waste heating content) - Highest recycling revenues							

* More: More expensive, Less: Less expensive

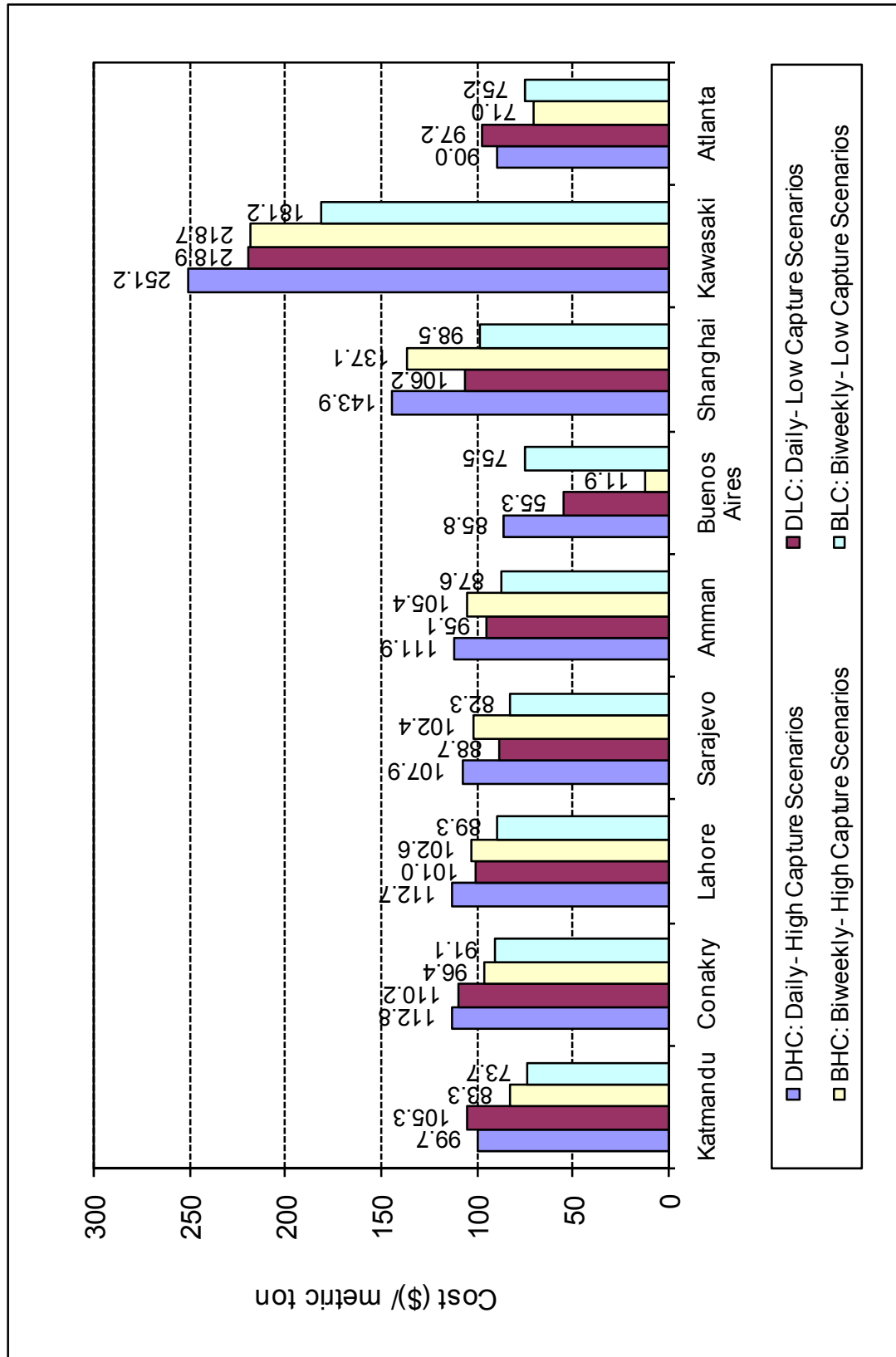


Figure 3.3-1 Group 3: Maximizing Materials Recovery (Via Mechanical Recycling and Composting)- Net Total Cost by City (with Land Price)

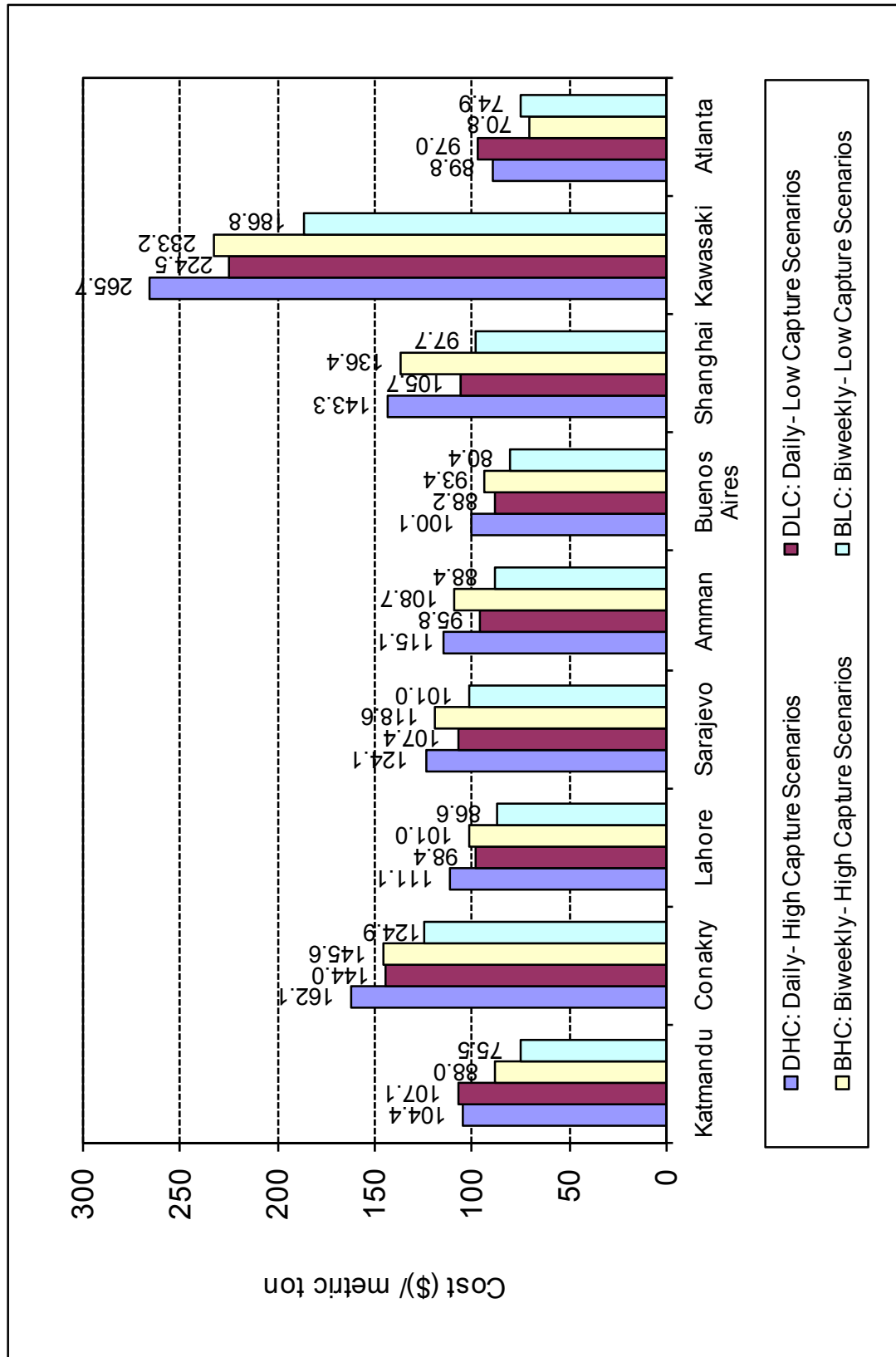


Figure 3.3-2 Group 3: Maximizing Materials Recovery (Via Mechanical Recycling and Composting)- Net Total Cost by City (without Land Price)

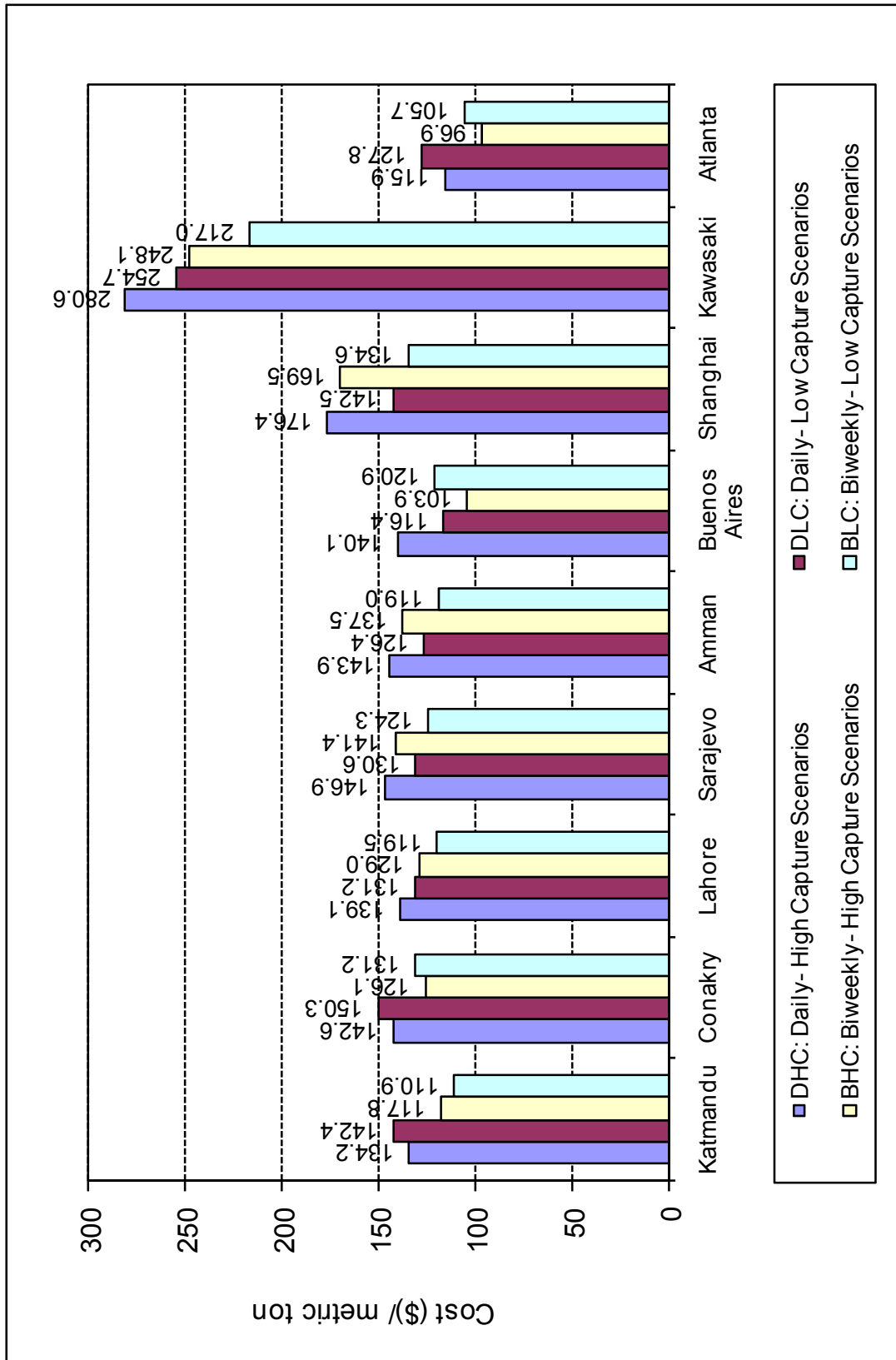


Figure 3.3-3 Group 3: Maximizing Materials Recovery (Via Mechanical Recycling and Composting)- Net Total Cost by City (with Land Price)

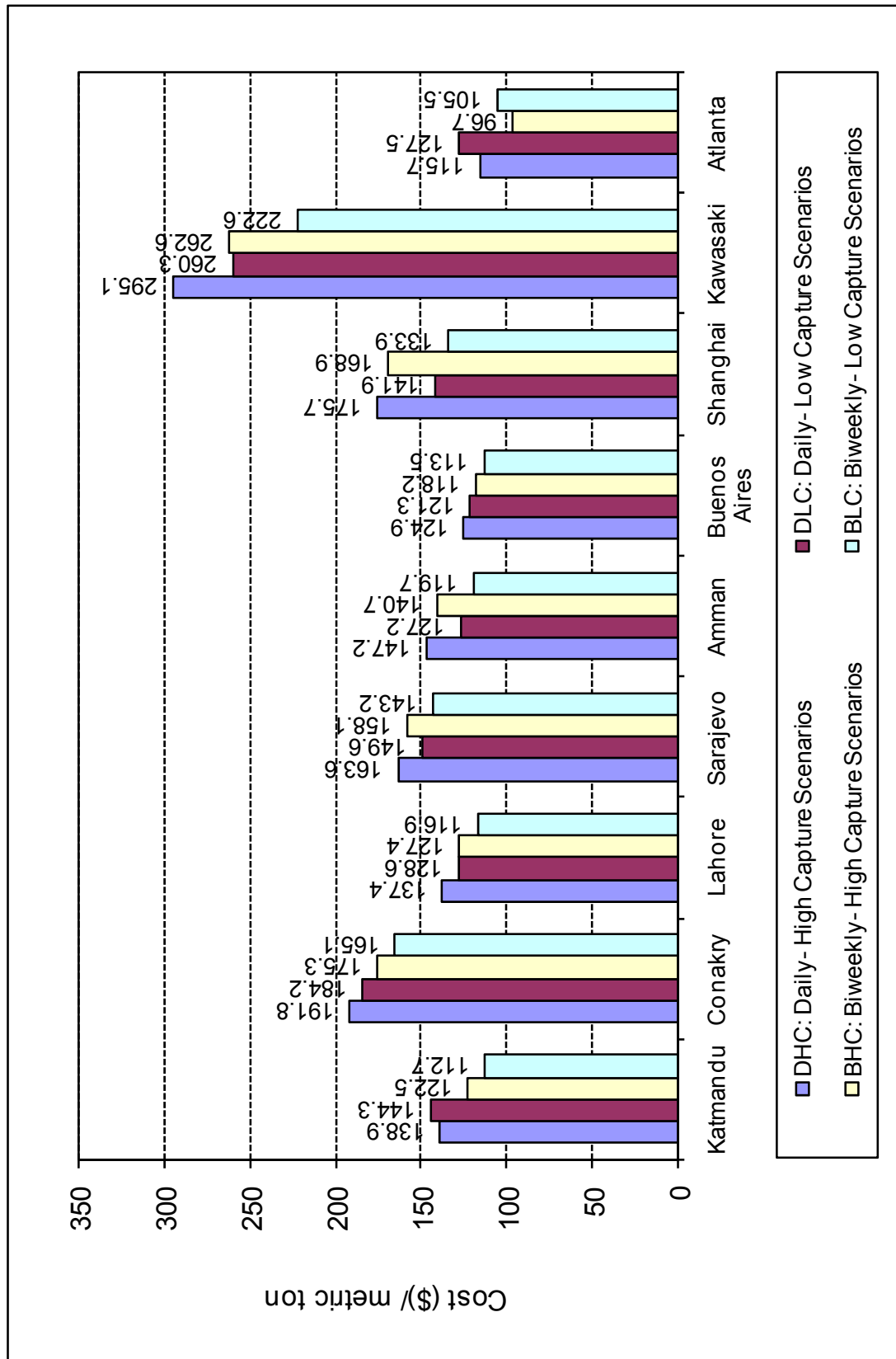


Figure 3.3-4 Group 3: Maximizing Materials Recovery (Via Mechanical Recycling and Composting)- Net Total Cost by City (without Land Price)

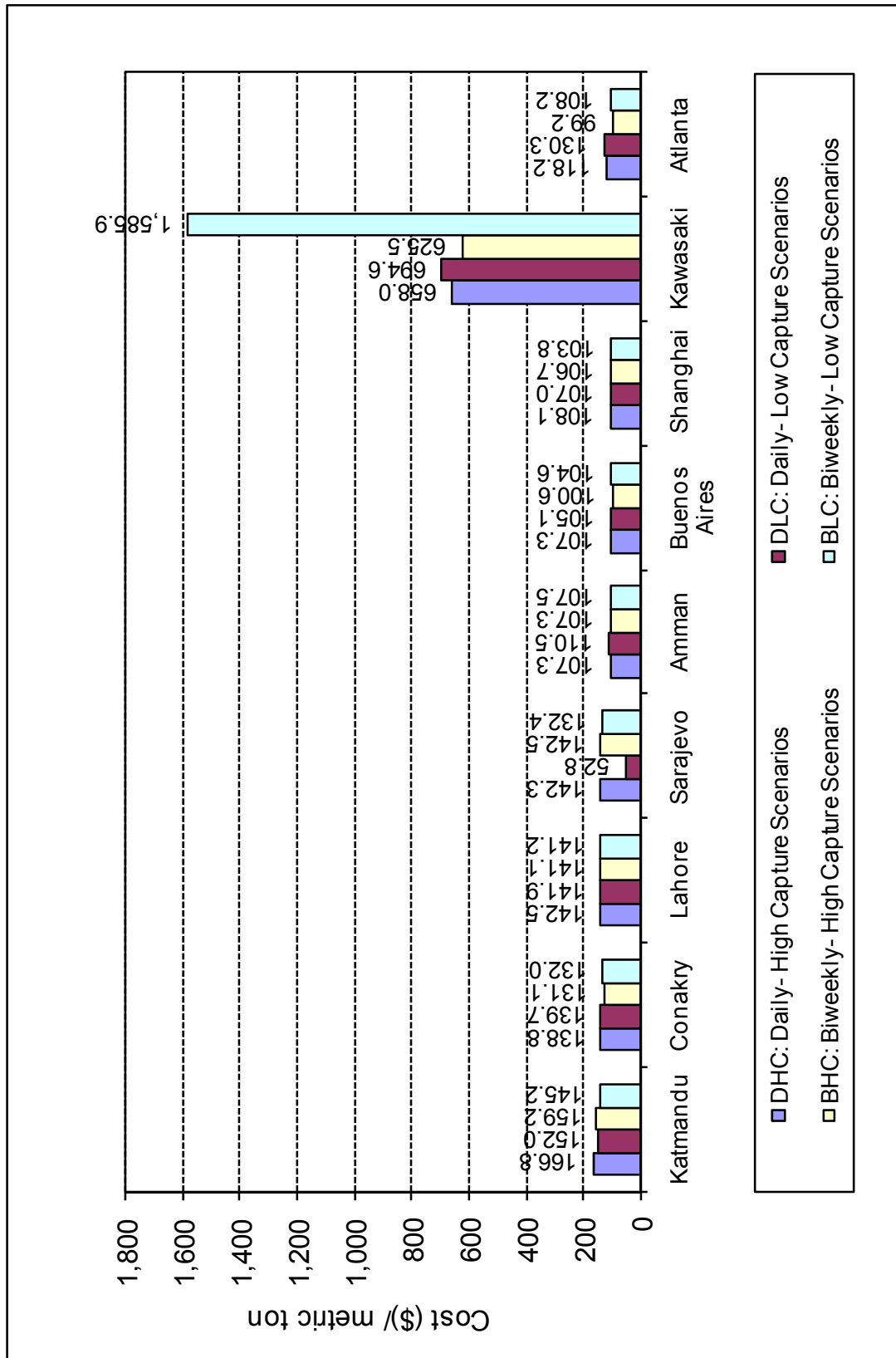


Figure 3.3-5 Group 4: Maximizing Energy Recovery - Net Total Cost by City (with Land Price)

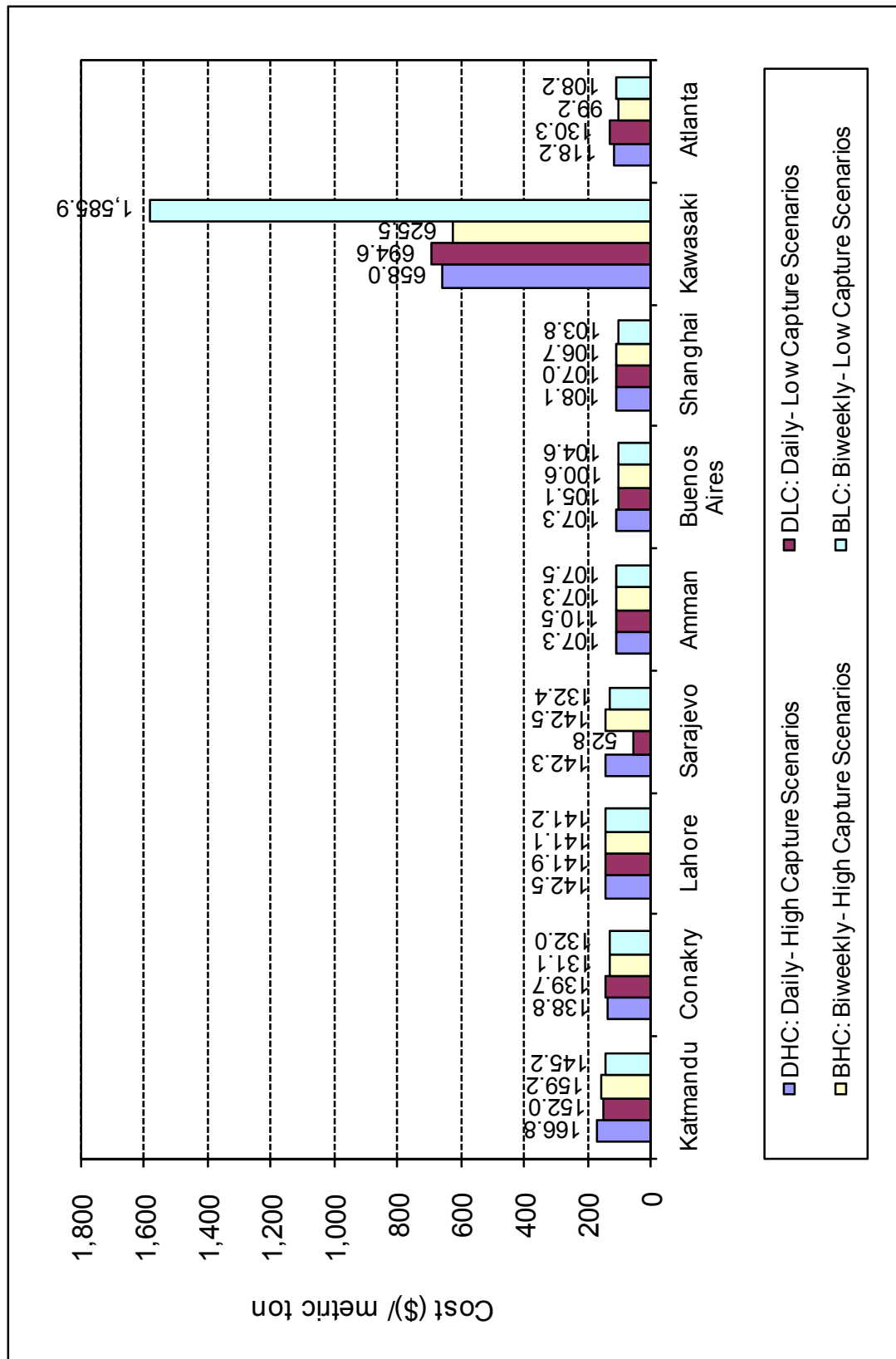


Figure 3.3-6 Group 4: Maximizing Energy Recovery- Net Total Cost by City (without Land Price)

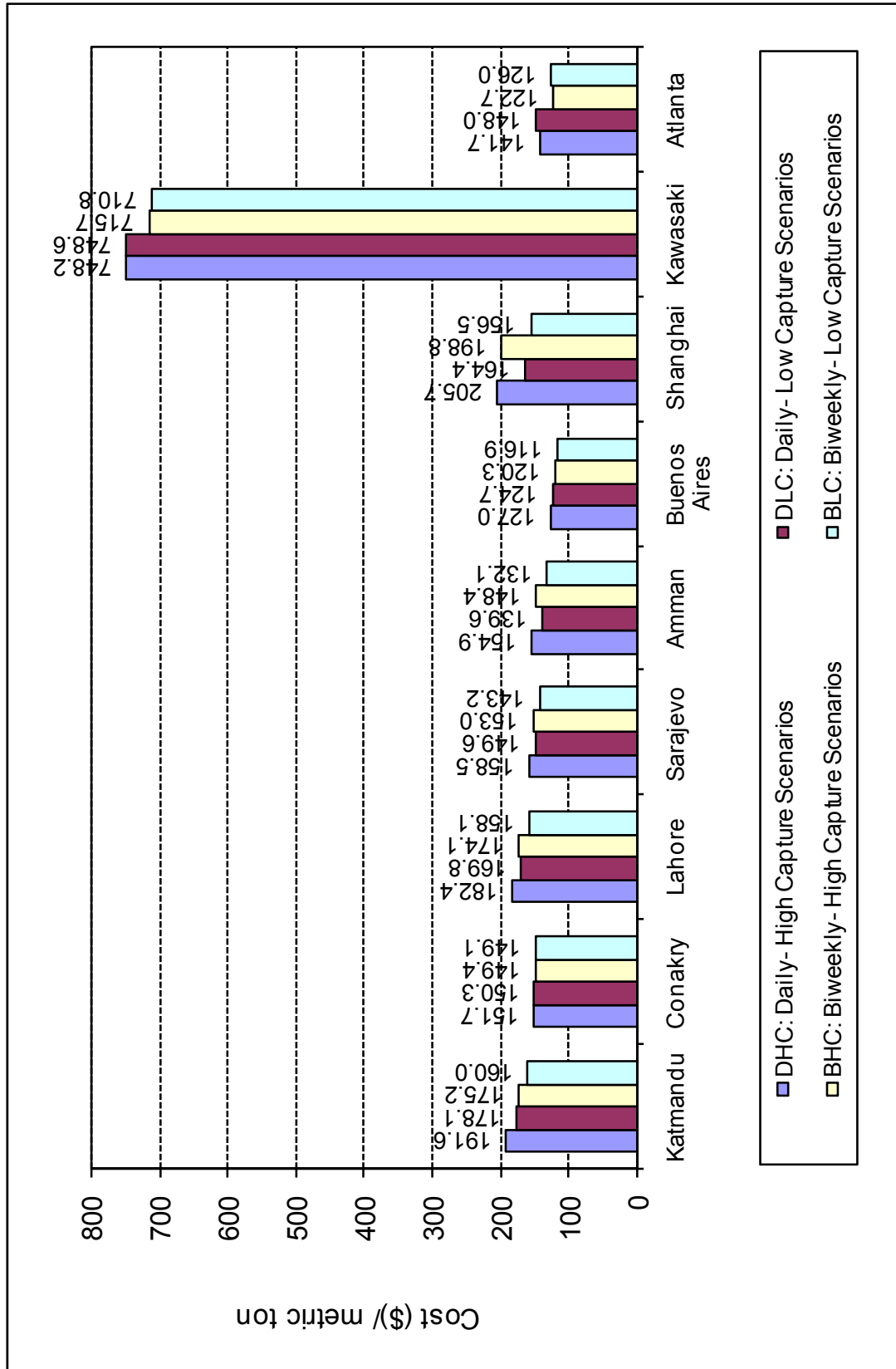


Figure 3.3-7 Group 5: Minimize Carbon (Global Warming) Emissions- Net Total Cost by City (with Land Price)

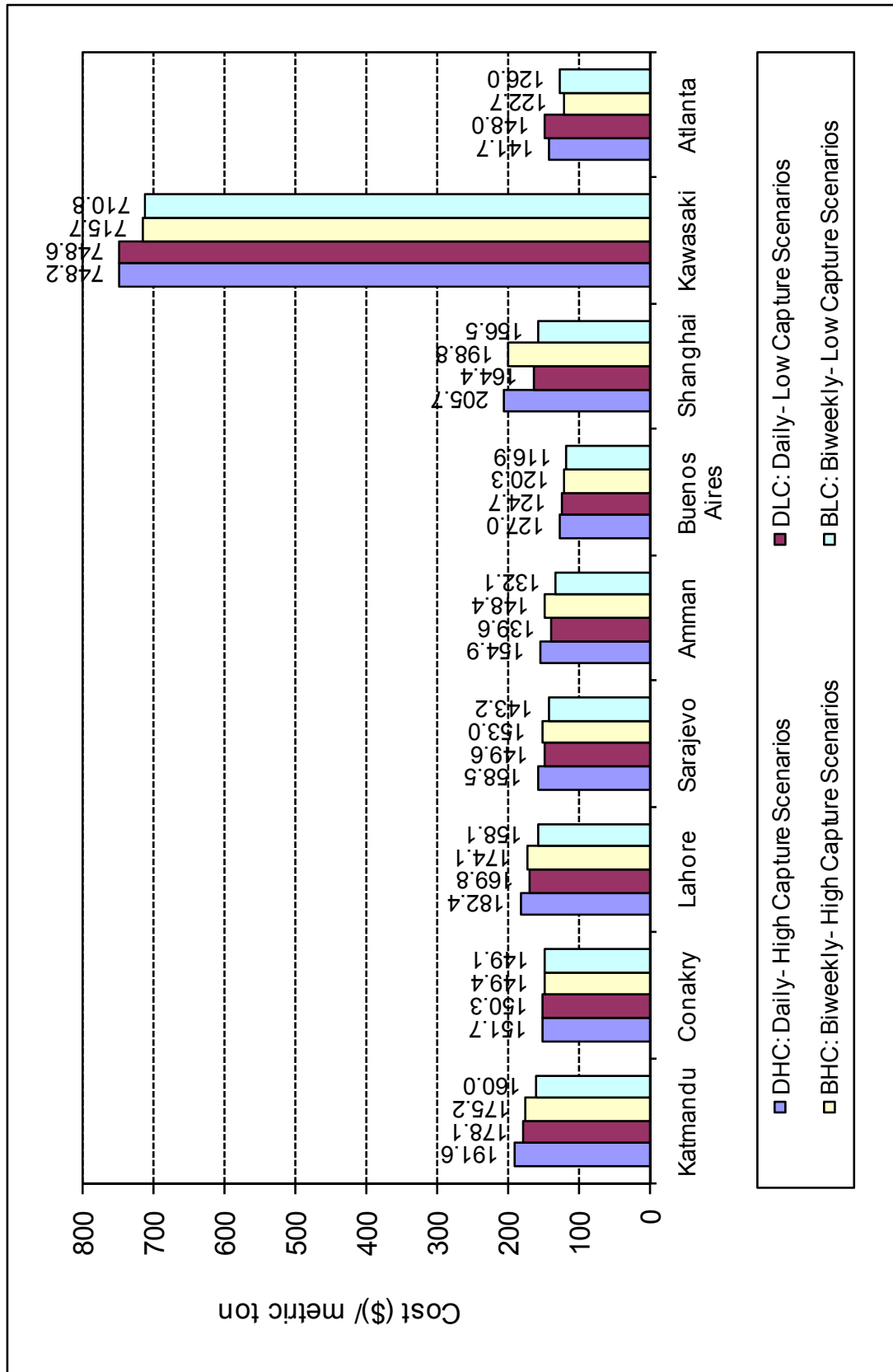


Figure 3.3-8 Group 5: Minimize Carbon (Global Warming) Emissions- Net Total Cost by City (without Land Price)

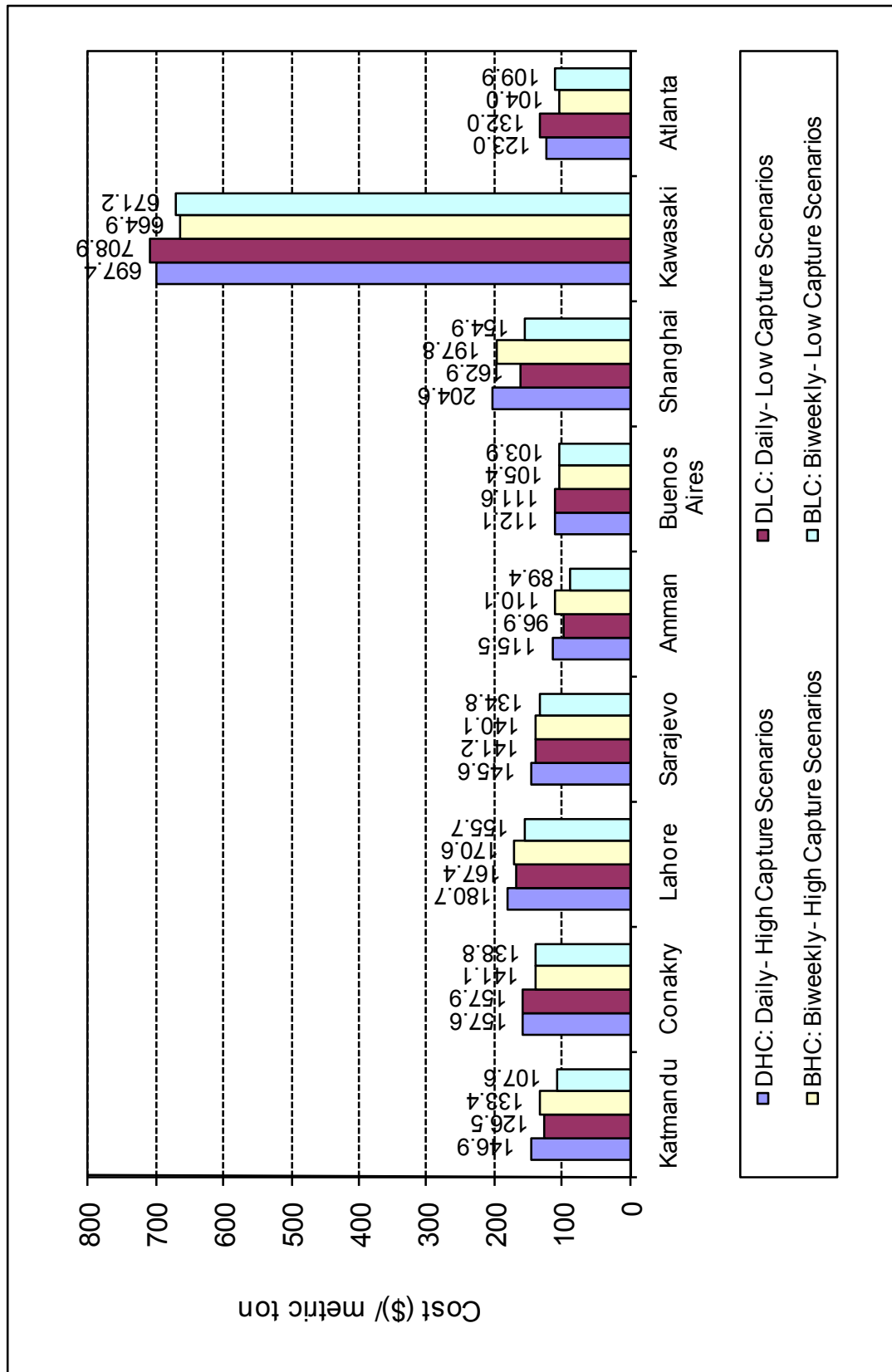


Figure 3.3-9 Group 5: Minimize Particulate Material (PM- Global Dimming) Emissions- Net Total Cost by City(with Land Price)

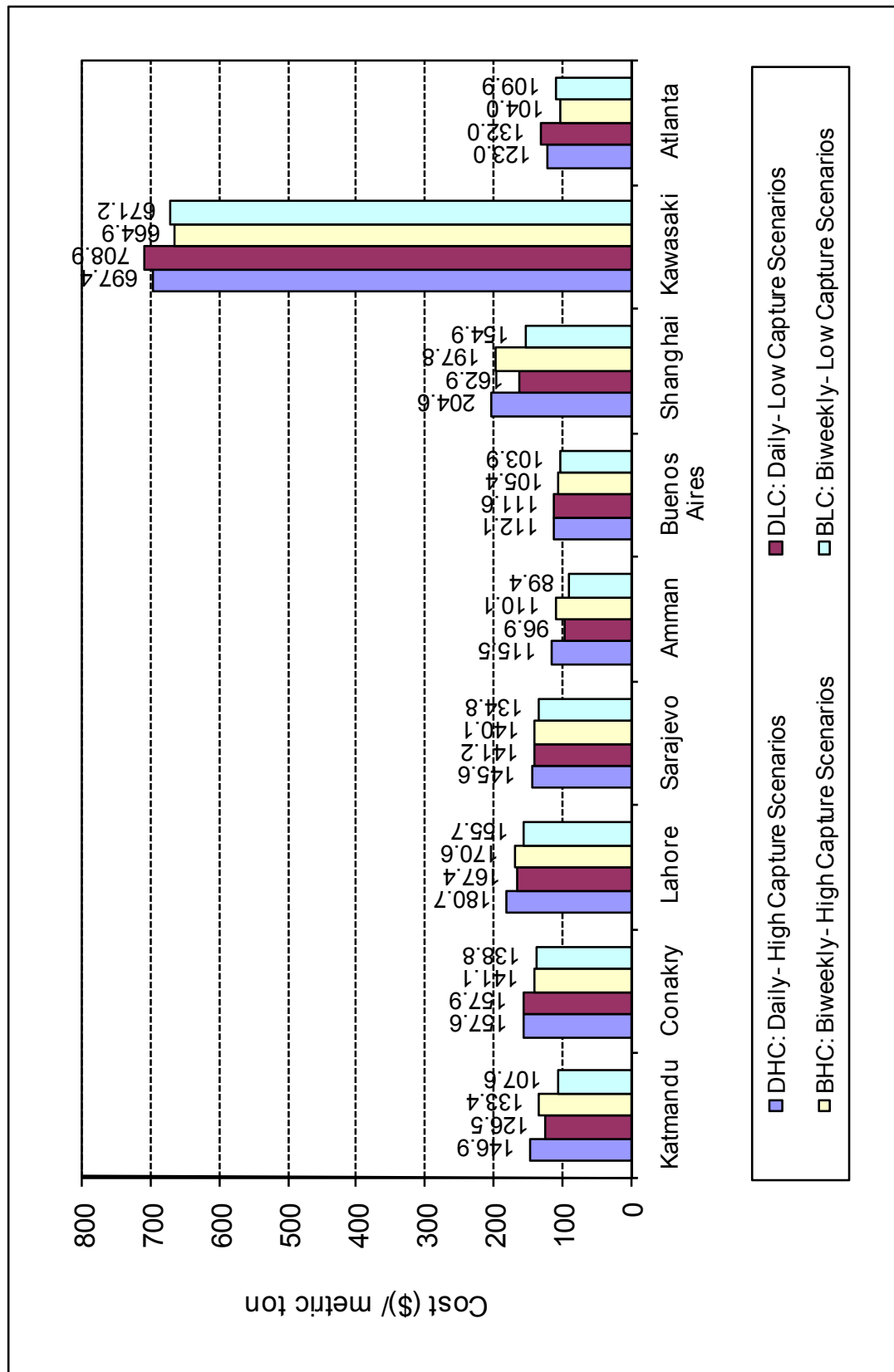


Figure 3.3-10 Group 5: Minimize Particulate Material (PM- Global Dimming) Emissions- Net Total Cost by City (without Land Price)

Variation by percent capture of recyclables

Scenarios with high or low capture will vary in cost depending on the amount of waste going to each of the selected management process (See Appendix 3.3.1. Optimization Scenarios Mass Flows by City and Management Process). In general, we found that the higher recyclables capture rate case is generally less expensive since it increases materials recovery (and associated revenues) and reduces landfill disposal costs. However, this behavior can be reversed by the lack of revenues/markets for recycling and/or a very low landfill disposal cost. For example, the Group 3 low capture scenario results would be less expensive than the high capture scenarios if composting and landfill disposal of additional material were cheaper than recycling that material (i.e., higher MRF cost and lack of significant revenues from the sale of recyclables).

A scenario with an optimization objective of minimizing energy will recover as much energy as possible from either recycling and/or incineration. A tradeoff exists between energy saved via recycling vs. incineration. For example, a city with low waste heating content and a high amount of recyclables (e.g., metals and plastics) will have more energy recovered from recycling. Therefore, for this city a scenario with high capture of recyclables will be less expensive since the additional revenues from increased recycling will offset the additional collection and MRF costs.

Cost variations among cities can be explained according to the process having the largest effect on the overall results (e.g., recycling vs. incineration) and the input parameters governing the results for that process. Tables 3.3-3 to 3.3-6 can be used to define the most influential processes. The lessons learned from the analysis of the simulation scenarios under Section 3.2 will aid determining the input parameters governing the results for those processes. Cities with the highest and lowest cost results were chosen under Table 3.3-2 to illustrate the cost variation. This table also provides explanations for the cost behavior of these cities. For example, Kawasaki is the city with the highest costs for all the optimization scenarios. For the Group 3 scenarios maximizing material recovery, the highest net costs are mainly due to (1) having the highest electricity cost, which affects the cost for all processes except collection and transportation, and (2) having the lowest recycling revenues. For the other optimization scenarios the most influential process is incineration with energy recovery, whose high net total cost is due to Kawasaki's highest capital and O&M costs.

Table 3.3-3 Group 3 Scenarios- Percentage of Net Total Cost Attributed to the Different Processes

City	Group 3: Maximizing Materials Recovery (Via Manual and Mechanical Recycling and Composting)																							
	Daily - High Capture						Daily - Low Capture						Biweekly Collection - High Capture						Biweekly Collection - Low Capture					
	Collection	Commingled Recycling	Composting	Landfill Disposal	Transportation	Remanufacturing*	Collection	Commingled Recycling	Composting	Landfill Disposal	Transportation	Remanufacturing*	Collection	Commingled Recycling	Composting	Landfill Disposal	Transportation	Remanufacturing*	Collection	Commingled Recycling	Composting	Landfill Disposal	Transportation	Remanufacturing*
Kathmandu	50.3%	4.7%	31.5%	5.9%	0.3%	7.4%	52.8%	2.1%	34.5%	6.8%	0.4%	3.3%	44.5%	5.2%	35.1%	6.6%	0.3%	8.2%	40.5%	2.7%	43.6%	8.6%	0.5%	4.1%
	50.4%	4.7%	31.5%	5.8%	0.3%	7.4%	52.9%	2.1%	34.6%	6.8%	0.4%	3.3%	44.6%	5.2%	35.1%	6.5%	0.3%	8.2%	40.5%	2.7%	43.6%	8.5%	0.5%	4.1%
Conakry	45.7%	3.3%	32.2%	10.3%	0.3%	8.2%	41.6%	1.5%	44.4%	8.3%	0.5%	3.7%	39.9%	3.6%	35.6%	11.4%	0.4%	9.1%	33.8%	1.7%	50.4%	9.4%	0.6%	4.1%
	45.9%	3.3%	32.3%	10.0%	0.3%	8.2%	41.7%	1.5%	44.5%	8.1%	0.5%	3.7%	40.1%	3.6%	35.8%	11.1%	0.4%	9.1%	33.9%	1.7%	50.5%	9.2%	0.6%	4.2%
Lahore	41.1%	10.0%	31.3%	9.1%	0.4%	8.2%	39.3%	5.2%	40.4%	10.6%	0.5%	4.1%	37.3%	10.6%	33.3%	9.7%	0.4%	8.7%	33.9%	5.6%	43.9%	11.5%	0.5%	4.5%
	41.9%	10.2%	31.9%	7.3%	0.4%	8.4%	40.2%	5.3%	41.3%	8.5%	0.5%	4.2%	38.0%	10.8%	34.0%	7.8%	0.4%	8.9%	34.7%	5.8%	45.1%	9.3%	0.5%	4.6%
Sarajevo	34.8%	16.1%	37.8%	2.5%	0.6%	8.2%	33.6%	8.8%	48.9%	3.6%	0.8%	4.3%	32.7%	16.7%	39.0%	2.5%	0.6%	8.5%	30.5%	9.2%	51.1%	3.7%	0.9%	4.5%
	34.8%	16.2%	37.9%	2.3%	0.6%	8.2%	33.7%	8.8%	49.0%	3.3%	0.8%	4.4%	32.7%	16.7%	39.1%	2.4%	0.6%	8.5%	30.6%	9.2%	51.3%	3.5%	0.9%	4.6%
Amman	47.2%	6.4%	29.9%	4.7%	0.4%	11.31%	42.3%	3.7%	36.3%	10.5%	0.5%	6.6%	45.3%	6.6%	31.0%	4.9%	0.4%	11.7%	39.2%	3.9%	38.2%	11.1%	0.5%	7.0%
	48.3%	6.6%	30.6%	2.5%	0.4%	11.57%	44.6%	3.9%	38.2%	5.8%	0.5%	7.0%	46.4%	6.8%	31.7%	2.6%	0.4%	12.0%	41.4%	4.2%	40.4%	6.1%	0.6%	7.4%
Buenos Aires	40.2%	9.4%	20.8%	4.9%	0.3%	24.4%	37.9%	5.7%	35.6%	6.6%	0.5%	13.7%	38.3%	9.7%	21.4%	5.1%	0.3%	25.1%	34.8%	5.9%	37.4%	7.0%	0.5%	14.4%
	41.0%	9.6%	21.1%	3.2%	0.3%	24.8%	38.9%	5.8%	36.5%	4.3%	0.5%	14.0%	39.1%	9.9%	21.8%	3.3%	0.3%	25.6%	35.7%	6.1%	38.4%	4.5%	0.5%	14.7%
Shanghai	46.2%	16.1%	27.6%	4.8%	0.3%	5.0%	41.5%	9.3%	38.7%	7.2%	0.4%	2.9%	44.3%	16.7%	28.6%	4.9%	0.3%	5.2%	38.4%	9.9%	40.6%	7.5%	0.5%	3.1%
	46.9%	16.3%	28.0%	3.5%	0.3%	5.1%	42.4%	9.5%	39.5%	5.2%	0.5%	2.9%	44.9%	16.9%	29.0%	3.6%	0.3%	5.3%	39.2%	10.1%	41.5%	5.5%	0.5%	3.2%
Kawasaki	50.2%	14.8%	13.8%	12.5%	0.3%	8.5%	47.9%	8.0%	19.8%	19.7%	0.4%	4.3%	44.9%	16.3%	15.2%	13.8%	0.3%	9.4%	39.7%	9.2%	22.9%	22.8%	0.5%	4.9%
	56.0%	16.5%	15.4%	2.3%	0.3%	9.5%	57.3%	9.5%	23.7%	3.9%	0.5%	5.1%	50.8%	18.5%	17.2%	2.6%	0.3%	10.6%	49.0%	11.4%	28.3%	4.6%	0.6%	6.1%
Atlanta	41.1%	9.4%	23.4%	3.1%	0.6%	22.3%	43.6%	5.2%	33.2%	4.8%	0.9%	12.3%	35.3%	10.4%	25.7%	3.4%	0.7%	24.5%	35.2%	6.0%	38.2%	5.5%	1.1%	14.1%
	41.2%	9.5%	23.4%	3.0%	0.6%	22.3%	43.7%	5.2%	33.3%	4.6%	0.9%	12.3%	35.3%	10.4%	25.7%	3.3%	0.7%	24.6%	35.2%	6.0%	38.3%	5.3%	1.1%	14.1%

* Upper percentage includeo land price for landfill disposal cost. Lower are is without land price
 * Net negative contributor to the net total cost. Remanufacturing includes recycling revenues.

Table 3.3-4 Group 4 Scenarios- Percentage of Net Total Cost Attributed to the Different Processes

City	Group 4: Maximizing Energy Recovery																											
	Daily - High Capture								Daily - Low Capture						Biweekly Collection - High Capture						Biweekly Collection - Low Capture							
	Collection	Separation		Incineration w/ER*	Landfill Disposal	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Landfill Disposal	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Landfill Disposal	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Landfill Disposal	Transportation	Remanufacturing*
		Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling				
Kathmandu	30.0%	15.3%	7.0%	36.4%	0.7%	1.2%	9.4%	27.1%	14.1%	1.6%	47.7%	0.4%	1.4%	7.6%	27.3%	15.9%	7.3%	37.8%	0.7%	1.3%	9.7%	23.8%	14.7%	1.6%	50.0%	0.6%	1.5%	7.9%
	30.0%	15.3%	7.0%	36.4%	0.7%	1.2%	9.4%	27.1%	14.1%	1.6%	47.7%	0.4%	1.4%	7.6%	27.3%	15.9%	7.3%	37.8%	0.7%	1.3%	9.7%	23.8%	14.7%	1.6%	50.0%	0.6%	1.5%	7.9%
Conakry	27.8%	5.7%	1.6%	53.2%	1.1%	1.5%	9.0%	25.5%	6.2%	0.7%	56.9%	1.2%	1.7%	7.7%	24.4%	6.0%	1.7%	55.7%	1.2%	1.6%	9.5%	21.9%	6.5%	0.8%	59.7%	1.3%	1.7%	8.1%
	27.8%	5.7%	1.6%	53.2%	1.1%	1.5%	9.0%	25.5%	6.2%	0.7%	56.9%	1.2%	1.7%	7.7%	24.4%	6.0%	1.7%	55.8%	1.1%	1.6%	9.5%	21.9%	6.5%	0.8%	59.7%	1.2%	1.7%	8.1%
Lahore	23.3%	12.7%	2.3%	50.2%	1.7%	1.6%	8.2%	22.3%	12.8%	1.2%	53.2%	1.8%	1.7%	7.0%	22.9%	12.4%	2.6%	50.6%	1.7%	1.7%	8.1%	22.1%	12.7%	1.3%	53.3%	1.8%	1.8%	7.1%
	23.4%	12.7%	2.3%	50.3%	1.4%	1.6%	8.2%	22.4%	12.8%	1.2%	53.3%	1.5%	1.8%	7.1%	23.0%	12.5%	2.6%	50.7%	1.4%	1.7%	8.2%	22.1%	12.8%	1.3%	53.5%	1.5%	1.8%	7.1%
Sarajevo	20.5%	14.1%	7.3%	45.4%	2.3%	1.6%	8.8%	20.0%	14.2%	3.6%	50.8%	2.5%	1.8%	7.0%	20.4%	13.7%	8.1%	45.1%	2.3%	1.6%	8.9%	18.8%	14.4%	3.6%	51.6%	2.6%	1.9%	7.1%
	20.6%	14.1%	7.3%	45.4%	2.2%	1.6%	8.8%	20.1%	14.2%	3.6%	50.9%	2.4%	1.8%	7.0%	20.4%	13.7%	8.1%	45.1%	2.2%	1.6%	8.9%	18.8%	14.4%	3.6%	51.7%	2.4%	1.9%	7.2%
Amman	27.0%	0.0%	0.9%	69.1%	2.2%	0.2%	0.7%	28.5%	0.0%	0.4%	68.3%	2.2%	0.2%	0.3%	27.0%	0.0%	0.9%	69.1%	2.2%	0.2%	0.7%	26.6%	0.0%	0.4%	70.2%	2.3%	0.2%	0.3%
	27.2%	0.0%	1.0%	69.7%	1.3%	0.2%	0.7%	28.8%	0.0%	0.4%	68.9%	1.4%	0.2%	0.3%	27.2%	0.0%	1.0%	69.7%	1.3%	0.2%	0.7%	26.8%	0.0%	0.4%	70.9%	1.4%	0.2%	0.3%
Buenos Aires	21.7%	11.2%	3.7%	37.3%	0.5%	1.1%	24.5%	18.5%	11.2%	1.6%	44.5%	0.6%	1.3%	22.2%	19.1%	11.6%	3.8%	38.5%	0.5%	1.1%	25.3%	18.4%	11.1%	1.8%	44.4%	0.6%	1.3%	22.3%
	21.7%	11.2%	3.7%	37.3%	0.4%	1.1%	24.5%	18.5%	11.2%	1.6%	44.5%	0.6%	1.3%	22.2%	19.1%	11.6%	3.8%	38.5%	0.5%	1.1%	25.3%	18.4%	11.1%	1.8%	44.4%	0.6%	1.3%	22.3%
Shanghai	27.4%	20.5%	2.1%	41.0%	1.2%	2.2%	5.5%	28.1%	19.4%	1.2%	43.1%	1.3%	2.3%	4.5%	26.8%	20.4%	2.4%	41.3%	1.2%	2.2%	5.8%	26.1%	20.0%	1.3%	44.3%	1.3%	2.4%	4.6%
	27.5%	20.5%	2.1%	41.2%	0.8%	2.2%	5.6%	28.3%	19.5%	1.2%	43.3%	0.9%	2.3%	4.5%	26.9%	20.4%	2.4%	41.5%	0.8%	2.2%	5.8%	26.3%	20.1%	1.3%	44.5%	0.9%	2.4%	4.6%
Kawasaki	12.0%	2.7%	1.6%	78.9%	0.9%	0.2%	3.6%	11.1%	3.5%	0.7%	81.0%	0.9%	0.3%	2.5%	8.9%	2.8%	1.7%	81.7%	0.9%	0.3%	3.8%	7.5%	3.6%	0.7%	84.3%	1.0%	0.3%	2.6%
	12.1%	2.7%	1.7%	79.5%	0.1%	0.2%	3.7%	11.2%	3.5%	0.7%	81.7%	0.2%	0.3%	2.5%	9.0%	2.8%	1.7%	82.3%	0.2%	0.3%	3.8%	7.6%	3.7%	0.7%	85.0%	0.2%	0.3%	2.6%
Atlanta	29.5%	13.3%	5.6%	23.5%	0.6%	0.8%	26.6%	30.6%	13.7%	3.0%	29.5%	0.8%	1.0%	21.4%	23.8%	14.4%	6.0%	25.4%	0.6%	0.9%	28.8%	23.2%	15.2%	3.3%	32.6%	0.9%	1.2%	23.7%
	29.5%	13.3%	5.6%	23.5%	0.6%	0.8%	26.6%	30.6%	13.7%	3.0%	29.5%	0.8%	1.0%	21.4%	23.8%	14.4%	6.0%	25.4%	0.6%	0.9%	28.8%	23.2%	15.2%	3.3%	32.6%	0.8%	1.2%	23.7%

* Upper percentage includeo land price for landfill disposal cost. Lower are is without land price
 * Net negative contributor to the net total cost. Remanufacturing includes recycling revenues and incineration with energy recovery includes energy sale revenues
 Due to rounding zero values may actually be very small values.

Table 3.3-5 Group 5 (Carbon) Scenarios- Percentage of Net Total Cost Attributed to the Different Processes

City	Group 5: Minimizing Carbon (Global Warming) Emissions																											
	Daily - High Capture							Daily - Low Capture						Biweekly Collection - High Capture						Biweekly Collection - Low Capture								
	Collection	Separation		Incineration w/ER*	Ash-Landfill	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Ash-Landfill	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Ash-Landfill	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Ash-Landfill	Transportation	Remanufacturing*
		Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling				
Kathmandu	28.5%	8.8%	6.6%	28.1%	0.3%	0.8%	26.9%	25.1%	10.8%	3.6%	36.4%	0.5%	1.1%	22.5%	26.7%	9.0%	6.8%	28.8%	0.3%	0.8%	27.5%	22.5%	11.2%	3.7%	37.7%	0.5%	1.6%	10.3%
	28.5%	8.8%	6.6%	28.1%	0.3%	0.8%	26.9%	25.1%	10.8%	3.6%	36.4%	0.5%	1.1%	22.5%	26.7%	9.0%	6.8%	28.8%	0.3%	0.8%	27.5%	22.5%	11.2%	3.7%	37.7%	0.5%	1.6%	10.3%
Conakry	28.5%	6.1%	1.8%	52.8%	1.1%	1.5%	8.2%	26.1%	6.7%	0.8%	57.9%	1.2%	1.7%	5.6%	27.8%	6.0%	2.0%	52.9%	1.1%	1.5%	8.7%	25.7%	6.6%	0.9%	58.0%	1.2%	1.4%	17.5%
	28.5%	6.1%	1.8%	52.8%	1.1%	1.5%	8.2%	26.1%	6.7%	0.8%	57.9%	1.2%	1.7%	5.6%	27.8%	6.0%	2.0%	53.0%	1.1%	1.5%	8.7%	25.7%	6.6%	0.9%	58.0%	1.2%	1.4%	17.5%
Lahore	30.6%	13.1%	7.2%	35.9%	1.2%	1.1%	10.9%	28.0%	14.9%	3.6%	42.1%	1.4%	1.3%	8.7%	28.1%	13.6%	7.5%	37.3%	1.2%	1.2%	11.3%	23.6%	15.8%	3.8%	44.6%	1.5%	1.9%	4.8%
	30.6%	13.2%	7.2%	36.0%	1.0%	1.1%	10.9%	28.0%	14.9%	3.6%	42.2%	1.2%	1.3%	8.7%	28.1%	13.6%	7.5%	37.3%	1.1%	1.2%	11.3%	23.7%	15.8%	3.8%	44.7%	1.3%	1.9%	4.8%
Sarajevo	26.1%	12.4%	5.5%	45.8%	2.2%	1.6%	6.4%	24.5%	13.4%	2.7%	50.4%	2.4%	1.8%	4.7%	23.9%	12.7%	5.7%	47.1%	2.3%	1.7%	6.6%	21.7%	13.9%	2.8%	52.3%	2.5%	1.1%	23.3%
	26.1%	12.4%	5.5%	45.8%	2.1%	1.6%	6.4%	24.6%	13.4%	2.7%	50.5%	2.3%	1.8%	4.7%	24.0%	12.7%	5.7%	47.2%	2.2%	1.7%	6.6%	21.7%	13.9%	2.8%	52.4%	2.4%	1.1%	23.3%
Amman	36.9%	7.5%	4.7%	35.7%	0.9%	1.2%	13.1%	32.4%	9.1%	2.5%	43.4%	1.2%	1.5%	9.8%	34.9%	7.7%	4.8%	36.9%	1.0%	1.2%	13.5%	29.4%	9.5%	2.6%	45.4%	1.3%	1.7%	5.8%
	37.0%	7.5%	4.7%	35.9%	0.6%	1.2%	13.2%	32.6%	9.1%	2.5%	43.6%	0.8%	1.5%	9.9%	35.0%	7.7%	4.9%	37.0%	0.6%	1.2%	13.6%	29.5%	9.5%	2.6%	45.6%	0.8%	1.7%	5.8%
Buenos Aires	28.5%	8.8%	6.6%	28.1%	0.3%	0.8%	26.9%	25.1%	10.8%	3.6%	36.4%	0.5%	1.1%	22.5%	26.7%	9.0%	6.8%	28.8%	0.4%	0.8%	27.5%	22.5%	11.2%	3.7%	37.7%	0.5%	1.4%	9.2%
	28.5%	8.8%	6.6%	28.1%	0.3%	0.8%	26.9%	25.1%	10.8%	3.6%	36.4%	0.5%	1.1%	22.5%	26.7%	9.0%	6.8%	28.8%	0.3%	0.8%	27.5%	22.5%	11.2%	3.7%	37.7%	0.5%	1.4%	9.3%
Shanghai	36.8%	17.6%	12.8%	24.8%	0.6%	1.0%	6.5%	32.4%	21.8%	7.2%	30.3%	0.8%	1.4%	6.2%	34.9%	18.2%	13.2%	25.5%	0.6%	1.1%	6.6%	29.5%	22.7%	7.5%	31.7%	0.8%	0.2%	2.5%
	36.8%	17.7%	12.8%	24.8%	0.4%	1.0%	6.5%	32.5%	21.8%	7.2%	30.4%	0.5%	1.4%	6.2%	34.9%	18.2%	13.2%	25.5%	0.4%	1.1%	6.7%	29.5%	22.8%	7.5%	31.7%	0.6%	0.2%	2.6%
Kawasaki	14.7%	3.9%	4.2%	73.1%	0.8%	0.2%	3.0%	12.1%	5.8%	1.9%	76.6%	0.9%	0.2%	2.5%	12.0%	4.0%	4.3%	75.5%	0.8%	0.2%	3.1%	8.8%	6.0%	1.9%	79.5%	0.9%	1.4%	6.5%
	14.8%	3.9%	4.2%	73.6%	0.1%	0.2%	3.0%	12.2%	5.8%	1.9%	77.2%	0.2%	0.2%	2.5%	12.1%	4.1%	4.4%	76.1%	0.1%	0.2%	3.1%	8.9%	6.0%	1.9%	80.2%	0.2%	1.4%	6.5%
Atlanta	29.5%	12.3%	5.6%	31.3%	0.7%	1.1%	19.5%	30.6%	13.5%	2.7%	35.4%	0.9%	1.2%	15.7%	23.2%	13.3%	6.1%	34.0%	0.8%	1.2%	21.3%	22.7%	15.0%	3.0%	39.4%	1.0%	1.1%	23.3%
	29.5%	12.3%	5.6%	31.3%	0.7%	1.1%	19.5%	30.7%	13.5%	2.7%	35.4%	0.9%	1.2%	15.7%	23.2%	13.3%	6.1%	34.0%	0.8%	1.2%	21.3%	22.7%	15.0%	3.0%	39.4%	1.0%	1.1%	23.3%

* Upper percentage includeo land price for landfill disposal cost. Lower are is without land price

* Net negative contributor to the net total cost. It includes recycling revenues. Remanufacturing includes recycling revenues and incineration with energy recovery includes energy sale revenues.

Table 3.3-6 Group 5 (PM) Scenarios- Percentage of Net Total Cost Attributed to the Different Processes

City	Group 5: Minimizing PM (Global Dimming) Emissions																															
	Daily - High Capture								Daily - Low Capture								Biweekly Collection - High Capture								Biweekly Collection - Low Capture							
	Collection	Separation		Incineration w/ER*	Disposal		Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Disposal		Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Disposal		Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Disposal		Transportation	Remanufacturing*
		Mixed Waste Recycling	Commingled Recycling		Landfill	Ash-landfill				Mixed Waste Recycling	Commingled Recycling		Landfill	Ash-landfill				Mixed Waste Recycling	Commingled Recycling		Landfill	Ash-landfill				Mixed Waste Recycling	Commingled Recycling		Landfill	Ash-landfill		
Kathmandu	29.6%	8.0%	6.9%	23.6%	0.0%	0.3%	0.7%	30.9%	25.3%	10.2%	3.8%	32.6%	0.0%	0.5%	1.0%	26.7%	27.9%	8.2%	7.1%	24.2%	0.0%	0.3%	0.7%	31.6%	22.8%	10.5%	3.9%	33.7%	0.0%	0.5%	1.0%	27.6%
	29.6%	8.0%	6.9%	23.6%	0.0%	0.3%	0.7%	30.9%	25.3%	10.2%	3.8%	32.6%	0.0%	0.5%	1.0%	26.7%	27.9%	8.2%	7.1%	24.2%	0.0%	0.3%	0.7%	31.6%	22.8%	10.5%	3.9%	33.7%	0.0%	0.5%	1.0%	27.6%
Conakry	37.7%	4.8%	2.7%	40.8%	0.0%	0.9%	1.2%	11.9%	34.8%	5.6%	1.3%	46.7%	0.0%	1.0%	1.4%	9.2%	32.4%	5.2%	2.9%	44.4%	0.0%	0.9%	1.3%	12.9%	27.7%	6.3%	1.4%	51.8%	0.0%	1.1%	1.5%	10.2%
	37.8%	4.8%	2.7%	40.9%	0.0%	0.8%	1.2%	11.9%	34.9%	5.6%	1.3%	46.7%	0.0%	1.0%	1.4%	9.2%	32.4%	5.2%	2.9%	44.4%	0.0%	0.9%	1.3%	12.9%	27.7%	6.3%	1.4%	51.8%	0.0%	1.1%	1.5%	10.2%
Lahore	31.1%	12.9%	7.4%	34.5%	0.0%	1.2%	1.1%	11.8%	28.1%	14.7%	3.8%	40.9%	0.0%	1.4%	1.3%	9.8%	28.0%	13.5%	7.8%	36.1%	0.0%	1.2%	1.1%	12.3%	23.8%	15.6%	4.0%	43.4%	0.0%	1.5%	1.4%	10.4%
	31.1%	12.9%	7.5%	34.6%	0.0%	1.0%	1.1%	11.8%	28.1%	14.7%	3.8%	41.0%	0.0%	1.2%	1.3%	9.8%	28.0%	13.5%	7.8%	36.1%	0.0%	1.0%	1.1%	12.4%	23.8%	15.6%	4.0%	43.5%	0.0%	1.2%	1.4%	10.4%
Sarajevo	24.3%	10.1%	8.4%	46.8%	0.0%	2.4%	1.7%	6.4%	23.9%	11.8%	4.0%	51.1%	0.0%	2.5%	1.9%	4.9%	21.9%	10.4%	8.7%	48.2%	0.0%	2.4%	1.8%	6.6%	20.9%	12.2%	4.1%	53.1%	0.0%	2.6%	2.0%	5.1%
	24.3%	10.1%	8.4%	46.8%	0.0%	2.3%	1.7%	6.4%	23.9%	11.8%	4.0%	51.1%	0.0%	2.4%	1.9%	4.9%	21.9%	10.4%	8.7%	48.3%	0.0%	2.3%	1.8%	6.6%	20.9%	12.2%	4.1%	53.1%	0.0%	2.5%	2.0%	5.1%
Amman	46.0%	7.6%	6.3%	0.0%	18.9%	0.0%	0.8%	20.3%	40.1%	10.2%	3.5%	0.0%	26.5%	0.0%	1.1%	18.5%	44.5%	7.8%	6.5%	0.0%	19.4%	0.0%	0.8%	20.9%	37.1%	10.7%	3.7%	0.0%	27.9%	0.0%	1.2%	19.4%
	47.4%	7.9%	6.5%	0.0%	0.0%	19.5%	0.8%	17.9%	41.2%	10.5%	3.6%	0.0%	0.0%	27.2%	1.2%	16.3%	45.9%	8.1%	6.7%	0.0%	0.0%	20.0%	0.9%	18.5%	38.1%	11.0%	3.8%	0.0%	0.0%	28.7%	1.2%	17.1%
Buenos Aires	29.6%	8.0%	6.9%	23.6%	0.0%	0.3%	0.7%	30.9%	25.3%	10.2%	3.8%	32.6%	0.0%	0.5%	1.0%	26.7%	27.9%	8.2%	7.1%	24.2%	0.0%	0.3%	0.7%	31.6%	22.8%	10.5%	3.9%	33.7%	0.0%	0.5%	1.0%	27.6%
	29.6%	8.0%	6.9%	23.6%	0.0%	0.3%	0.7%	30.9%	25.3%	10.2%	3.8%	32.6%	0.0%	0.5%	1.0%	26.7%	27.9%	8.2%	7.1%	24.2%	0.0%	0.3%	0.7%	31.6%	22.8%	10.5%	3.9%	33.7%	0.0%	0.5%	1.0%	27.6%
Shanghai	37.3%	16.9%	13.0%	23.0%	0.0%	0.5%	0.9%	8.3%	32.7%	21.3%	7.4%	28.9%	0.0%	0.7%	1.3%	7.7%	35.5%	17.4%	13.4%	23.6%	0.0%	0.5%	0.9%	8.6%	29.9%	22.3%	7.7%	30.1%	0.0%	0.8%	1.3%	8.0%
	37.4%	17.0%	13.0%	23.0%	0.0%	0.3%	0.9%	8.3%	32.8%	21.4%	7.4%	28.9%	0.0%	0.5%	1.3%	7.7%	35.6%	17.5%	13.4%	23.7%	0.0%	0.4%	0.9%	8.6%	29.9%	22.3%	7.7%	30.2%	0.0%	0.5%	1.3%	8.0%
Kawasaki	16.6%	4.1%	4.8%	69.1%	0.0%	0.8%	0.2%	4.4%	13.1%	6.1%	2.1%	74.1%	0.0%	0.9%	0.2%	3.4%	13.8%	4.2%	5.0%	71.4%	0.0%	0.8%	0.2%	4.6%	9.7%	6.4%	2.2%	77.0%	0.0%	0.9%	0.2%	3.5%
	16.7%	4.1%	4.8%	69.5%	0.0%	0.1%	0.2%	4.4%	13.2%	6.2%	2.1%	74.6%	0.0%	0.2%	0.2%	3.4%	13.9%	4.3%	5.0%	71.9%	0.0%	0.1%	0.2%	4.6%	9.8%	6.4%	2.2%	77.6%	0.0%	0.2%	0.2%	3.6%
Atlanta	31.4%	11.1%	7.0%	22.7%	0.0%	0.6%	0.8%	26.4%	31.2%	13.1%	3.5%	29.0%	0.0%	0.8%	1.0%	21.4%	26.0%	11.9%	7.5%	24.5%	0.0%	0.6%	0.9%	28.5%	23.9%	14.5%	3.9%	32.0%	0.0%	0.9%	1.1%	23.7%
	31.4%	11.1%	7.0%	22.7%	0.0%	0.6%	0.8%	26.4%	31.2%	13.1%	3.5%	29.0%	0.0%	0.8%	1.0%	21.5%	26.0%	11.9%	7.5%	24.5%	0.0%	0.6%	0.9%	28.5%	23.9%	14.5%	3.9%	32.0%	0.0%	0.8%	1.1%	23.7%

* Upper percentage includeo land price for landfill disposal cost. Lower are is without land price

* Net negative contributor to the net total cost. It includes recycling revenues. Remanufacturing includes recycling revenues and incineration with energy recovery includes energy sale revenues.

Due to rounding zero values may actually be very small values.

3.3.2 Energy Results

Energy in the form of fuel and/or electricity is consumed by all processes. Some processes produce energy (e.g., incineration and landfill disposal with gas collection and energy recovery). Other processes, such as recycling, may avoid (or offset) energy use. The most significant parameters affecting the energy consumption results include:

- Quantity and composition of recyclable materials in the waste stream.
- Waste heating value.
- Electricity grid mix

In addition, the optimization scenario energy results were found to exhibit the following general trends:

- The combination manual MRF and composting consumes less energy than mechanical MRF and composting.
- Daily collection typically consumes more energy than biweekly
- High capture typically has less net energy requirements than low capture

Additional details about the energy results can be found in Table 3.3-7 and Figures 3.3-11 to 3.3-15.

Variation by process design in the scenarios maximizing materials recovery

Figures 3.3-11 and 3.3-12 show the energy variation by MRF and composting process design. Consistently in all the scenarios and settings, the net energy consumed by the manual design is lower than by the mechanical design. In both cases there are net energy savings due to recycling related offsets.

Variation by collection frequency

It is expected that daily collection consumes more energy than biweekly collection as is observed in the results for all the cities (see Figures 3.3-11 and 3.3-12). This is due to the difference between daily and biweekly energy requirements since collection trucks going to the same number of stops daily vs. biweekly will consume more fuel.

Table 3.3-7 Summary of Energy Variation by Scenario and Scenario Settings

Criteria	Maximize Materials Recovery (via recycling and composting)				Maximize Energy Recovery				Minimize Carbon (Global Warming) Emissions				Minimize PM (Global Dimming) Emissions			
	Manual and Mechanical				Daily High Capture	Daily Low Capture	Biweekly High Capture	Biweekly Low Capture	Daily High Capture	Daily Low Capture	Biweekly High Capture	Biweekly Low Capture	Daily High Capture	Daily Low Capture	Biweekly High Capture	Biweekly Low Capture
	Daily High Capture	Daily Low Capture	Biweekly High Capture	Biweekly Low Capture												
Energy Consumption Variation																
By Collection Frequency (See Figures 3.3.6 to 3.3.10)	More energy consumption		Less energy consumption		More energy consumption		Less energy consumption		More energy consumption		Less energy consumption		More energy consumption		Less energy consumption	
By Percent Capture of Recyclables (See Figures 3.3.6 to 3.3.10)	Less energy	More energy	Less energy	More energy	Less energy	More energy	Less energy	More energy	Less energy	More energy	Less energy	More energy	Less energy	More energy	Less energy	More energy
By city (See Tables 3.3.8 to 3.3.11)	Sarajevo: highest net energy consumption due to: - Lowest energy savings from recycling (Lowest amounts of recyclables and metals among them).				Sarajevo and Kathmandu: highest net energy consumption due to: - Lowest energy savings from incineration and recycling (Lowest waste heating value, lowest energy requirements for electricity production due to the large percent of hydro in their grid mix, and low amounts of ferrous material for recycling).								Kathmandu: highest net energy consumption due to: - Lowest energy savings from incineration and recycling (Lowest waste heating value, lowest energy requirements for electricity production due to the large percent of hydro in their grid mix, and low amounts of ferrous material for recycling).			
	Atlanta: lowest net energy consumption due to: - Highest energy savings from recycling (Highest amounts of recyclables and metals among them).				Atlanta: lowest net energy consumption due to: - Highest energy savings from recycling and incineration (Highest waste heating value and amounts of metals for recycling).											

3-81

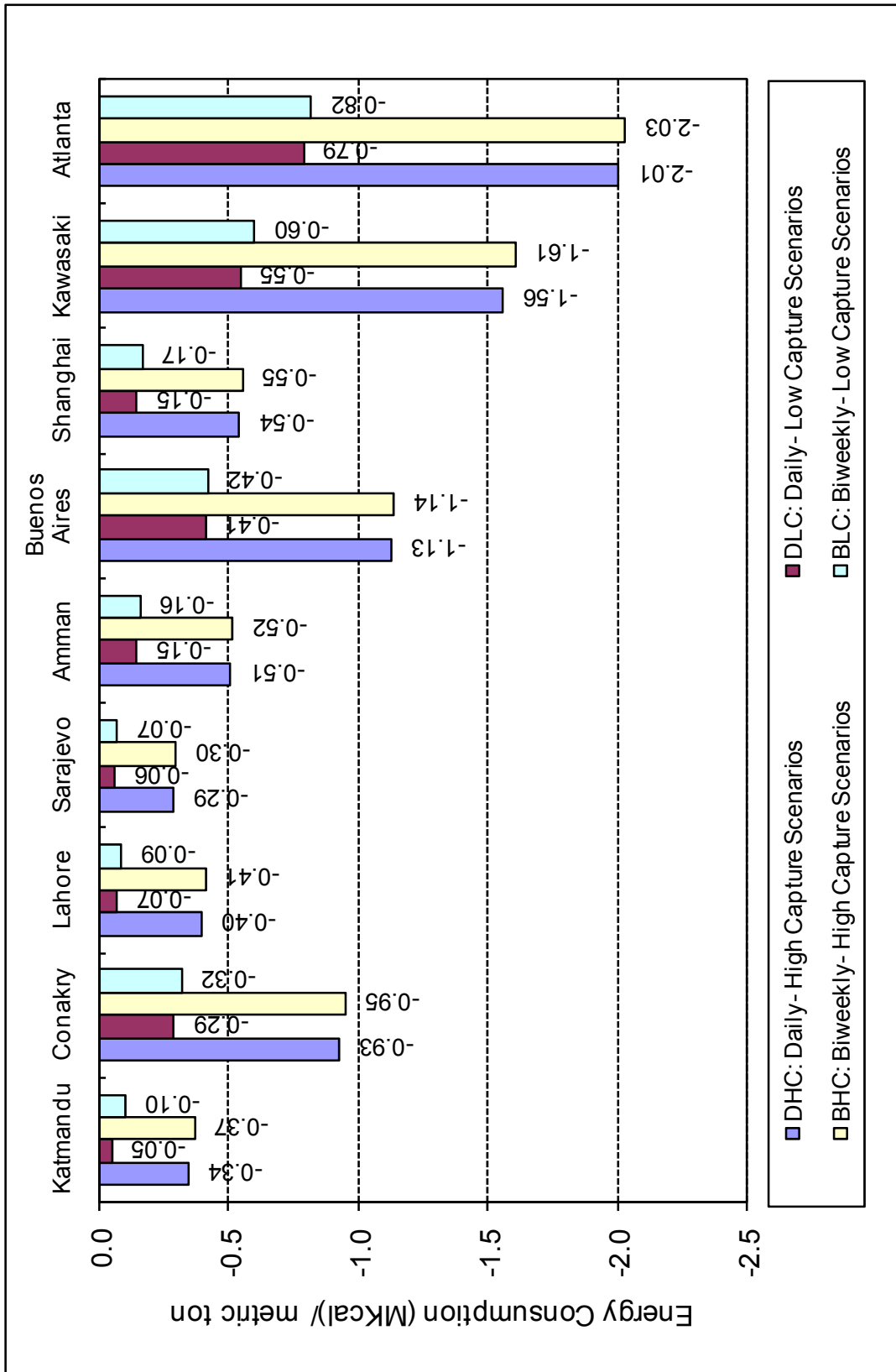


Figure 3.3-11 Group 3: Maximizing Materials Recovery (Via Manual Recycling and Composting)- Net Total Energy Consumption by City

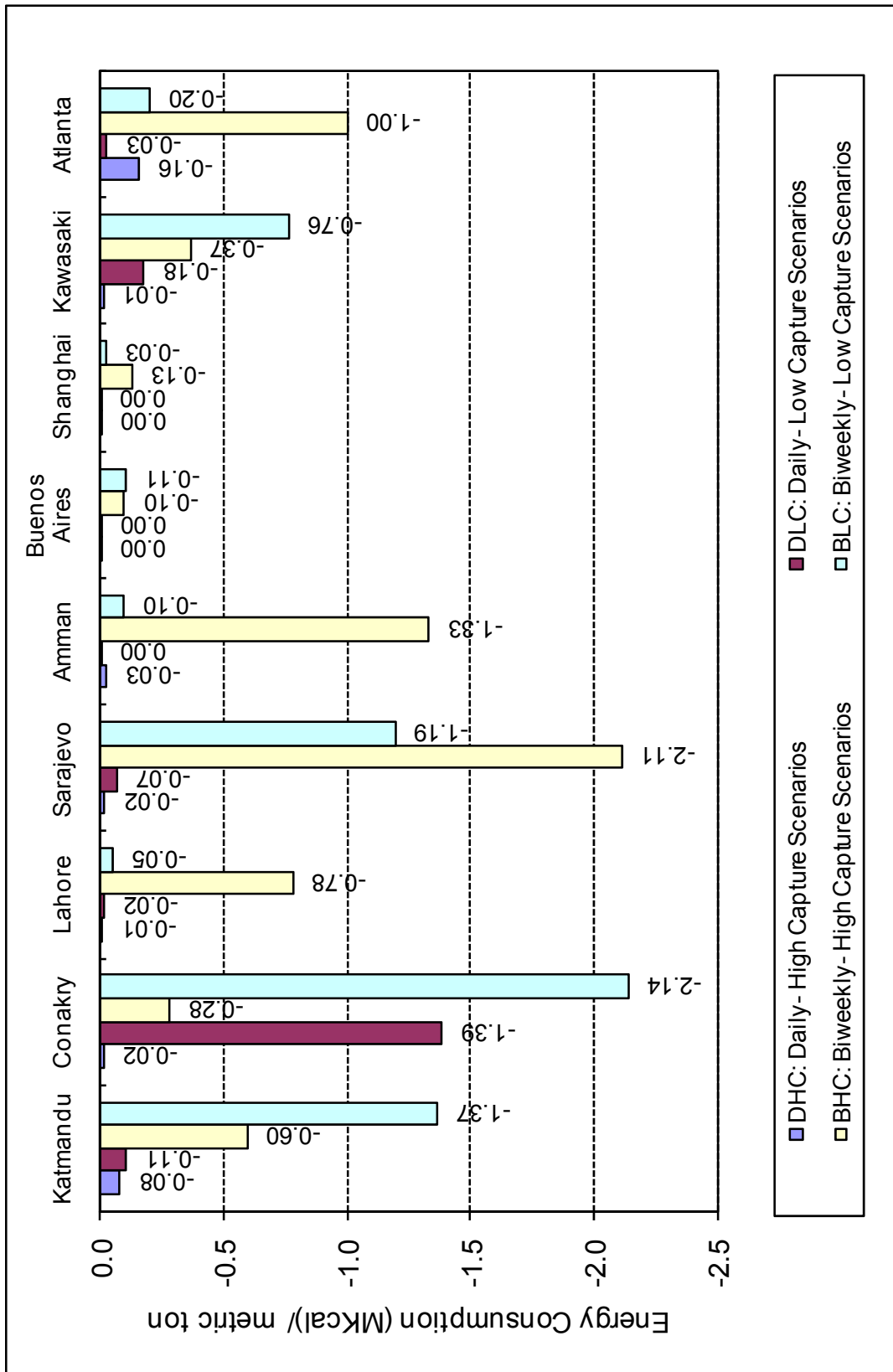


Figure 3.3-12 Group 3: Maximizing Materials Recovery (Via Mechanical Recycling and Composting)- Net Total Energy Consumption by City

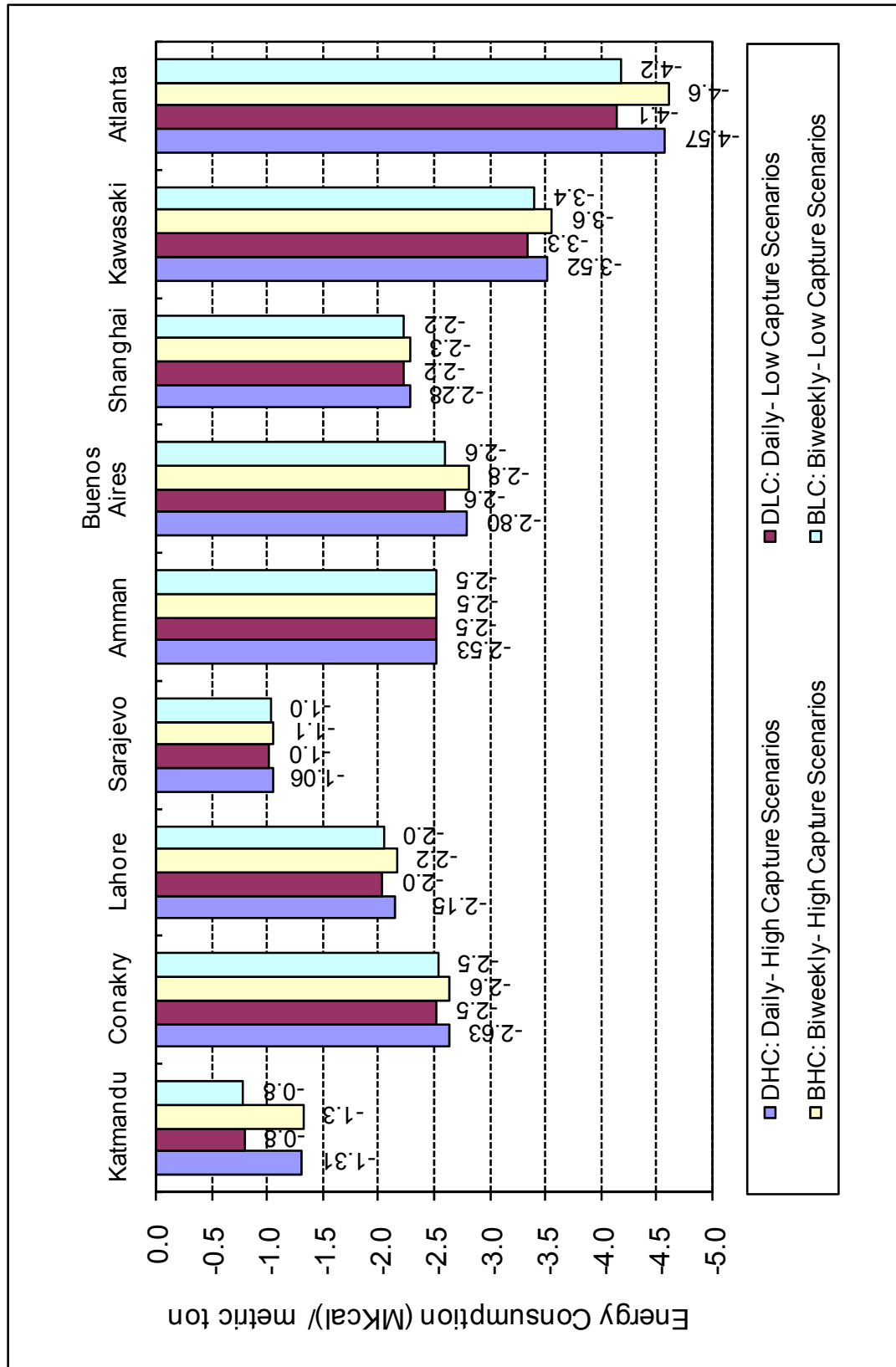


Figure 3.3-13 Group 4: Maximizing Energy Recovery- Net Total Energy Consumption by City

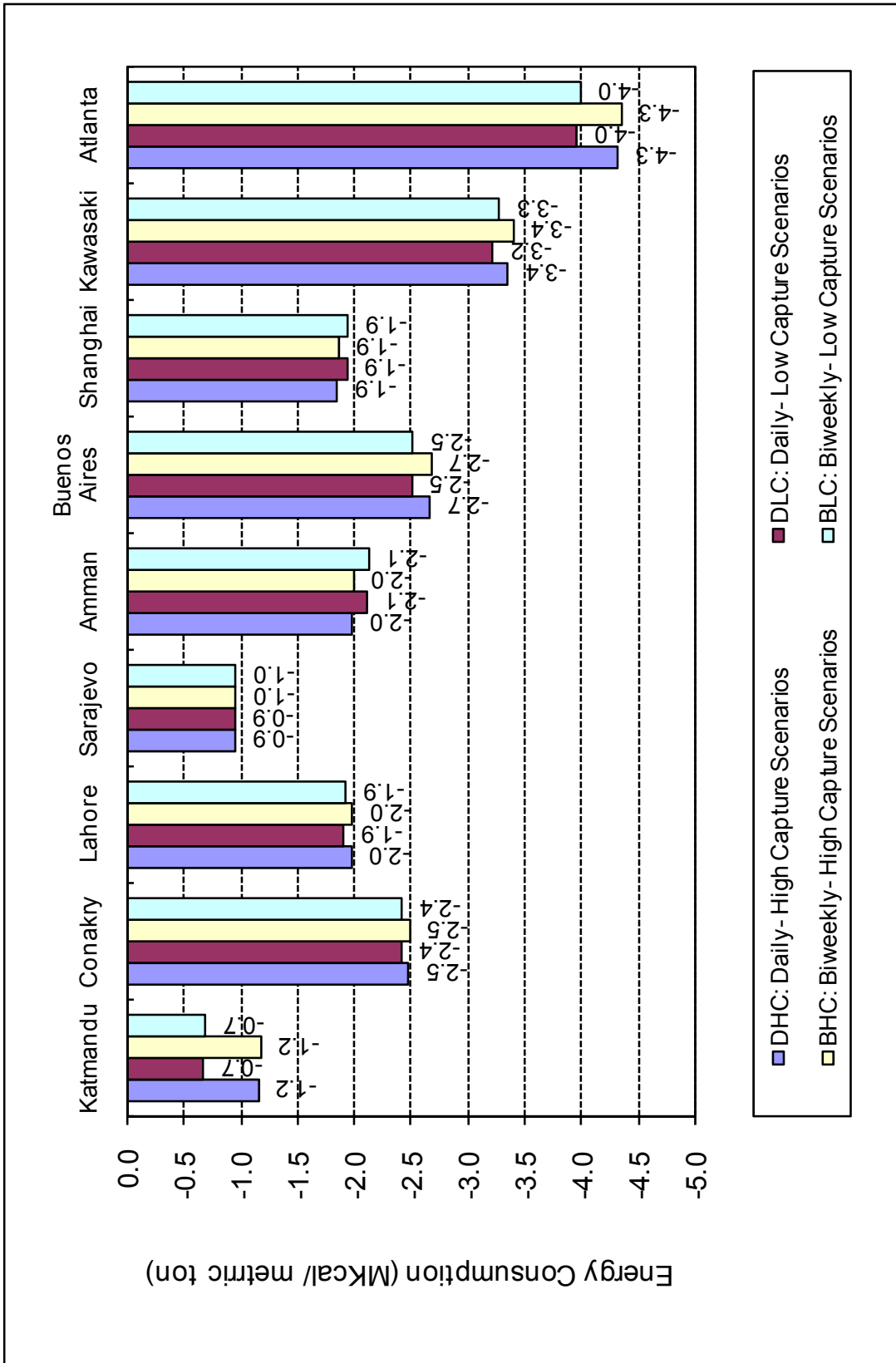


Figure 3.3-14 Group 5: Minimize Carbon (Global Warming) Emissions- Net Total Energy Consumption by City

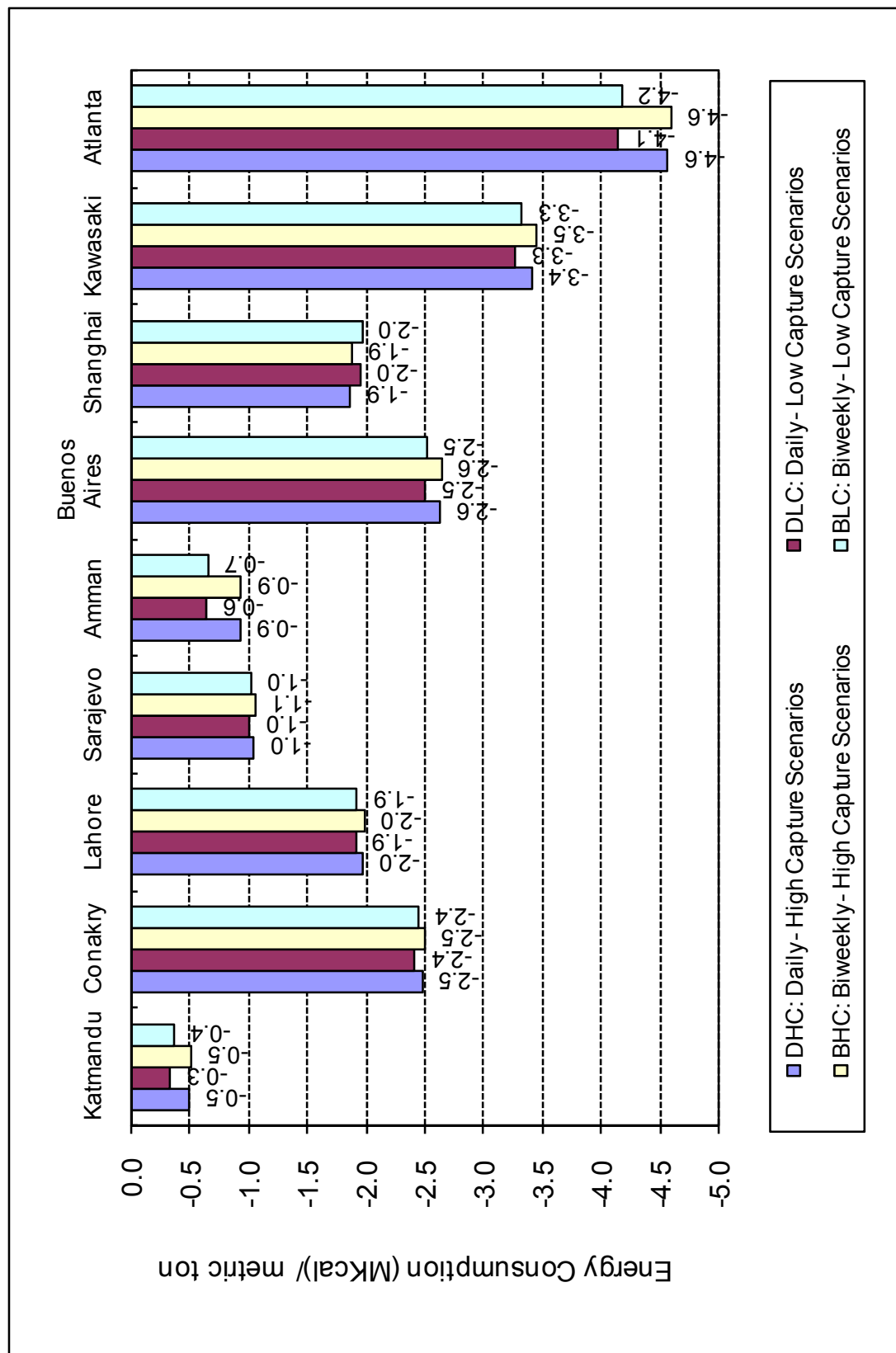


Figure 3.3-15 Group 5: Minimize Particulate Material (PM- Global Dimming) Emissions- Net Total Cost by City

Variation by percent capture of recyclables

In general, the energy variation by percent capture of recyclables depends on:

- Segregated vs. non-segregated collection energy requirements
- MRF energy requirements
- Energy savings associated with materials recycling
- Energy recovery from incineration
- Energy requirements for residuals landfill disposal

It is expected that high capture scenarios will have less net energy consumption than low capture scenarios due to energy savings associated with recycling. However, this trend could be reversed in a city where most of the recyclables are paper and/or glass, which generally produce less energy savings than metals.

Energy consumption variation among cities can be explained according to the process (e.g., recycling vs. incineration) having the largest effect on the overall results and the input parameters driving the results for that process. Tables 3.3-8 to 3.3-11 can be used to define the most influential processes. The lessons learned from the analysis of the simulation scenarios under Section 3.2 will aid determining the input parameters governing the results for those processes. Cities with the highest and lowest energy consumption results were chosen under Table 3.3-7 to illustrate the energy consumption variation. This table also provides explanations for the energy consumption behavior of these cities. For example, Atlanta is the city with the lowest net energy consumption for all the optimization scenarios. For the Group 3 scenarios (maximizing material recovery) having the lowest energy consumption is mainly due to Atlanta's highest amount of recyclables and metals in particular, which produce the highest energy offsets from recycling. For the other optimization scenarios Atlanta's highest waste heating value explains its high energy offsets from incineration with energy recovery and having the highest amounts of metals explains the offsets from recycling.

Table 3.3-8 Group 3 Scenarios- Percentage of Net Total Energy Attributed to the Different

City	Group 3: Maximizing Materials Recovery (Via Manual and Mechanical Recycling and Composting)																							
	Daily- High Capture						Daily - Low Capture						Biweekly Collection - High Capture						Biweekly Collection - Low Capture					
	Collection	Commingled Recycling	Composting	Landfill Disposal	Transportation	Remanufacturing*	Collection	Commingled Recycling	Composting	Landfill Disposal	Transportation	Remanufacturing*	Collection	Commingled Recycling	Composting	Landfill Disposal	Transportation	Remanufacturing*	Collection	Commingled Recycling	Composting	Landfill Disposal	Transportation	Remanufacturing*
Kathmandu	15.0	1.0	5.2	3.4	0.3	75.0	28.5	0.7	9.1	6.5	0.6	54.6	12.0	1.0	5.4	3.5	0.3	77.7	17.4	0.8	10.5	7.5	0.7	63.1
Conakry	7.0	1.2	5.2	3.9	0.2	82.4	11.7	1.0	12.7	6.0	0.5	68.0	5.5	1.2	5.3	4.0	0.2	83.8	8.3	1.0	13.2	6.3	0.5	70.6
Lahore	10.2	1.7	8.7	6.5	0.3	72.6	14.9	1.3	16.5	11.4	0.6	55.3	8.7	1.7	8.8	6.6	0.3	73.8	11.7	1.3	17.1	11.8	0.6	57.4
Sarajevo	12.7	1.7	9.2	2.8	0.8	72.7	17.7	1.4	17.0	6.2	1.5	56.3	11.6	1.8	9.3	2.9	0.8	73.6	15.4	1.4	17.4	6.3	1.5	57.9
Amman	10.8	3.4	9.7	1.9	0.4	73.86	13.6	2.8	16.1	6.0	0.6	60.9	10.0	3.4	9.8	1.9	0.4	74.5	11.9	2.9	16.4	6.1	0.6	62.1
Buenos Aires	6.8	1.8	3.6	2.3	0.2	85.3	9.6	1.5	9.1	4.8	0.5	74.5	6.3	1.8	3.7	2.3	0.2	85.8	8.3	1.6	9.2	4.9	0.5	75.6
Shanghai	10.8	2.7	8.7	2.4	0.3	75.1	13.9	2.2	17.0	5.2	0.5	61.2	10.0	2.7	8.8	2.5	0.3	75.8	12.0	2.3	17.1	5.3	0.5	62.9
Kawasaki	9.9	1.6	2.8	1.2	0.2	84.3	15.6	1.4	6.4	3.2	0.5	72.9	8.0	1.6	2.9	1.3	0.2	86.1	11.3	1.4	6.7	3.4	0.5	76.6
Atlanta	4.6	0.9	2.0	1.2	0.2	91.0	8.3	0.8	4.7	3.2	0.6	82.4	3.6	0.9	2.0	1.3	0.3	92.0	5.8	0.8	4.9	3.3	0.6	84.7

*Net negative contributor to the net total energy. Remanufacturing includes recycling energy offsets

Table 3.3-9 Group 4 Scenarios- Percentage of Net Total Energy Attributed to the Different Processes

City	Group 4: Maximizing Energy Recovery																											
	Daily- High Capture							Daily - Low Capture							Biweekly Collection - High Capture						Biweekly Collection - Low Capture							
	Collection	Separation		Incineration w/ER*	Landfill Disposal	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Landfill Disposal	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Landfill Disposal	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Landfill Disposal	Transportation	Remanufacturing*
		Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling				
Kathmandu	4.9	1.7	0.4	43.0	0.2	0.4	49.5	6.2	2.8	0.2	29.6	0.2	0.6	60.4	4.3	1.7	0.4	43.2	0.2	0.4	49.9	5.2	2.9	0.3	29.9	0.2	0.6	61.0
Conakry	2.0	1.6	0.3	38.5	0.1	0.2	57.3	1.9	1.7	0.1	43.2	0.1	0.2	52.7	1.7	1.6	0.3	38.6	0.1	0.2	57.5	1.5	1.7	0.1	43.4	0.1	0.2	52.8
Lahore	2.0	2.3	0.3	59.0	0.2	0.3	35.9	2.0	2.5	0.2	65.4	0.2	0.3	29.5	2.0	2.2	0.3	58.7	0.2	0.3	36.3	2.0	2.4	0.2	65.0	0.2	0.3	29.9
Sarajevo	3.7	3.0	0.4	50.7	0.6	0.5	41.1	3.4	3.1	0.2	62.2	0.6	0.6	29.9	3.7	2.9	0.4	50.0	0.6	0.5	41.9	3.2	3.1	0.2	62.4	0.6	0.6	30.0
Amman	1.4	0.0	0.1	96.6	0.1	0.0	1.9	1.5	0.0	0.0	97.5	0.1	0.0	0.8	1.4	0.0	0.1	96.6	0.1	0.0	1.9	1.3	0.0	0.0	97.7	0.1	0.0	0.8
Buenos Aires	1.9	1.6	0.4	39.7	0.1	0.2	56.2	1.5	1.8	0.2	47.5	0.1	0.2	48.7	1.6	1.6	0.4	39.8	0.1	0.2	56.4	1.5	1.8	0.2	47.2	0.1	0.2	49.1
Shanghai	1.6	2.4	0.1	78.7	0.1	0.2	16.8	1.7	2.4	0.1	81.5	0.1	0.2	14.0	1.6	2.4	0.1	78.5	0.1	0.2	17.0	1.5	2.4	0.1	81.7	0.1	0.2	14.0
Kawasaki	3.8	1.2	0.5	37.7	0.1	0.1	56.7	3.9	1.4	0.2	42.0	0.1	0.1	52.3	2.7	1.2	0.5	38.2	0.1	0.1	57.3	2.5	1.4	0.2	42.6	0.1	0.2	53.1
Atlanta	2.0	0.8	0.3	23.7	0.1	0.1	73.0	2.1	0.9	0.2	29.0	0.1	0.1	67.6	1.5	0.8	0.3	23.9	0.1	0.1	73.4	1.4	0.9	0.2	29.2	0.1	0.1	68.1

*Net negative contributor to the net total energy. Remanufacturing and incineration with energy recovery include energy offsets. Due to rounding zero values may actually be very small values.

Table 3.3-10 Group 5 (Carbon) Scenarios- Percentage of Net Total Energy Attributed to the Different Processes

City	Group 5: Minimizing Carbon (Global Warming) Emissions																											
	Daily- High Capture							Daily - Low Capture							Biweekly Collection - High Capture						Biweekly Collection - Low Capture							
	Collection	Separation		Incineration w/ER*	Ash-Landfill	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Ash-Landfill	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Ash-Landfill	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Ash-Landfill	Transportation	Remanufacturing*
		Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling				
Kathmandu	3.2	1.5	0.7	27.5	0.1	0.2	66.8	2.6	1.8	0.3	37.3	0.1	0.2	57.7	2.9	1.5	0.7	27.6	0.1	0.2	67.0	2.2	1.8	0.3	37.5	0.1	0.3	36.5
Conakry	2.3	1.8	0.2	38.1	0.1	0.2	57.2	2.1	1.9	0.1	43.0	0.1	0.2	52.6	2.3	1.8	0.3	37.9	0.1	0.2	57.5	2.1	1.9	0.1	42.7	0.1	0.2	24.5
Lahore	3.8	2.3	0.7	39.4	0.2	0.3	53.2	3.4	2.6	0.3	50.3	0.2	0.3	42.9	3.4	2.3	0.7	39.6	0.2	0.3	53.5	2.6	2.6	0.3	50.7	0.2	0.3	43.2
Sarajevo	5.3	3.1	0.3	57.3	0.7	0.6	32.6	4.7	3.2	0.2	66.0	0.7	0.6	24.6	4.7	3.2	0.3	57.7	0.7	0.6	32.8	3.9	3.2	0.2	66.5	0.7	0.2	52.9
Amman	4.1	2.8	0.9	58.2	0.1	0.2	33.7	2.9	2.8	0.4	69.2	0.1	0.2	24.4	3.7	2.8	0.9	58.5	0.1	0.2	33.9	2.5	2.8	0.4	69.5	0.1	0.2	61.2
Buenos Aires	3.2	1.5	0.7	27.5	0.1	0.2	66.8	2.6	1.8	0.3	37.3	0.1	0.2	57.7	2.9	1.5	0.7	27.6	0.1	0.2	67.0	2.2	1.8	0.3	37.5	0.1	0.2	58.0
Shanghai	4.8	2.6	1.0	43.2	0.1	0.2	48.1	3.4	2.8	0.5	56.7	0.1	0.3	36.3	4.4	2.7	1.0	43.4	0.1	0.2	48.3	2.9	2.8	0.5	57.0	0.1	0.6	24.8
Kawasaki	5.1	1.2	0.6	27.8	0.1	0.1	65.1	4.6	1.5	0.3	33.2	0.1	0.2	60.3	4.0	1.2	0.6	28.2	0.1	0.1	65.8	3.1	1.5	0.3	33.7	0.1	0.2	58.0
Atlanta	1.9	0.9	0.2	30.8	0.1	0.1	66.0	2.1	1.0	0.1	34.7	0.1	0.1	61.9	1.4	0.9	0.2	31.0	0.1	0.1	66.4	1.3	1.0	0.1	34.9	0.1	0.1	62.4

*Net negative contributor to the net total energy. Remanufacturing and incineration with energy recovery include energy offsets.

Table 3.3-11 Group 5 (PM) Scenarios- Percentage of Net Total Energy Attributed to the Different Processes

City	Group 5: Minimizing PM (Global Dimming) Emissions																															
	Daily- High Capture							Daily - Low Capture							Biweekly Collection - High Capture							Biweekly Collection - Low Capture										
	Collection	Separation		Incineration w/ER*	Disposal		Transportation	Remanufacturing*	Collection	Separatio n		Incineration w/ER*	Disposal		Transportation	Remanufacturing*	Collection	Separatio n		Incineration w/ER*	Disposal		Transportation	Remanufacturing*								
		Mixed Waste Recycling	Commingled Recycling		Landfill	Ash-landfill				Mixed Waste Recycling	Commingled Recycling		Landfill	Ash-landfill				Mixed Waste Recycling	Commingled Recycling		Landfill	Ash-landfill			Mixed Waste Recycling	Commingled Recycling	Landfill	Ash-landfill				
Kathmandu	3.6	1.4	0.9	22.0	0.0	0.0	0.2	71.9	2.7	1.8	0.4	33.7	0.0	0.1	0.2	61.1	3.3	1.4	0.9	22.1	0.0	0.0	0.2	72.1	2.3	1.8	0.4	33.8	0.0	0.1	0.2	61.3
Conakry	3.5	1.6	0.6	26.1	0.0	0.1	0.2	67.9	3.3	1.8	0.3	34.0	0.0	0.1	0.2	60.4	2.7	1.6	0.6	26.3	0.0	0.1	0.2	68.5	2.2	1.8	0.3	34.4	0.0	0.1	0.2	61.0
Lahore	4.0	2.3	0.8	36.6	0.0	0.2	0.3	55.8	3.4	2.6	0.4	48.4	0.0	0.2	0.3	44.7	3.4	2.3	0.8	36.9	0.0	0.2	0.3	56.2	2.6	2.6	0.4	48.8	0.0	0.2	0.3	45.1
Sarajevo	4.3	2.7	0.4	64.7	0.0	0.6	0.5	26.7	4.2	2.9	0.2	72.8	0.0	0.6	0.6	18.7	3.7	2.7	0.4	65.1	0.0	0.6	0.5	26.9	3.5	3.0	0.2	73.3	0.0	0.6	0.6	18.8
Amman	7.4	4.0	2.4	0.0	4.8	0.0	0.3	81.1	6.8	5.8	1.4	0.0	7.3	0.0	0.4	78.2	7.0	4.0	2.4	0.0	4.8	0.0	0.3	81.5	5.9	5.9	1.4	0.0	7.4	0.0	0.4	79.0
Buenos Aires	3.6	1.4	0.9	22.0	0.0	0.0	0.2	71.9	2.7	1.8	0.4	33.7	0.0	0.1	0.2	61.1	3.3	1.4	0.9	22.1	0.0	0.0	0.2	72.1	2.3	1.8	0.4	33.8	0.0	0.1	0.2	61.3
Shanghai	5.0	2.5	1.3	35.9	0.0	0.1	0.2	55.1	3.5	2.7	0.6	51.6	0.0	0.1	0.2	41.3	4.6	2.5	1.3	36.0	0.0	0.1	0.2	55.3	3.0	2.7	0.6	51.9	0.0	0.1	0.2	41.5
Kawasaki	5.3	1.1	0.8	22.3	0.0	0.1	0.1	70.4	4.7	1.4	0.4	28.7	0.0	0.1	0.1	64.6	4.3	1.1	0.8	22.5	0.0	0.1	0.1	71.2	3.2	1.5	0.4	29.1	0.0	0.1	0.1	65.6
Atlanta	2.2	0.7	0.4	23.3	0.0	0.1	0.1	73.2	2.2	0.9	0.2	28.7	0.0	0.1	0.1	67.8	1.6	0.7	0.4	23.5	0.0	0.1	0.1	73.6	1.5	0.9	0.2	28.9	0.0	0.1	0.1	68.3

*Net negative contributor to the net total energy. Remanufacturing and incineration with energy recovery include energy offsets. Due to rounding zero values may actually be very small values.

3.3.3 Emissions Results

In the optimization scenario analysis, carbon and PM emissions were selected for their contribution to global warming and global dimming, respectively. PM emissions from solid waste systems result from any handling, loading, sorting, and turning operations. When operations occur within buildings, or are part of processes such as incineration, air pollution control systems are used to reduce emissions from the buildings or process equipment. Carbon and PM emissions result from the combustion of fossil fuels or products (e.g., plastic). Carbon emissions in the form of methane are also produced via anaerobic decomposition in landfills. Carbon emissions are analyzed for all the optimization scenarios and both carbon and PM emissions are analyzed for Group 5—minimizing PM emissions.

We found the key parameters that affect the carbon and PM emissions results to include:

Quantity and composition of recyclables (metals and plastics recycling produce higher carbon emission offsets and aluminum and corrugated cardboard recycling produces higher PM emissions offsets).

Residuals amount and composition being disposed at a LF (food and yard waste generate the highest amounts of methane at a LF).

The electricity grid mix (cities with a high percent of hydro in their grid mix will not have as high emission offsets from recycling and incineration with energy recovery as cities with a mostly fossil based grid mix)

In addition, the carbon and PM optimization scenario results were found to exhibit the following general trends:

The combination manual MRF and composting produces less carbon emissions than mechanical MRF and composting.

Daily collection typically produces more carbon emissions than biweekly. It also produces more carbon and PM emissions than biweekly collection for the scenario minimizing PM emissions.

High capture of recyclables typically results in less carbon emissions than low capture of recyclables. This is consistent with the lower energy consumption trend and also based on less waste going to the landfill where it can produce methane.

Additional details about the energy results can be found in Table 3.3-12 and Figures 3.3-16 to 3.3-21.

Variation by process design in the scenarios maximizing materials recovery

Figures 3.3-16 and 3.3-17 show the carbon emissions variation by MRF and composting process design. Consistently in all the scenarios and settings, the net carbon emissions

from the manual design are lower than from the mechanical design. This is due to emissions from fuel combustion or electricity consumption by equipment in the mechanical design.

Variation by collection frequency

It is expected that daily collection produces more carbon and PM emissions than biweekly collection as observed in the results for all the cities (see Figures 3.3-16 and 3.3-17). This is due to much higher fuel consumption by collection trucks in the daily collection system.

Variation by percent capture of recyclables

In general, the carbon and PM emissions variation by percent capture of recyclables depends on:

- Segregated vs. non-segregated collection vehicle emissions
- MRF emissions
- Emission offsets from recycling
- Emissions savings from incineration energy recovery
- Emissions from residuals LF disposal

Consistent with the energy results, it is expected that high capture scenarios will have less net carbon and PM emissions than low capture scenarios. Different behavior for carbon emissions could be observed in cities where most of the recyclables are paper and/or glass, which produce less carbon emissions offsets from recycling than other recyclables categories such metals and plastics. Aluminum recycling also produces the highest PM emissions offsets followed by corrugated cardboard and ferrous materials recycling.

Carbon and PM emissions variation among cities can be explained according to the process (e.g., recycling vs. incineration) having the largest effect on the overall results and the input parameters driving the results for that process. Tables 3.3-13 to 3.3-17 can be used to define the most influential processes. The lessons learned from the analysis of the simulation scenarios under Section 3.2 will aid determining the input parameters governing the results for those processes. Cities with the highest and lowest cost results were chosen under Table 3.3-12 to illustrate the emissions variation. This table also provides explanations for the emissions behavior of these cities. For example, for Group 3 (maximizing material recovery) scenarios, Conakry is the city with the highest carbon emissions mainly due to (1) the lack of recyclables, in particular aluminum and plastics, which are responsible for high carbon emission offsets and (2) having high amounts of methane producing waste going to the landfill.

For Group 4—maximizing energy recovery and Group 5—minimizing carbon emissions and minimizing PM emissions, Kathmandu has the lowest waste heating content and an electricity grid mix with 90% hydro, which explain why this city has the lowest carbon emission offsets and consequently the highest carbon emissions. For Group 5—minimizing PM emissions Lahore is the city with the highest PM emissions due to having the lowest amounts of recyclables and consequently the lowest emission offsets.

Table 3.3-12 Summary of Carbon and PM Emissions Variation by Scenario and Scenario Settings

Criteria	Maximize Materials Recovery (via recycling and composting)				Maximize Energy Recovery				Minimize Carbon (Global Warming) Emissions				Minimize PM (Global Dimming) Emissions			
	Manual and Mechanical				Daily High Capture	Daily Low Capture	Biweekly High Capture	Biweekly Low Capture	Daily High Capture	Daily Low Capture	Biweekly High Capture	Biweekly Low Capture	Daily High Capture	Daily Low Capture	Biweekly High Capture	Biweekly Low Capture
	Daily High Capture	Daily Low Capture	Biweekly High Capture	Biweekly Low Capture												
Carbon and PM Emissions Variation																
By Collection Frequency (See Figures 3.3.11 to 3.3.16)	More carbon emissions		Less carbon emissions		More carbon emissions		Less carbon emissions		More carbon emissions		Less carbon emissions		More carbon and PM emissions		Less carbon and PM emissions	
By Percent Capture of Recyclables (See Figures 3.3.11 to 3.3.16)	Less carbon emission.	More carbon emissions	Less carbon emission.	More carbon emissions	Less carbon emission.	More carbon emissions	Less carbon emission.	More carbon emissions	Less carbon emission.	More carbon emissions	Less carbon emission.	More carbon emissions	Less carbon and PM emissions	More carbon and PM emissions	Less carbon and PM emissions	More carbon and PM emissions
By city (See Tables 3.3.13 to 3.3.17)	Conakry: highest net carbon emissions due to: - Lowest carbon emission offsets from recycling (Among the lowest amounts of recyclables and the lowest amount of aluminum and plastic materials among them). - High carbon emissions from LF (Among the highest amounts of material going to the LF).				Kathmandu: highest net carbon emissions due to: - Lowest carbon emission offsets from recycling and incineration (Lowest waste heating content and an electricity grid mix with 90% hydroelectricity).								Kathmandu: highest net carbon emissions due to: - Lowest carbon emission offsets from recycling and incineration (Lowest waste heating content and an electricity grid mix with 90% hydroelectricity). Lahore: highest net PM emissions due to: - Lowest PM emission offsets from recycling (Lowest amount of recyclables).			
	Buenos Aires and Kawasaki: lowest net carbon emissions due to: - Highest carbon emission offsets from recycling (Highest amounts of recyclables and aluminum and plastic materials among them).				Sarajevo: lowest net carbon emissions due to: - Lowest carbon emissions from incineration (Lowest amounts of plastics and aluminum material).				Kawasaki: lowest net carbon emissions due to: - Highest carbon emissions offsets from recycling and incineration (Among the highest amounts of metals for recycling, the second highest waste heating content and not as many plastics as other cities with similar waste heating content).				Atlanta: lowest net PM emissions due to: - Highest PM emissions offsets from recycling and incineration (The highest amounts of metals and corrugated cardboard for recycling, the highest waste heating content).			

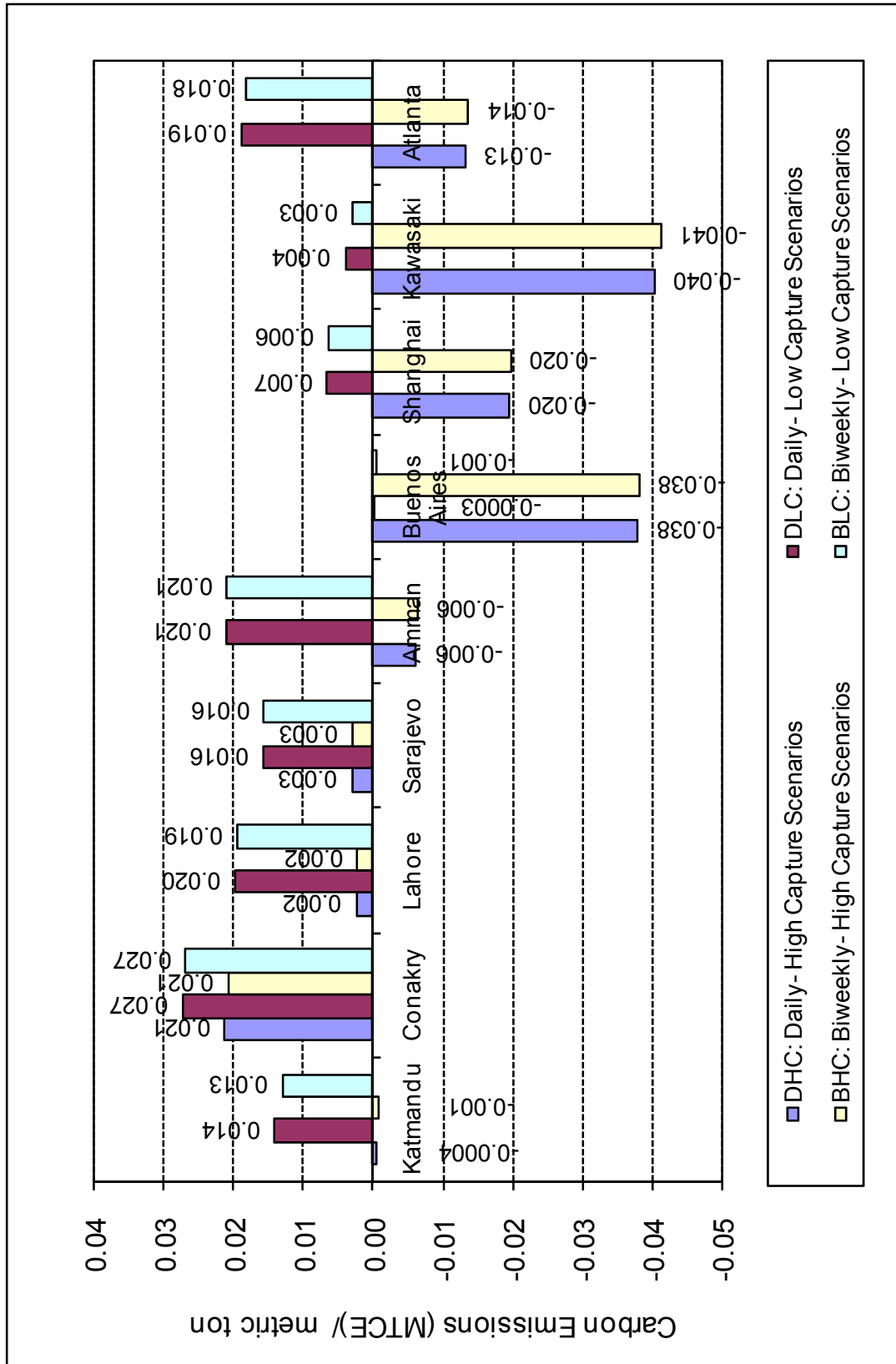


Figure 3.3-16 Group 3: Maximizing Materials Recovery (Via Manual Recycling and Composting)- Net Total Carbon Emissions by City

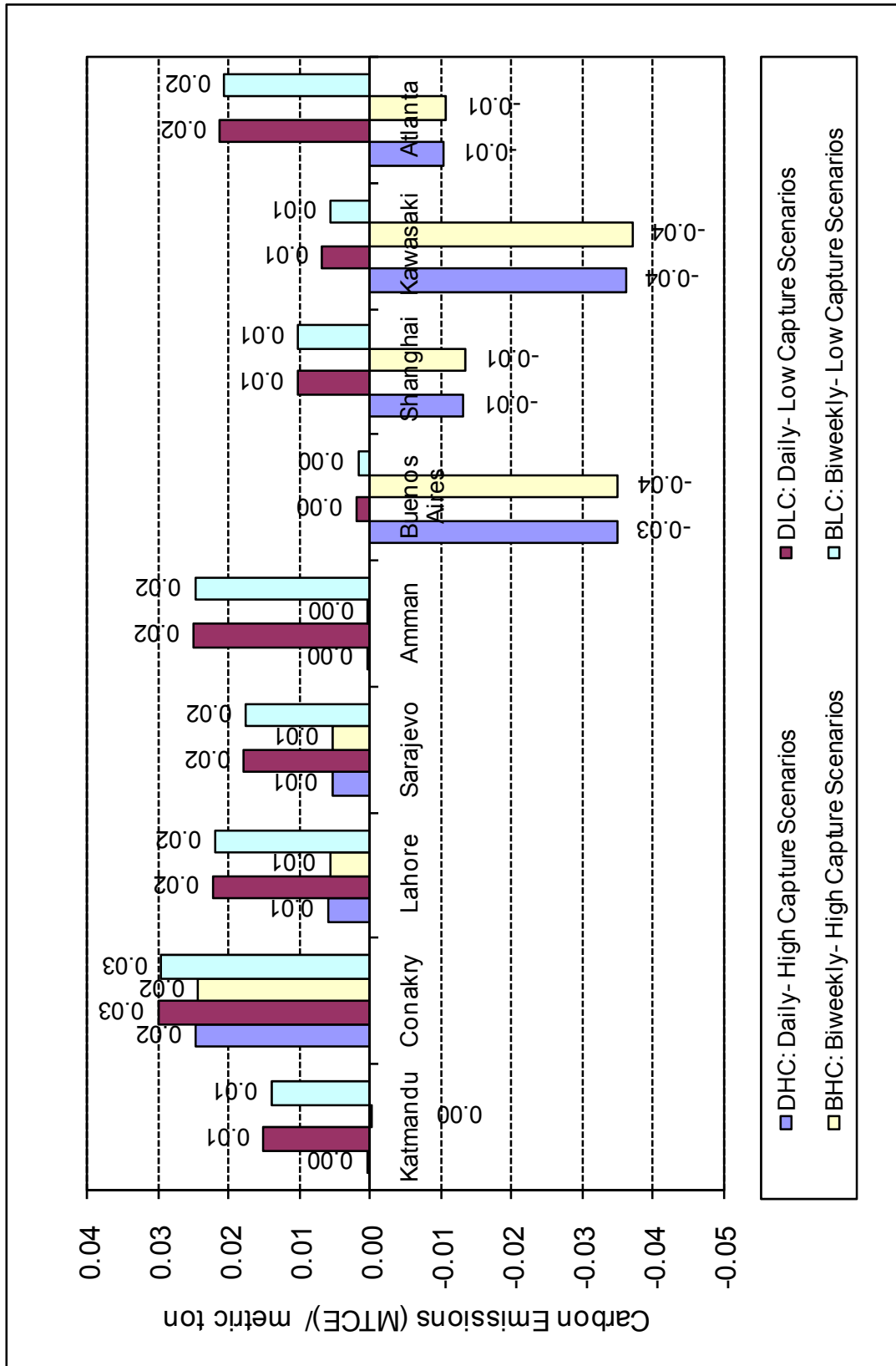


Figure 3.3-17 Group 3: Maximizing Materials Recovery (Via Mechanical Recycling and Composting)- Net Total Carbon Emissions by City

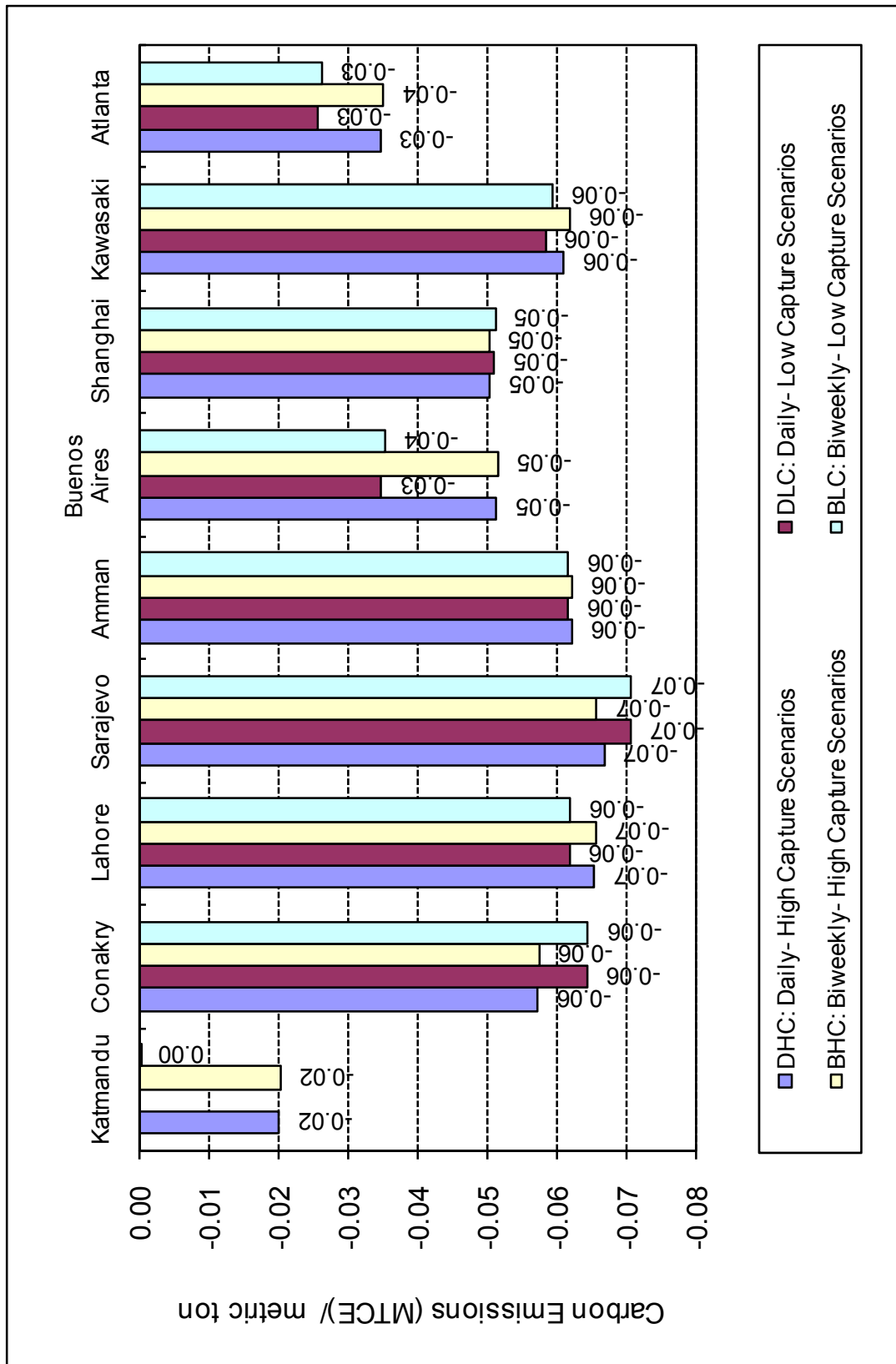


Figure 3.3-18 Group 4: Maximizing Energy Recovery- Net Total Carbon Emissions by City

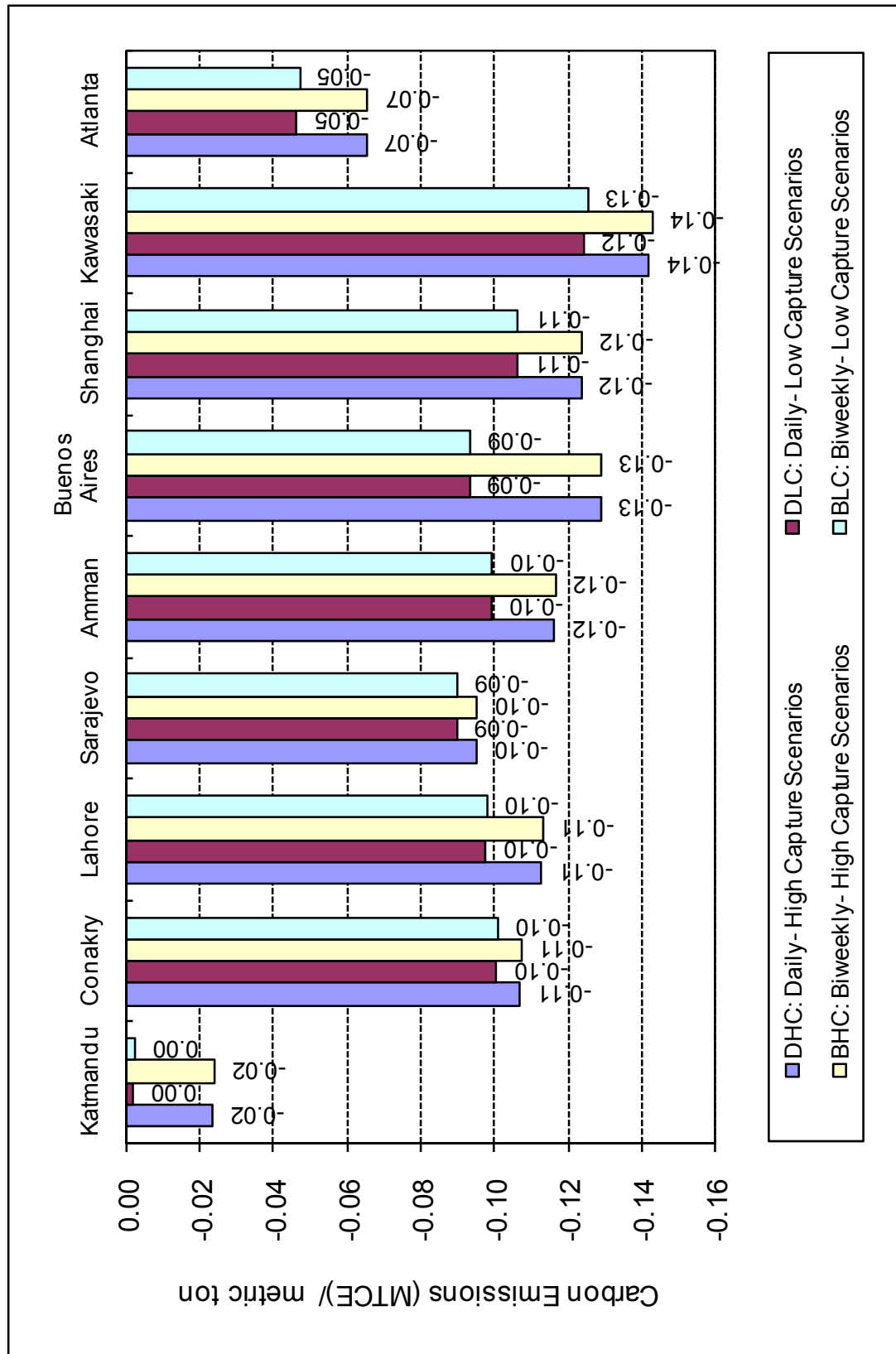


Figure 3.3-19 Group 5: Minimize Carbon (Global Warming) Emissions- Net Total Carbon Emissions by City

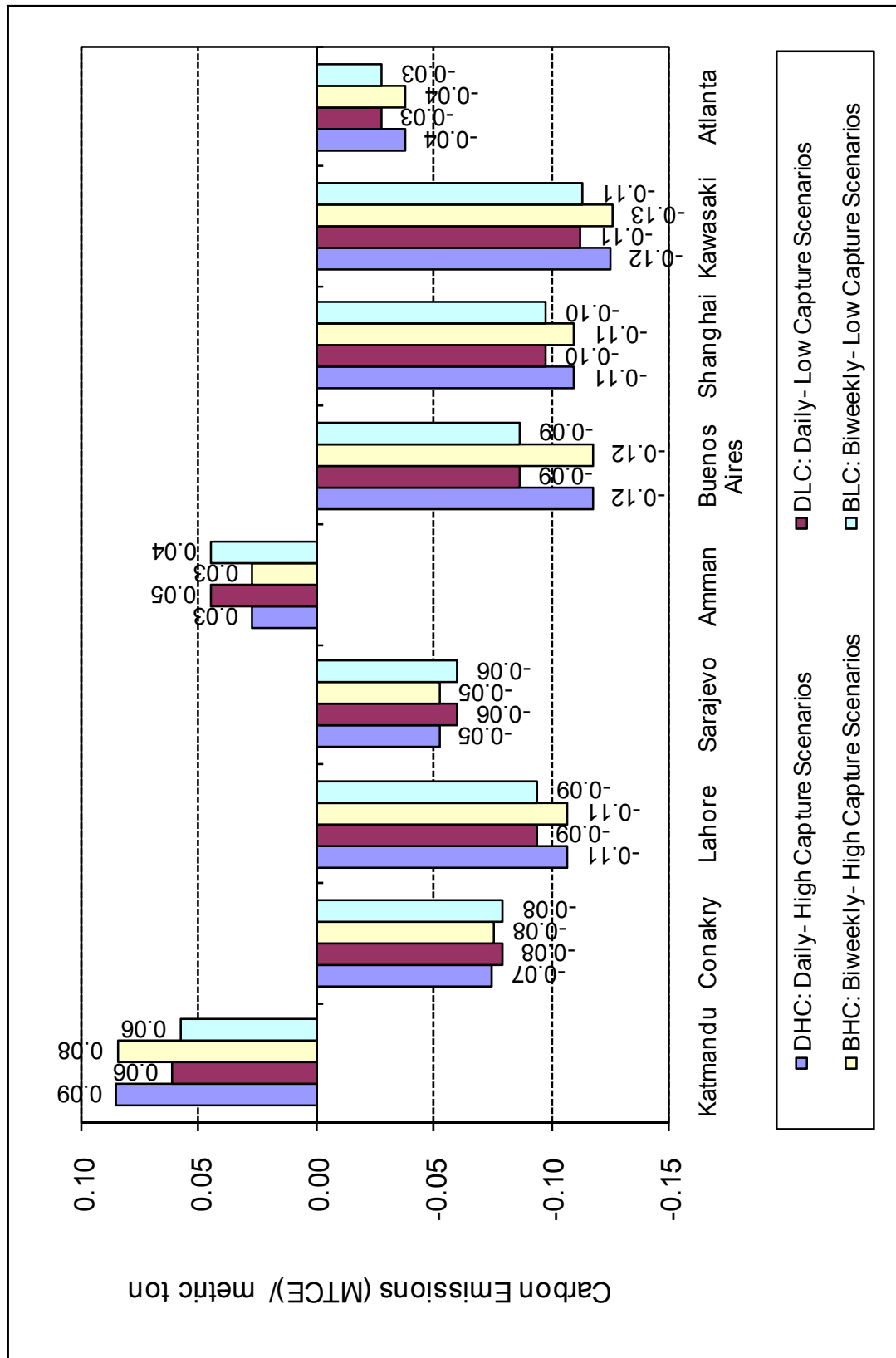


Figure 3.3-20 Group 5: Minimize Particulate Material (PM- Global Dimming) Emissions- Net Total Carbon Emissions by City

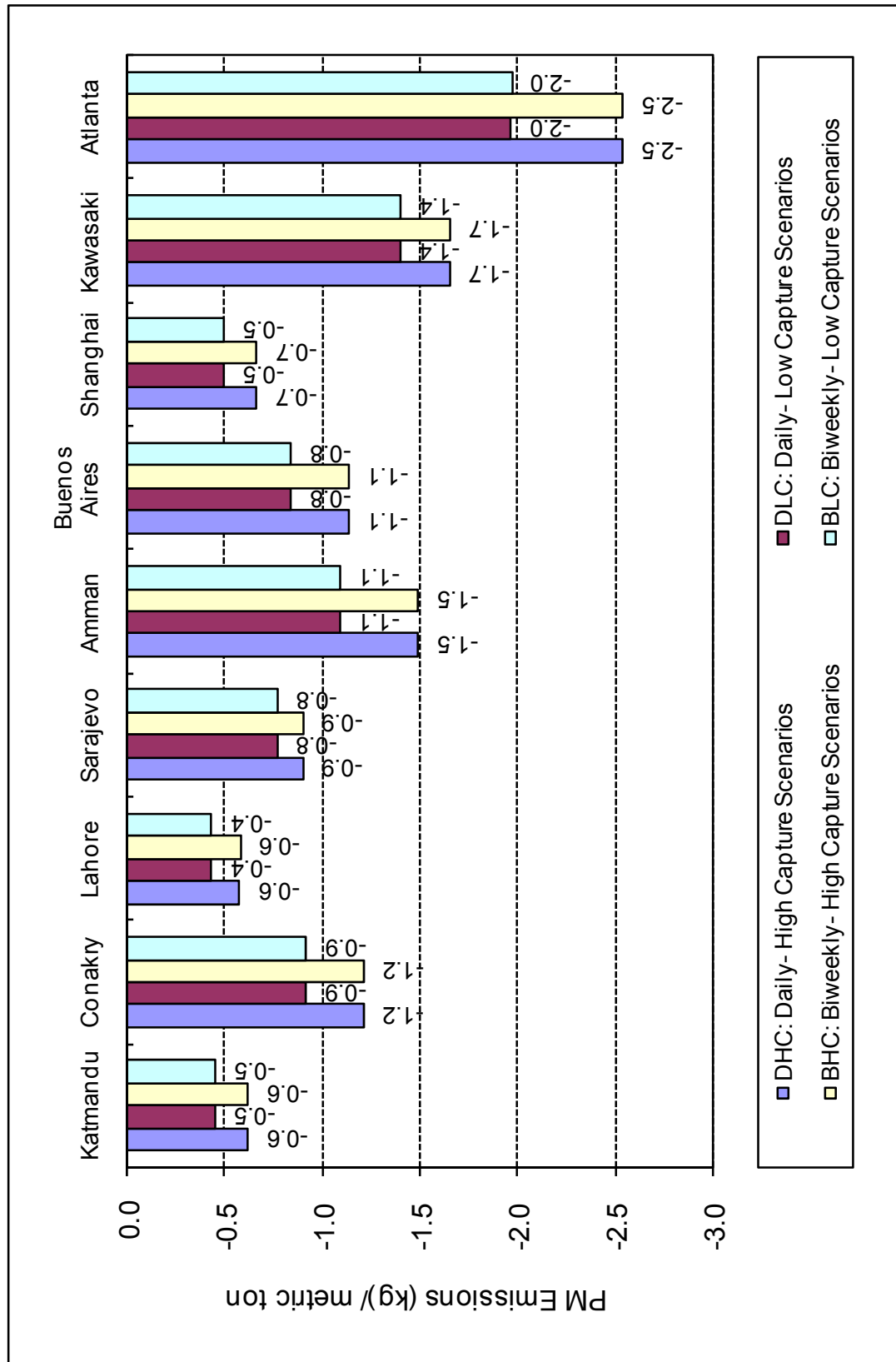


Figure 3.3-21 Group 5: Minimize Particulate Material (PM- Global Dimming) Emissions- Net Total PM Emissions by City

Table 3.3-13 Group 3 Scenarios- Percentage of Net Total Carbon Emissions Attributed to the Different Processes

City	Group 3: Maximizing Materials Recovery (Via Manual and Mechanical Recycling and Composting)																							
	Daily- High Capture						Daily - Low Capture						Biweekly Collection - High Capture						Biweekly Collection - Low Capture					
	Collection	Commingled Recycling	Composting	Landfill Disposal	Transportation	Remanufacturing *	Collection	Commingled Recycling	Composting	Landfill Disposal	Transportation	Remanufacturing *	Collection	Commingled Recycling	Composting	Landfill Disposal	Transportation	Remanufacturing *	Collection	Commingled Recycling	Composting	Landfill Disposal	Transportation	Remanufacturing *
Kathmandu	6.1	0.4	2.0	41.5	0.5	49.5	8.1	0.2	2.7	60.5	0.7	27.8	5.1	0.4	2.0	42.0	0.5	50.0	5.1	0.2	2.8	62.5	0.7	28.7
Conakry	4.2	6.4	9.9	49.1	0.4	30.1	4.7	3.8	17.3	55.8	0.7	17.8	3.5	6.4	10.0	49.5	0.4	30.3	3.6	3.8	17.5	56.4	0.7	18.0
Lahore	3.3	5.6	8.1	36.9	0.3	45.8	3.7	3.4	12.5	51.7	0.5	28.2	2.9	5.6	8.2	37.1	0.3	45.9	3.1	3.4	12.6	52.0	0.5	28.4
Sarajevo	5.3	4.2	12.2	34.0	1.1	43.2	5.0	2.3	15.5	52.8	1.4	23.1	5.0	4.2	12.3	34.1	1.1	43.3	4.5	2.3	15.6	53.1	1.4	23.2
Amman	4.1	13.6	9.5	22.7	0.4	49.71	3.8	8.4	11.7	47.6	0.5	28.0	3.9	13.6	9.5	22.7	0.4	49.8	3.4	8.4	11.8	47.7	0.5	28.1
Buenos Aires	3.0	4.4	3.5	21.4	0.2	67.4	3.4	3.1	7.2	37.3	0.5	48.4	2.8	4.4	3.5	21.5	0.2	67.6	3.0	3.2	7.2	37.5	0.5	48.6
Shanghai	3.7	10.8	9.1	18.5	0.3	57.7	4.0	7.8	15.5	31.6	0.5	40.6	3.5	10.8	9.1	18.6	0.3	57.8	3.6	8.0	15.6	31.6	0.5	40.6
Kawasaki	5.2	6.3	3.8	18.1	0.3	66.3	6.1	4.3	6.9	36.7	0.7	45.4	4.4	6.4	3.8	18.2	0.3	66.8	4.7	4.4	7.0	37.3	0.7	46.0
Atlanta	3.5	4.1	4.5	31.0	0.6	56.3	3.9	2.4	6.9	52.8	1.0	33.1	2.9	4.2	4.6	31.2	0.6	56.6	2.9	2.5	7.0	53.3	1.0	33.4

*Net negative contributor to the net total carbon emissions. Remanufacturing includes emission offsets.

Table 3.3-14 Group 4 Scenarios- Percentage of Net Total Carbon Emissions Attributed to the Different Processes

City	Group 4: Maximizing Energy Recovery																											
	Daily- High Capture							Daily - Low Capture							Biweekly Collection - High Capture						Biweekly Collection - Low Capture							
	Collection	Separation		Incineration w/ER*	Landfill Disposal	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Landfill Disposal	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Landfill Disposal	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Landfill Disposal	Transportation	Remanufacturing*
		Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling				
Kathmandu	4.4	2.9	0.3	19.7	0.2	1.1	71.5	3.2	2.9	0.1	43.0	0.1	1.0	49.8	4.0	2.9	0.3	19.7	0.2	1.1	71.8	2.8	2.9	0.1	43.1	0.1	1.0	50.0
Conakry	1.9	11.1	2.4	70.6	0.1	0.6	13.2	1.5	11.0	1.0	74.6	0.1	0.6	11.2	1.6	11.2	2.4	70.8	0.1	0.6	13.3	1.3	11.0	1.0	74.8	0.1	0.6	11.2
Lahore	1.4	13.3	2.0	44.5	0.1	0.5	38.2	1.3	14.3	1.1	52.4	0.1	0.6	30.2	1.3	13.2	2.2	44.0	0.1	0.5	38.7	1.3	14.2	1.2	51.9	0.1	0.6	30.7
Sarajevo	1.6	6.5	0.9	65.6	0.2	0.7	24.4	1.4	6.3	0.4	72.9	0.2	0.7	18.1	1.6	6.5	1.0	65.3	0.2	0.7	24.6	1.3	6.3	0.4	73.0	0.2	0.7	18.1
Amman	1.6	0.0	0.9	91.9	0.1	0.1	5.5	1.7	0.0	0.4	95.2	0.1	0.1	2.5	1.6	0.0	0.9	91.9	0.1	0.1	5.5	1.6	0.0	0.4	95.3	0.1	0.1	2.5
Buenos Aires	1.6	7.4	1.8	12.0	0.0	0.5	76.7	1.6	9.8	0.9	13.7	0.1	0.7	73.2	1.4	7.4	1.8	12.0	0.0	0.5	76.8	1.6	9.6	1.0	13.8	0.1	0.7	73.3
Shanghai	1.3	19.4	1.0	60.7	0.0	0.6	16.9	1.3	19.2	0.8	63.9	0.1	0.6	14.2	1.2	19.4	1.2	60.5	0.0	0.6	17.1	1.2	19.2	0.8	64.0	0.1	0.6	14.2
Kawasaki	4.0	8.8	3.8	18.8	0.1	0.5	64.0	3.9	10.6	1.8	25.7	0.1	0.6	57.3	3.1	8.9	3.8	18.9	0.1	0.5	64.6	2.8	10.8	1.8	26.0	0.1	0.6	58.0
Atlanta	2.2	5.0	2.3	24.7	0.1	0.4	65.4	2.5	6.8	1.3	24.5	0.1	0.5	64.2	1.7	5.0	2.3	24.8	0.1	0.4	65.7	1.8	6.9	1.3	24.7	0.1	0.5	64.6

*Net negative contributor to the net total carbon emissions. Remanufacturing and incineration with energy recovery include emission offsets. Due to rounding zero values may actually be very small values.

Table 3.3-15 Group 5 (Carbon) Scenarios- Percentage of Net Total Carbon Emissions Attributed to the Different Processes

City	Group 5: Minimizing Carbon (Global Warming) Emissions																											
	Daily- High Capture							Daily - Low Capture						Biweekly Collection - High Capture						Biweekly Collection - Low Capture								
	Collection	Separation		Incineration w/ER*	Ash-Landfill	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Ash-Landfill	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Ash-Landfill	Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Ash-Landfill	Transportation	Remanufacturing*
		Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling						Mixed Waste Recycling	Commingled Recycling				
Kathmandu	1.7	4.4	2.1	21.5	0.0	0.3	70.0	1.7	6.4	1.2	19.7	0.0	0.4	70.5	1.6	4.4	2.1	21.5	0.0	0.3	70.0	1.5	6.4	1.2	19.8	0.0	0.4	70.6
Conakry	1.3	7.5	1.1	65.3	0.1	0.4	24.3	1.2	8.0	0.5	69.3	0.1	0.4	20.4	1.3	7.3	1.2	65.2	0.1	0.4	24.5	1.2	8.0	0.6	69.2	0.1	0.3	58.4
Lahore	1.6	8.6	3.1	39.9	0.1	0.3	46.5	1.4	10.4	1.6	46.3	0.1	0.4	39.8	1.4	8.5	3.1	40.0	0.1	0.3	46.6	1.2	10.4	1.6	46.4	0.1	0.4	31.4
Sarajevo	1.5	4.8	0.6	65.0	0.2	0.5	27.3	1.4	5.1	0.3	70.9	0.2	0.6	21.5	1.4	4.8	0.6	65.1	0.2	0.5	27.4	1.2	5.1	0.3	71.0	0.2	0.4	20.6
Amman	1.6	10.3	3.8	48.0	0.0	0.3	36.1	1.3	12.4	1.9	52.6	0.0	0.4	31.3	1.5	10.3	3.8	48.0	0.0	0.3	36.1	1.2	12.4	1.9	52.7	0.0	0.6	21.6
Buenos Aires	1.7	4.4	2.1	21.5	0.0	0.3	70.0	1.7	6.4	1.2	19.7	0.0	0.4	70.5	1.6	4.4	2.1	21.5	0.0	0.3	70.0	1.5	6.4	1.2	19.8	0.0	0.4	70.6
Shanghai	1.7	9.7	4.4	42.0	0.0	0.3	41.9	1.3	12.0	2.3	47.7	0.0	0.3	36.4	1.6	9.8	4.4	42.1	0.0	0.3	41.9	1.2	12.0	2.3	47.7	0.0	0.4	39.9
Kawasaki	2.8	4.8	2.6	28.4	0.0	0.3	61.2	2.6	6.3	1.3	31.3	0.0	0.3	58.1	2.4	4.8	2.6	28.5	0.0	0.3	61.5	1.9	6.4	1.3	31.6	0.1	0.7	79.3
Atlanta	2.2	5.9	1.5	7.0	0.1	0.5	82.8	2.6	7.7	0.8	9.4	0.1	0.7	78.7	1.7	5.9	1.5	7.0	0.1	0.5	83.3	1.9	7.7	0.8	9.5	0.1	0.3	36.5

*Net negative contributor to the net total carbon emissions. Remanufacturing and incineration with energy recovery include emission offsets. Due to rounding zero values may actually be very small values.

Table 3.3-16 Group 5 (PM) Scenarios- Percentage of Net Total Carbon Emissions Attributed to the Different Processes

City		Group 5: Minimizing PM (Global Dimming) Emissions																															
		Daily- High Capture							Daily - Low Capture							Biweekly Collection - High Capture							Biweekly Collection - Low Capture										
		Collection	Separation		Incineration w/ER*	Disposal		Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Disposal		Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Disposal		Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Disposal		Transportation	Remanufacturing*
			Mixed Waste Recycling	Commingled Recycling		Landfill	Ash-landfill				Mixed Waste Recycling	Commingled Recycling		Landfill	Ash-landfill				Mixed Waste Recycling	Commingled Recycling		Landfill	Ash-landfill				Mixed Waste Recycling	Commingled Recycling		Landfill	Ash-landfill		
Kathmandu	2.1	4.4	3.0	16.7	0.0	0.0	0.3	73.6	1.9	6.6	1.8	16.0	0.0	0.0	0.4	73.2	2.0	4.4	3.0	16.7	0.0	0.0	0.3	73.7	1.7	6.6	1.8	16.1	0.0	0.0	0.4	73.4	
Conakry	2.4	8.5	3.7	56.6	0.0	0.1	0.5	28.3	2.0	9.2	1.6	64.1	0.0	0.1	0.5	22.5	2.0	8.5	3.7	56.8	0.0	0.1	0.5	28.5	1.5	9.2	1.6	64.4	0.0	0.1	0.5	22.7	
Lahore	1.7	8.8	3.6	38.1	0.0	0.1	0.3	47.5	1.5	10.6	1.8	45.2	0.0	0.1	0.4	40.4	1.5	8.8	3.6	38.1	0.0	0.1	0.3	47.6	1.2	10.7	1.8	45.3	0.0	0.1	0.4	40.5	
Sarajevo	2.2	7.2	1.2	82.0	0.0	0.3	0.9	6.3	1.8	6.8	0.5	84.7	0.0	0.3	0.8	5.1	2.0	7.2	1.2	82.2	0.0	0.3	0.9	6.3	1.6	6.8	0.5	84.9	0.0	0.3	0.8	5.1	
Amman	2.2	11.5	7.6	0.0	38.1	0.0	0.2	40.4	1.6	13.7	3.6	0.0	48.0	0.0	0.3	32.8	2.1	11.5	7.6	0.0	38.1	0.0	0.2	40.5	1.5	13.7	3.6	0.0	48.0	0.0	0.3	32.9	
Buenos Aires	2.1	4.4	3.0	16.7	0.0	0.0	0.3	73.6	1.9	6.6	1.8	16.0	0.0	0.0	0.4	73.2	2.0	4.4	3.0	16.7	0.0	0.0	0.3	73.7	1.7	6.6	1.8	16.1	0.0	0.0	0.4	73.4	
Shanghai	1.9	10.1	5.7	36.2	0.0	0.0	0.3	45.8	1.5	12.5	2.9	43.4	0.0	0.0	0.3	39.4	1.8	10.1	5.7	36.3	0.0	0.0	0.3	45.9	1.3	12.5	2.9	43.5	0.0	0.0	0.3	39.4	
Kawasaki	3.3	4.9	3.7	23.6	0.0	0.0	0.3	64.2	2.9	6.7	1.8	27.6	0.0	0.1	0.3	60.6	2.8	4.9	3.7	23.8	0.0	0.0	0.3	64.5	2.2	6.8	1.8	27.8	0.0	0.1	0.3	61.0	
Atlanta	2.4	4.8	2.6	23.3	0.0	0.1	0.4	66.5	2.6	6.7	1.4	23.5	0.0	0.1	0.5	65.1	1.9	4.8	2.6	23.4	0.0	0.1	0.4	66.8	1.9	6.8	1.5	23.7	0.0	0.1	0.5	65.6	

*Net negative contributor to the net total carbon emissions. Remanufacturing and incineration with energy recovery include emission offsets. Due to rounding zero values may actually be very small values.

Table 3.3-17 Group 5 (PM) Scenarios- Percentage of Net Total PM Emissions Attributed to the Different Processes

City	Group 5: Minimizing PM (Global Dimming) Emissions																															
	Daily- High Capture								Daily - Low Capture								Biweekly Collection - High Capture								Biweekly Collection - Low Capture							
	Collection	Separation		Incineration w/ER*	Disposal		Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Disposal		Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Disposal		Transportation	Remanufacturing*	Collection	Separation		Incineration w/ER*	Disposal		Transportation	Remanufacturing*
		Mixed Waste Recycling	Commingled Recycling		Landfill	Ash-landfill				Mixed Waste Recycling	Commingled Recycling		Landfill	Ash-landfill				Mixed Waste Recycling	Commingled Recycling		Landfill	Ash-landfill				Mixed Waste Recycling	Commingled Recycling		Landfill	Ash-landfill		
Kathmandu	0.4	0.4	0.2	1.7	0.0	0.0	0.1	97.2	0.4	0.6	0.1	2.4	0.0	0.0	0.2	96.3	0.4	0.4	0.2	1.7	0.0	0.0	0.1	97.2	0.3	0.6	0.1	2.4	0.0	0.0	0.2	96.3
Conakry	0.3	0.5	0.2	0.4	0.0	0.0	0.2	98.4	0.4	0.7	0.1	0.2	0.0	0.0	0.2	98.3	0.3	0.5	0.2	0.4	0.0	0.0	0.2	98.5	0.3	0.7	0.1	0.2	0.0	0.0	0.2	98.4
Lahore	0.7	1.6	0.6	1.0	0.0	0.1	0.3	95.6	0.7	2.3	0.3	2.6	0.0	0.1	0.5	93.5	0.6	1.6	0.6	1.0	0.0	0.1	0.3	95.7	0.6	2.3	0.3	2.6	0.0	0.1	0.5	93.6
Sarajevo	0.3	1.8	0.3	38.0	0.0	0.1	0.3	59.3	0.3	2.2	0.2	48.0	0.0	0.1	0.3	49.0	0.2	1.8	0.3	38.0	0.0	0.1	0.3	59.3	0.2	2.2	0.2	48.0	0.0	0.1	0.3	49.0
Amman	0.3	0.3	0.1	0.0	1.6	0.0	0.1	97.6	0.3	0.4	0.1	0.0	2.4	0.0	0.1	96.7	0.3	0.3	0.1	0.0	1.6	0.0	0.1	97.6	0.3	0.4	0.1	0.0	2.4	0.0	0.1	96.7
Buenos Aires	0.4	0.4	0.2	1.7	0.0	0.0	0.1	97.2	0.4	0.6	0.1	2.4	0.0	0.0	0.2	96.3	0.4	0.4	0.2	1.7	0.0	0.0	0.1	97.2	0.3	0.6	0.1	2.4	0.0	0.0	0.2	96.3
Shanghai	0.8	1.2	0.6	0.5	0.0	0.0	0.3	96.6	0.7	1.7	0.3	2.5	0.0	0.0	0.4	94.4	0.7	1.2	0.6	0.5	0.0	0.0	0.3	96.7	0.6	1.7	0.3	2.5	0.0	0.0	0.4	94.5
Kawasaki	0.5	1.0	0.8	5.2	0.0	0.0	0.1	92.4	0.5	1.5	0.4	7.6	0.0	0.0	0.1	89.8	0.5	1.0	0.8	5.2	0.0	0.0	0.1	92.4	0.4	1.5	0.4	7.6	0.0	0.0	0.1	89.9
Atlanta	0.2	0.5	0.3	6.1	0.0	0.0	0.1	92.8	0.2	0.7	0.2	8.8	0.0	0.0	0.1	90.0	0.1	0.5	0.3	6.1	0.0	0.0	0.1	92.9	0.1	0.7	0.2	8.8	0.0	0.0	0.1	90.0

* Net negative contributor to the net total PM emissions. Remanufacturing and incineration with energy recovery include emission offsets. Due to rounding zero values may actually be very small values

3.4 Option Comparison per City

This section shows summary charts that compare the technology options per city so that each target city may consider which option would be better to be adopted from the viewpoints of cost, energy consumption and carbon emissions.

However, since the comparison charts include various assumptions and default data, it should be noted that the results in this report should be seen only as a reference for each city to gain a rough idea of adoption of a suitable waste treatment option.

3.4.1 Amman

Summary of Simulation Scenarios

Costs Results

Figures 3.4-1 and 3.4-2 show the cost results of the simulation scenarios using one primary technology. The total unit cost per tonne-waste including collection cost (which is same for all options) for incineration only is most expensive than that for composting with windrow turner, and incineration with energy recovery follows. The cheapest option is landfill with energy recovery in both case with and without land price for landfill cost.

Energy Recovery Results

Figure 3.4-3 shows the energy recovery results. As is easily understood, adoption of incineration with energy recovery contributes greatly by saving energy. Energy recovery by collecting the landfill gas can be also expected as well as saving energy through the use of recovered material by recycling.

Carbon Emission Results

As Figure 3.4-4 shows, the carbon emission results show that the worst option can be said to be landfill with gas venting. The second worst option is incineration only. Incineration with energy recovery is the best option because of offsetting electricity generation emissions from the utility sector. Composting with both manual turning and windrow turner is a better option with less carbon emissions.

Summary of Optimization Scenarios

Costs Results

Figures 3.4-5 and 3.4-6 show the cost results of the optimization scenarios. It shows that the unit cost per tonne-waste is less expensive for the scenario which is maximizing material recovery with manual MRF and composting with manual turning, than other options. On the

other hand, the cost for the scenario for minimizing carbon emissions is rather more expensive than others.

Energy Recovery Results

Figure 3.4-7 shows the energy recovery results. Needless to say, the energy optimization scenario achieves the lowest energy consumption, then the scenario for minimizing carbon emissions follows. The scenario for maximizing material recovery but with a low capture rate contributes much less for reduction of energy consumption.

Carbon Emission Results

As Figure 3.4-8 shows, other than the scenario for minimizing carbon emissions, only the scenario for energy optimization will contribute to the reduction of carbon emissions. The other scenarios, maximizing the material recovery and minimizing PM emissions, still show positive carbon emissions except the material recovery case with manual operation and high capture rate.

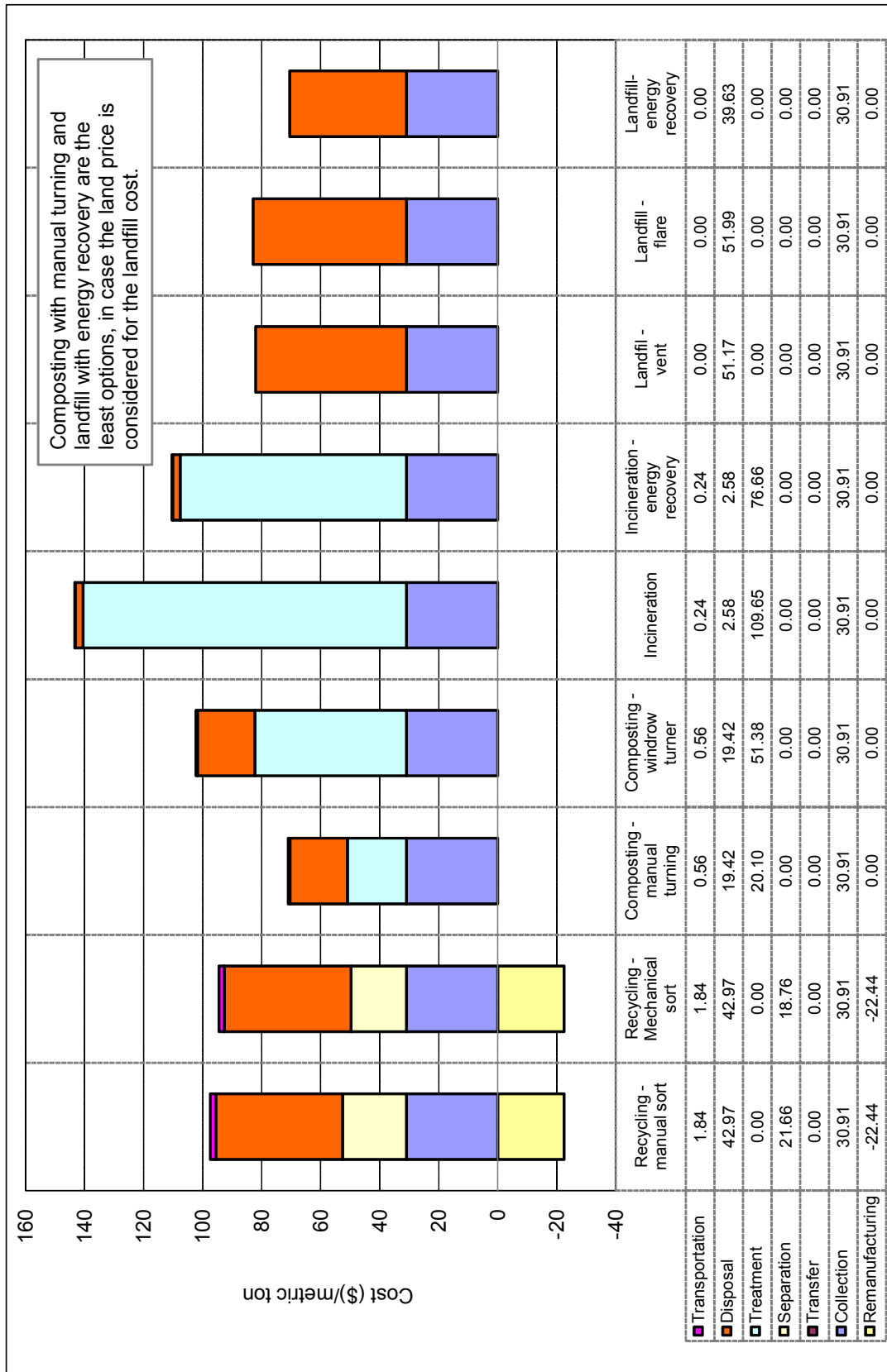


Figure 3.4-1 Cost Results of Simulation Scenarios (Amman: with Land Price)

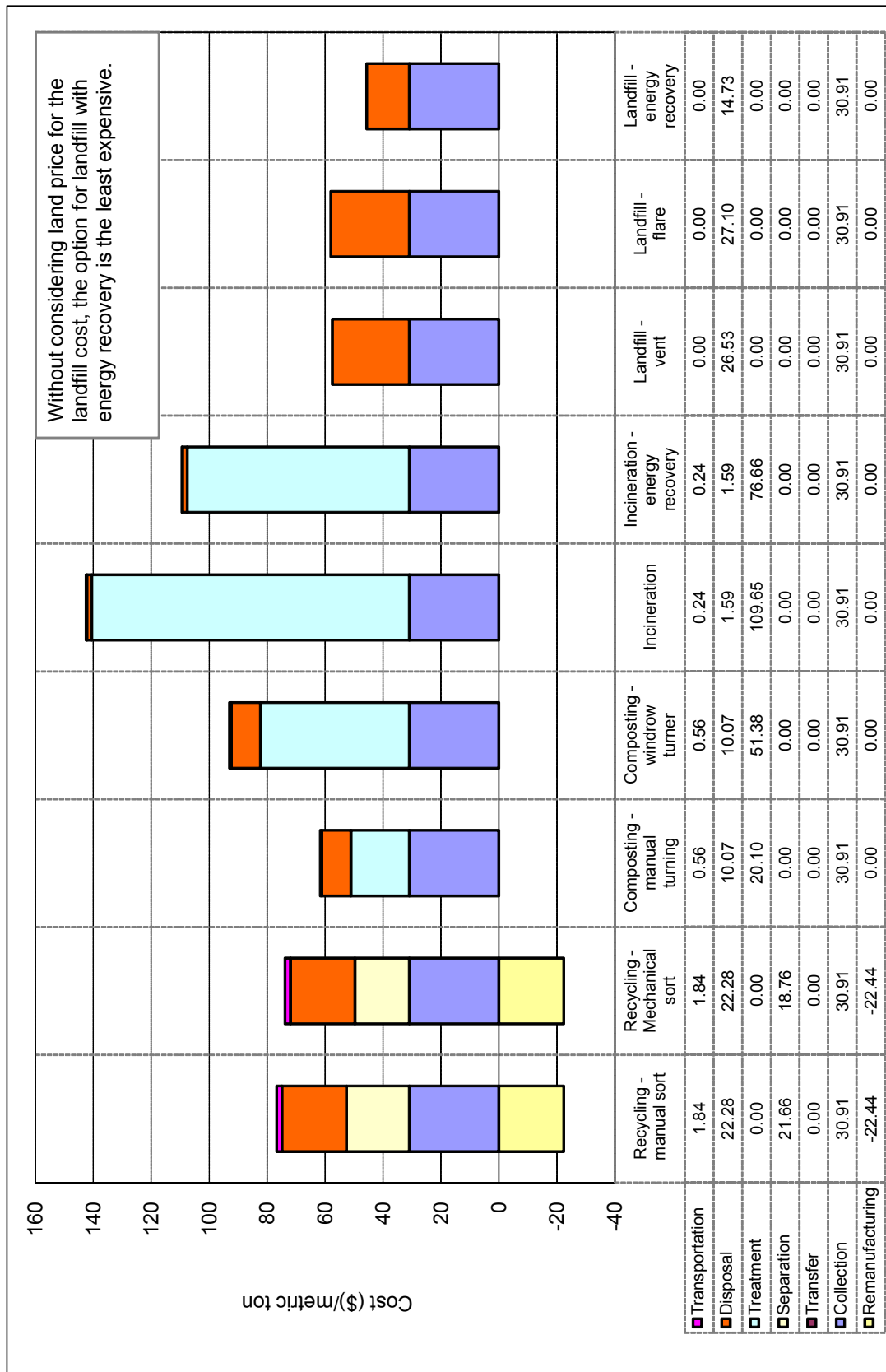


Figure 3.4-2 Cost Results of Simulation Scenarios (Amman: without Land Price)

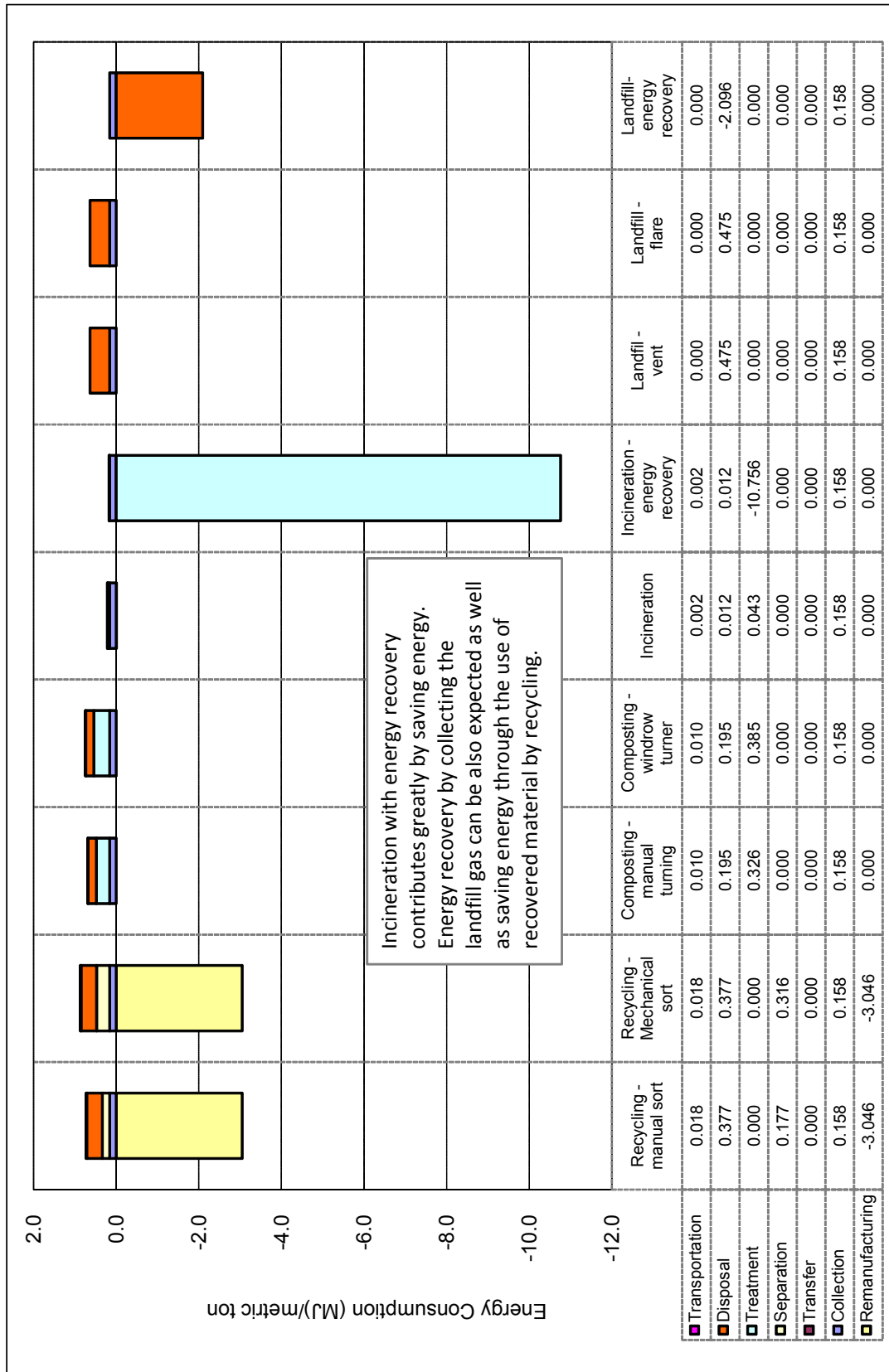


Figure 3.4-3 Energy Recovery Results of Simulation Scenarios (Amman)

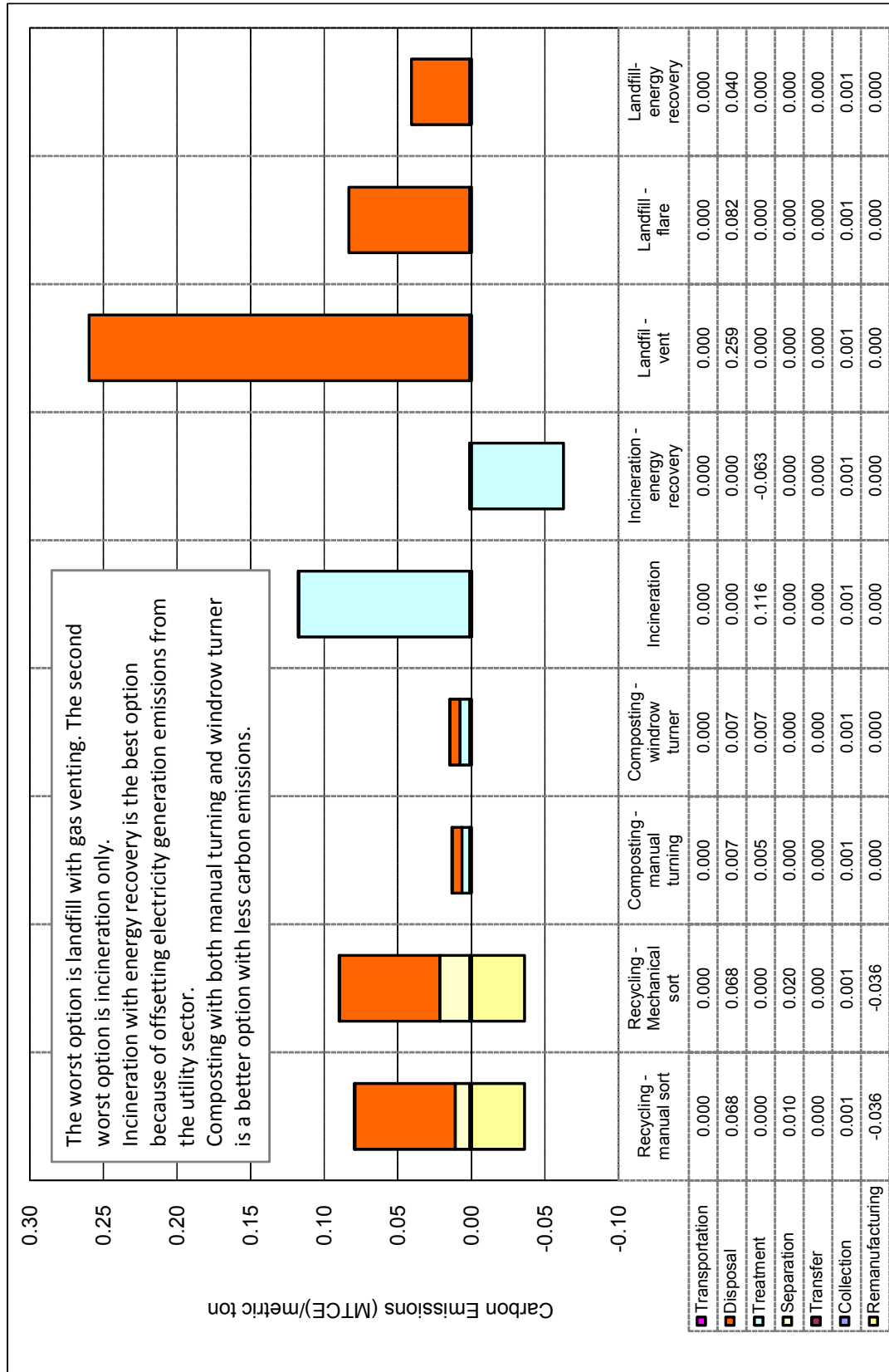


Figure 3.4-4 Carbon Emissions Results of Simulation Scenarios (Amman)

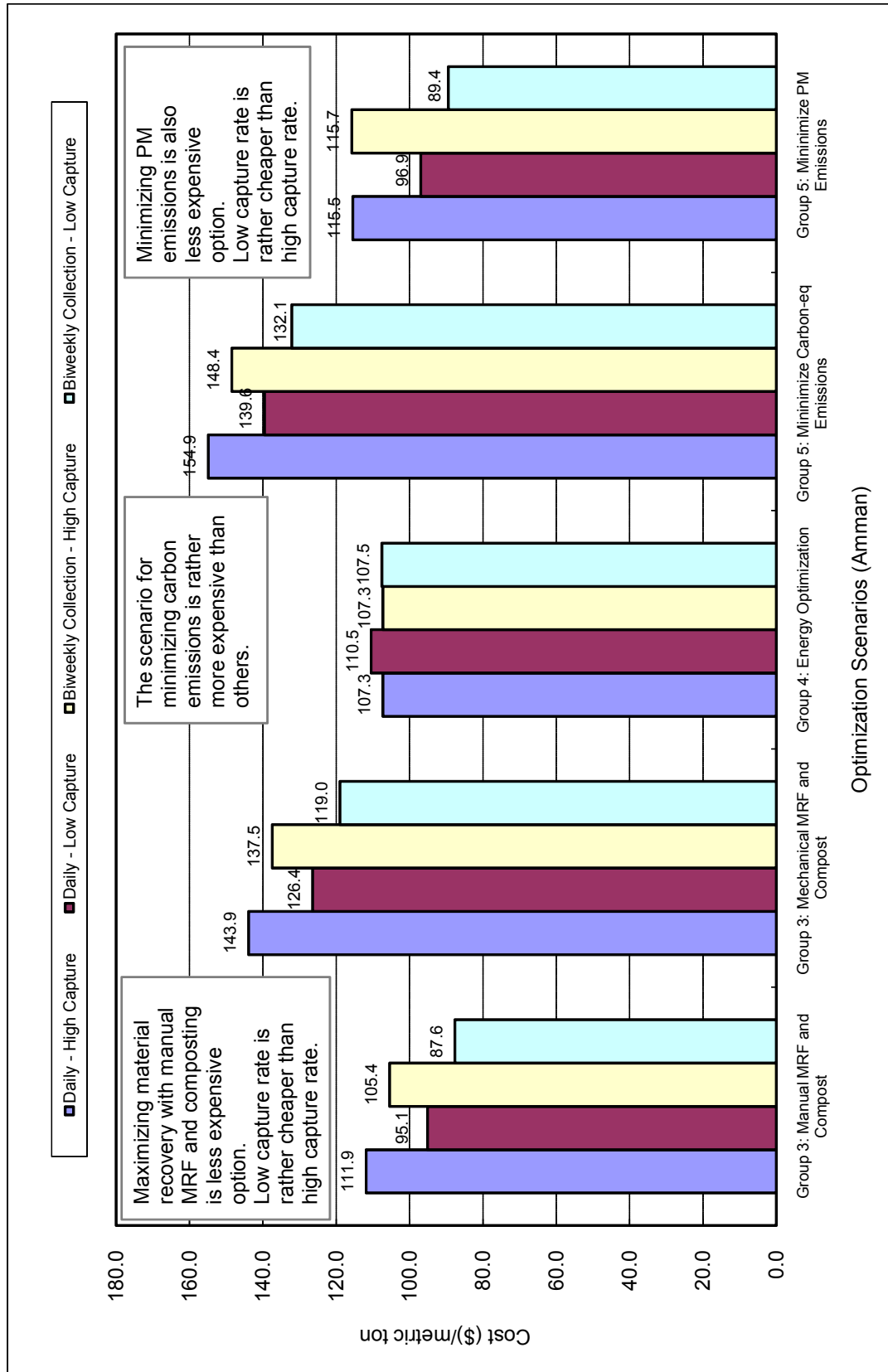


Figure 3.4-5 Cost Results of Optimizations Scenarios (Amman: with Land Price)

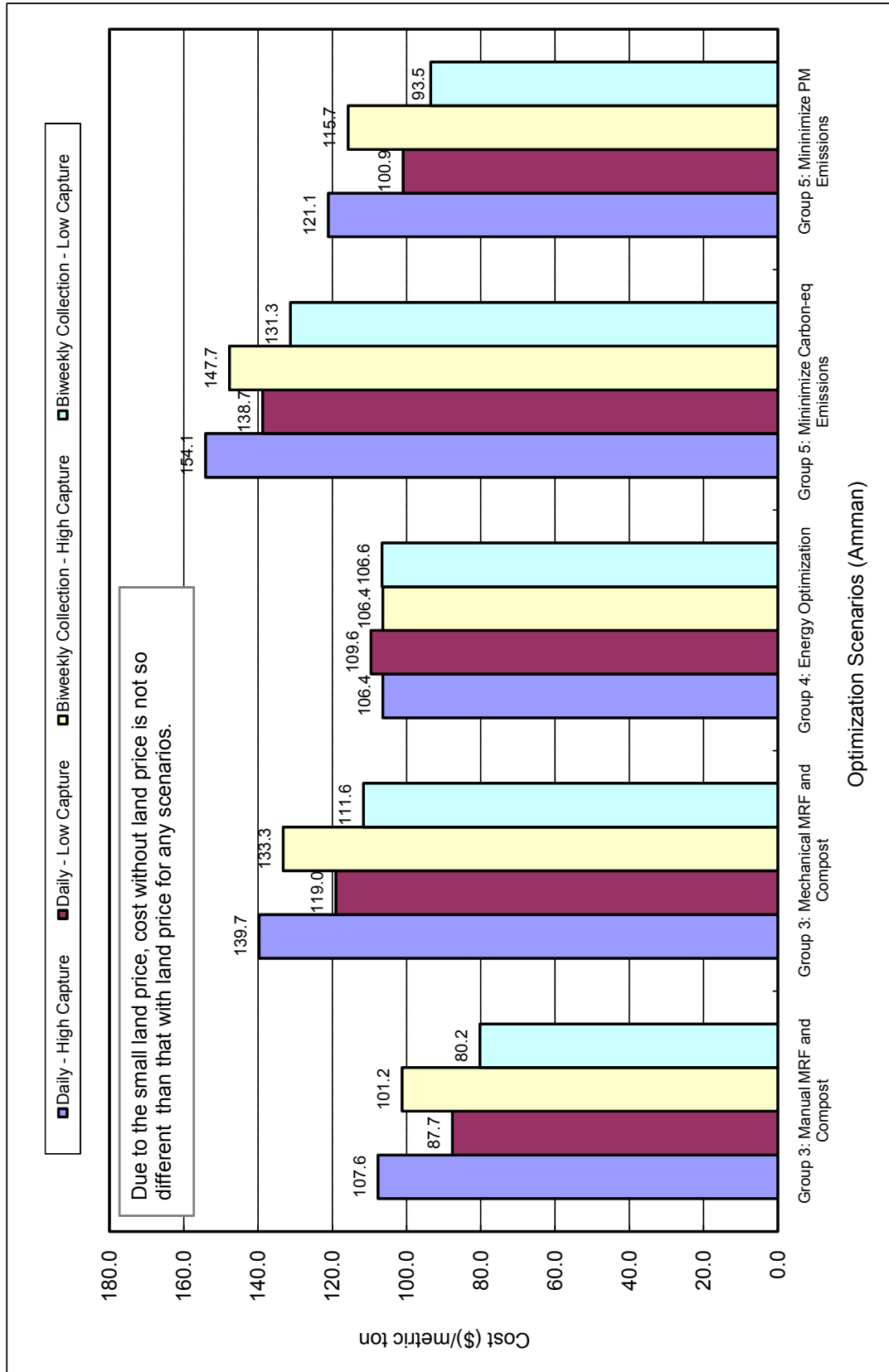


Figure 3.4-6 Cost Results of Optimizations Scenarios (Amman: without Land Price)

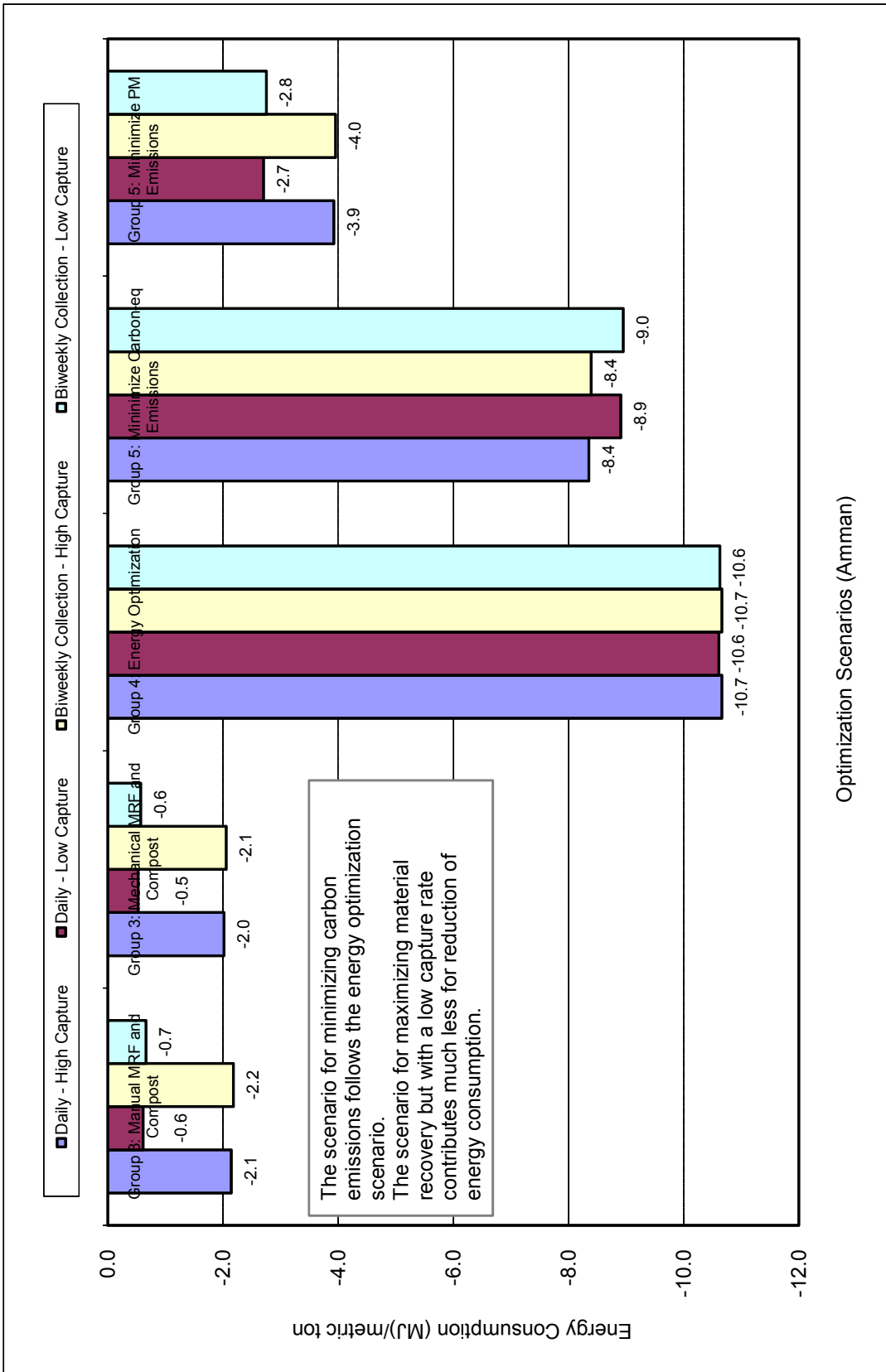


Figure 3.4-7 Energy Recovery Results of Optimizations Results (Amman)

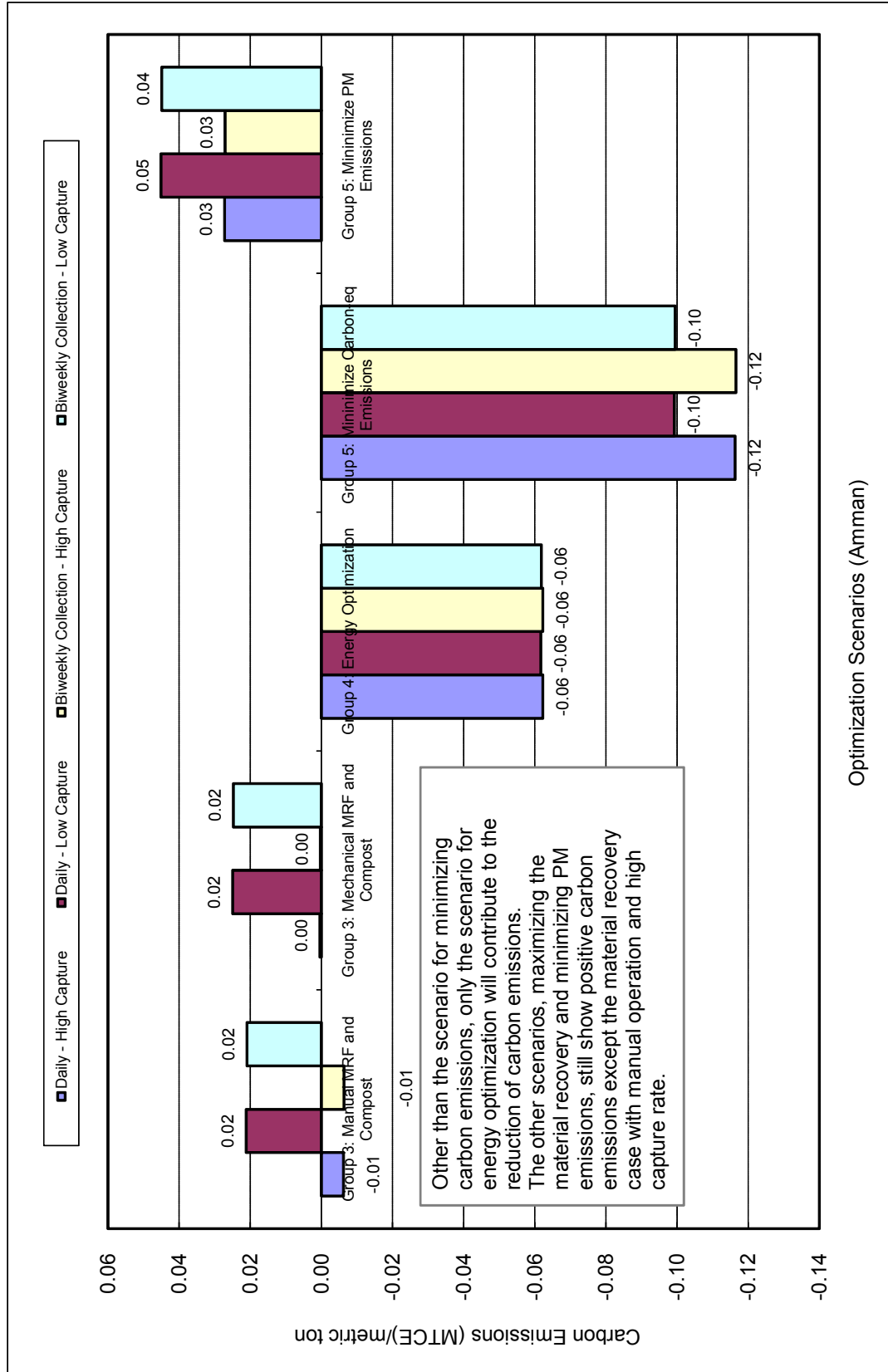


Figure 3.4-8 Carbon Emissions Results of Optimizations Results (Amman)

3.4.2 Buenos Aires

Summary of Simulation Scenarios

Costs Results

Figures 3.4-9 and 3.4-10 show the cost results of the simulation scenarios using one primary technology. The total unit cost per tonne-waste including collection cost (which is same for all options) for incineration with and without energy recovery is rather expensive. Composting with manual turning and landfill with any gas treatment options are less expensive options.

Energy Recovery Results

Figure 3.4-11 shows the energy recovery results. As is easily understood, adoption of incineration with energy recovery contributes greatly by saving energy. Greater energy recovery can be also expected by material recovery scenarios with both manual and mechanical operation.

Carbon Emission Results

As Figure 3.4-12 shows, the carbon emission results show that the worst option can be said to be landfill with gas venting. Composting and incineration with energy recovery produce less carbon emissions. Material recycling can also contribute greater reduction of carbon emissions.

Summary of Optimization Scenarios

Costs Results

Figures 3.4-13 and 3.4-14 show the cost results of the optimization scenarios. It shows that the unit cost per tonne-waste is less expensive for the scenario which is maximizing material recovery with manual MRF and composting with manual turning, than other options.

Energy Recovery Results

Figure 3.4-15 shows the energy recovery results. Scenarios for minimizing carbon and for minimizing PM emissions can reduce energy consumption into the same level as the energy optimization scenario.

Carbon Emission Results

As Figure 3.4-16 shows, as well as the scenario for minimizing carbon emissions, the scenario for minimizing PM emissions can also largely reduces carbon emissions. Scenarios for energy optimization and maximizing the material recovery with high capture rate will contribute to the reduction of carbon emissions but less than previous mentioned scenarios.

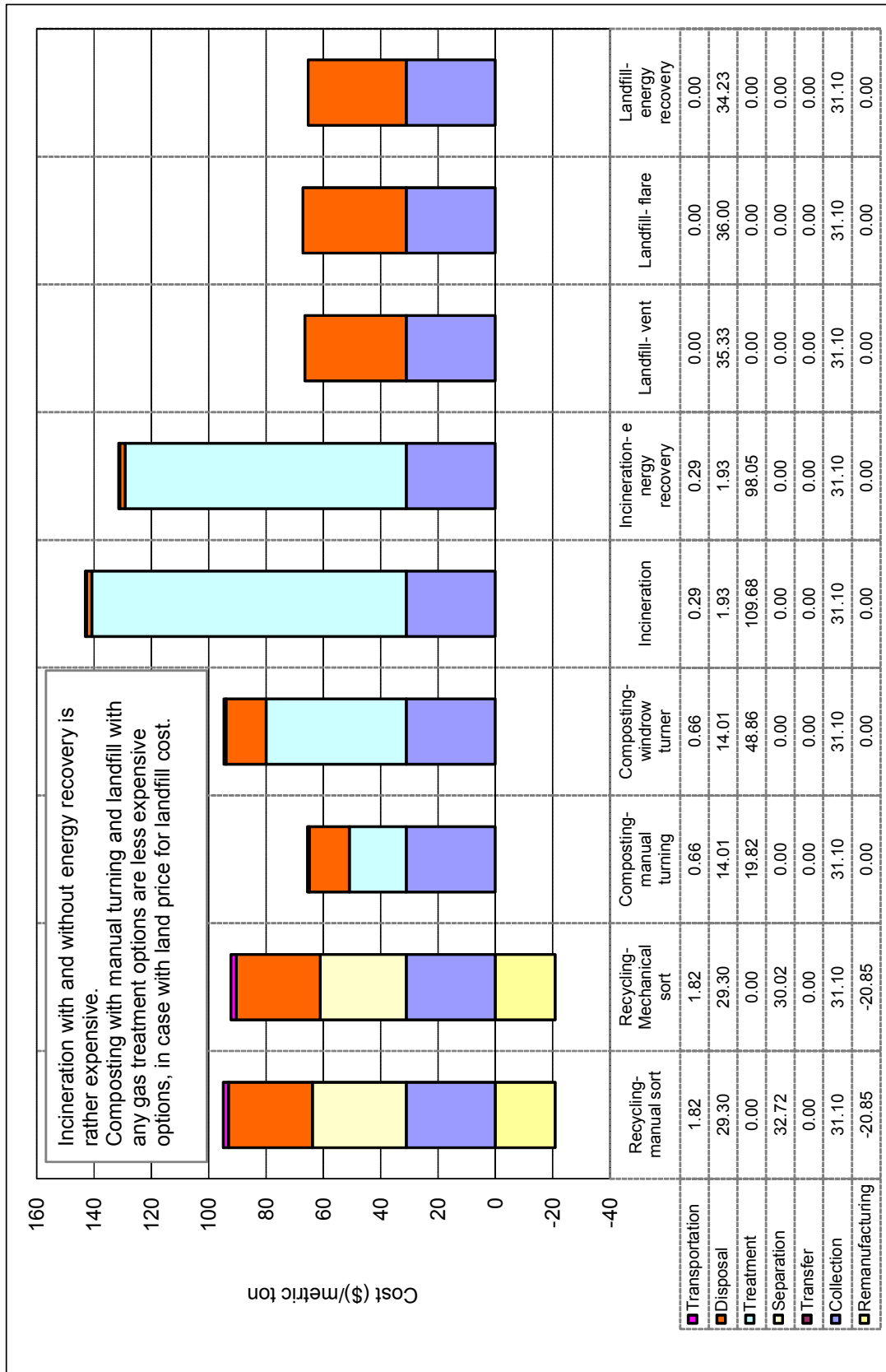


Figure 3.4-9 Cost Results of Simulation Scenarios (Buenos Aires: with Land Price)

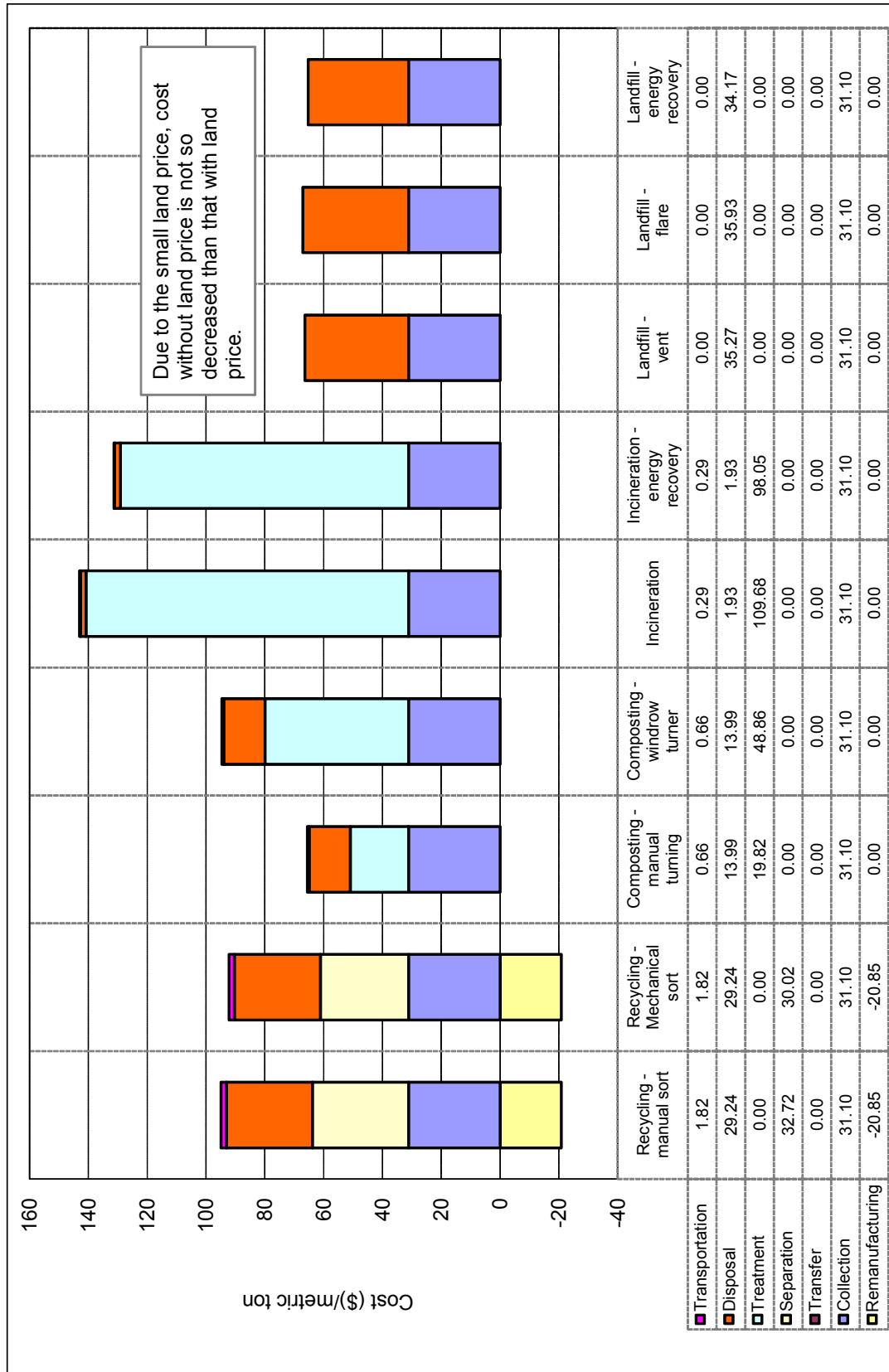


Figure 3.4-10 Cost Results of Simulation Scenarios (Buenos Aires: without Land Price)

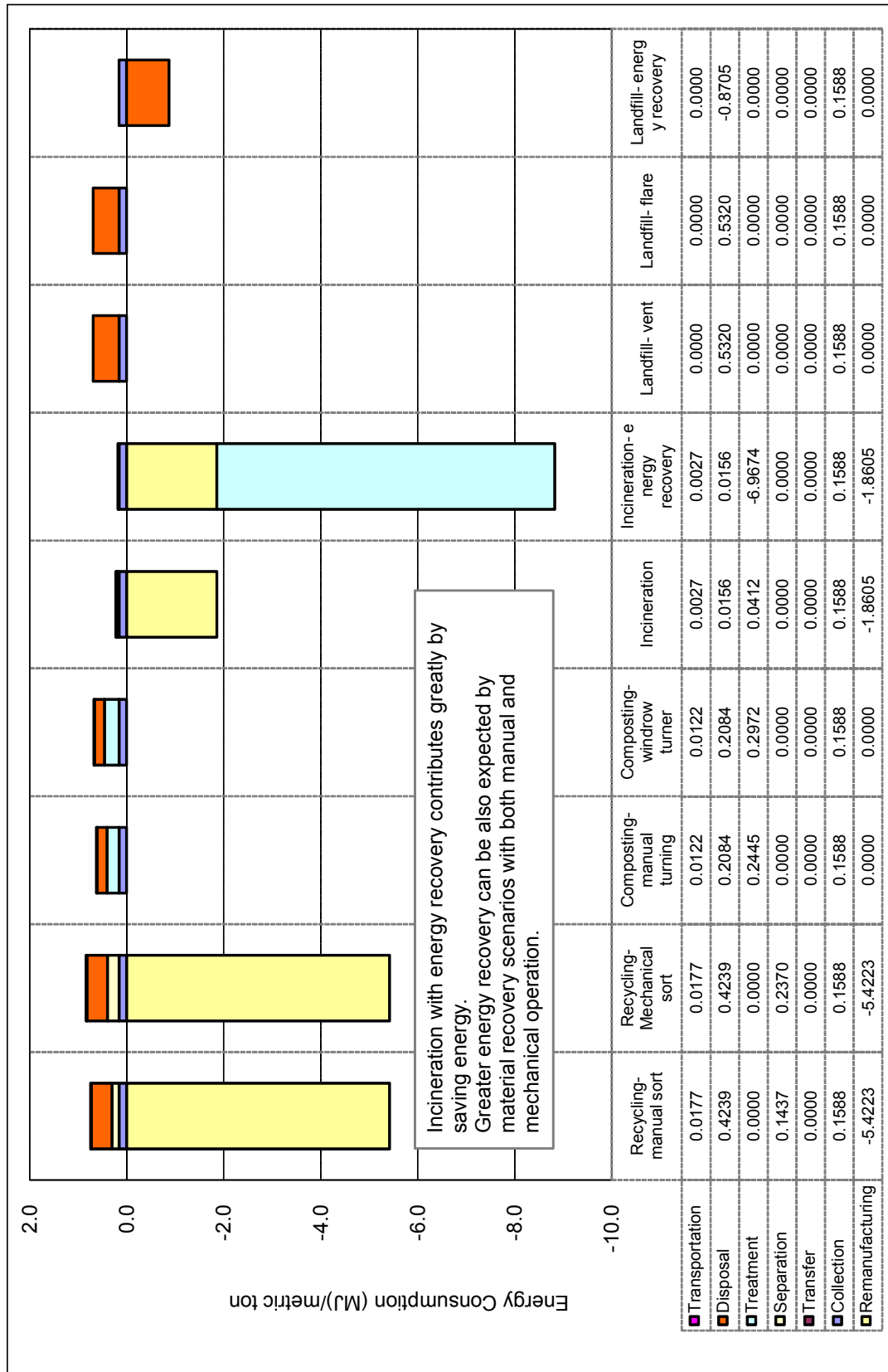


Figure 3.4-11 Energy Recovery Results of Simulation Scenarios (Buenos Aires)

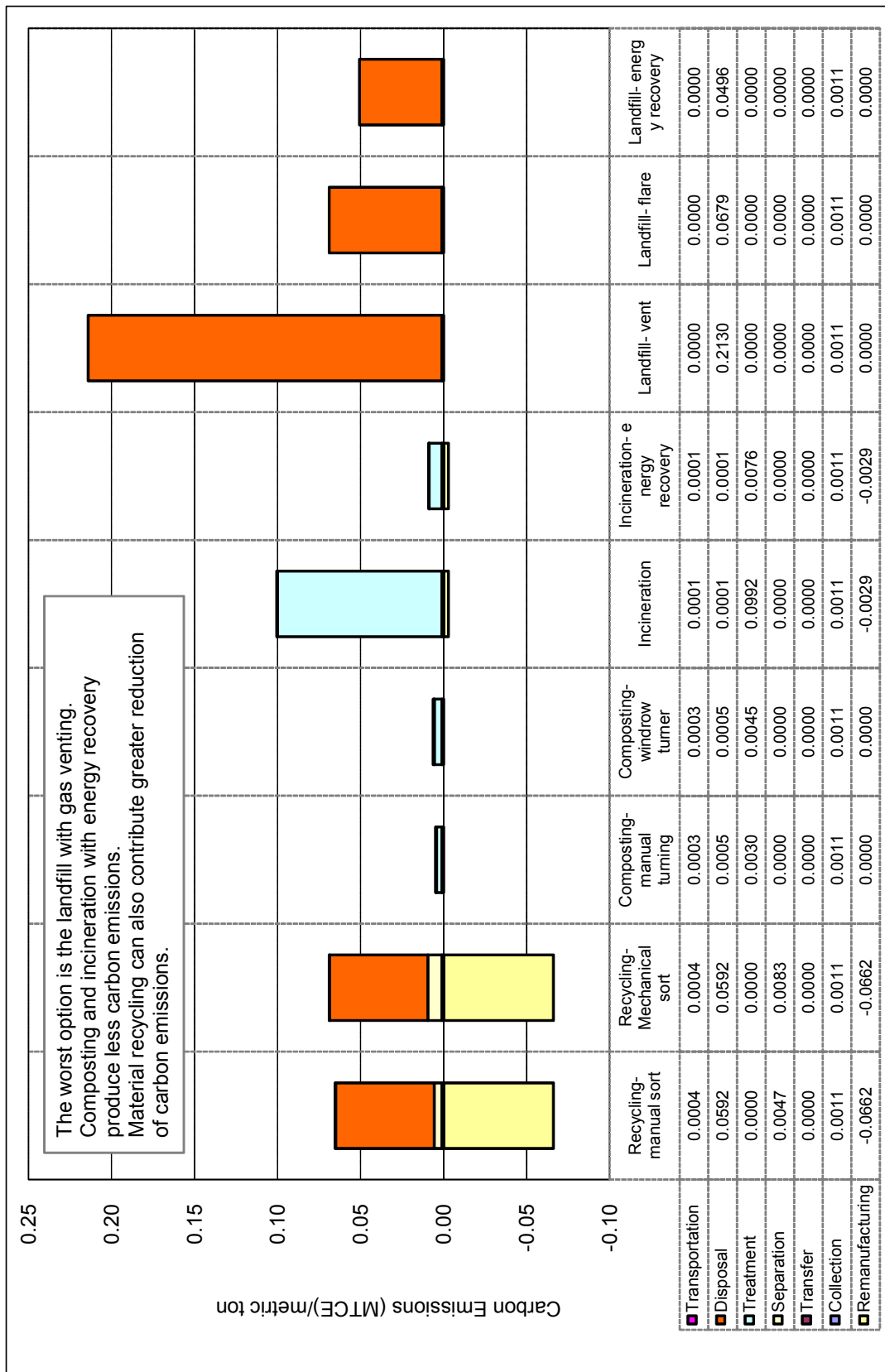


Figure 3.4-12 Carbon Emissions Results of Simulation Scenarios (Buenos Aires)

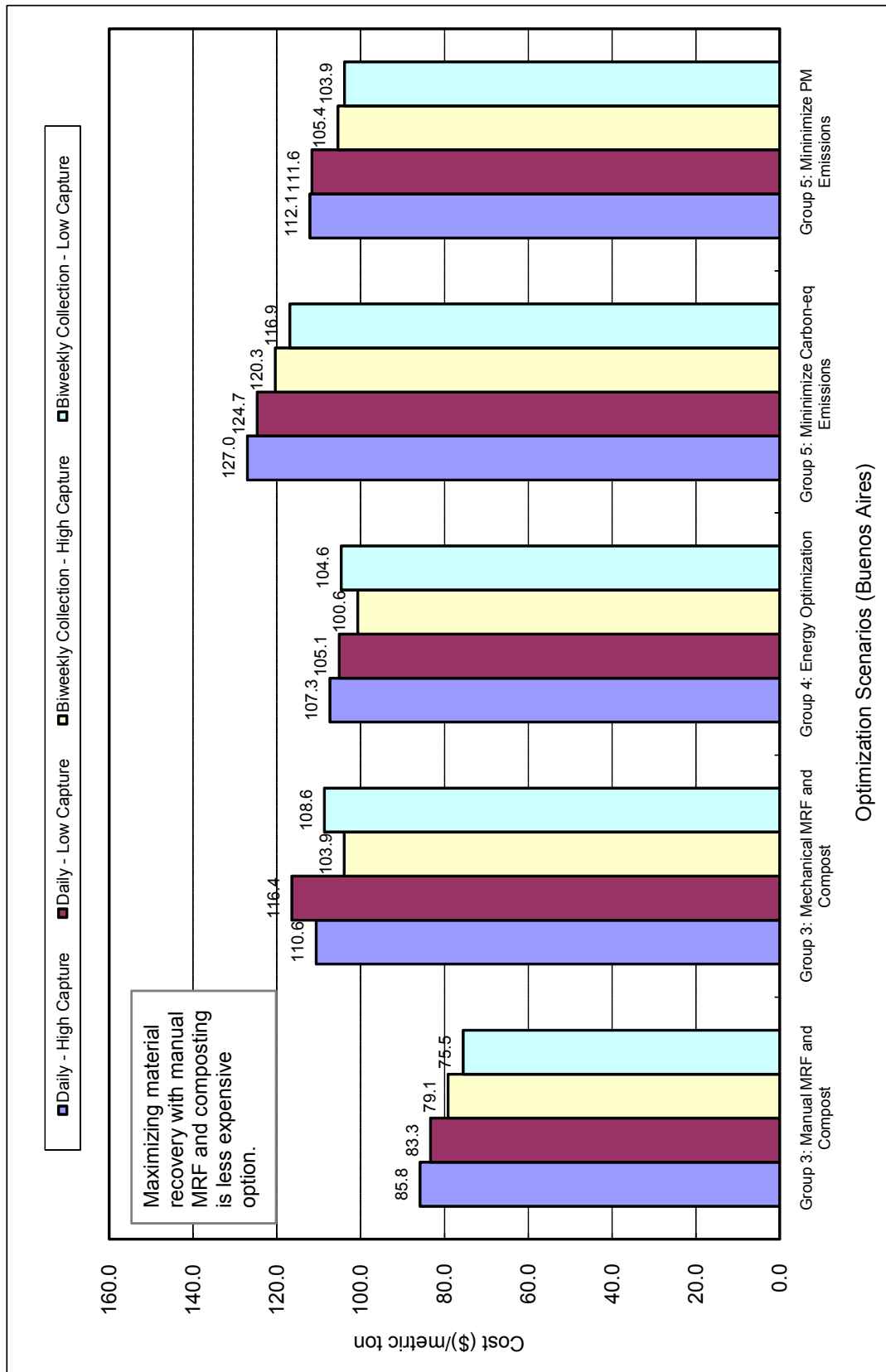


Figure 3.4-13 Cost Results of Optimizations Scenarios (Buenos Aires: with Land Price)

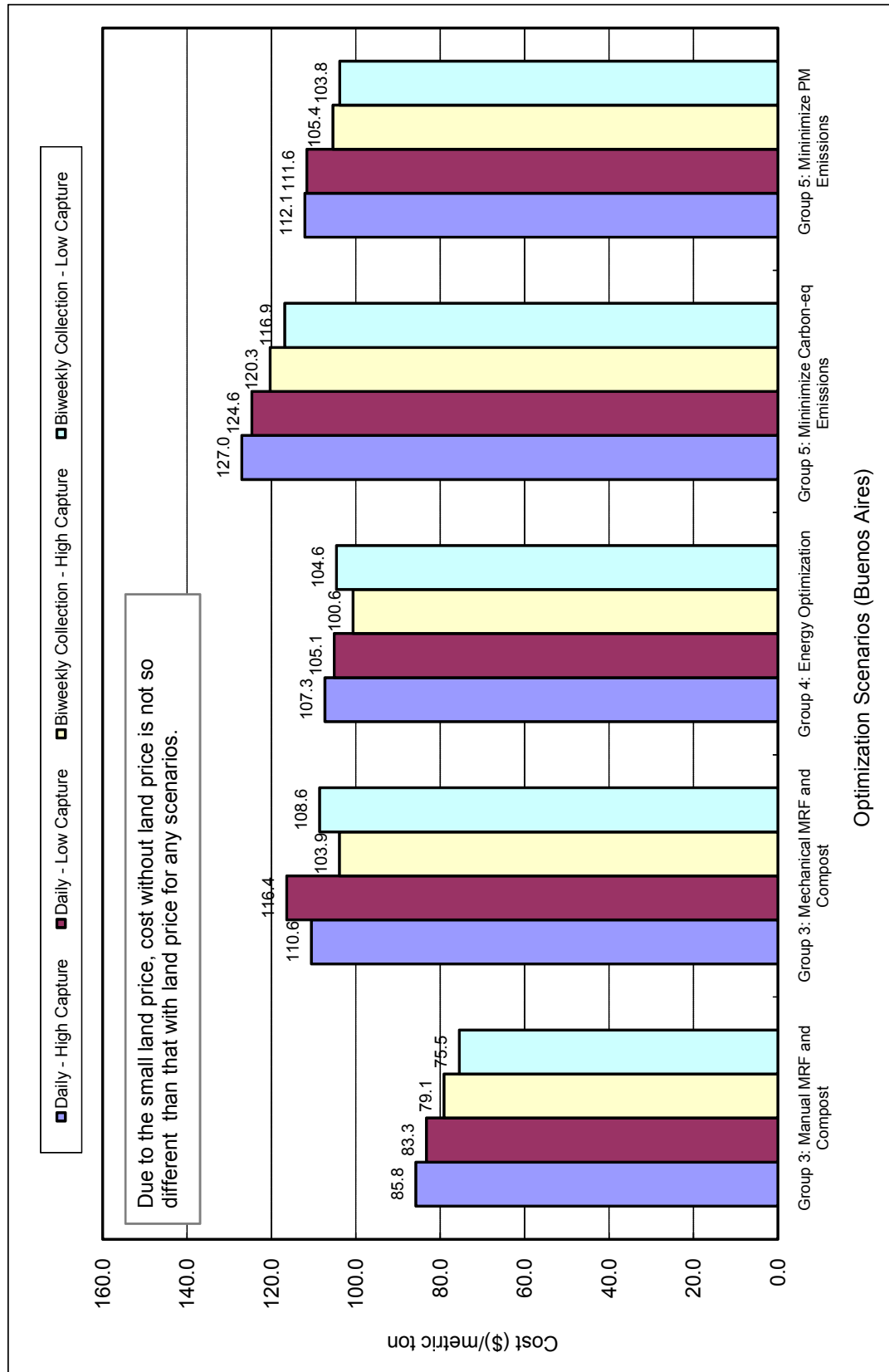


Figure 3.4-14 Cost Results of Optimizations Scenarios (Buenos Aires: without Land Price)

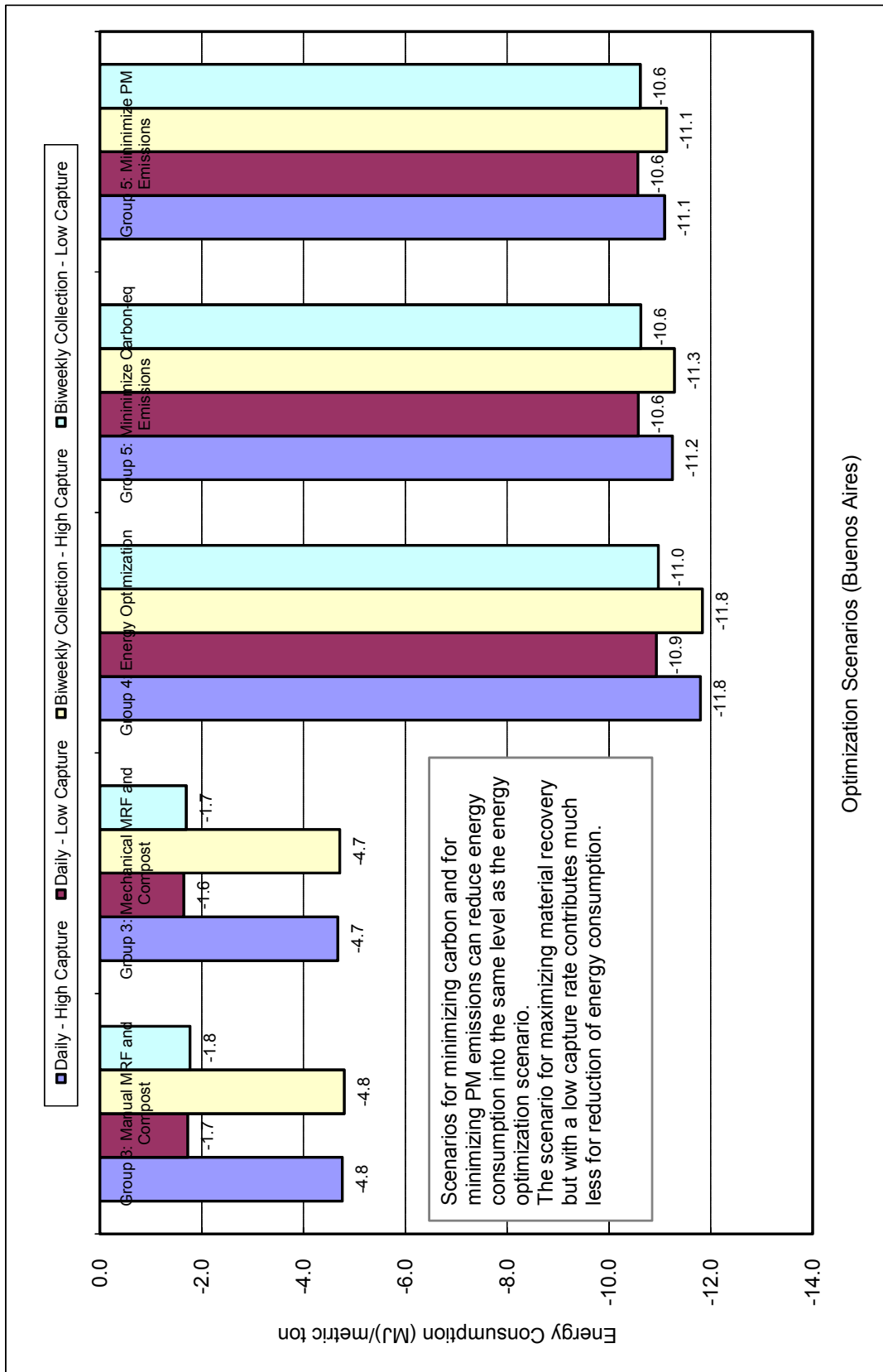


Figure 3.4-15 Energy Recovery Results of Optimizations Results (Buenos Aires)

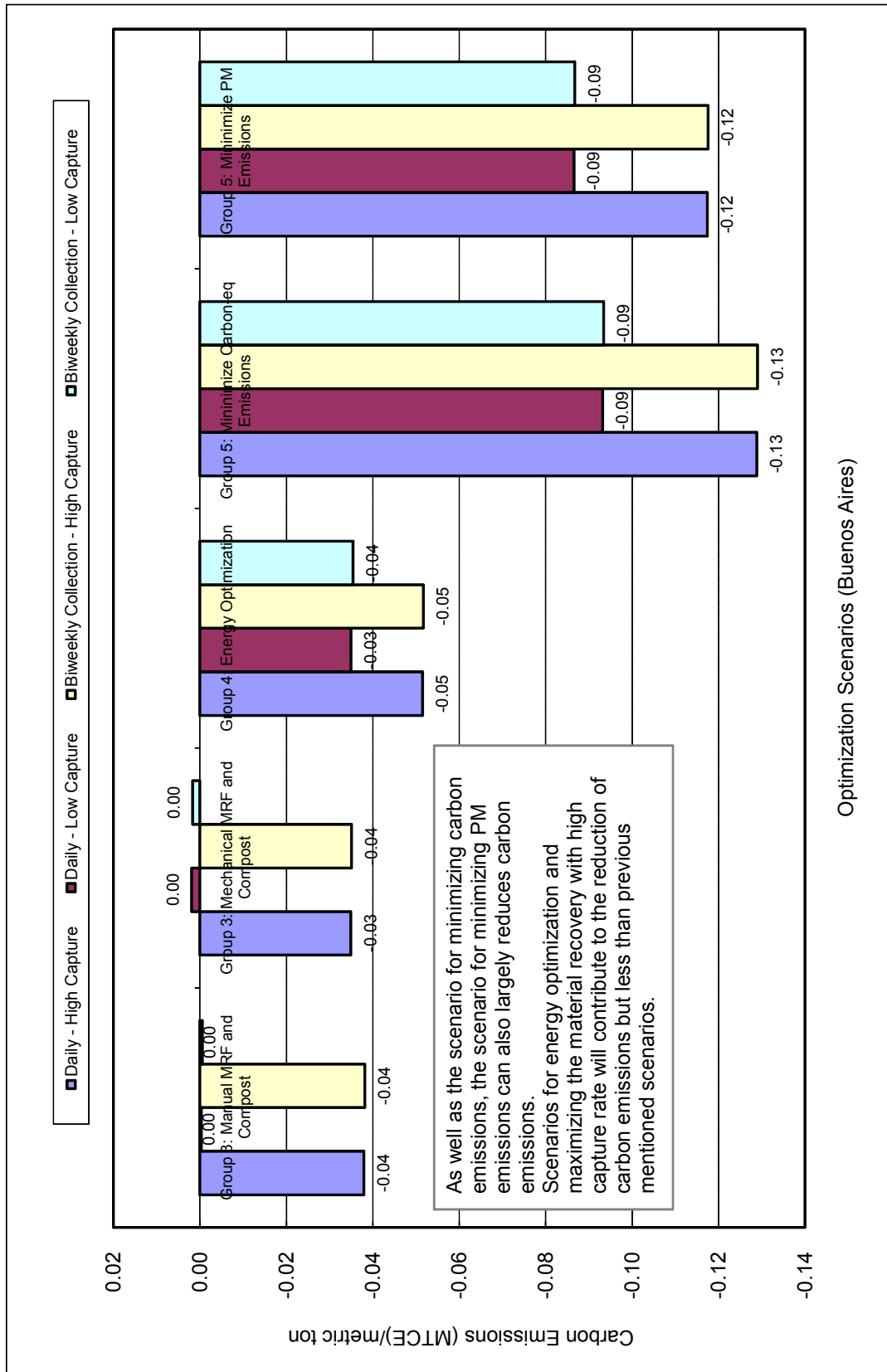


Figure 3.4-16 Carbon Emissions Results of Optimizations Results (Buenos Aires)

3.4.3 Conakry

Summary of Simulation Scenarios

Costs Results

Figures 3.4-17 and 3.4-18 show the cost results of the simulation scenarios using one primary technology. Since the total unit cost per tonne-waste for incineration with and without energy recovery is rather expensive. Other options except composting with windrow turner are ranked as less expensive options.

Energy Recovery Results

Figure 3.4-19 shows the energy recovery results. As is easily understood, adoption of incineration with energy recovery contributes greatly by saving energy. Greater energy recovery can be also expected by material recovery scenarios with both manual and mechanical operation.

Carbon Emission Results

As Figure 3.4-20 shows, the carbon emission results show that the worst option can be said to be landfill with gas venting. Scenarios for composting with both manual and mechanical turning produce less carbon emissions.

Summary of Optimization Scenarios

Costs Results

Figures 3.4-21 and 3.4-22 show the cost results of the optimization scenarios. It shows that the unit cost per tonne-waste is less expensive for the scenario which is maximizing material recovery with manual MRF and composting with manual turning under the condition of biweekly collection and low capture rate. Other options are almost same level of the cost.

Energy Recovery Results

Figure 3.4-23 shows the energy recovery results. Scenarios for minimizing carbon and for minimizing PM emissions can reduce energy consumption into the same level as the energy optimization scenario.

Carbon Emission Results

As Figure 3.4-24 shows, as well as the scenario for minimizing carbon emissions, the scenarios for minimizing PM emissions and energy optimization can also reduce carbon emissions. Scenarios for maximizing the material recovery will still discharge carbon emissions through its treatment processes.

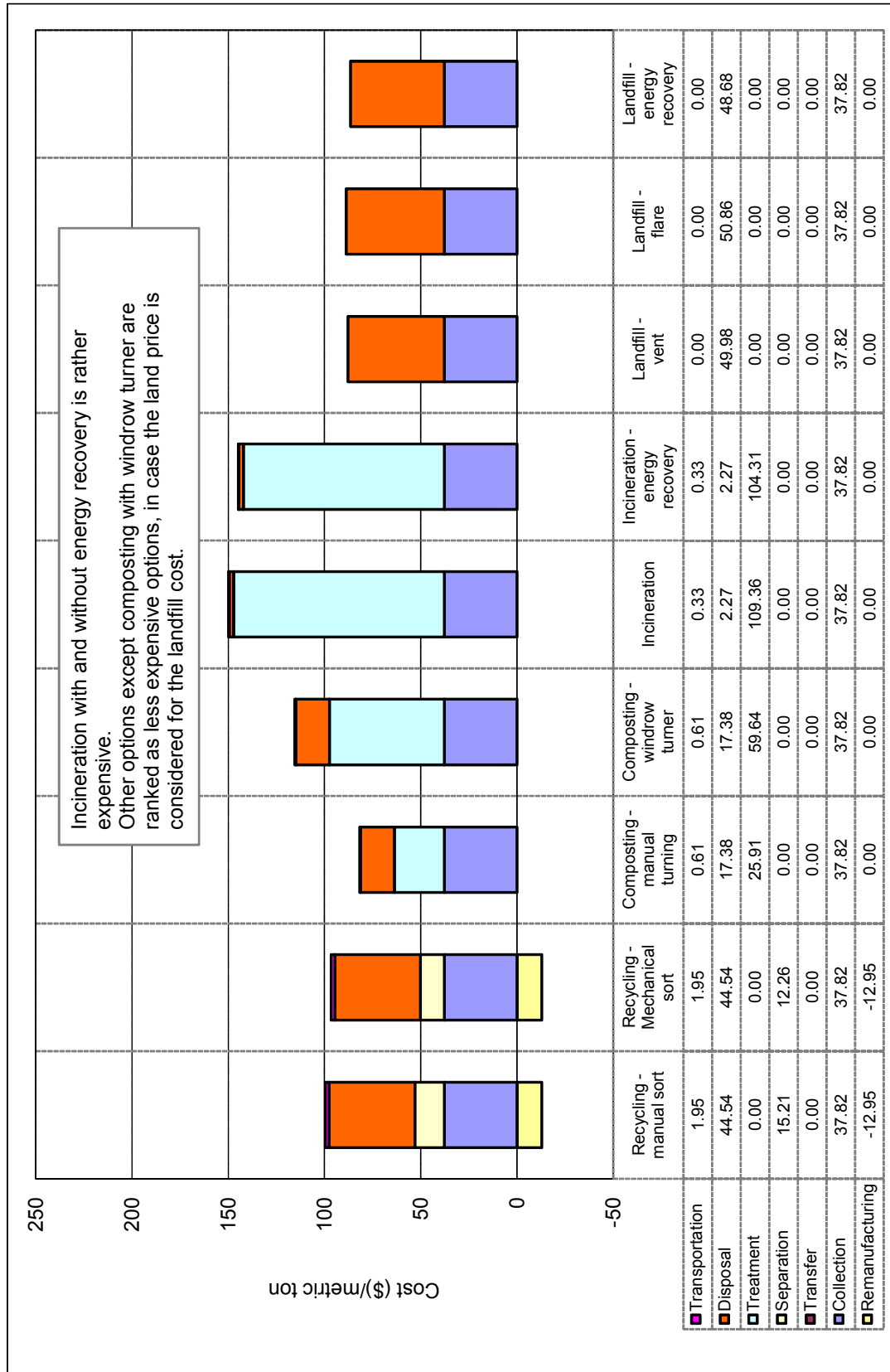


Figure 3.4-17 Cost Results of Simulation Scenarios (Conakry: with Land Price)

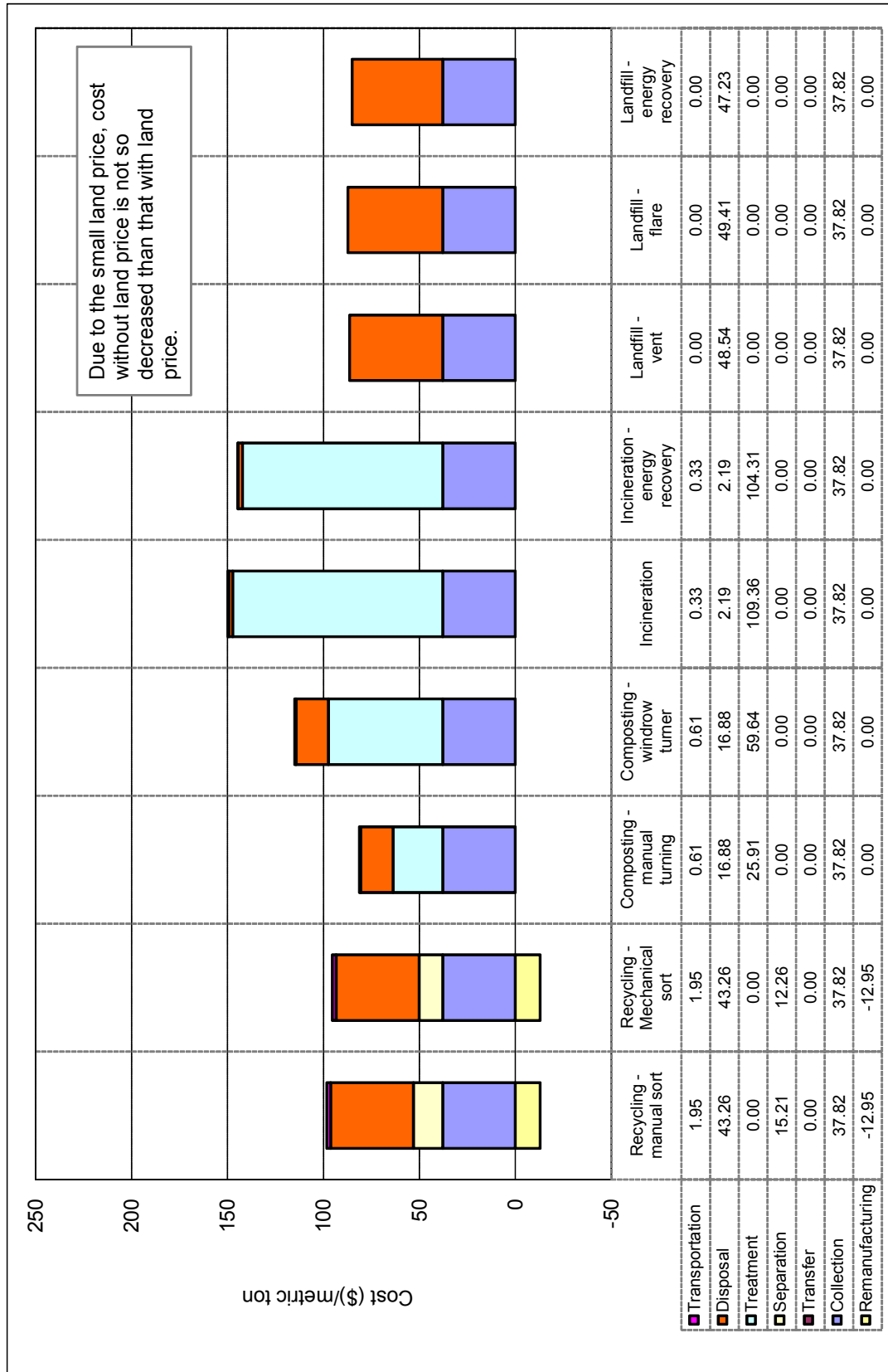


Figure 3.4-18 Cost Results of Simulation Scenarios (Conakry: without Land Price)

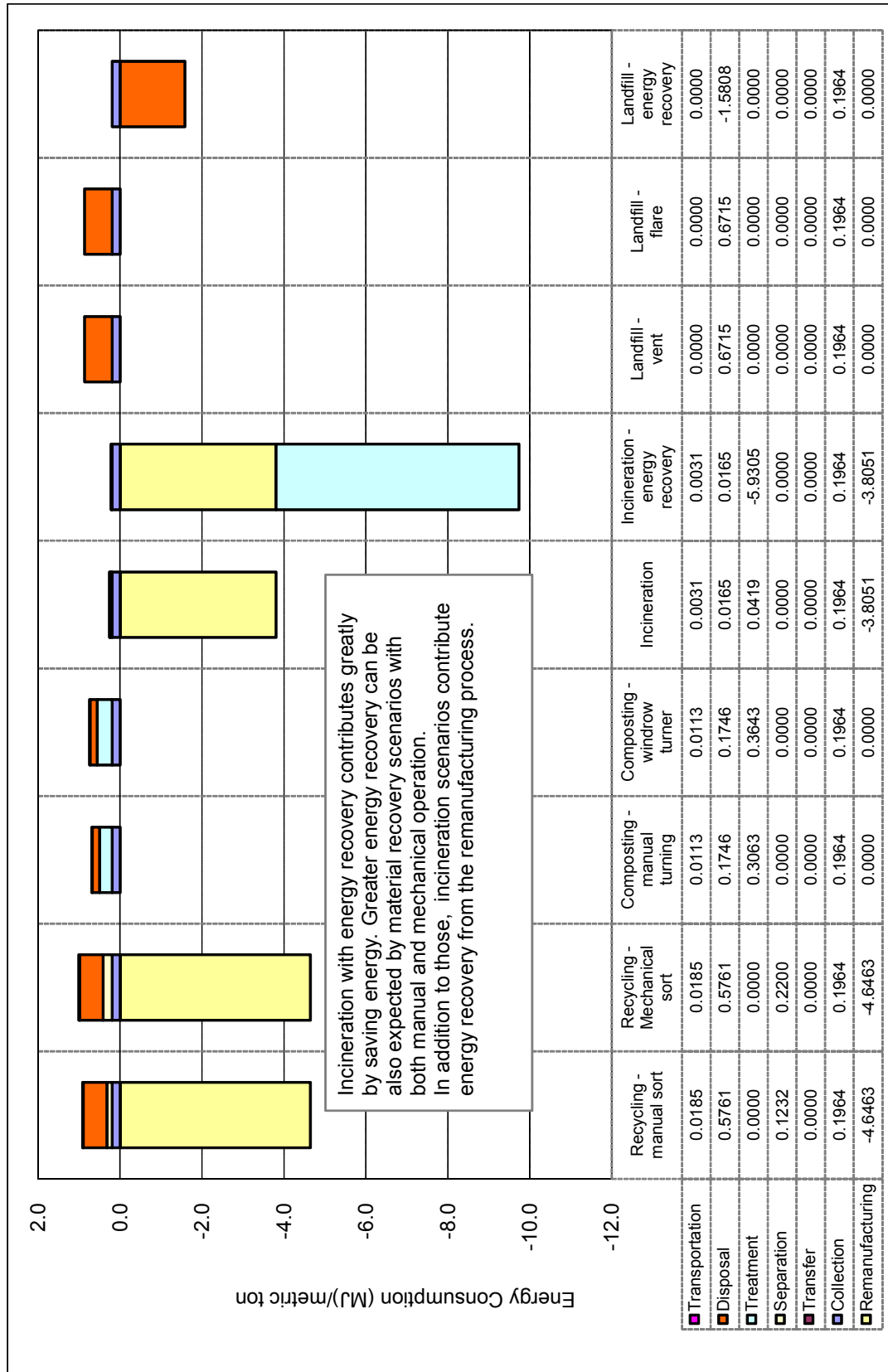


Figure 3.4-19 Energy Recovery Results of Simulation Scenarios (Conakry)

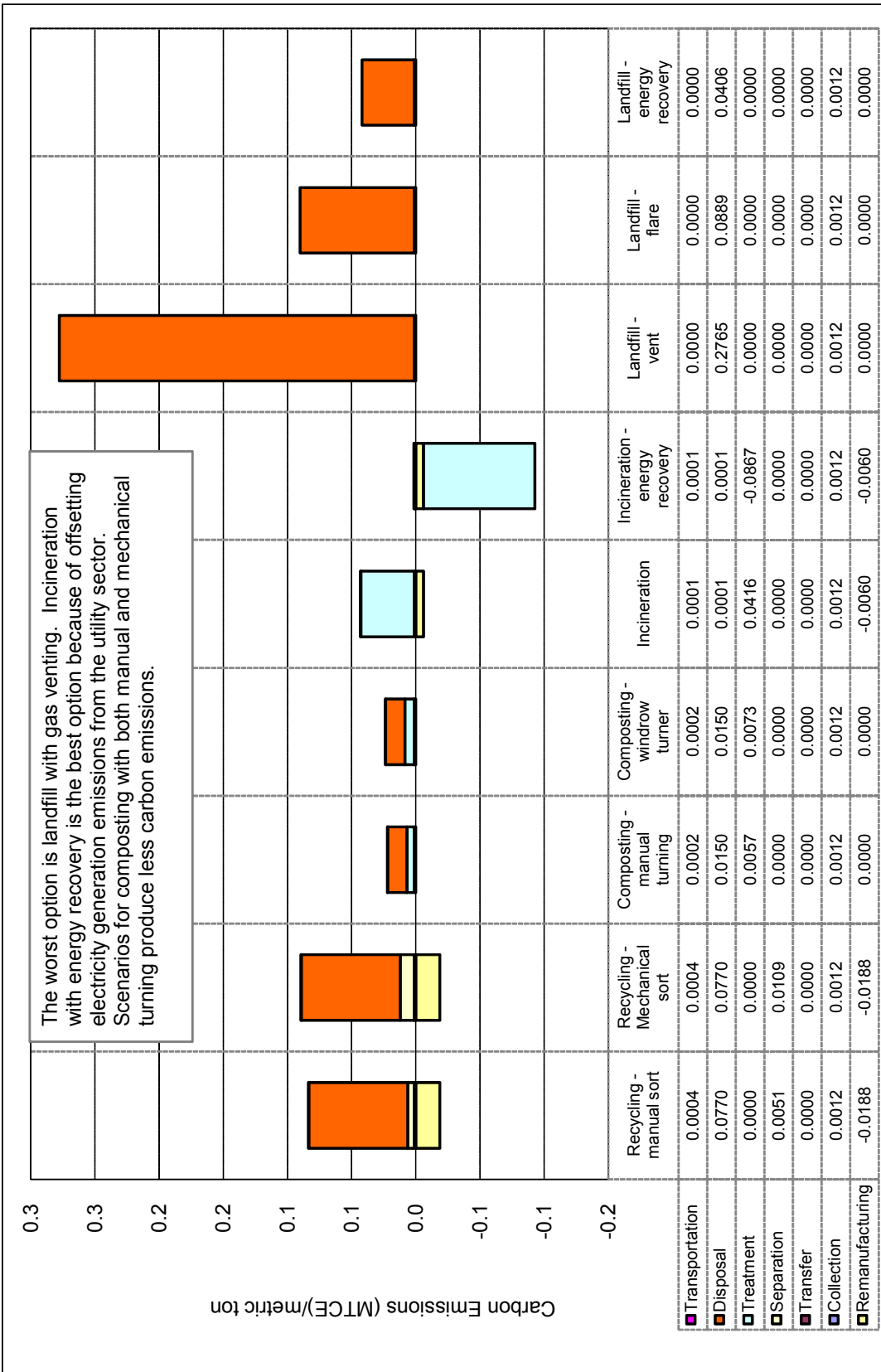


Figure 3.4-20 Carbon Emissions Results of Simulation Scenarios (Conakry)

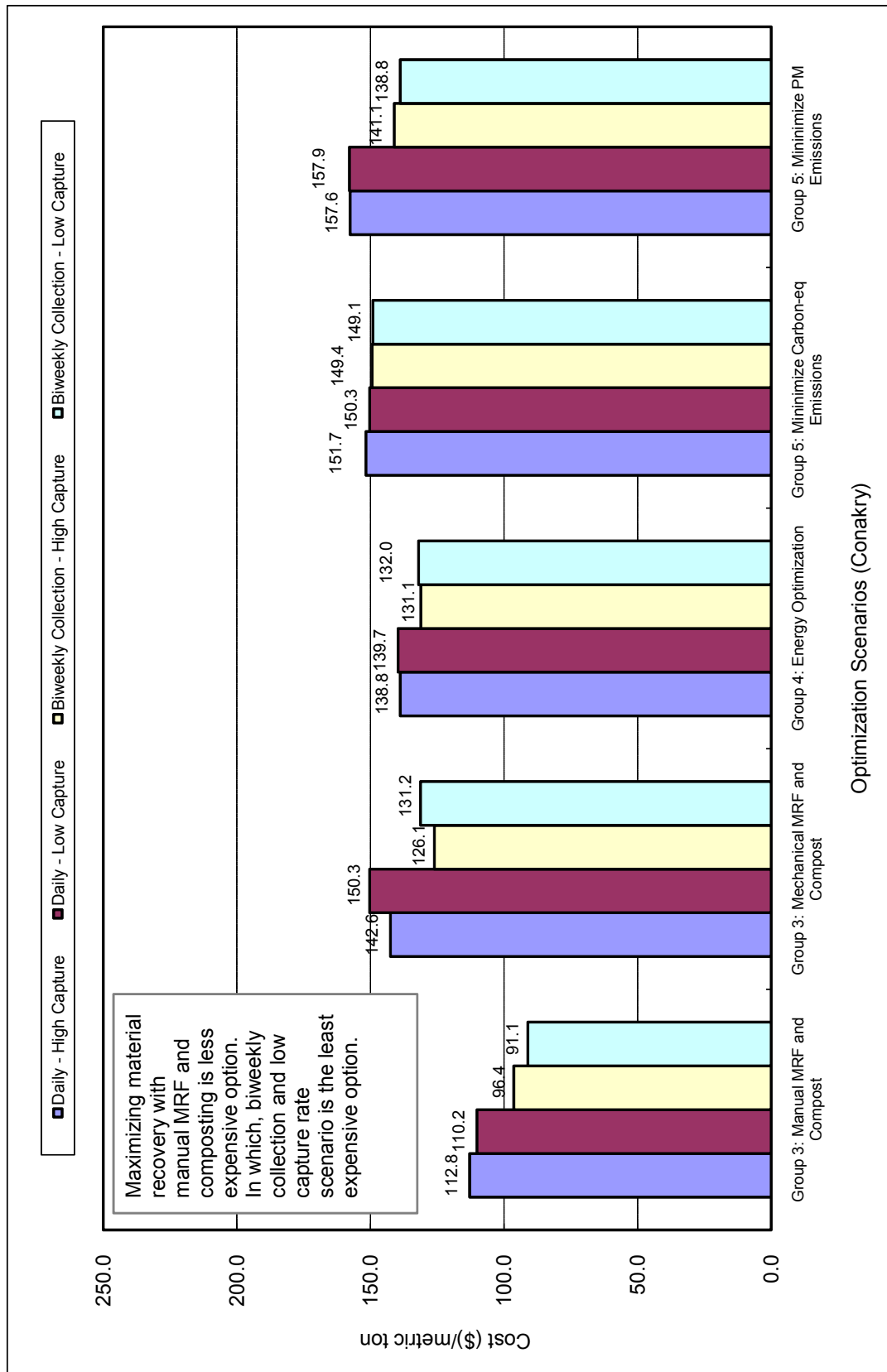


Figure 3.4-21 Cost Results of Optimizations Scenarios (Conakry: with Land Price)

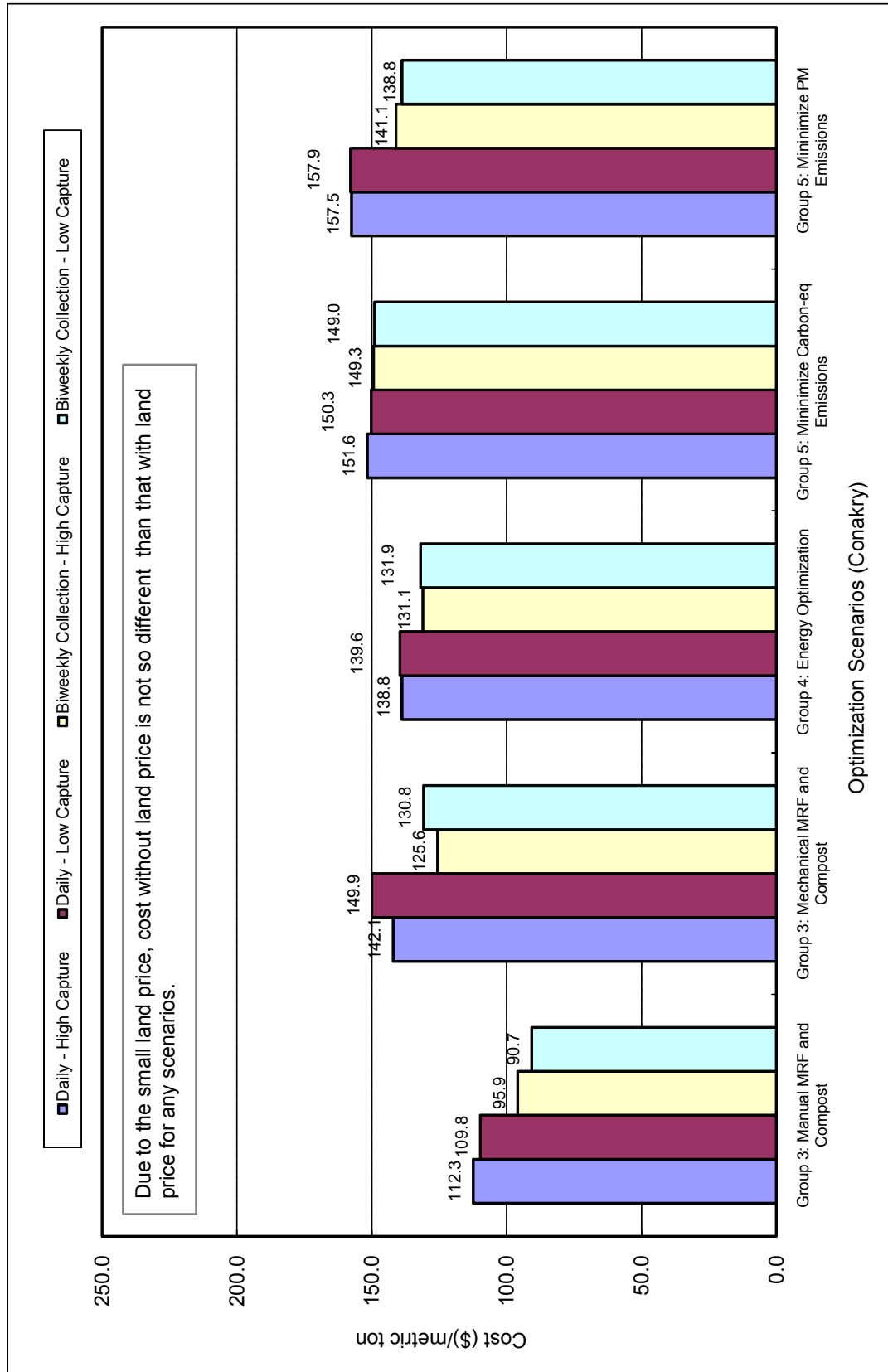


Figure 3.4-22 Cost Results of Optimizations Scenarios (Conakry: without Land Price)

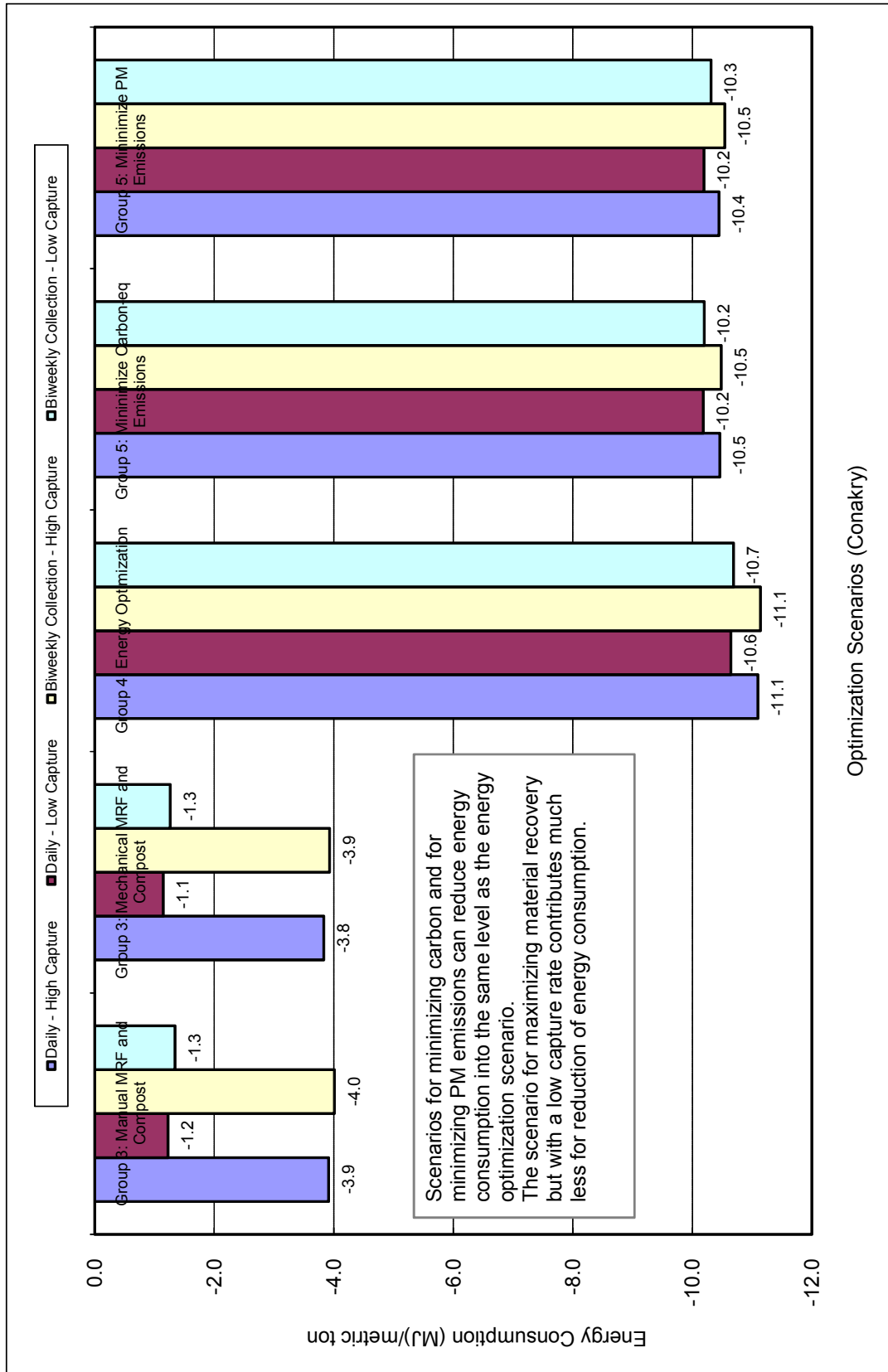


Figure 3.4-23 Energy Recovery Results of Optimizations Results (Conakry)

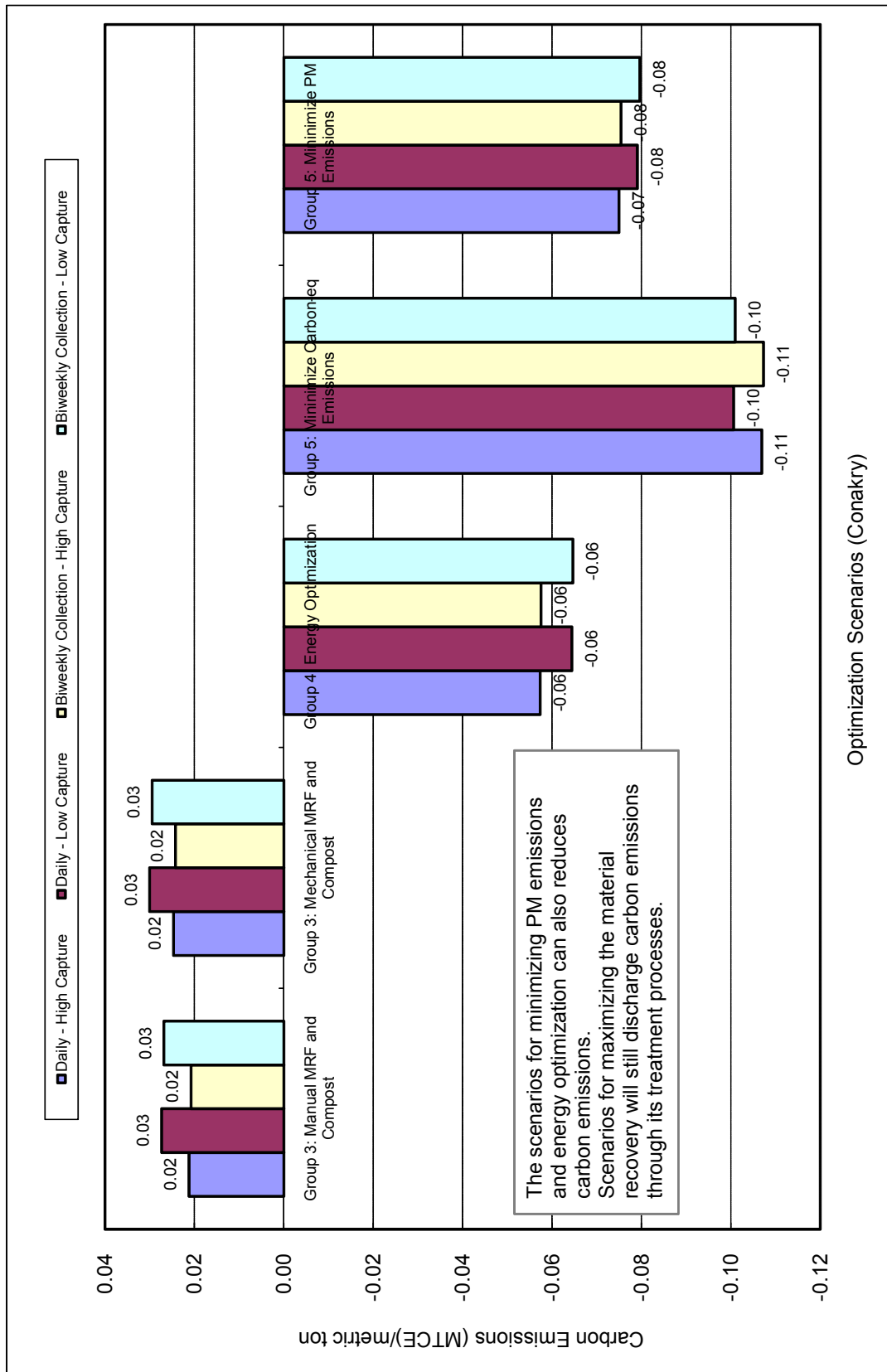


Figure 3.4-24 Carbon Emissions Results of Optimizations Results (Conakry)

3.4.4 Kathmandu

Summary of Simulation Scenarios

Costs Results

Figures 3.4-25 and 3.4-26 show the cost results of the simulation scenarios using one primary technology. The total unit cost per tonne-waste including collection cost (which is same for all options) for incineration is rather expensive than other options. The cheapest option is composting with manual turner because of the low treatment cost and reduction of waste to be buried at the landfill.

Energy Recovery Results

Figure 3.4-27 shows the energy recovery results. As is easily understood, adoption of incineration with energy recovery contributes greatly by saving energy. In addition, material recovery by recycling can also contribute large saving of energy consumption.

Carbon Emission Results

As Figure 3.4-28 shows, the carbon emission results show that the worst option can be said to be landfill with gas venting. Composting, irrespective of its operation method, can produce much less carbon emissions than others.

Summary of Optimization Scenarios

Costs Results

Figures 3.4-29 and 3.4-30 show the cost results of the optimization scenarios. It shows that the unit cost per tonne-waste is less expensive for the scenario which is maximizing material recovery with manual MRF and composting with manual turning, than other options. On the other hand, the cost for the scenario for minimizing carbon emissions is rather more expensive than others.

Energy Recovery Results

Figure 3.4-31 shows the energy recovery results. Needless to say, the energy optimization scenario achieves the lowest energy consumption, then the scenario for minimizing carbon emissions follows. It is interesting in Kathmandu that there is a big gap of energy consumption for all scenarios between the capture rate, high and low.

Carbon Emission Results

As Figure 3.4-32 shows, other than the scenario for minimizing carbon emissions, only the scenario for energy optimization will contribute to the reduction of carbon emissions. However, carbon emissions by the scenario for minimizing PM emissions will be much higher than others.

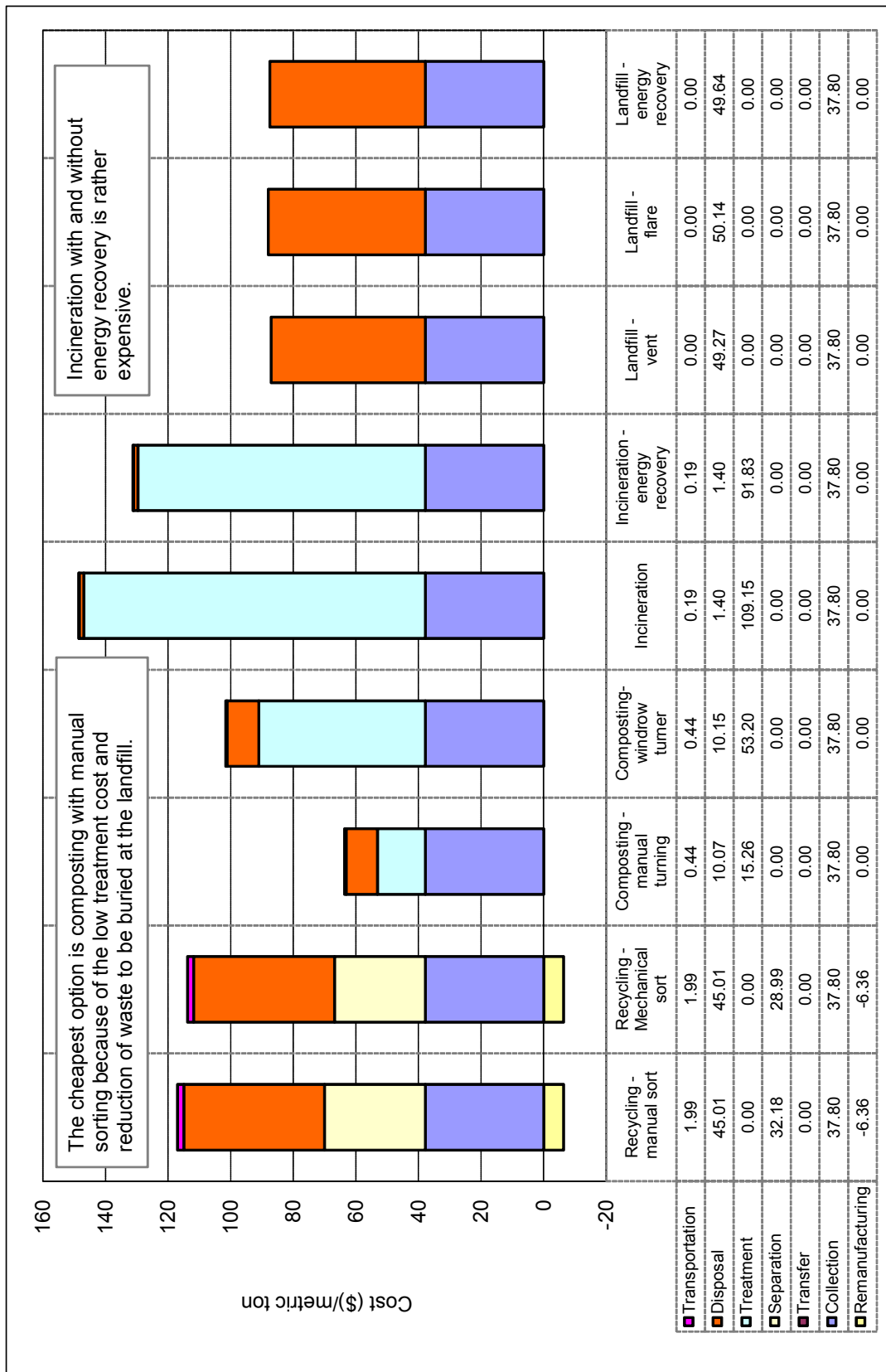


Figure 3.4-25 Cost Results of Simulation Scenarios (Kathmandu: with Land Price)

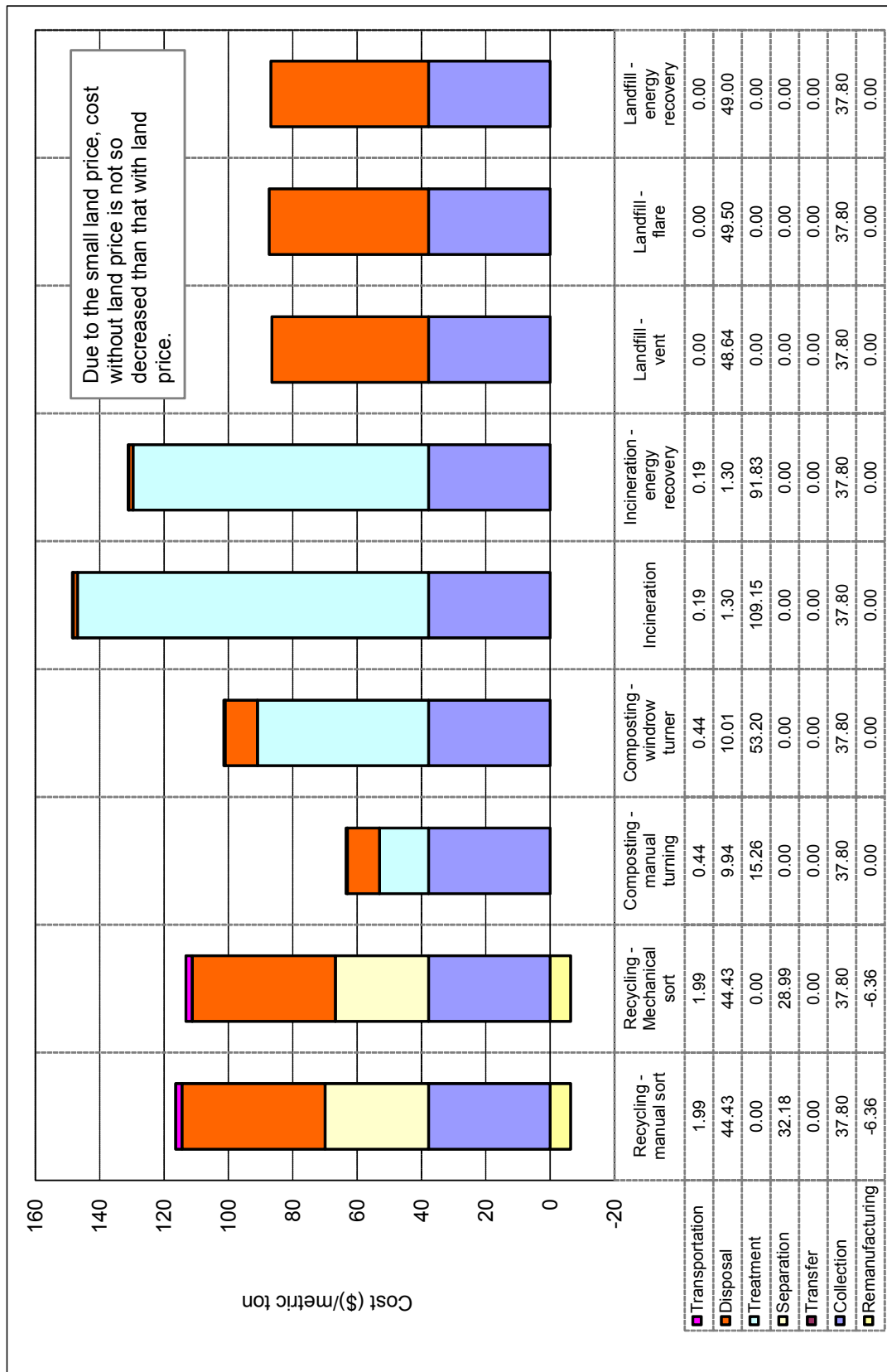


Figure 3.4-26 Cost Results of Simulation Scenarios (Kathmandu: without Land Price)

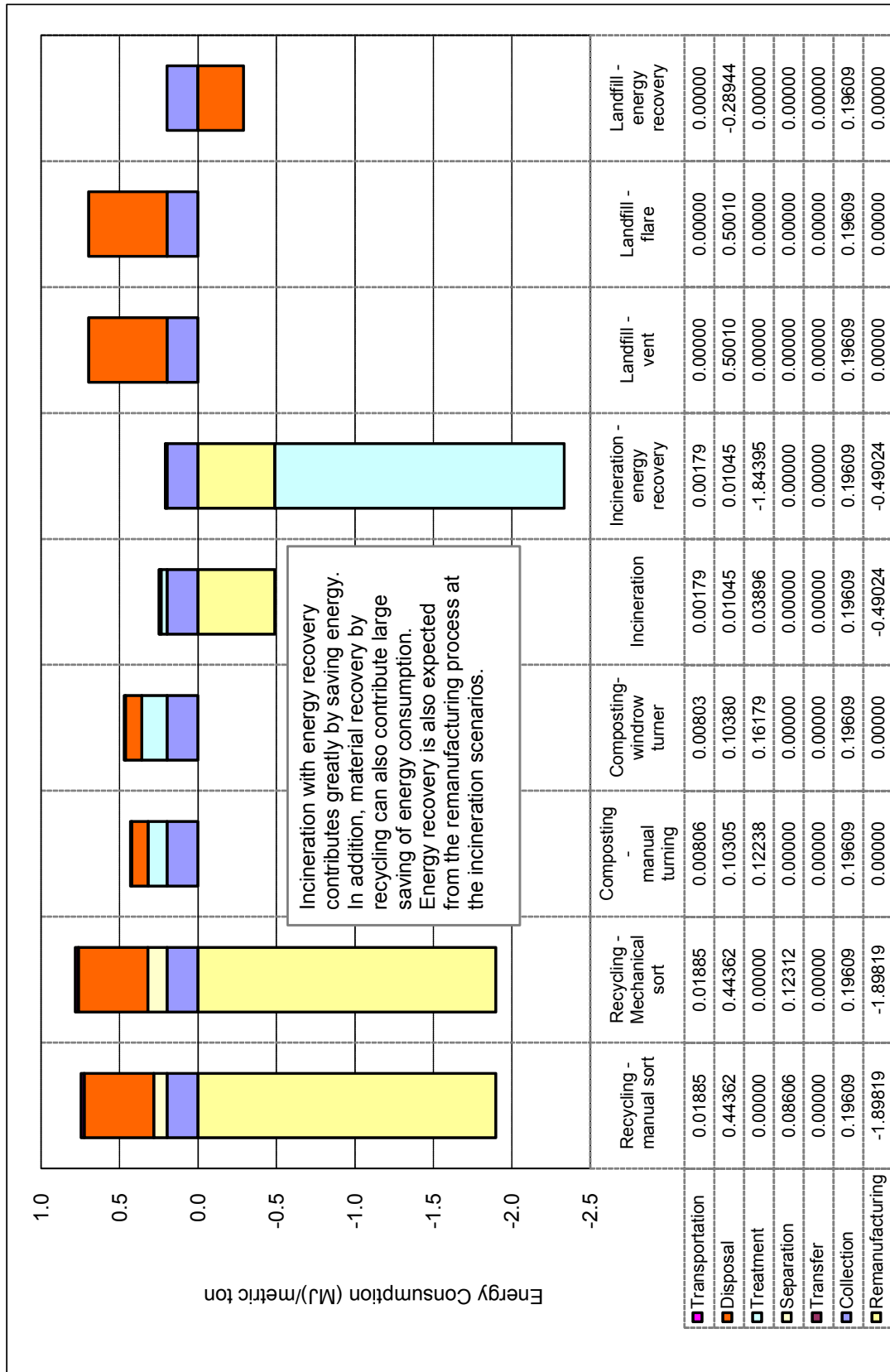


Figure 3.4-27 Energy Recovery Results of Simulation Scenarios (Kathmandu)

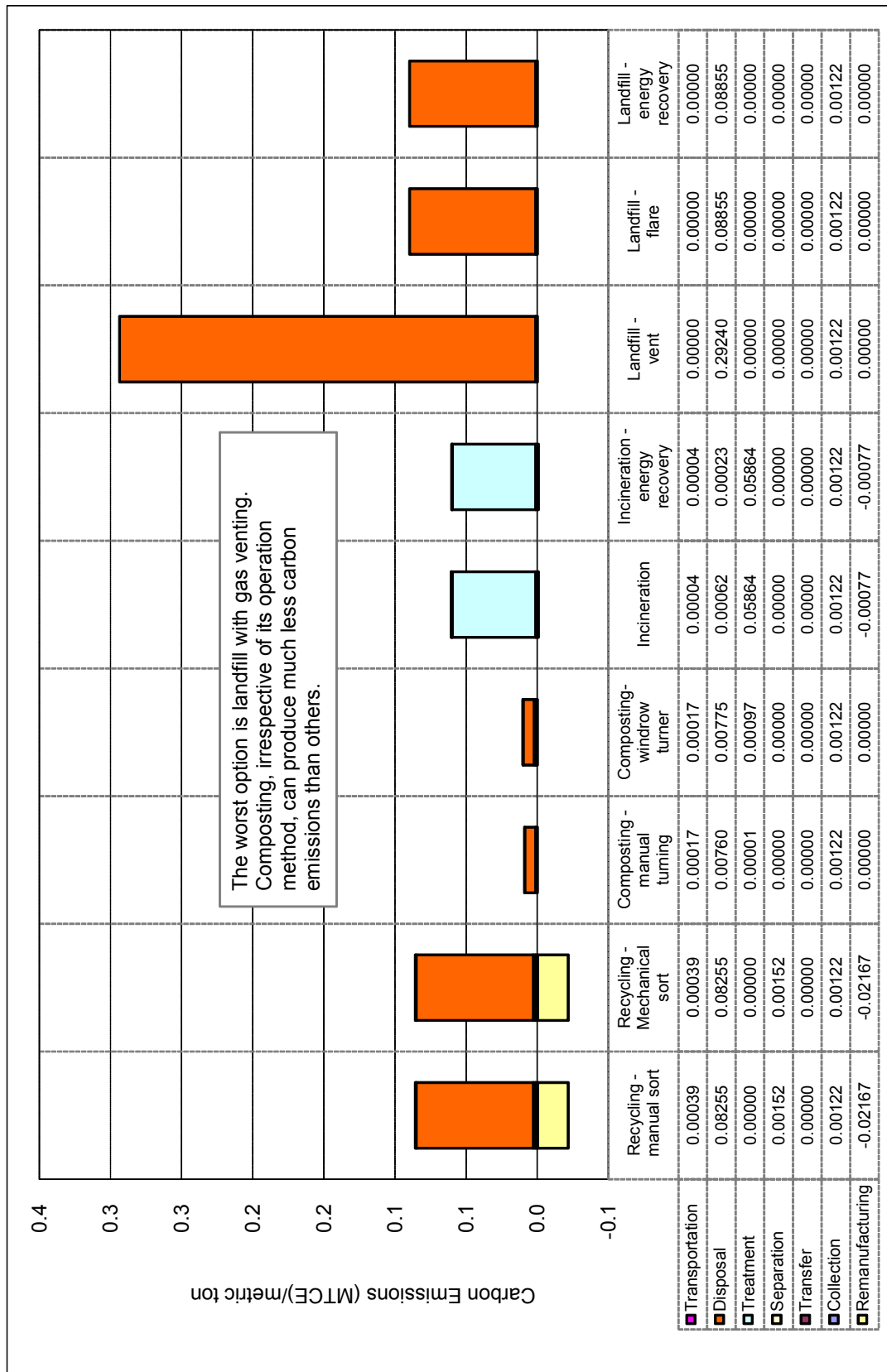


Figure 3.4-28 Carbon Emissions Results of Simulation Scenarios (Kathmandu)

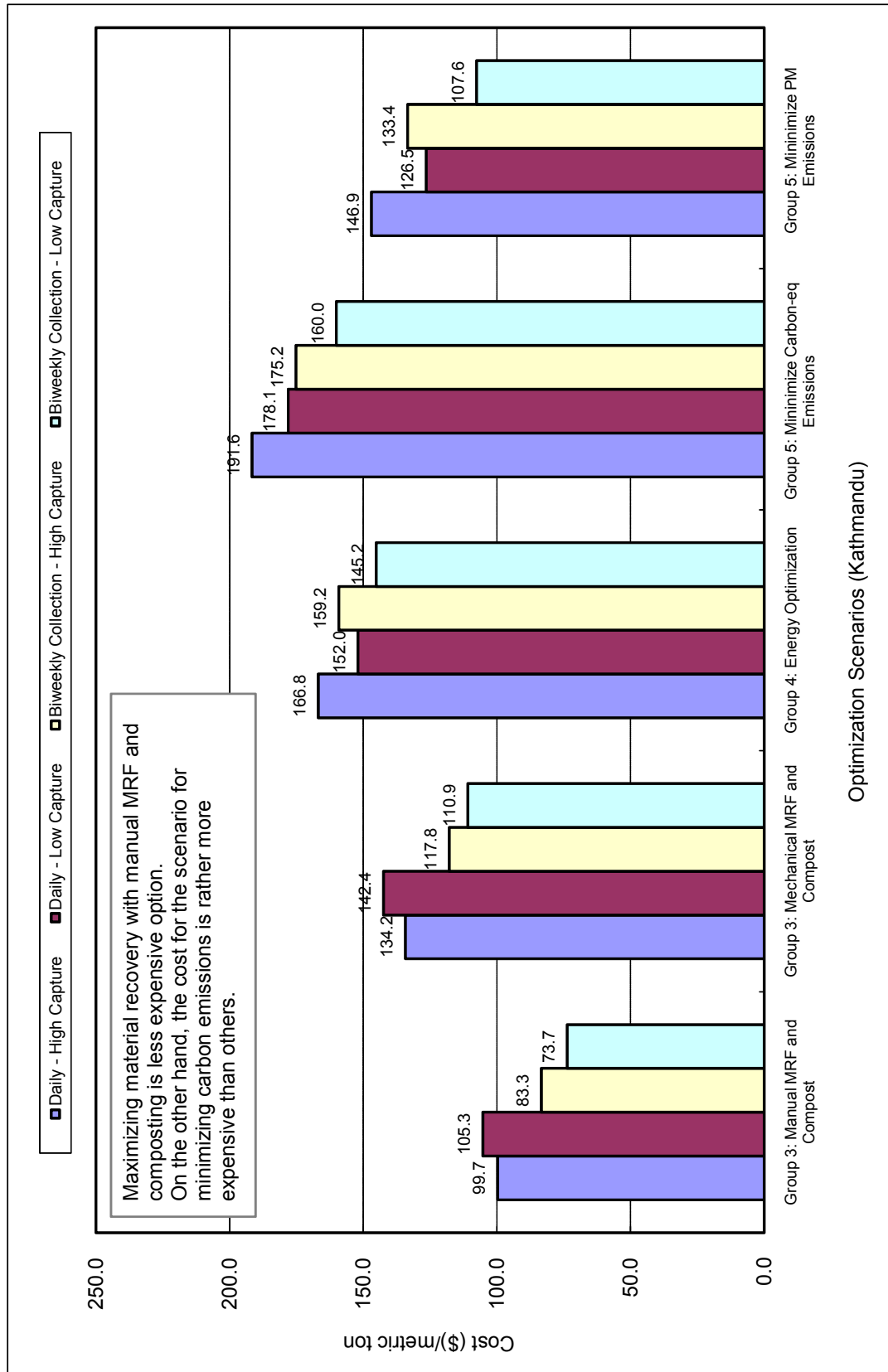


Figure 3.4-29 Cost Results of Optimizations Scenarios (Kathmandu: with Land Price)

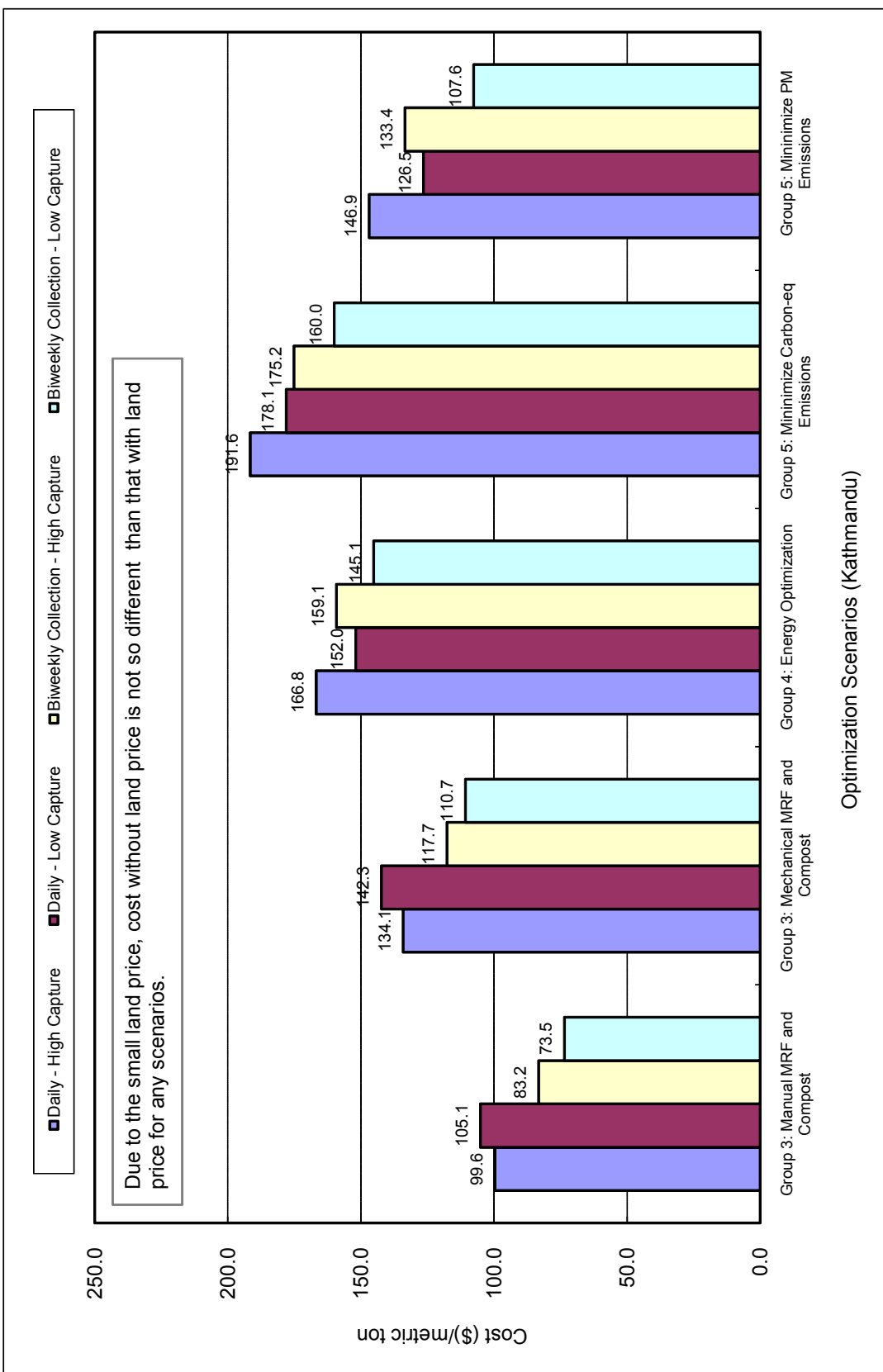


Figure 3.4-30 Cost Results of Optimizations Scenarios (Kathmandu: without Land Price)

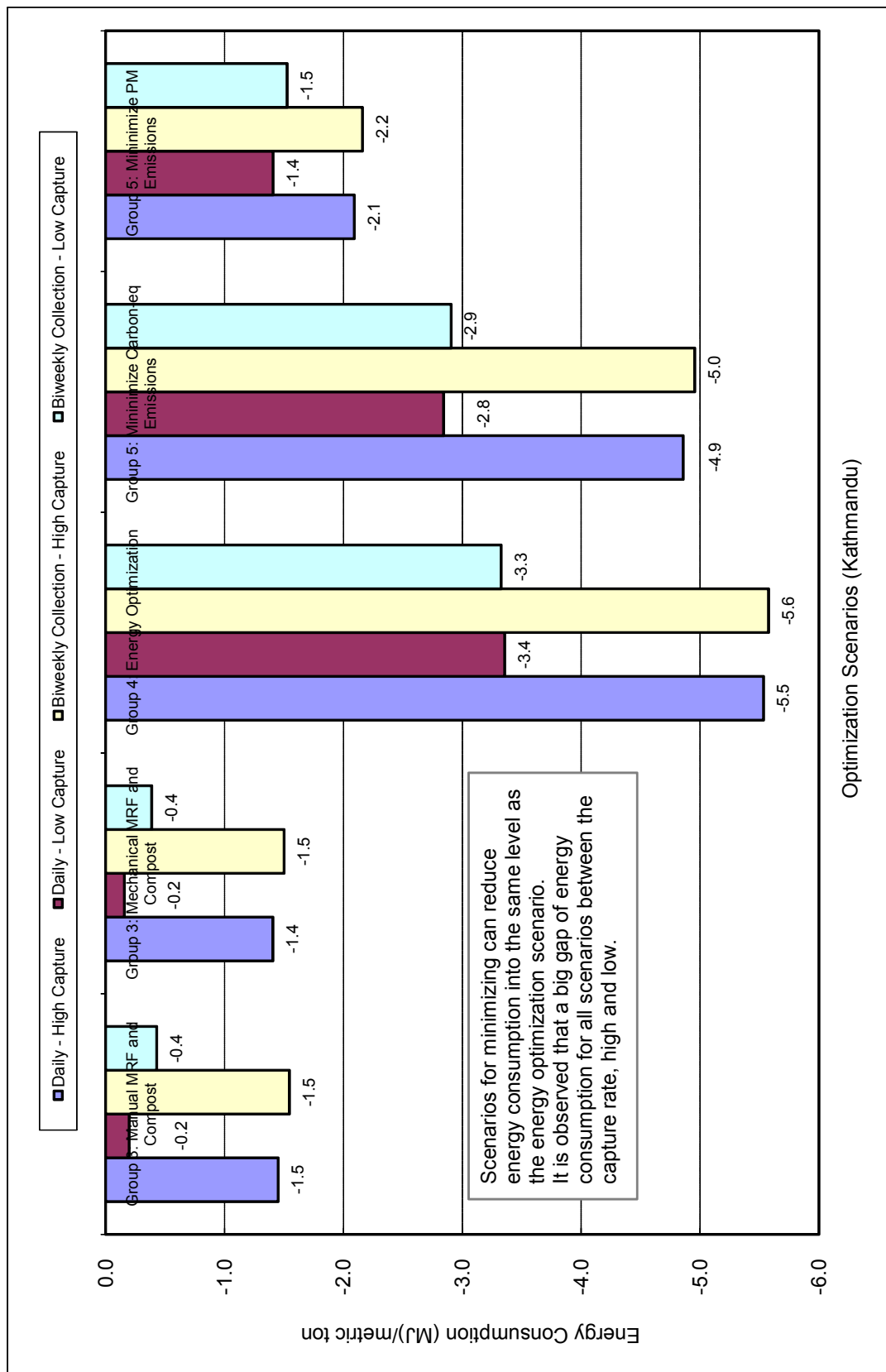


Figure 3.4-31 Energy Recovery Results of Optimizations Results (Kathmandu)

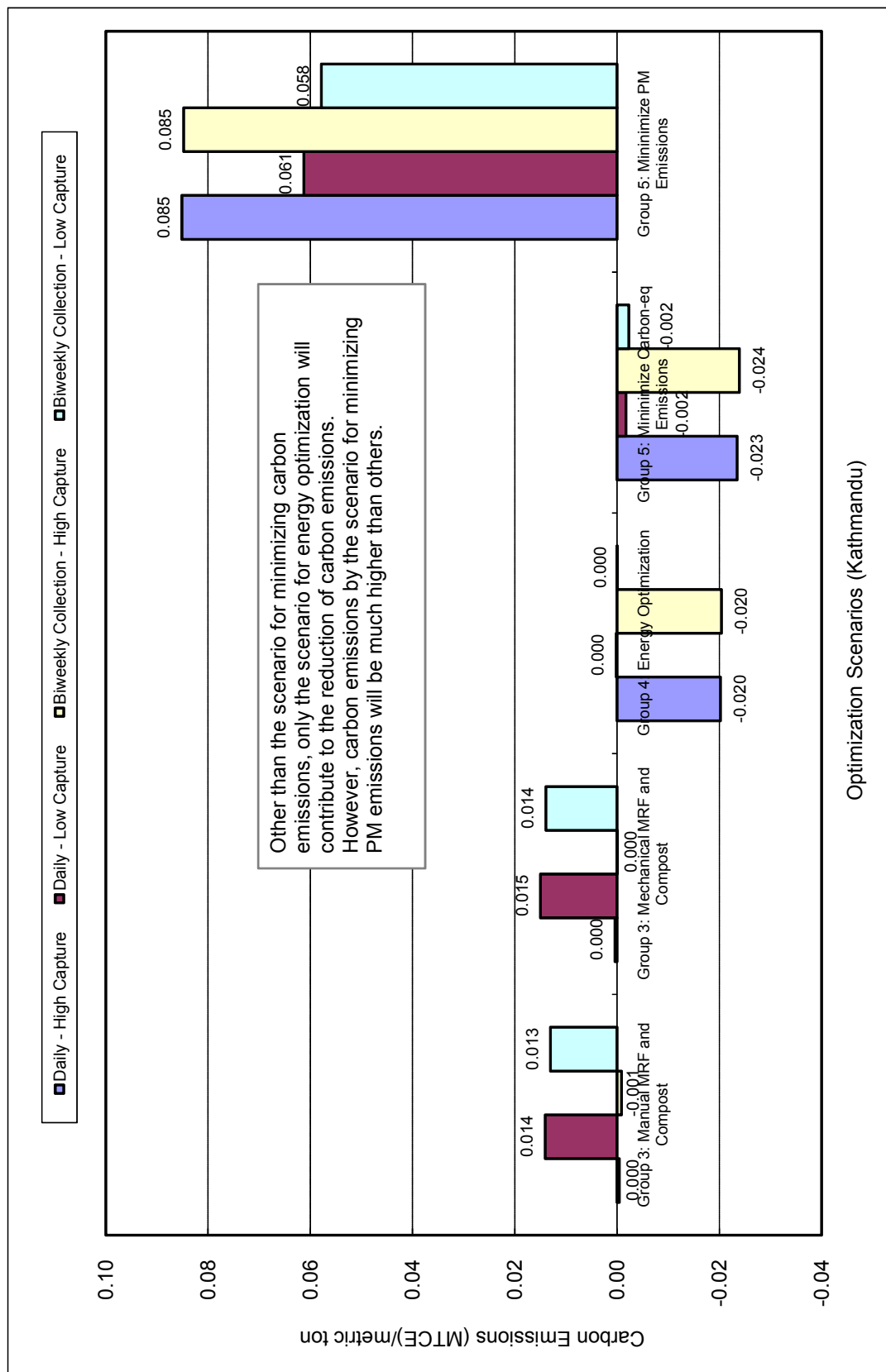


Figure 3.4-32 Carbon Emissions Results of Optimizations Results (Kathmandu)

3.4.5 Lahore

Summary of Simulation Scenarios

Costs Results

Figures 3.4-33 and 3.4-34 show the cost results of the simulation scenarios using one primary technology. The total unit cost per tonne-waste including collection cost (which is same for all options) for incineration only is most expensive than that for incineration with energy recovery follows. Direct landfill is the least expensive options than any other options with intermediate treatment.

Energy Recovery Results

Figure 3.4-35 shows the energy recovery results. As is easily understood, adoption of incineration with energy recovery contributes greatly by saving energy. Greater energy recovery can be also expected by material recovery scenarios with both manual and mechanical operation.

Carbon Emission Results

As Figure 3.4-36 shows, the carbon emission results show that the worst option can be said to be landfill with gas venting. Incineration with energy recovery produces least carbon emissions.

Summary of Optimization Scenarios

Costs Results

Figures 3.4-37 and 3.4-38 show the cost results of the optimization scenarios. It shows that the unit cost per tonne-waste is less expensive for the scenario which is maximizing material recovery with manual MRF and composting with manual turning, than other options. On the other hand, the cost for the scenario for minimizing carbon emissions and PM emissions is rather more expensive than others.

Energy Recovery Results

Figure 3.4-39 shows the energy recovery results. Scenarios for minimizing carbon and for minimizing PM emissions can reduce energy consumption into the same level as the energy optimization scenario.

Carbon Emission Results

As Figure 3.4-40 shows, as well as the scenario for minimizing carbon emissions, the scenario for minimizing PM emissions can also largely reduces carbon emissions. Scenarios for energy optimization will also contribute to the reduction of carbon emissions but those for maximizing material recovery still show the positive carbon emissions.

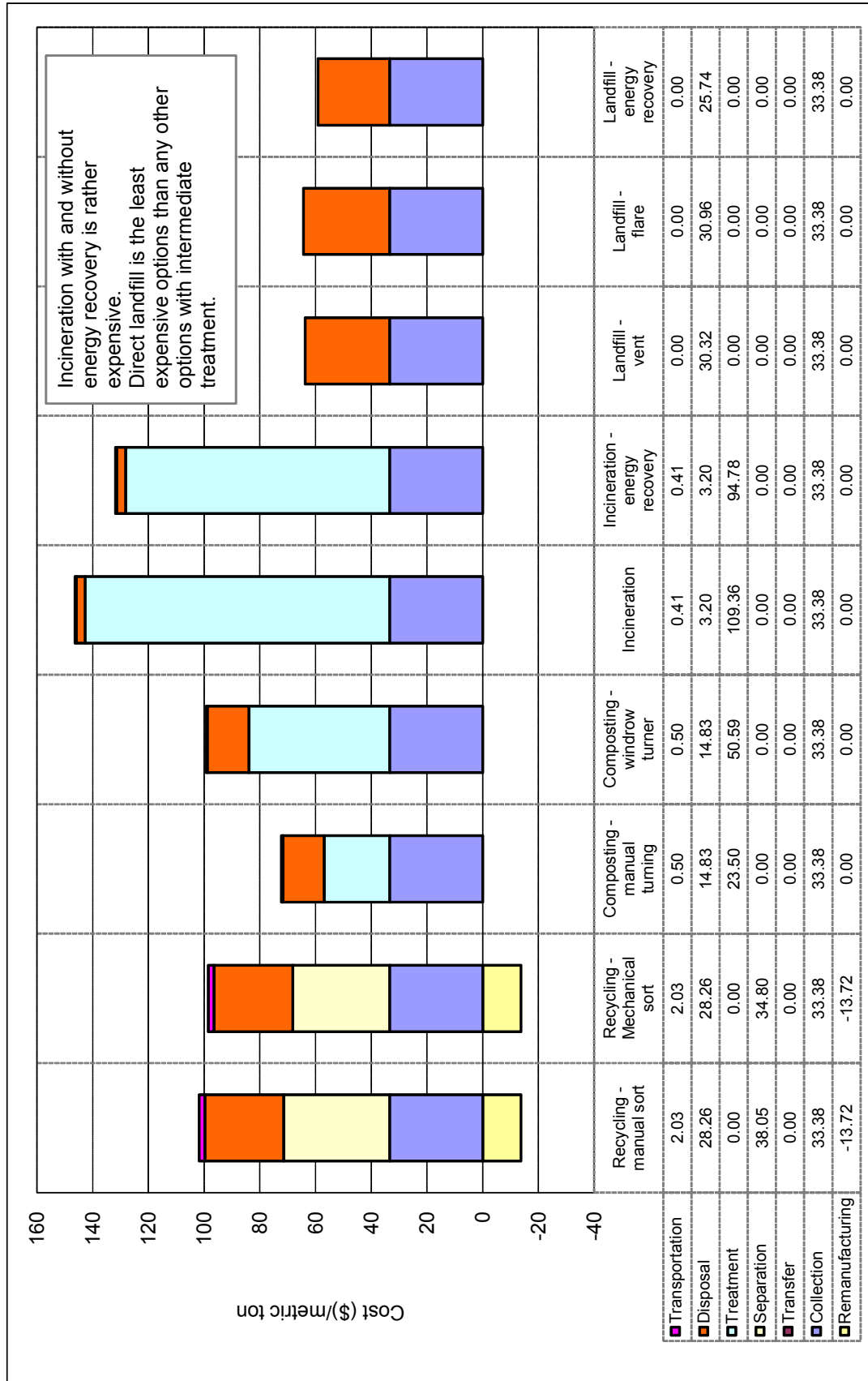


Figure 3.4-33 Cost Results of Simulation Scenarios (Lahore: with Land Price)

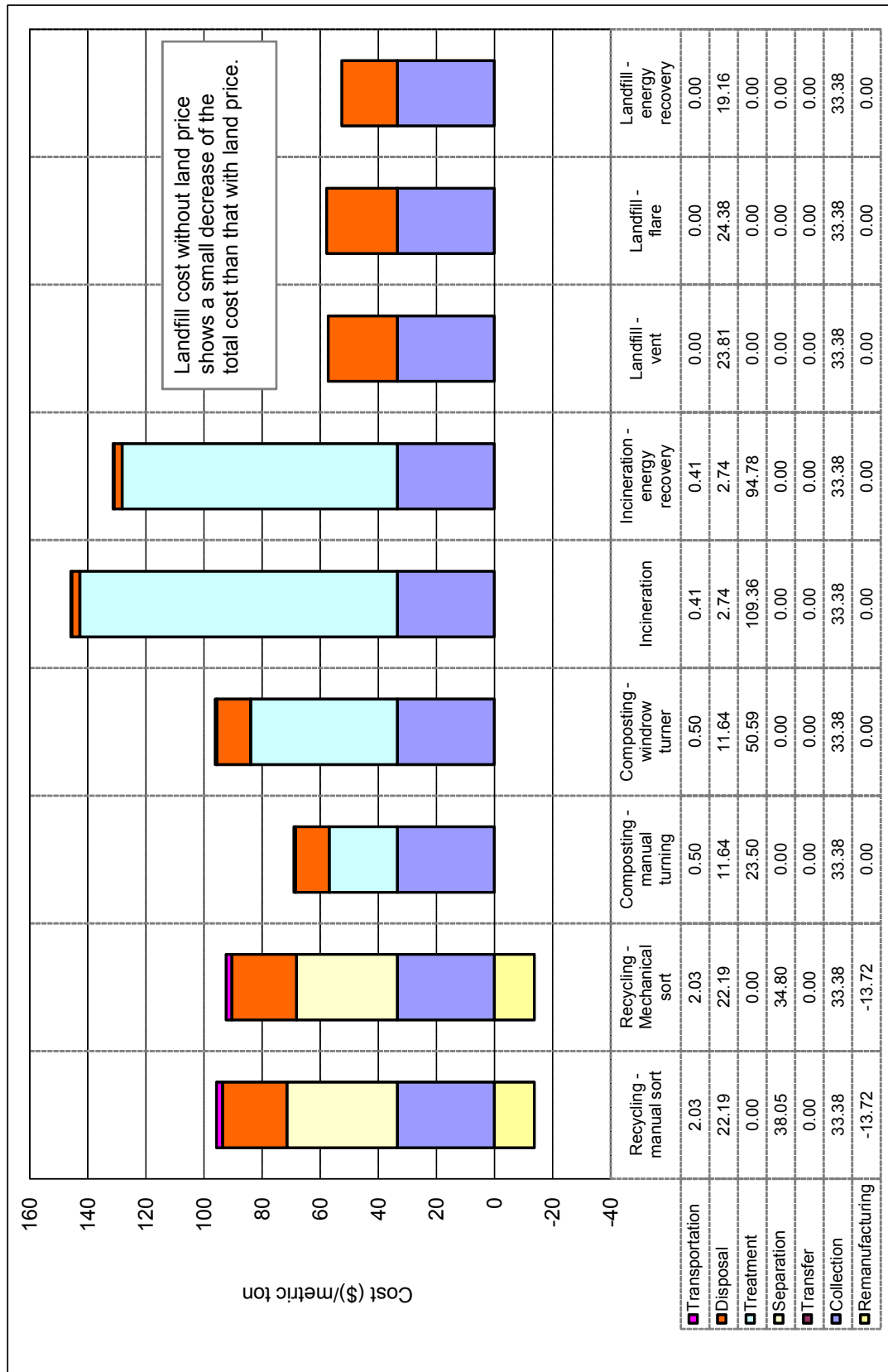


Figure 3.4-34 Cost Results of Simulation Scenarios (Lahore: without Land Price)

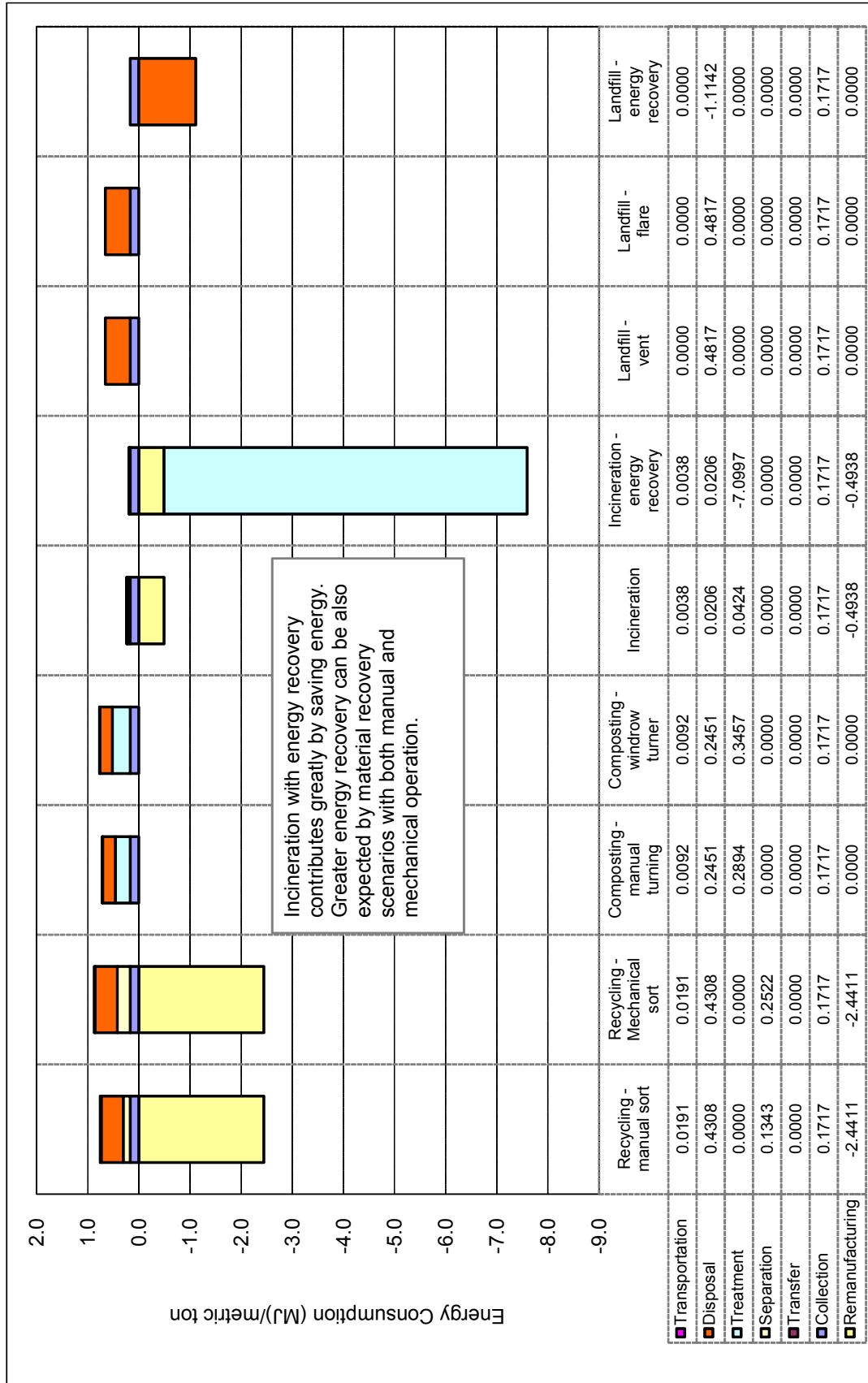


Figure 3.4-35 Energy Recovery Results of Simulation Scenarios (Lahore)

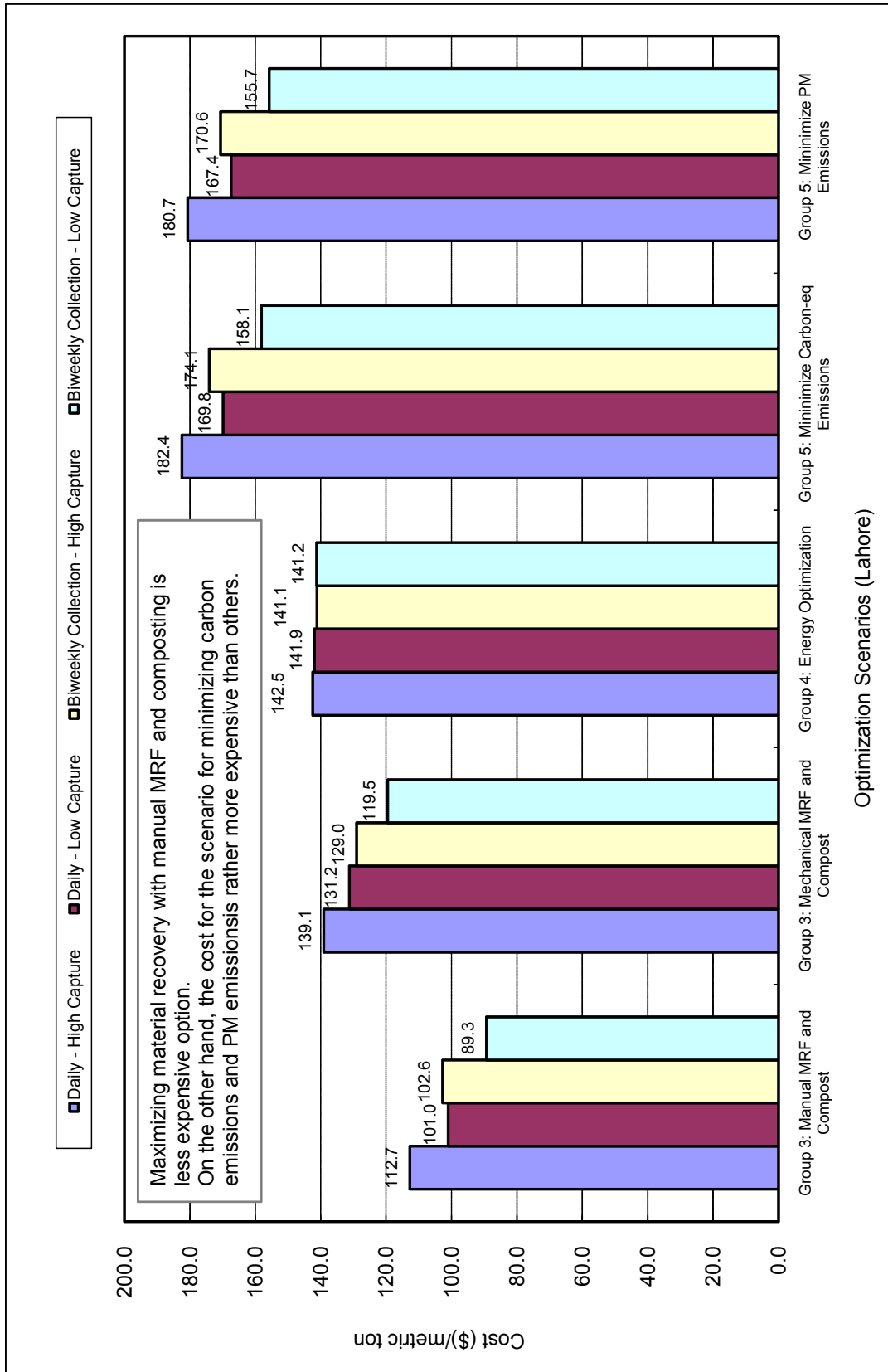


Figure 3.4-37 Cost Results of Optimizations Scenarios (Lahore: with Land Price)

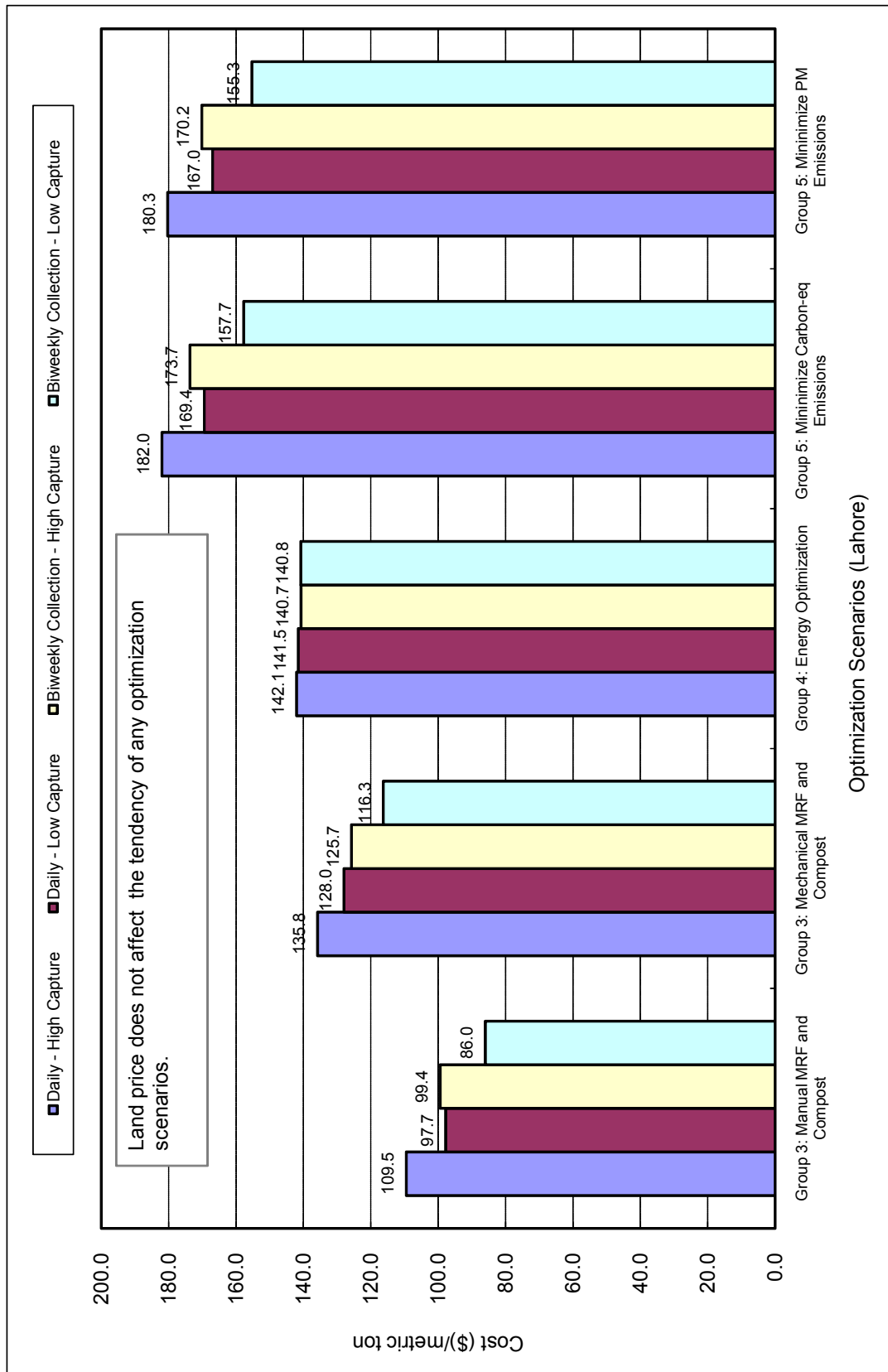


Figure 3.4-38 Cost Results of Optimizations Scenarios (Lahore: without Land Price)

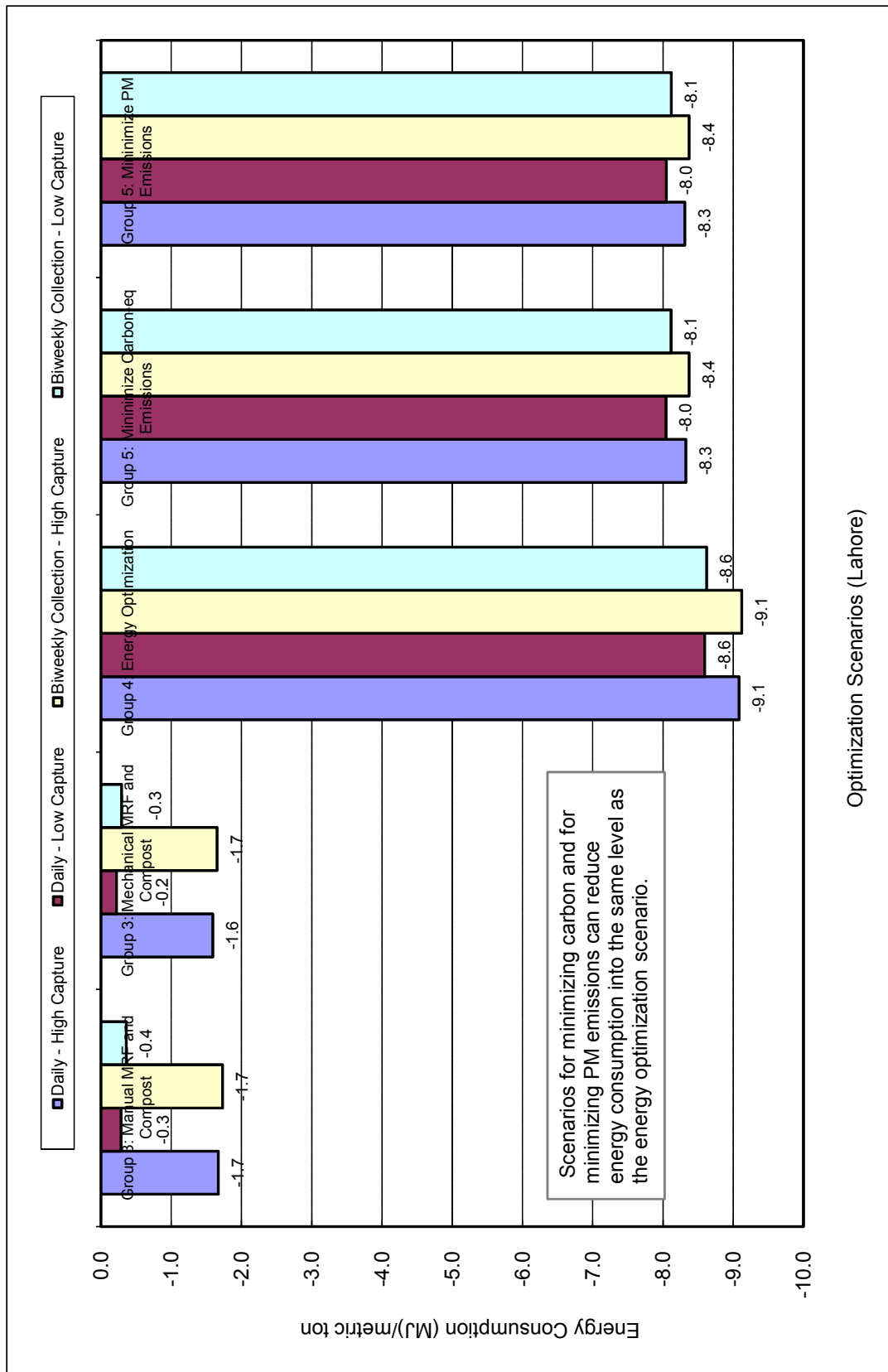


Figure 3.4-39 Energy Recovery Results of Optimizations Results (Lahore)

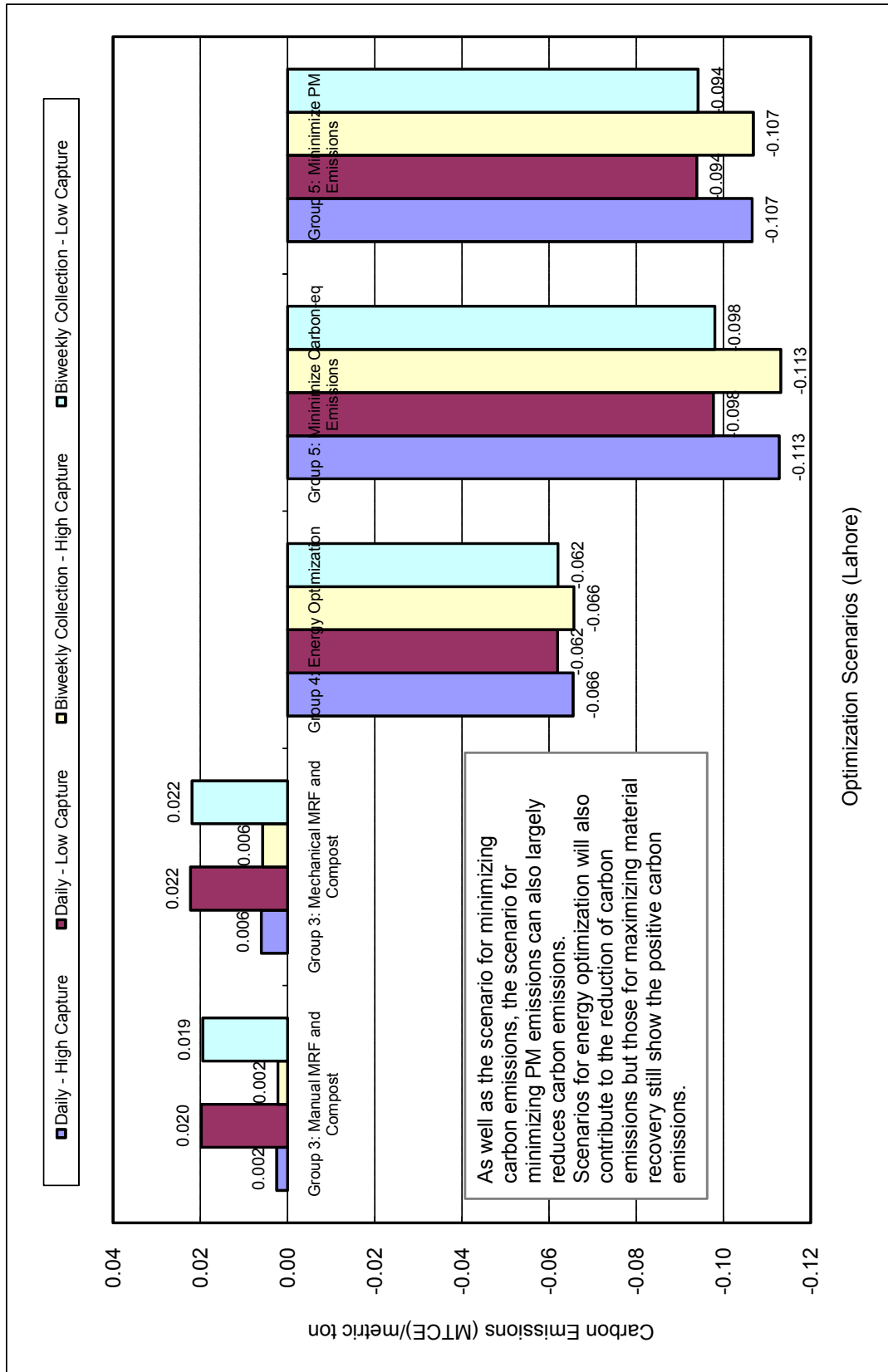


Figure 3.4-40 Carbon Emissions Results of Optimizations Results (Lahore)

3.4.6 Sarajevo

Summary of Simulation Scenarios

Costs Results

Figures 3.4-41 and 3.4-42 show the cost results of the simulation scenarios using one primary technology. Since the total unit cost per tonne-waste for incineration with and without energy recovery is rather expensive. Other options except composting with windrow turner are ranked as less expensive options. The cheapest option is landfill with energy recovery.

Energy Recovery Results

Figure 3.4-43 shows the energy recovery results. As is easily understood, adoption of incineration with energy recovery contributes greatly by saving energy. Greater energy recovery can be also expected by material recovery scenarios with both manual and mechanical operation and by landfill with energy recovery.

Carbon Emission Results

As Figure 3.4-44 shows, the carbon emission results show that the worst option can be said to be landfill with gas venting as well as most of other cities. Scenarios for composting with both manual and mechanical turning produce less carbon emissions.

Summary of Optimization Scenarios

Costs Results

Figures 3.4-45 and 3.4-46 show the cost results of the optimization scenarios. It shows that the unit cost per tonne-waste is less expensive for the scenario which is maximizing material recovery with manual MRF and composting with manual turning, than other options.

Energy Recovery Results

Figure 3.4-47 shows the energy recovery results. Scenarios for minimizing carbon and for minimizing PM emissions can reduce energy consumption into the almost same level as the energy optimization scenario. Material recovery with high capture rate can also save energy consumption more than low capture rate.

Carbon Emission Results

As Figure 3.4-48 shows, as well as the scenario for minimizing carbon emissions, the scenarios for minimizing PM emissions and energy optimization can also reduce carbon emissions. Scenarios for maximizing the material recovery will still discharge carbon emissions through its treatment processes.

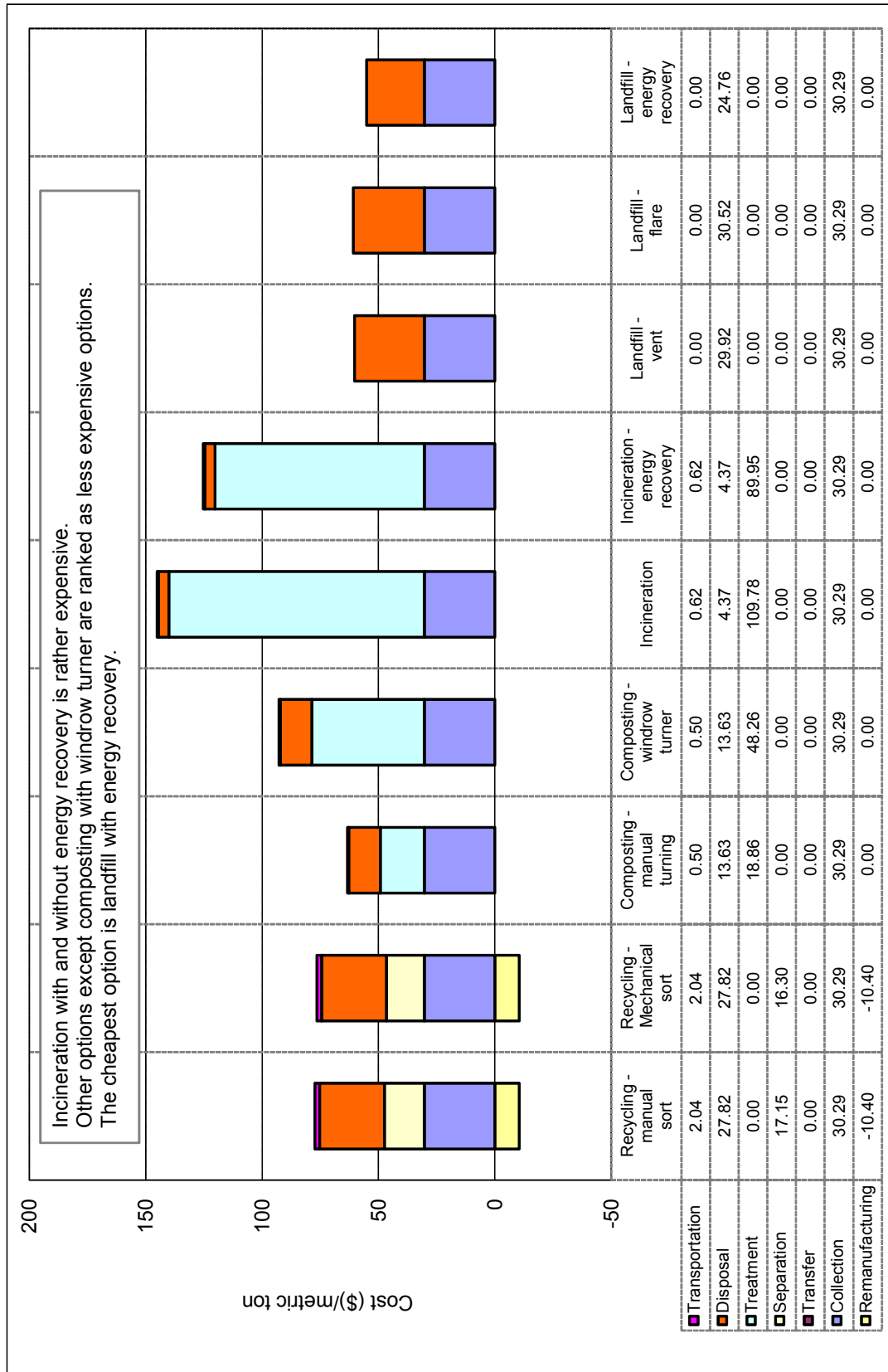


Figure 3.4-41 Cost Results of Simulation Scenarios (Sarajevo: with Land Price)

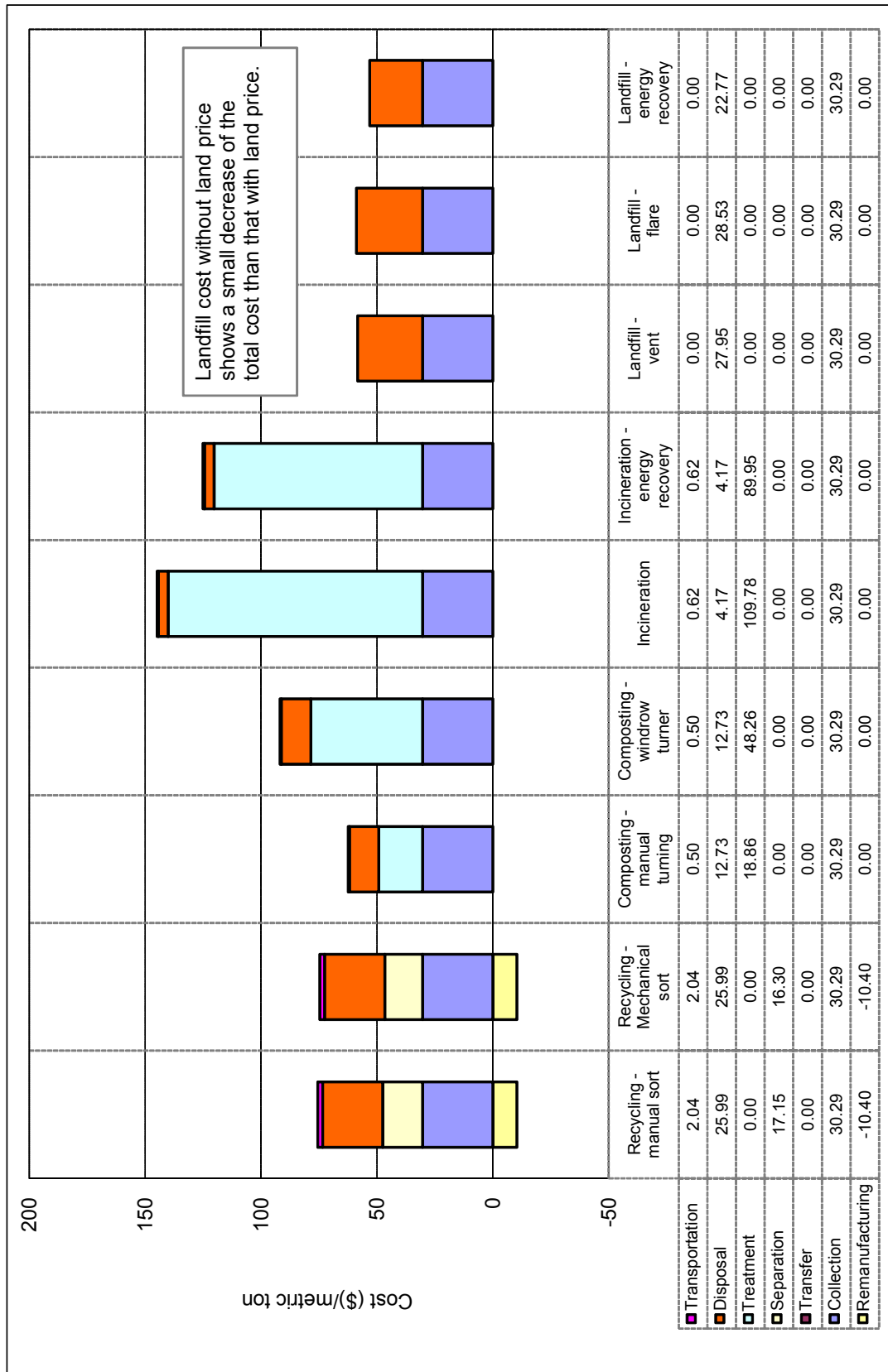


Figure 3.4-42 Cost Results of Simulation Scenarios (Sarajevo: without Land Price)

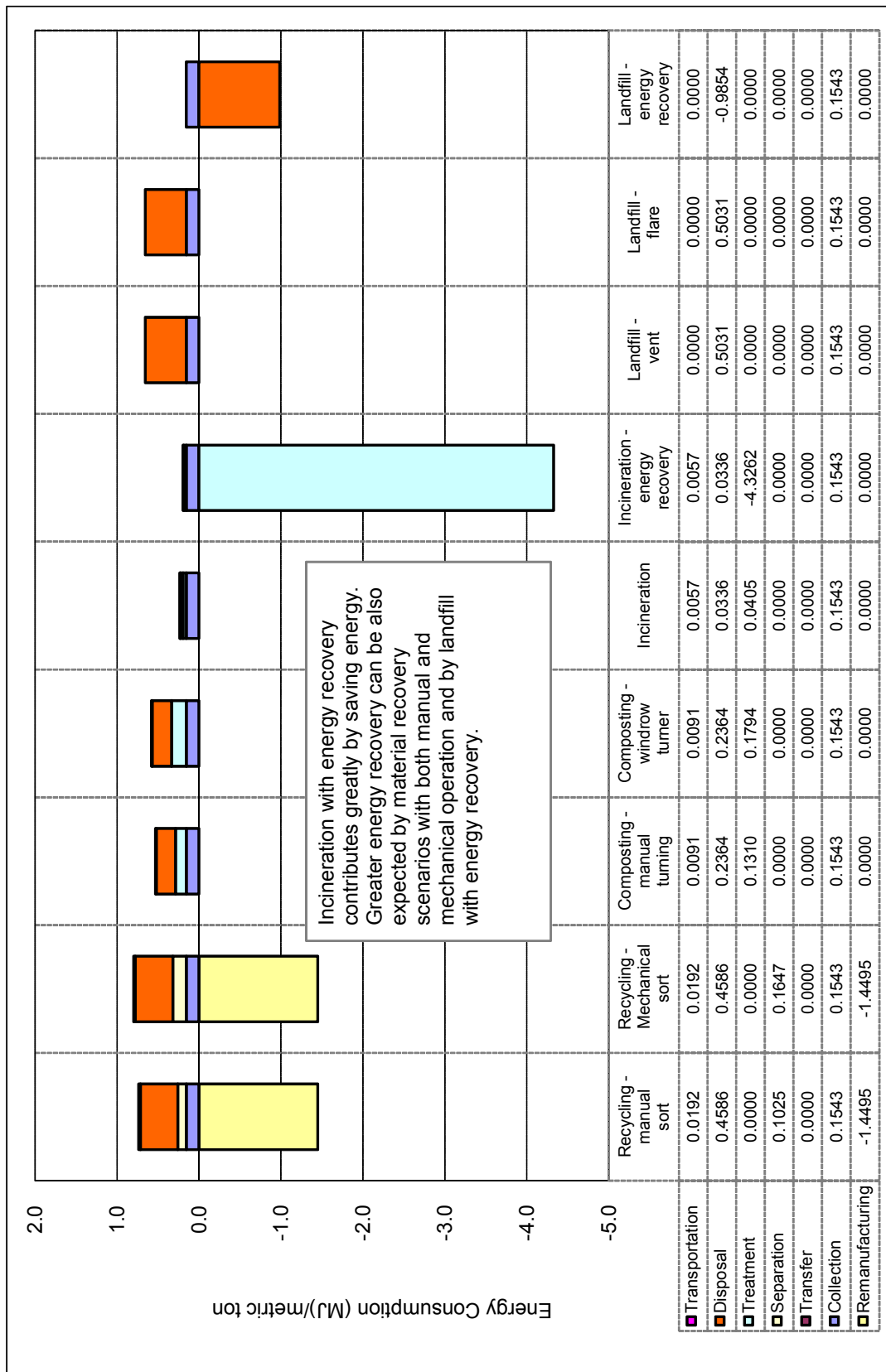


Figure 3.4-43 Energy Recovery Results of Simulation Scenarios (Sarajevo)

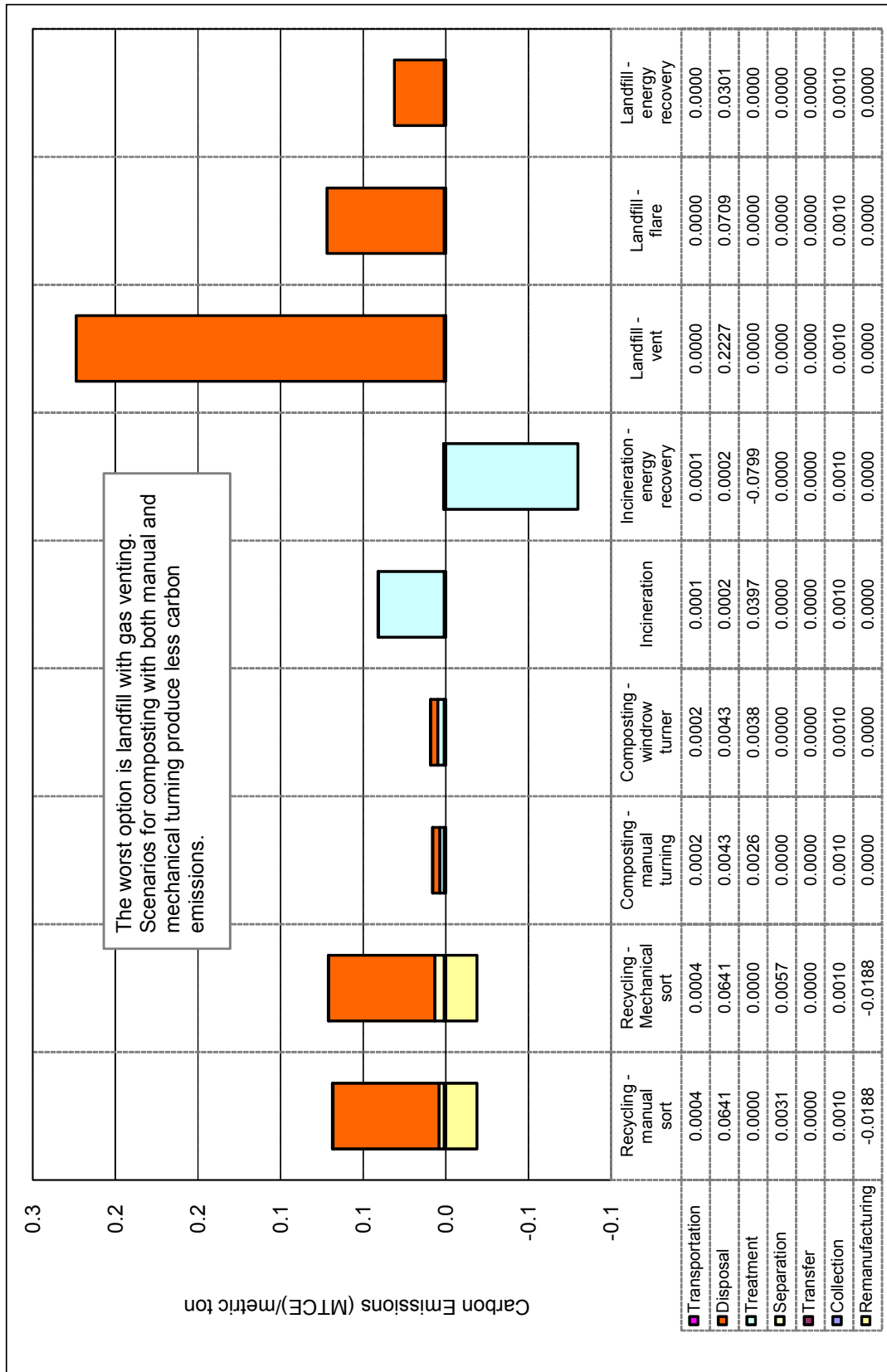


Figure 3.4-44 Carbon Emissions Results of Simulation Scenarios (Sarajevo)

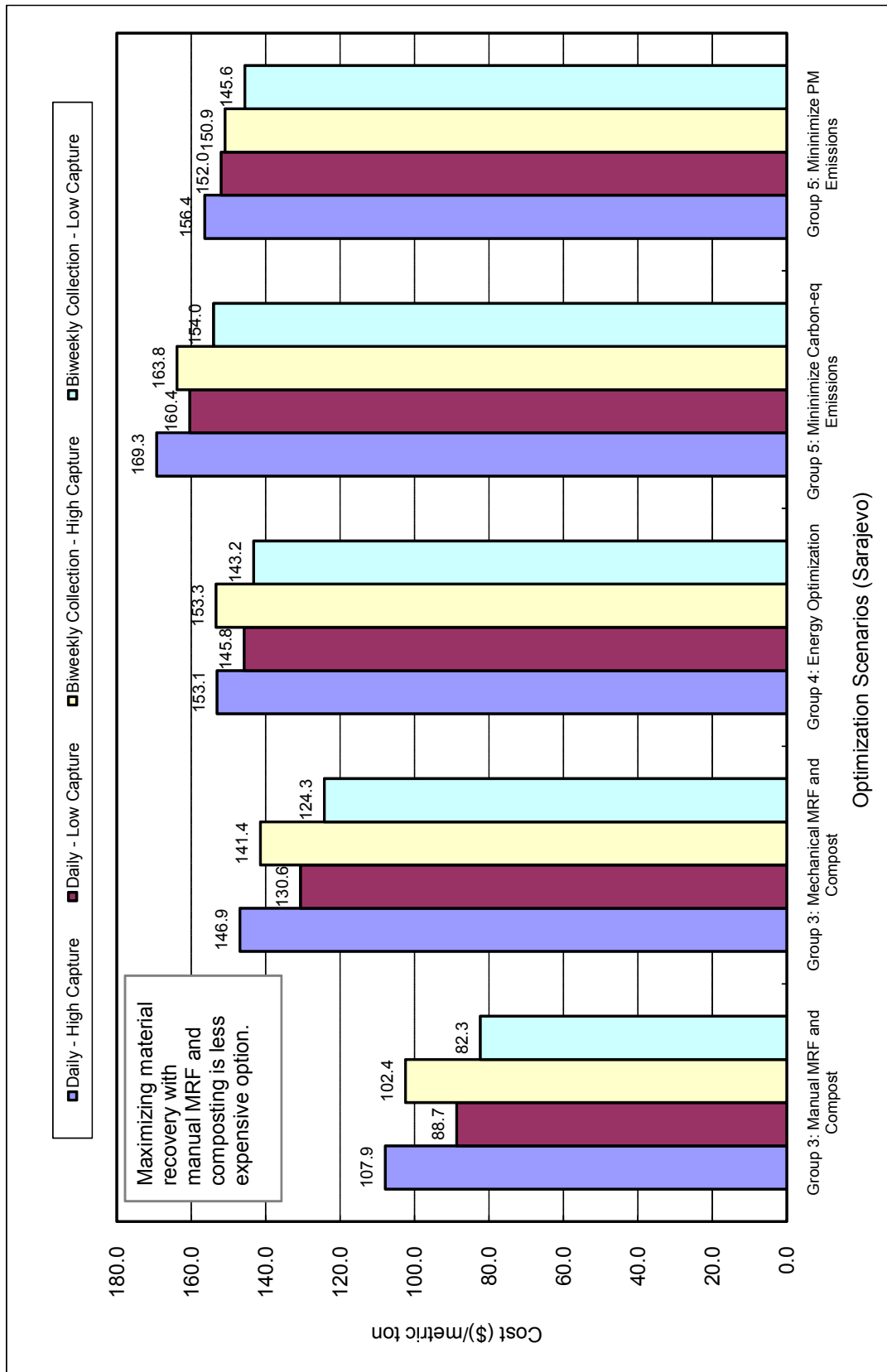


Figure 3.4-45 Cost Results of Optimizations Scenarios (Sarajevo: with Land Price)

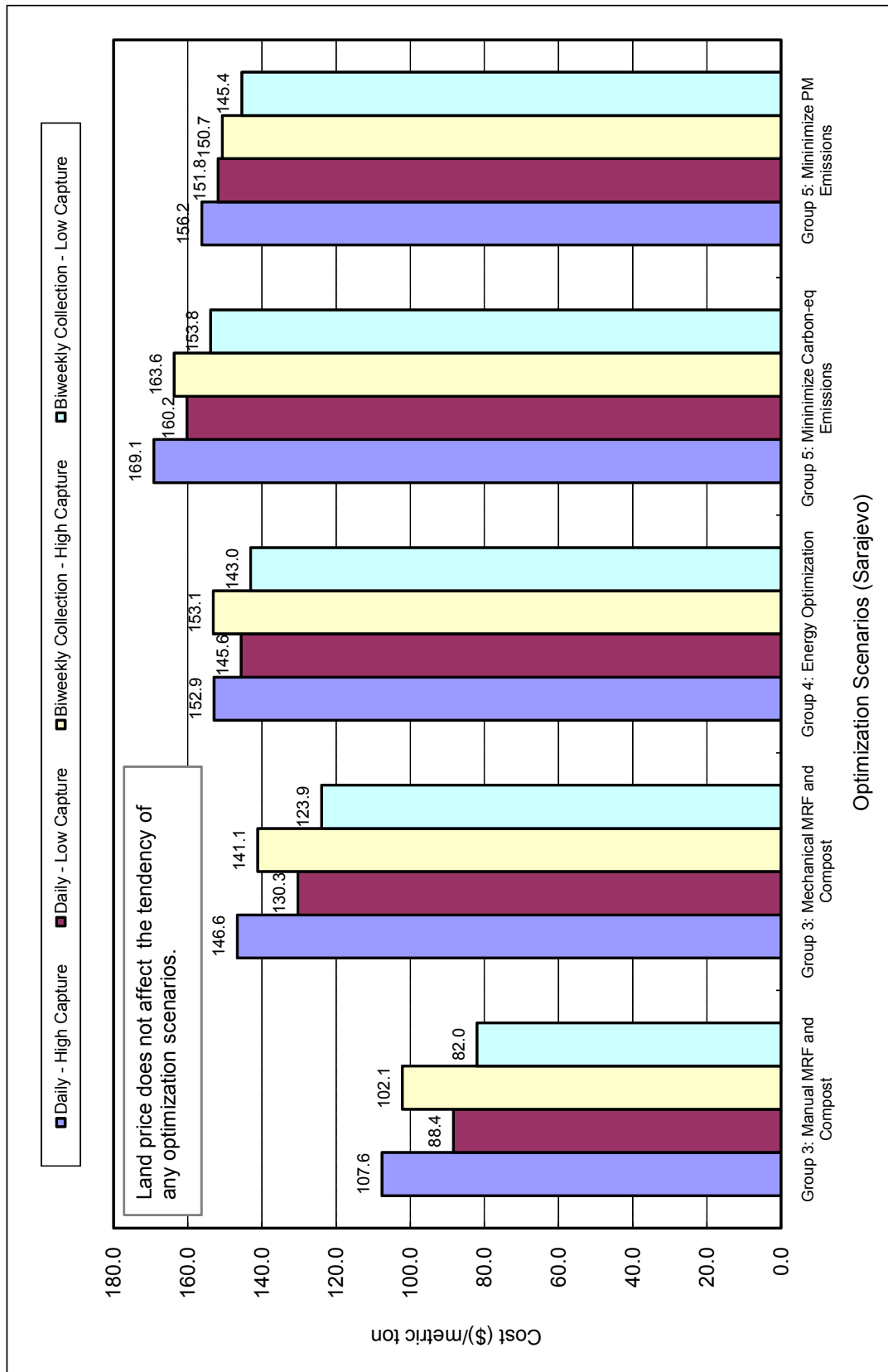


Figure 3.4-46 Cost Results of Optimizations Scenarios (Sarajevo: without Land Price)

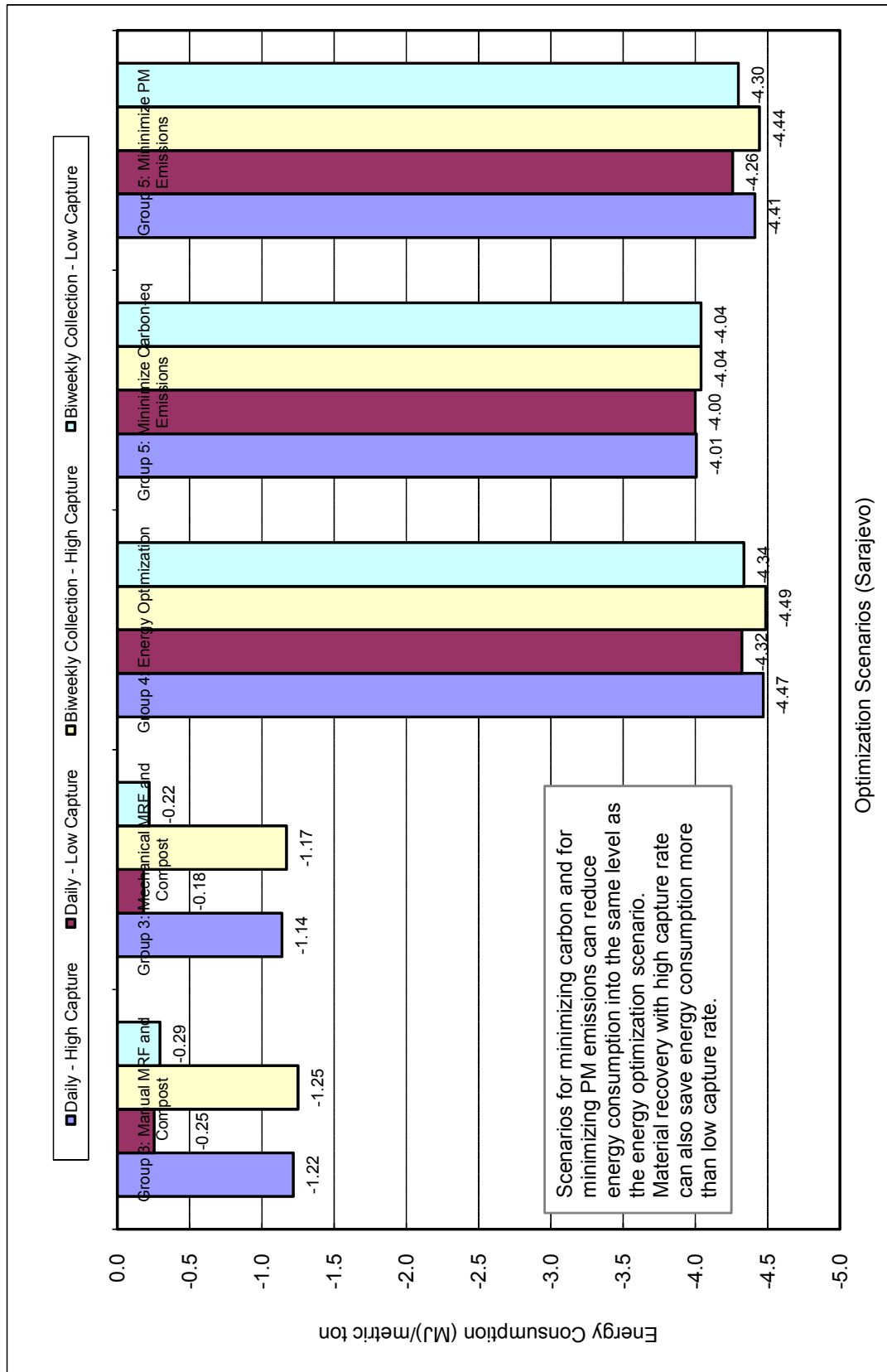


Figure 3.4-47 Energy Recovery Results of Optimizations Results (Sarajevo)

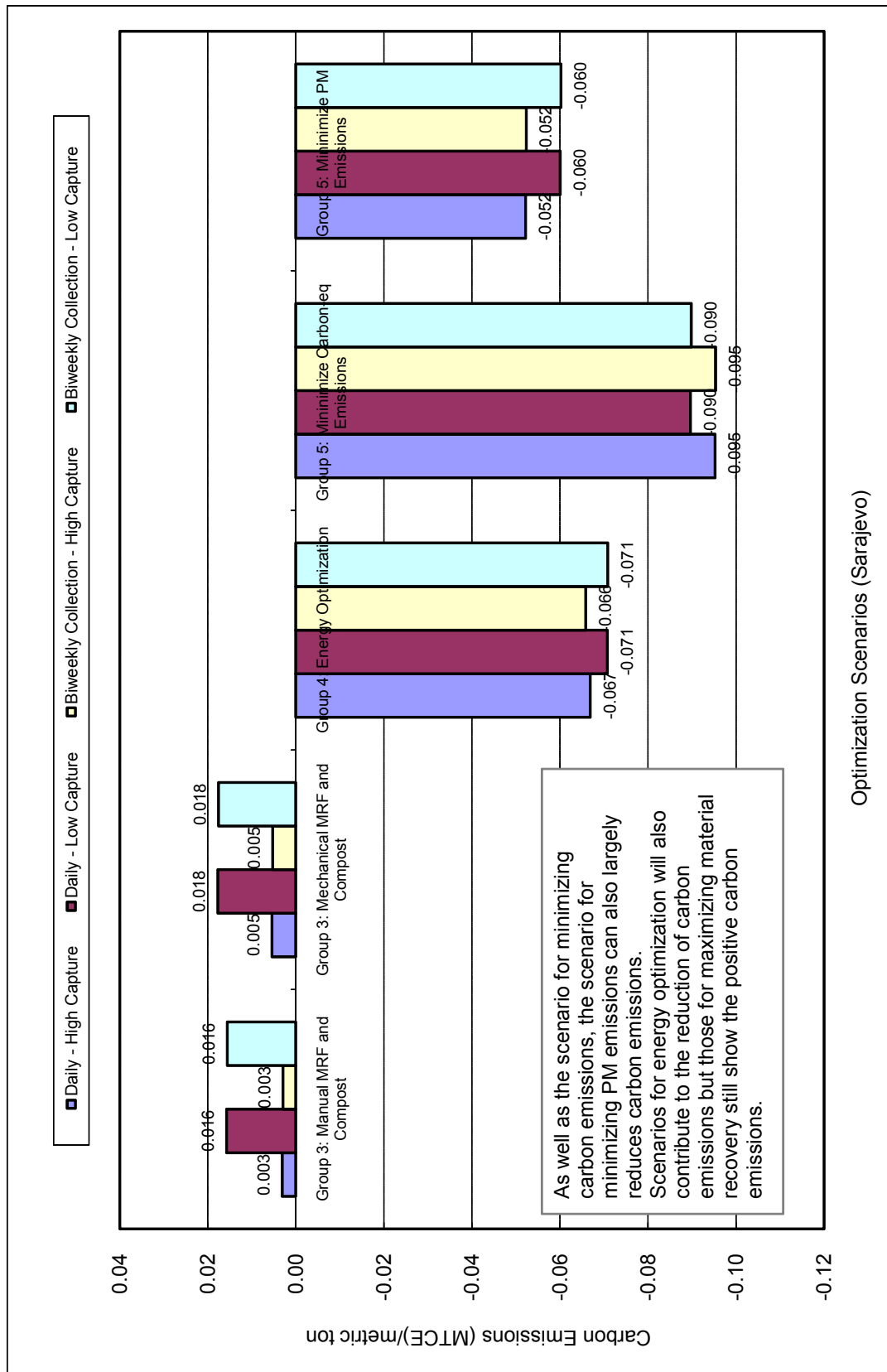


Figure 3.4-48 Carbon Emissions Results of Optimizations Results (Sarajevo)

3.4.7 Shanghai

Summary of Simulation Scenarios

Costs Results

Figures 3.4-49 and 3.4-50 show the cost results of the simulation scenarios using one primary technology. The total unit cost per tonne-waste including collection cost (which is same for all options) for recycling at MRF and incineration without energy recovery is more expensive than others. Composting with manual turning is less expensive option as well as the option for landfill with energy recovery.

Energy Recovery Results

Figure 3.4-51 shows the energy recovery results. As is easily understood, adoption of incineration with energy recovery contributes greatly by saving energy. Greater energy recovery can be also expected by material recovery scenarios with both manual and mechanical operation.

Carbon Emission Results

As Figure 3.4-52 shows, the carbon emission results show that the worst option can be said to be landfill with gas venting. The second worst option is incineration without energy recovery. However, incineration with energy recovery can contribute to reduce the carbon emissions greatly. Composting with both manual turning and windrow turner is a better option with less carbon emissions.

Summary of Optimization Scenarios

Costs Results

Figures 3.4-53 and 3.4-54 show the cost results of the optimization scenarios. It clearly shows that the unit cost per tonne-waste is less expensive for the scenario which is energy optimization, than other options except the scenario for maximizing material recovery with low capture rate.

Energy Recovery Results

Figure 3.4-55 shows the energy recovery results. Needless to say, the energy optimization scenario achieves the lowest energy consumption, then the scenarios for minimizing carbon emissions and PM emissions follow. The scenario for maximizing material recovery contributes much less for reduction of energy consumption. There are more energy savings for recycling options with high capture rate than low capture rate.

Carbon Emission Results

As Figure 3.4-56 shows, other than the scenario for minimizing carbon emissions, scenarios for energy optimization and minimizing PM emissions will contribute to the reduction of carbon emissions. Recycling options with high capture rate can contribute to reduce the carbon emissions more than low capture rate.

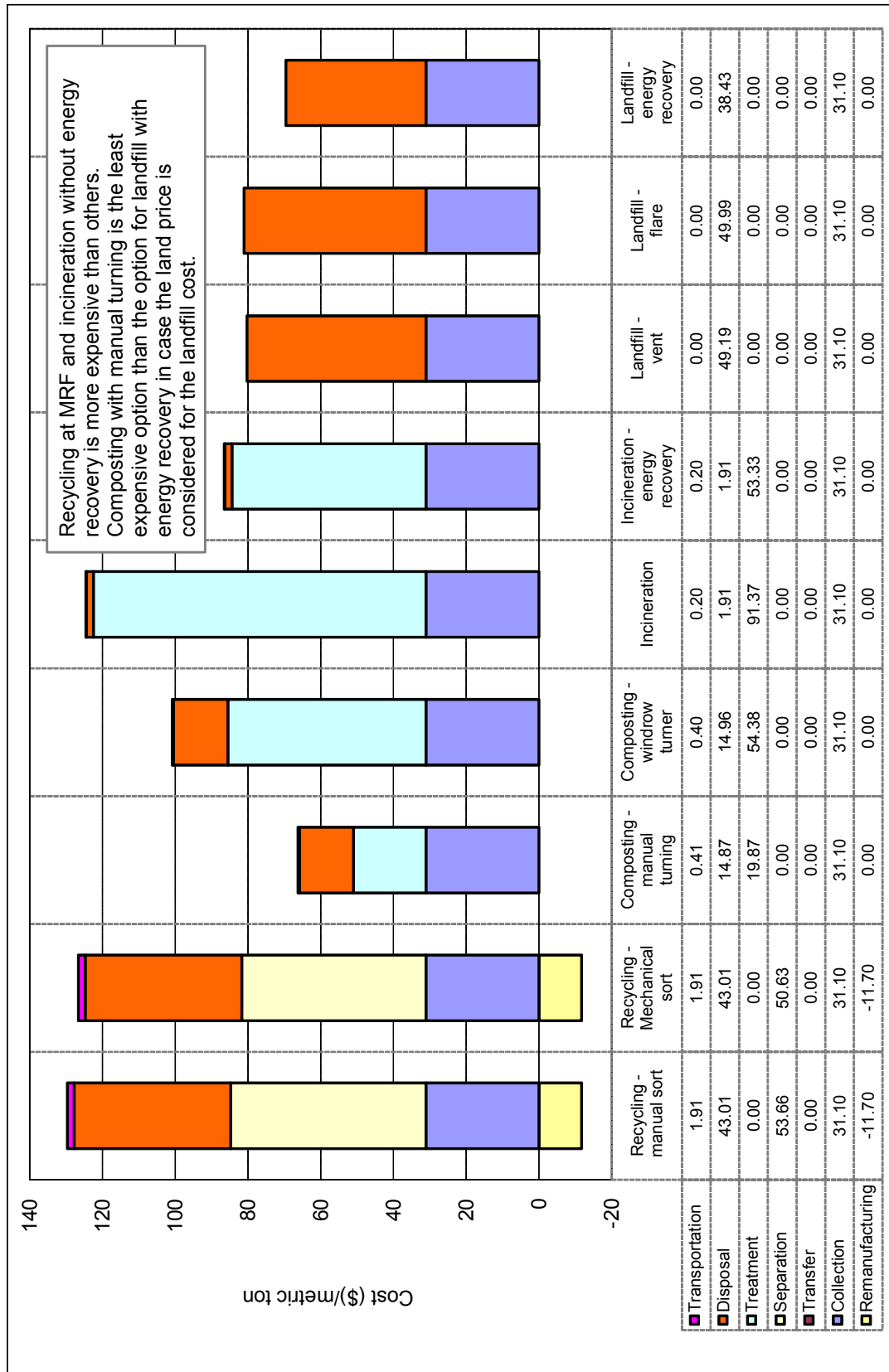


Figure 3.4-49 Cost Results of Simulation Scenarios (Shanghai: with Land Price)

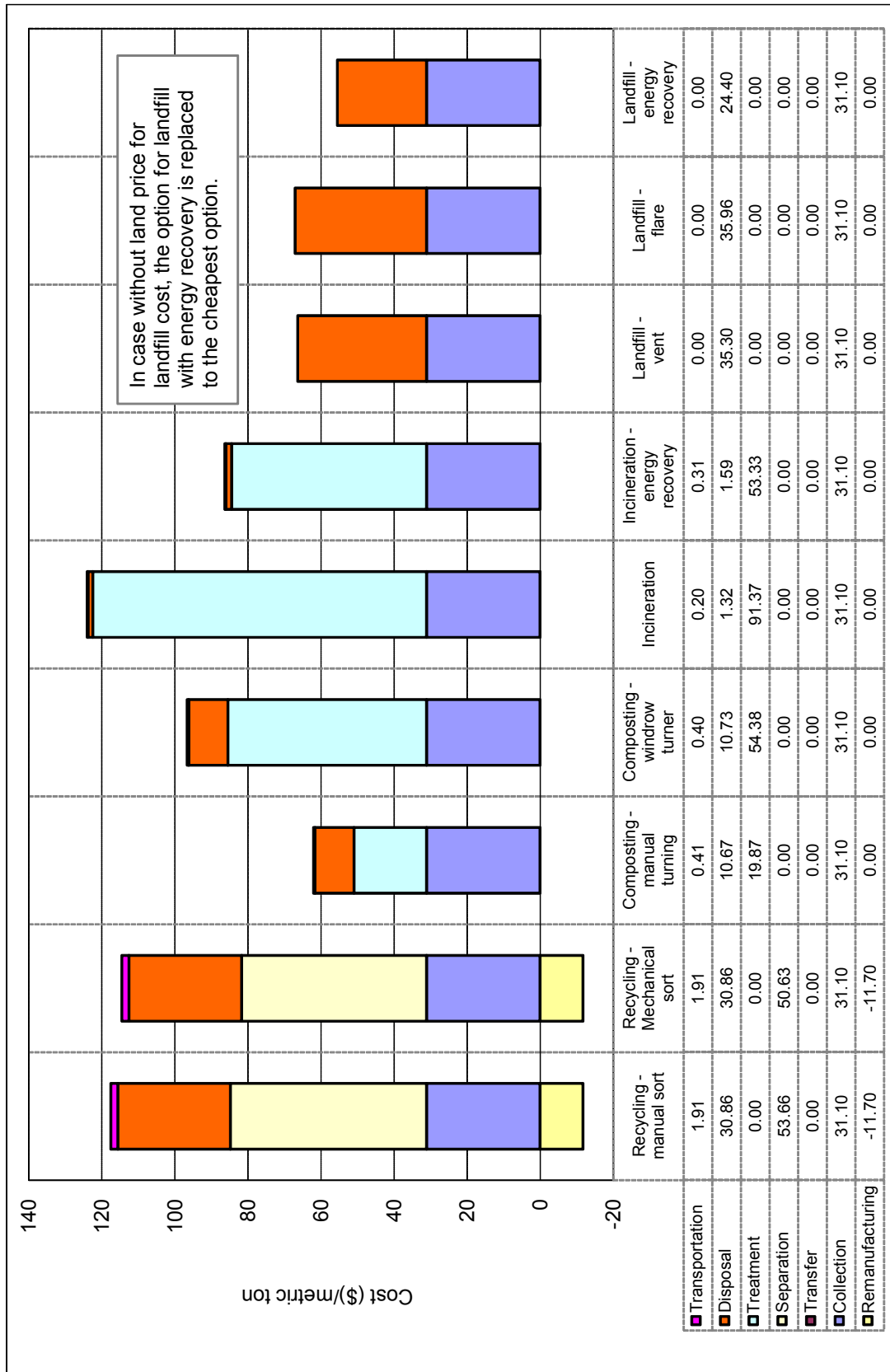


Figure 3.4-50 Cost Results of Simulation Scenarios (Shanghai: without Land Price)

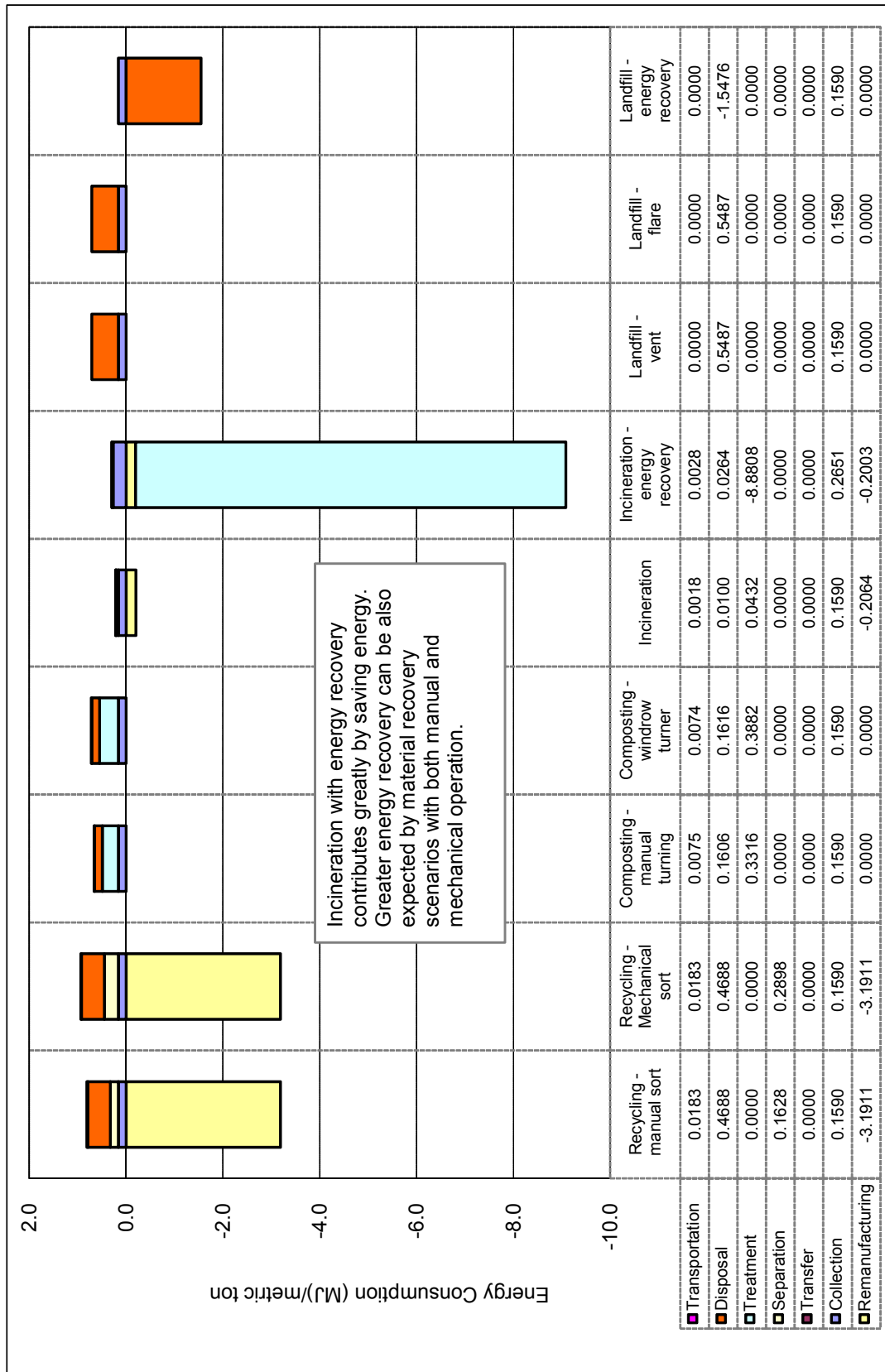


Figure 3.4-51 Energy Recovery Results of Simulation Scenarios (Shanghai)

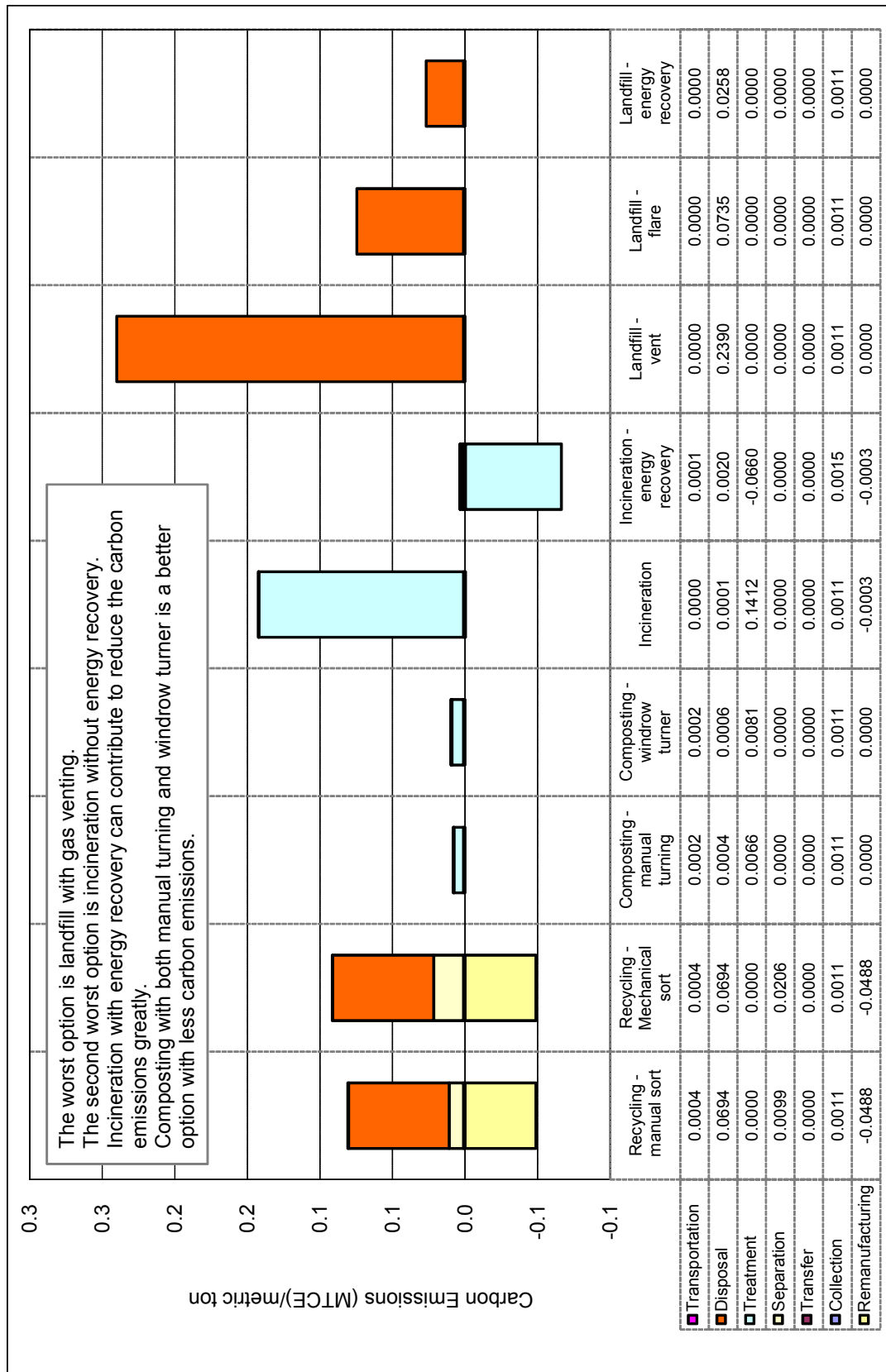


Figure 3.4-52 Carbon Emissions Results of Simulation Scenarios (Shanghai)

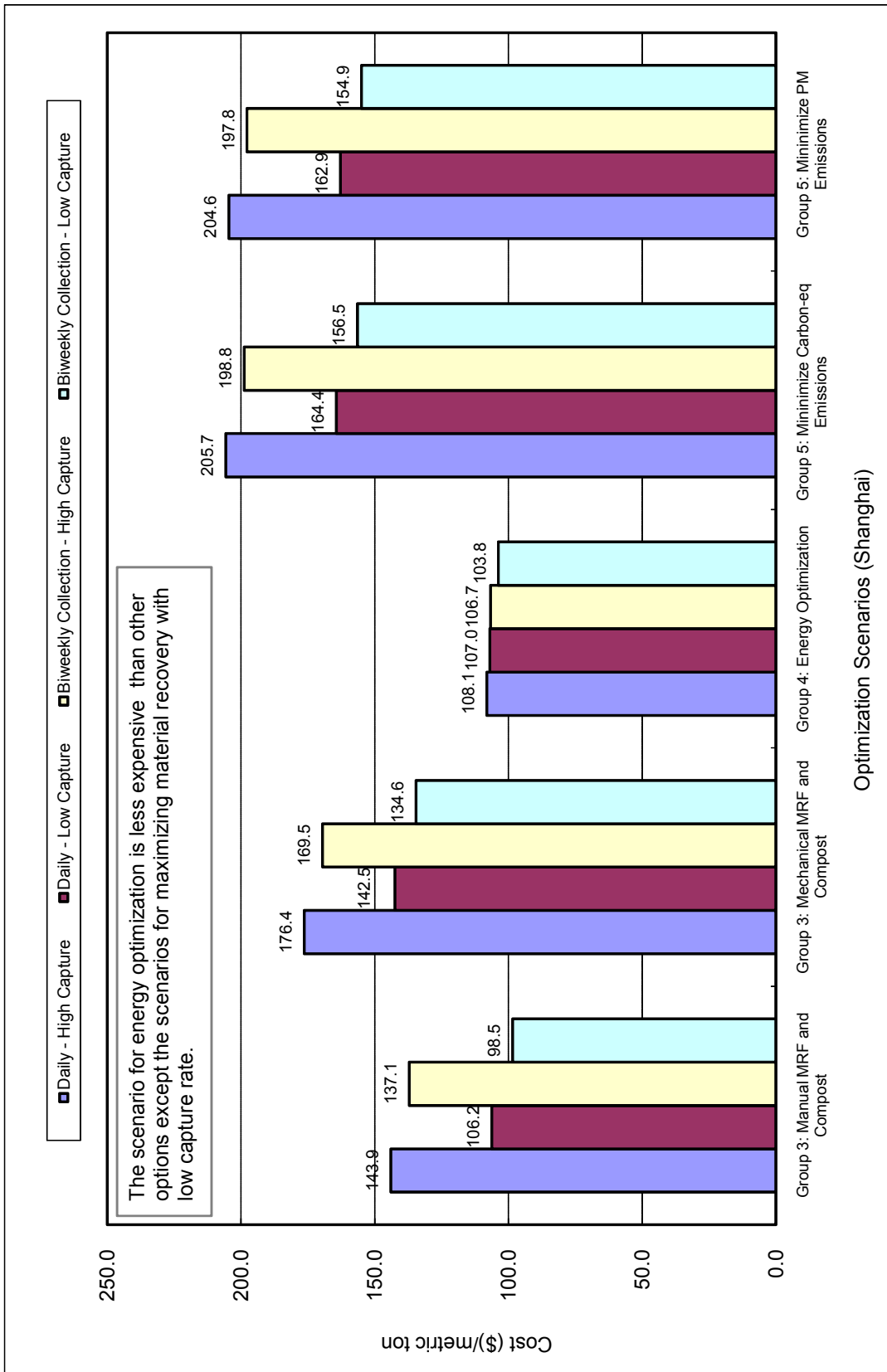


Figure 3-4-53 Cost Results of Optimizations Scenarios (Shanghai: with Land Price)

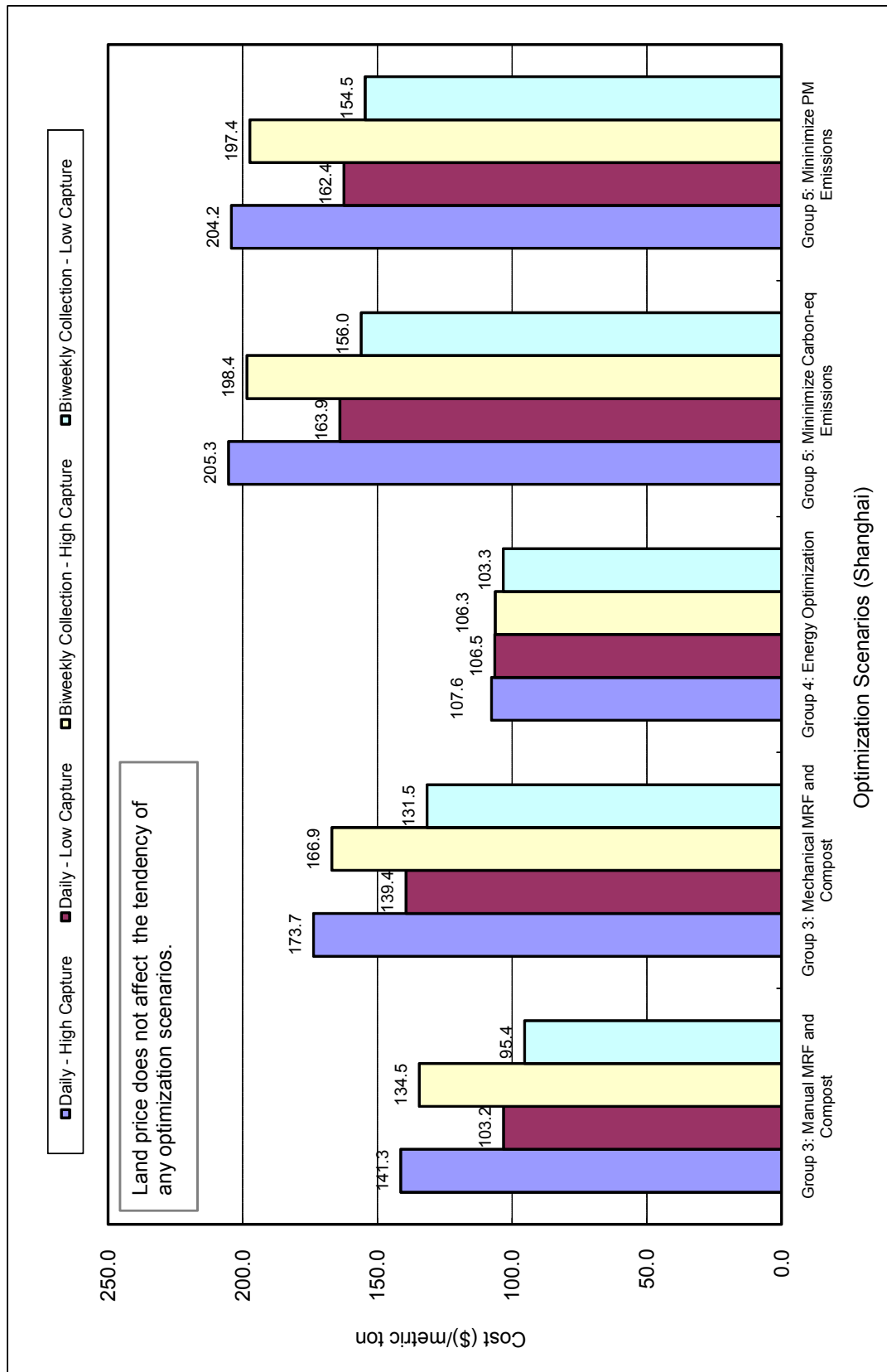


Figure 3.4-54 Cost Results of Optimizations Scenarios (Shanghai: without Land Price)

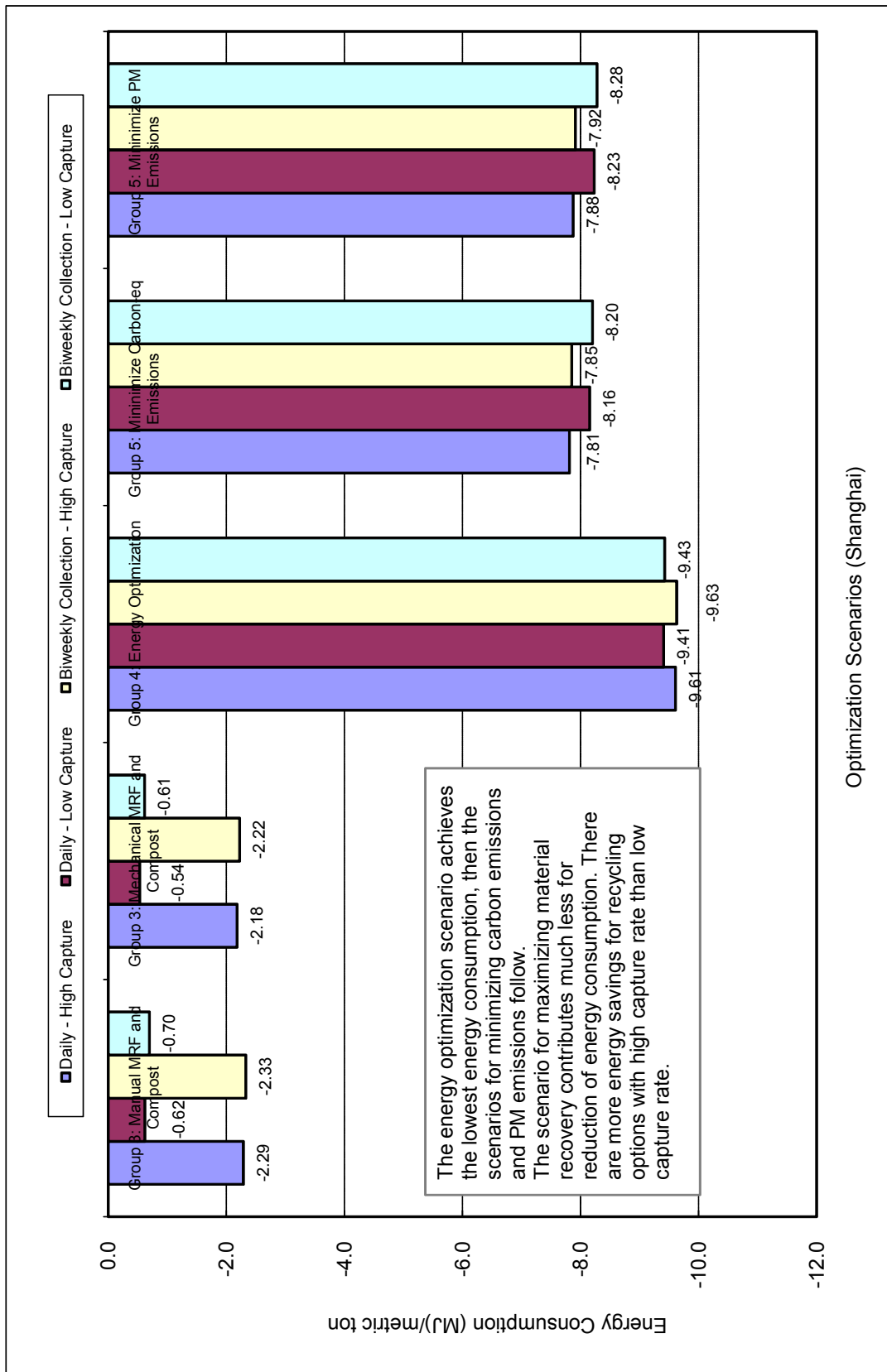


Figure 3.4-55 Energy Recovery Results of Optimizations Results (Shanghai)

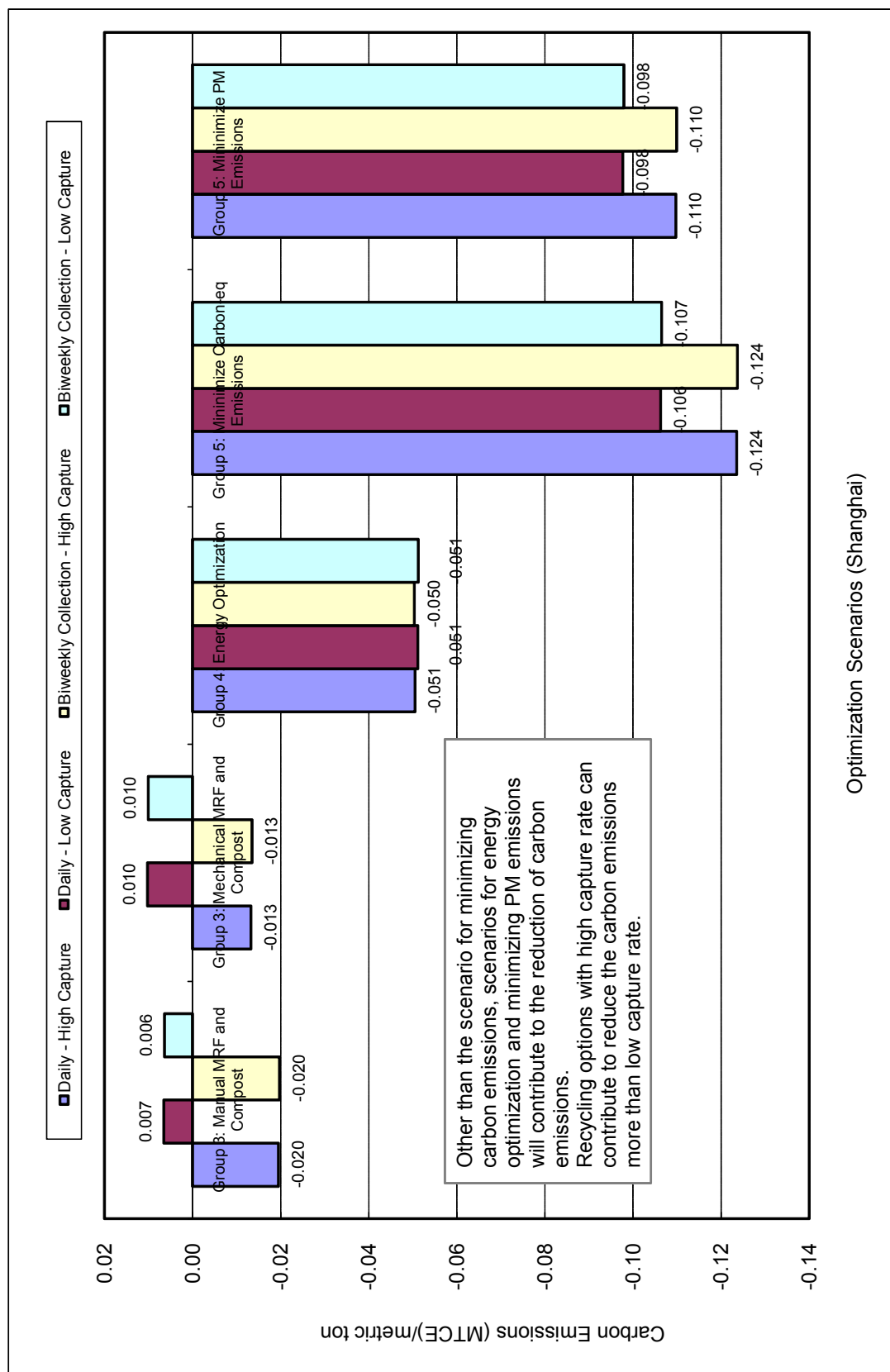


Figure 3.4-56 Carbon Emissions Results of Optimizations Results (Shanghai)

3.4.8 Kawasaki

Summary of Simulation Scenarios

Costs Results

Figures 3.4-57 and 3.4-58 show the cost results of the simulation scenarios using one primary technology. The total unit cost per tonne-waste including collection cost (which is same for all options) for incineration is most expensive than other options.

Energy Recovery Results

Figure 3.4-59 shows the energy recovery results. As is easily understood, adoption of incineration with energy recovery contributes greatly by saving energy. In addition, recycling can also save energy consumption.

Carbon Emission Results

As Figure 3.4-60 shows, the carbon emission results show that the worst option can be said to be landfill with gas venting. On the other hand, scenarios for recycling, composting and incineration with energy recovery produce less carbon emissions.

Summary of Optimization Scenarios

Costs Results

Figures 3.4-61 and 3.4-62 show the cost results of the optimization scenarios. It shows that the unit cost per tonne-waste is less expensive for the scenario which is maximizing material recovery, than other options.

Energy Recovery Results

Figure 3.4-63 shows the energy recovery results. Scenarios for minimizing carbon and for minimizing PM emissions can reduce energy consumption into the same level as the energy optimization scenario.

Carbon Emission Results

As Figure 3.4-64 shows, as well as the scenario for minimizing carbon emissions, the scenarios for minimizing PM emissions and energy optimization can also reduce carbon emissions. The other scenario for maximizing the material recovery with low capture rate still shows little positive carbon emissions.

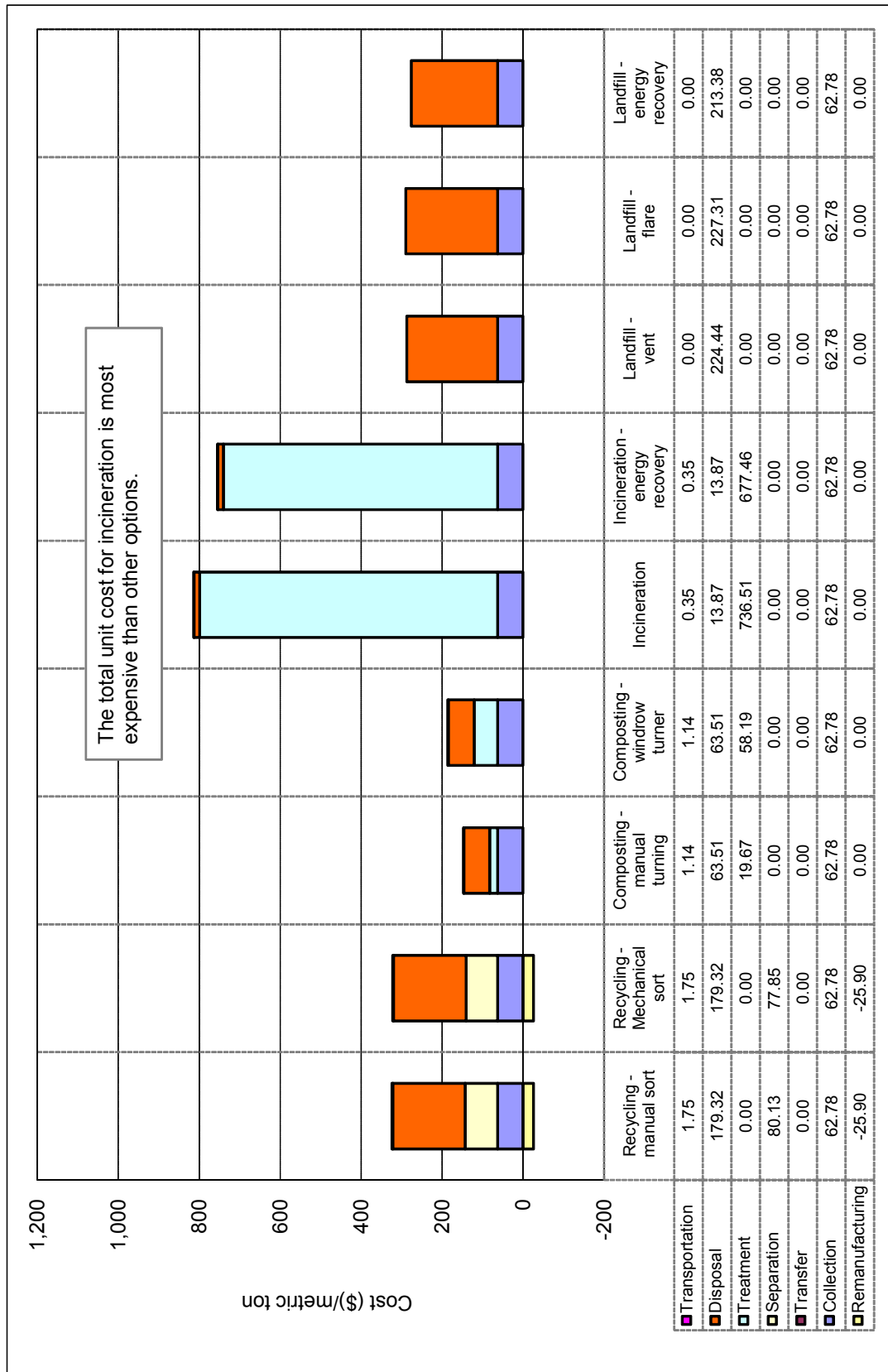


Figure 3.4-57 Cost Results of Simulation Scenarios (Kawasaki: with Land Price)

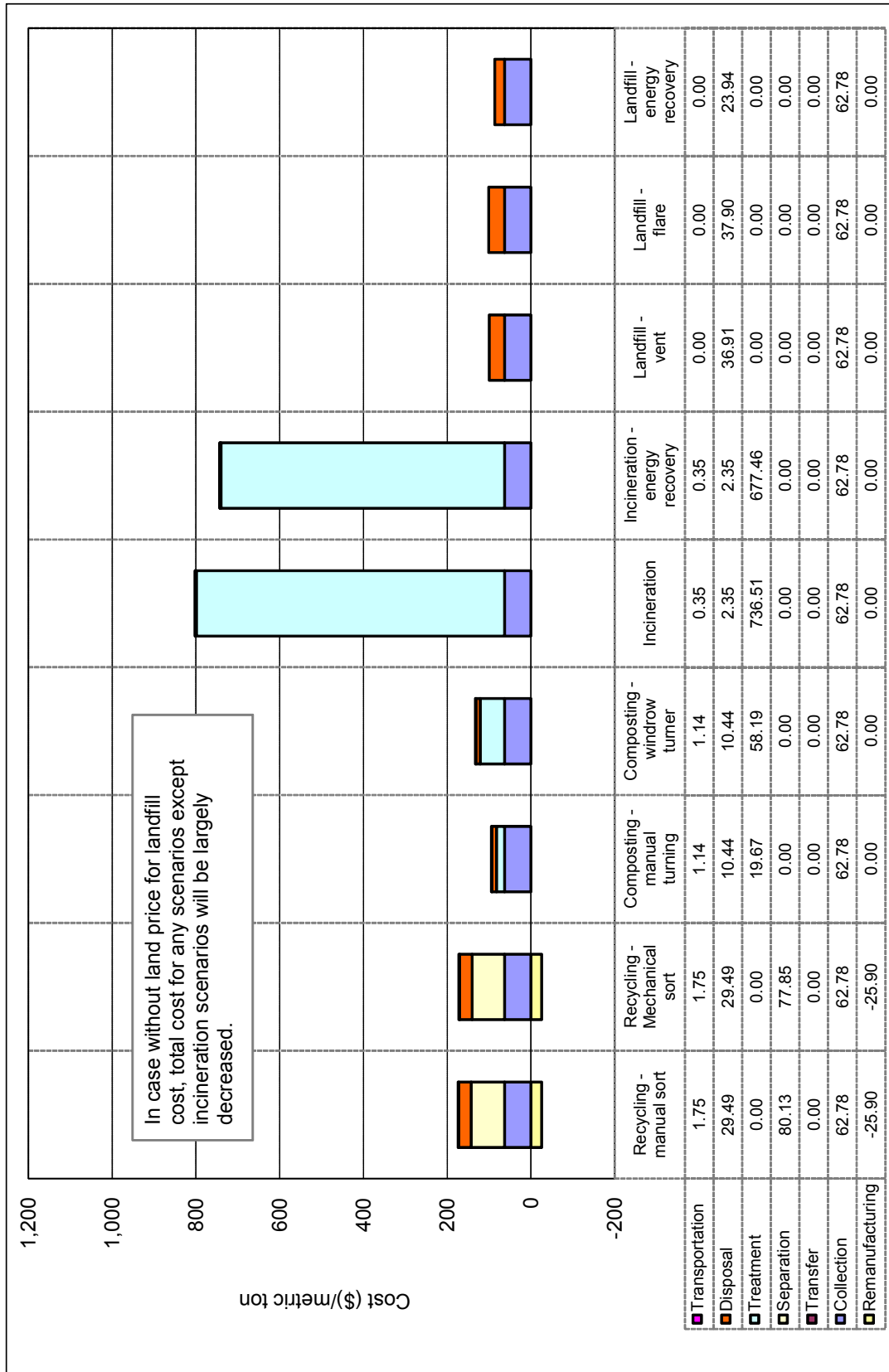


Figure 3.4-58 Cost Results of Simulation Scenarios (Kawasaki: without Land Price)

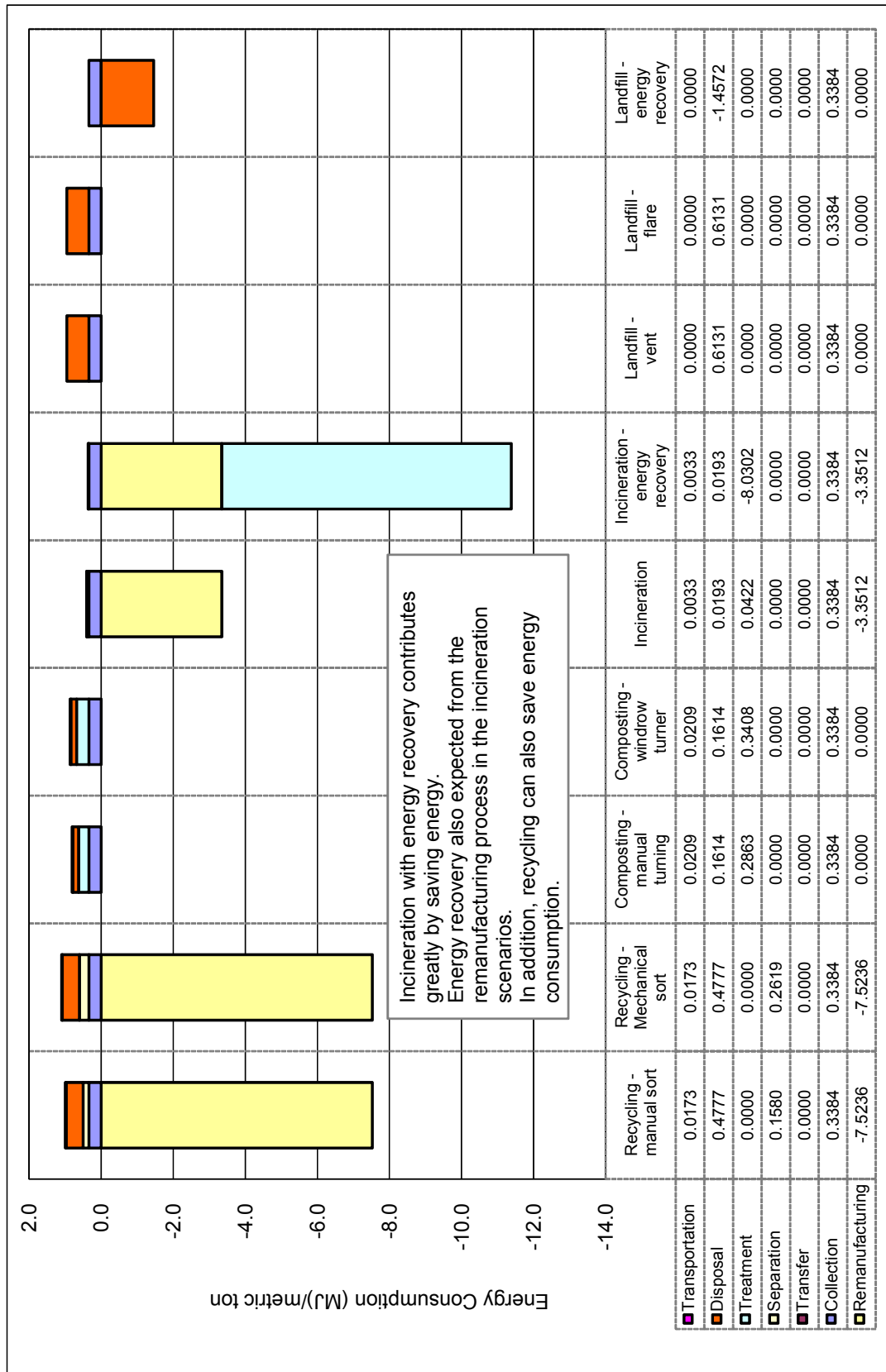


Figure 3.4-59 Energy Recovery Results of Simulation Scenarios (Kawasaki)

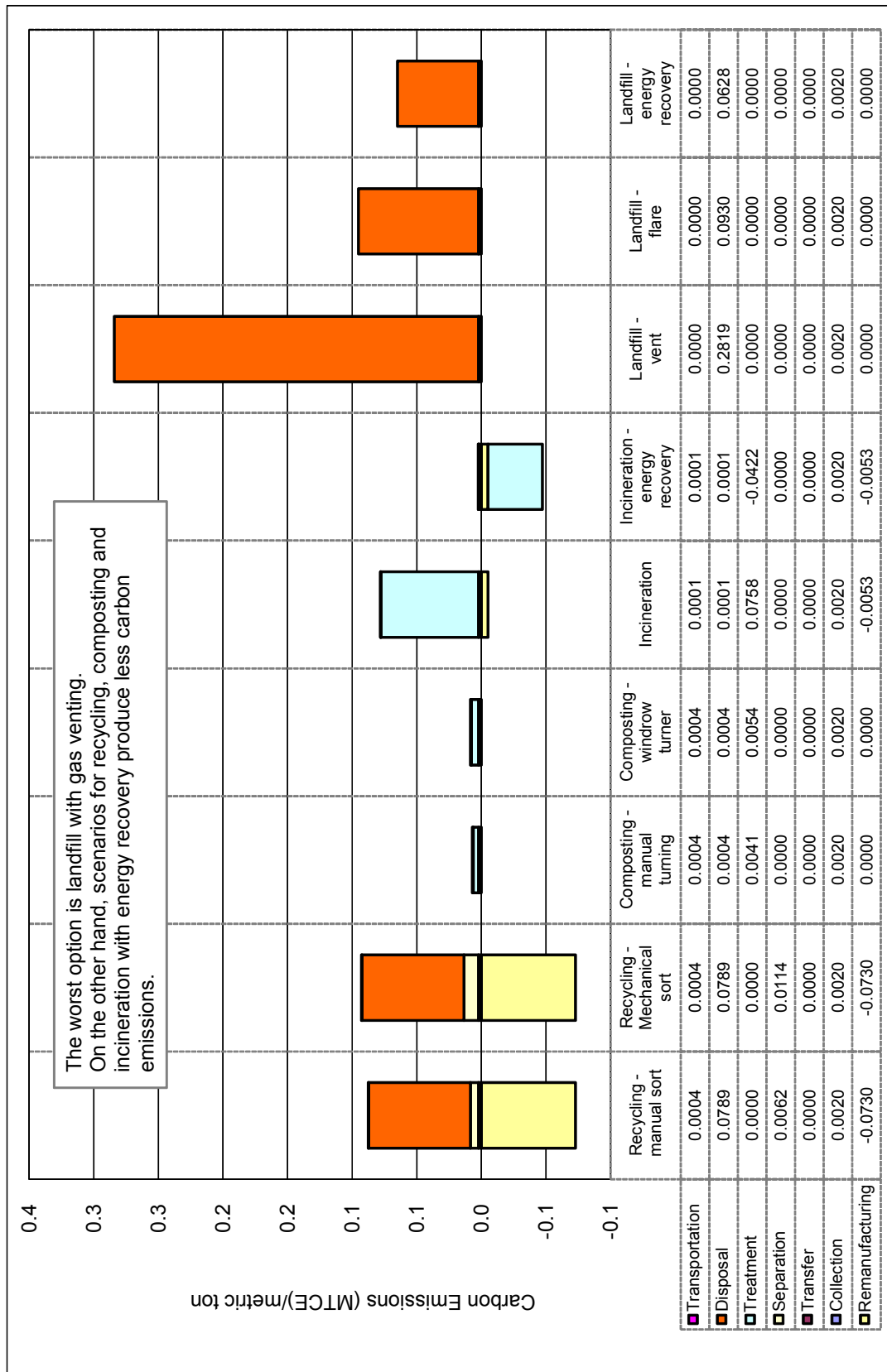


Figure 3.4-60 Carbon Emissions Results of Simulation Scenarios (Kawasaki)

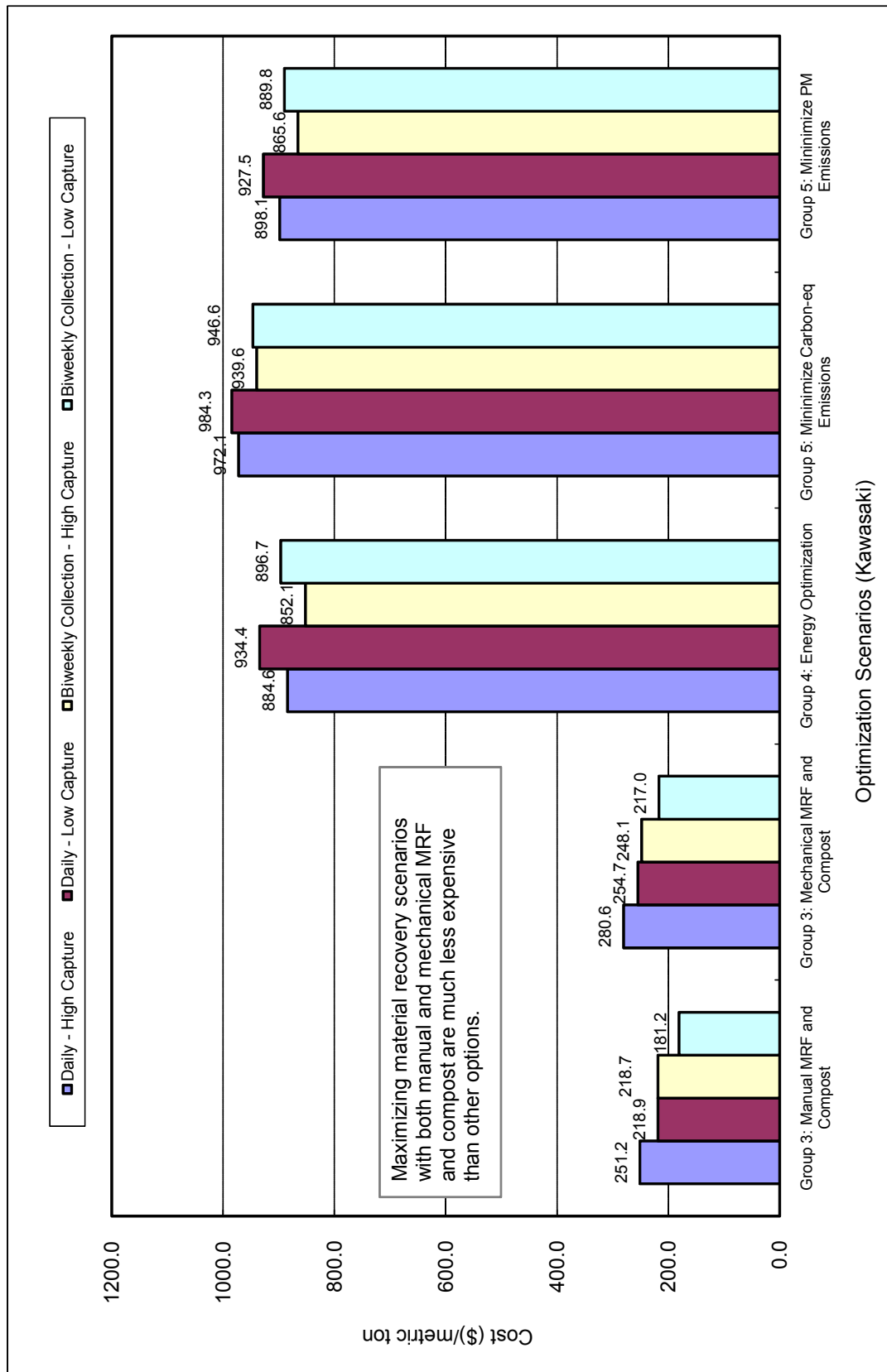


Figure 3.4-61 Cost Results of Optimizations Scenarios (Kawasaki: with Land Price)

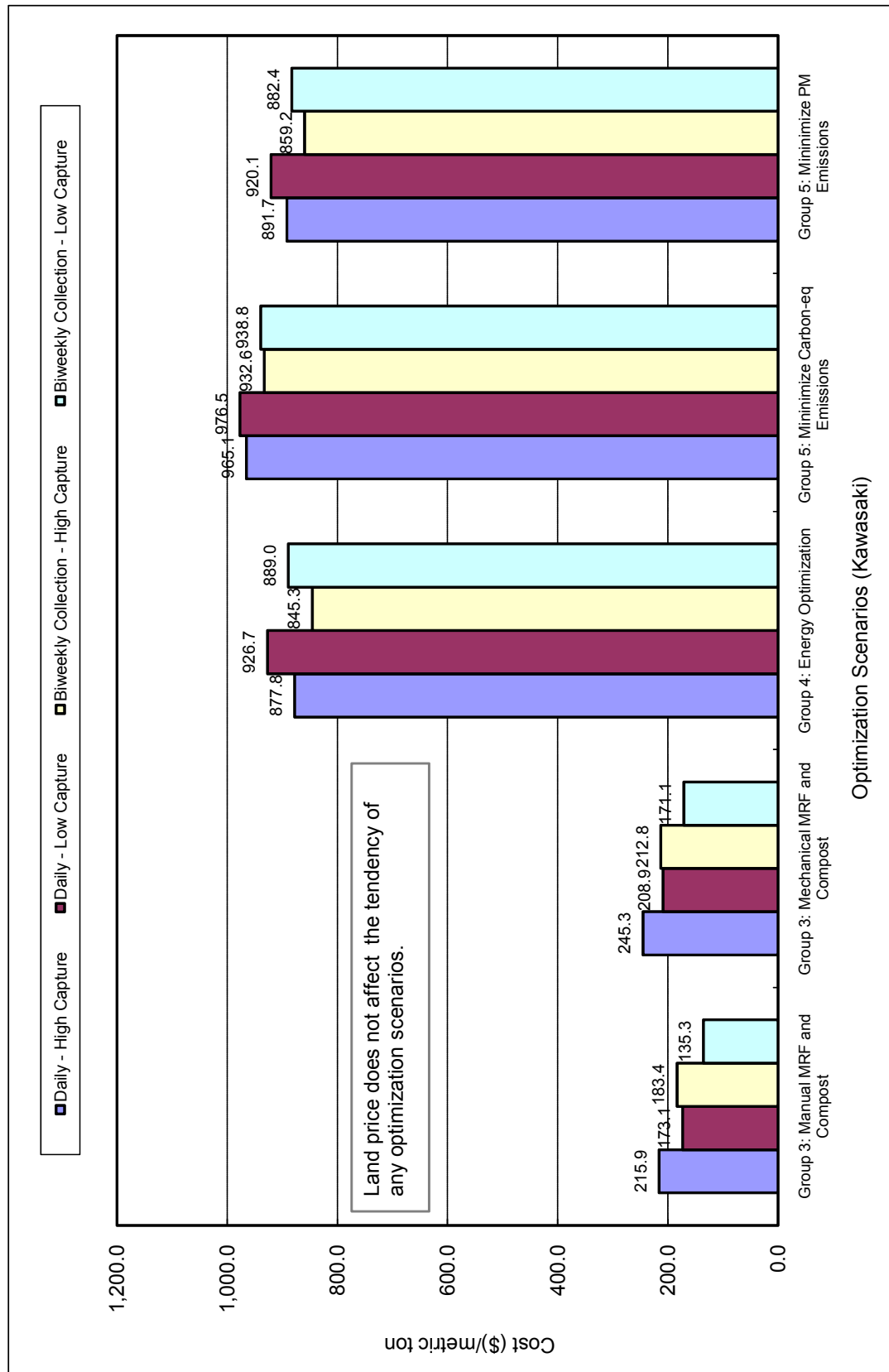


Figure 3.4-62 Cost Results of Optimizations Scenarios (Kawasaki: without Land Price)

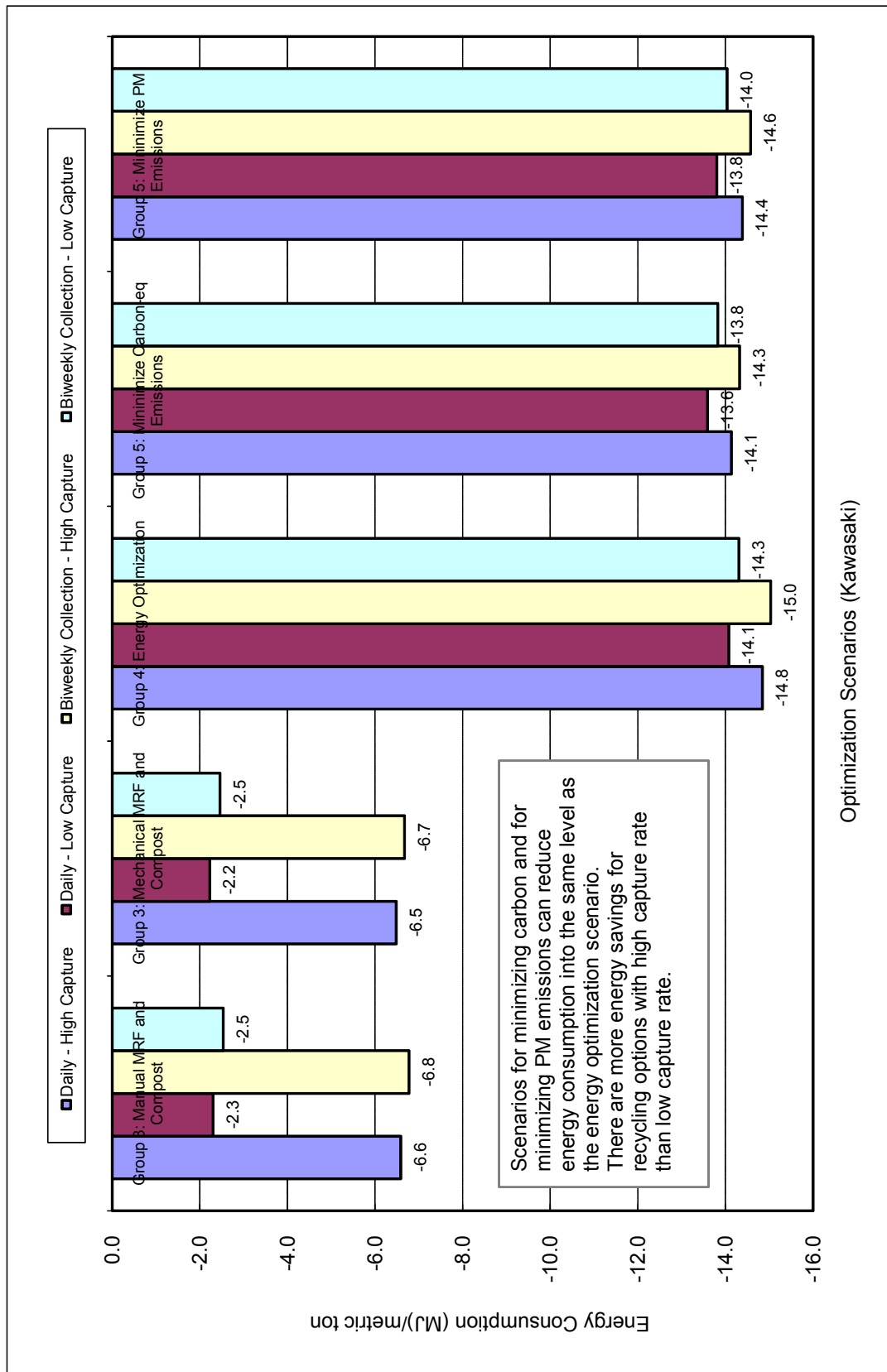


Figure 3.4-63 Energy Recovery Results of Optimizations Results (Kawasaki)

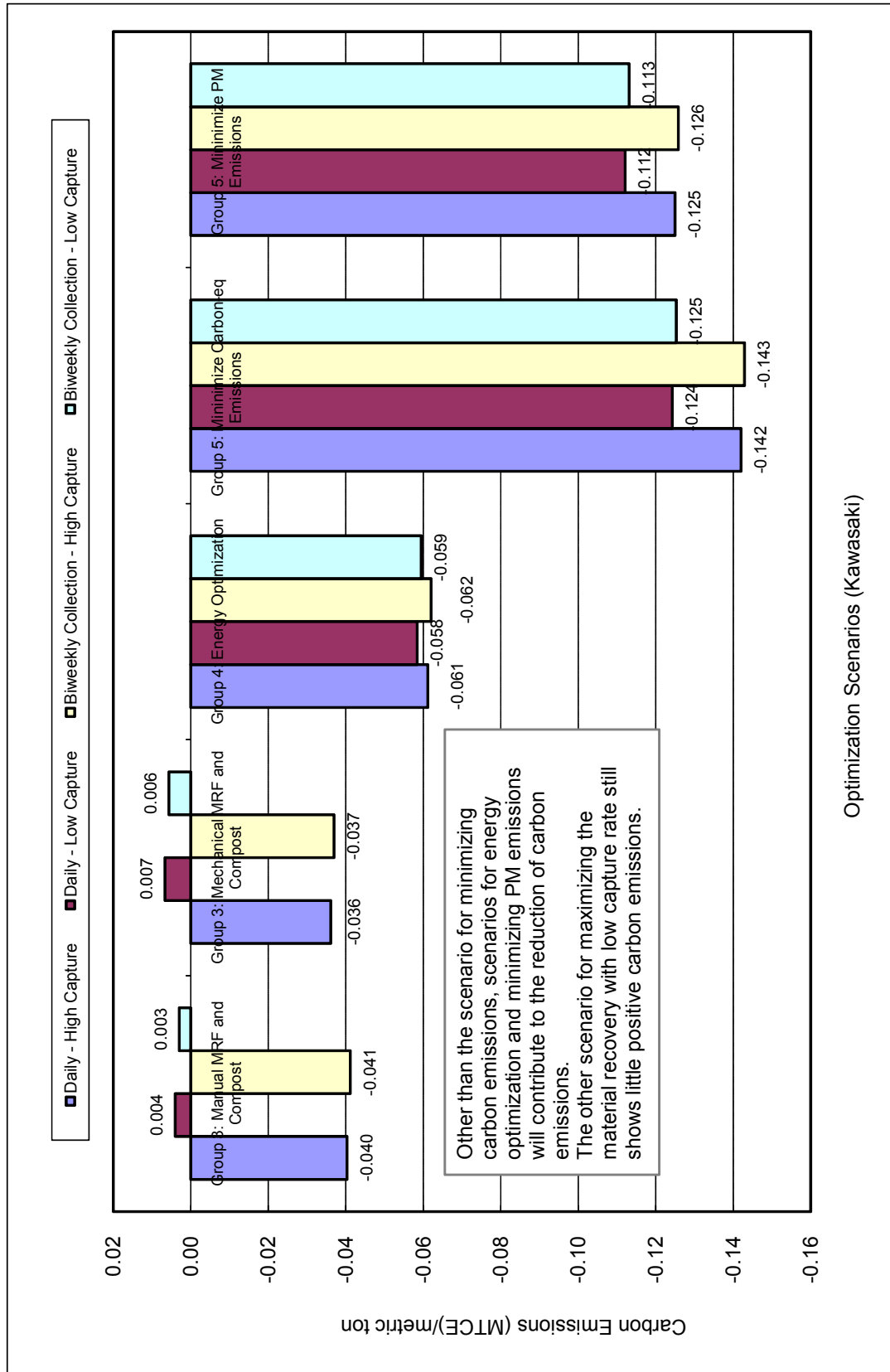


Figure 3.4-64 Carbon Emissions Results of Optimizations (Kawasaki)

3.4.9 Atlanta

Summary of Simulation Scenarios

Costs Results

Figures 3.4-65 and 3.4-66 show the cost results of the simulation scenarios using one primary technology. The total unit cost per tonne-waste including collection cost (which is same for all options) for incineration is most expensive than others. The less expensive option is still direct landfill. Considering the revenue from sales of collected recyclables, recycling options are also the less expensive alternatives.

Energy Recovery Results

Figure 3.4-67 shows the energy recovery results. As is easily understood, adoption of incineration with energy recovery contributes greatly by saving energy. In addition, recycling can also save energy consumption.

Carbon Emission Results

As Figure 3.4-68 shows, the carbon emission results show that the worst option can be said to be landfill with gas venting. On the other hand, scenarios for recycling, composting and incineration with energy recovery produce less carbon emissions. In which, incineration with energy recovery is least option for carbon emissions.

Summary of Optimization Scenarios

Costs Results

Figures 3.4-69 and 3.4-70 show the cost results of the optimization scenarios. It shows that the unit cost per tonne-waste is less expensive for the scenario which is maximizing material recovery with manual operation and biweekly collection, than other options.

Energy Recovery Results

Figure 3.4-71 shows the energy recovery results. Scenarios for minimizing carbon and for minimizing PM emissions can reduce energy consumption into the same level as the energy optimization scenario.

Carbon Emission Results

As Figure 3.4-72 shows, as well as the scenario for minimizing carbon emissions, the scenarios for minimizing PM emissions and energy optimization can also reduce carbon emissions. The other scenario for maximizing the material recovery with low capture rate still shows little positive carbon emissions.

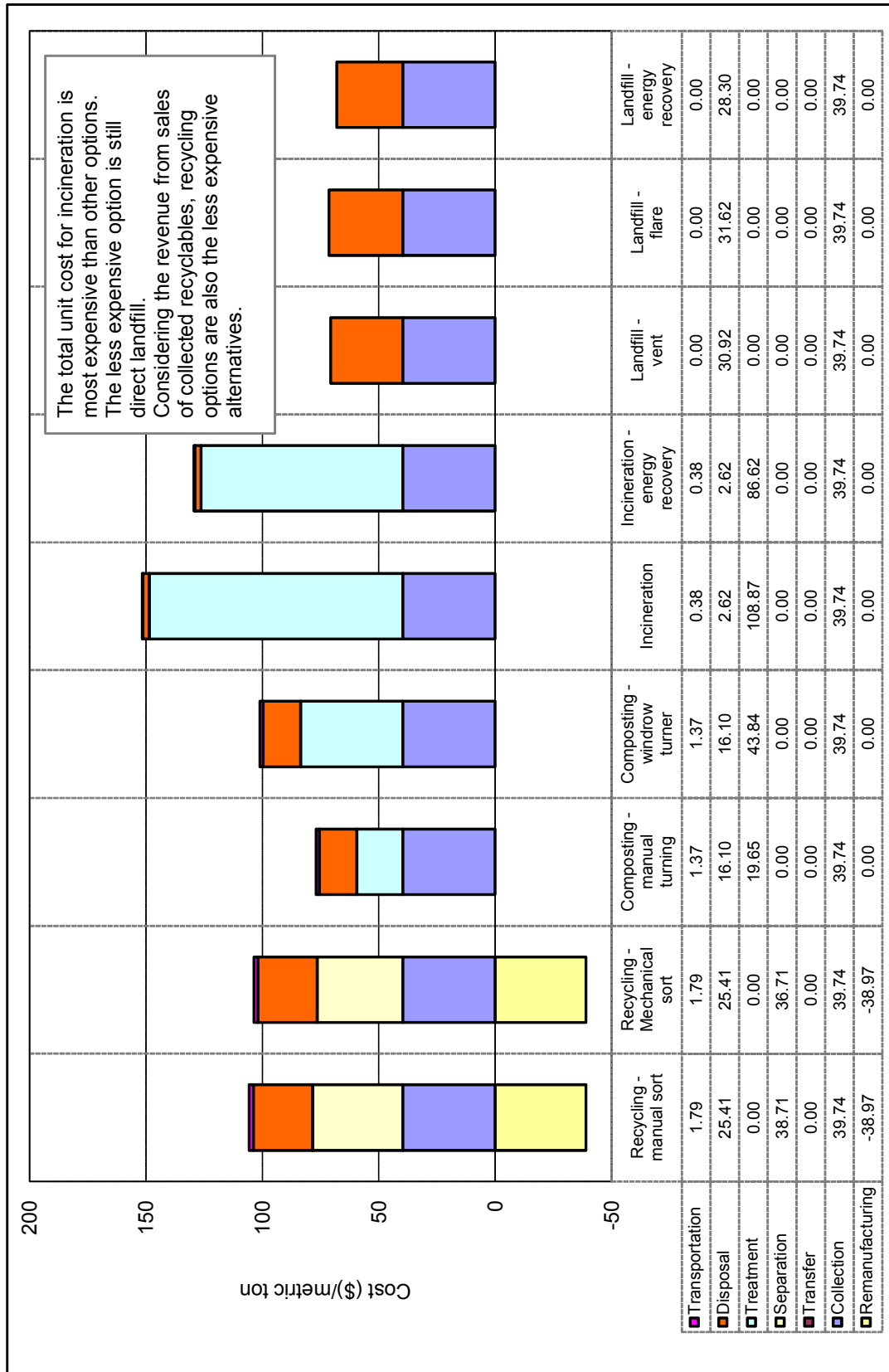


Figure 3.4-65 Cost Results of Simulation Scenarios (Atlanta: with Land Price)

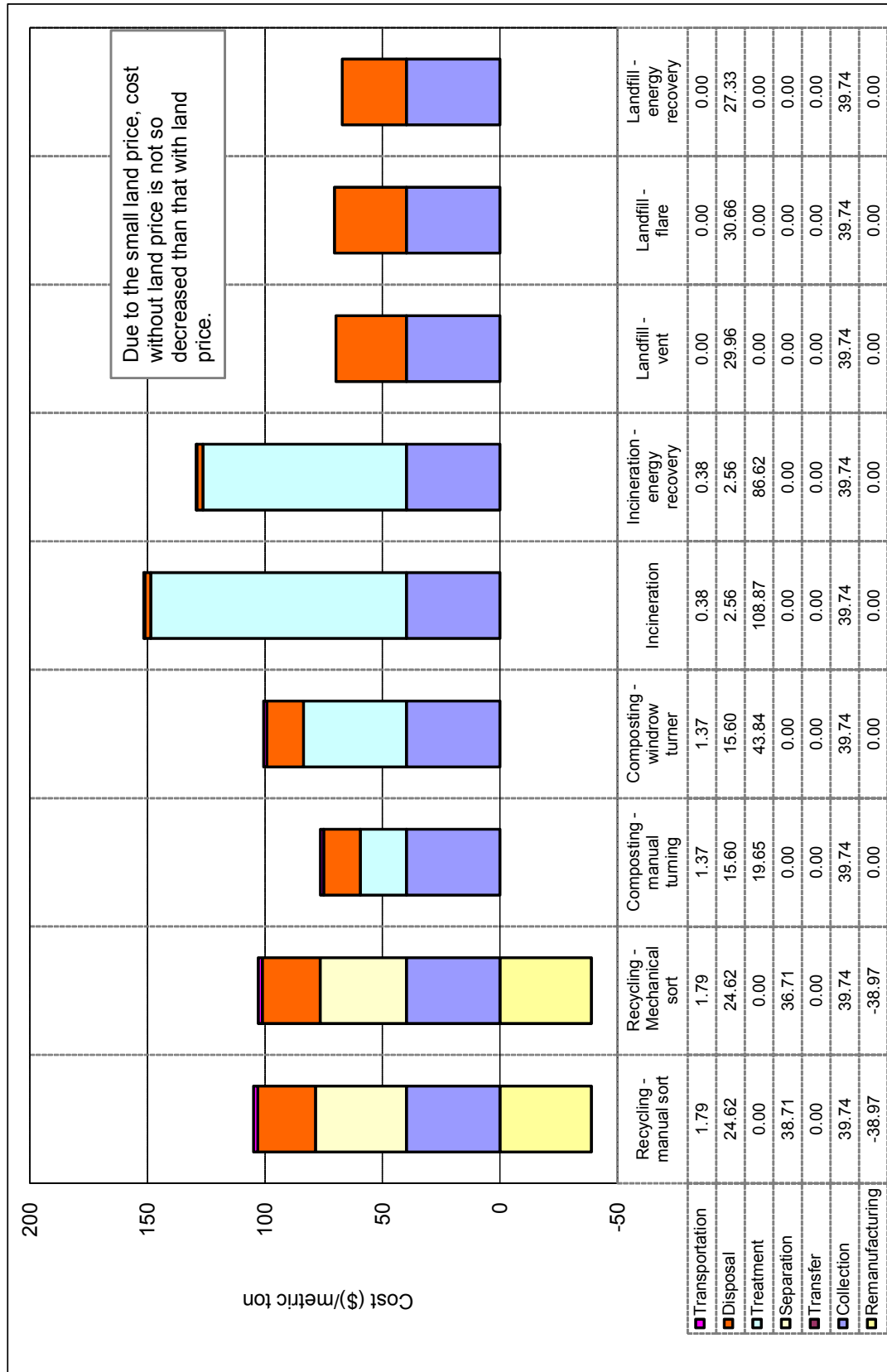


Figure 3.4-66 Cost Results of Simulation Scenarios (Atlanta: without Land Price)

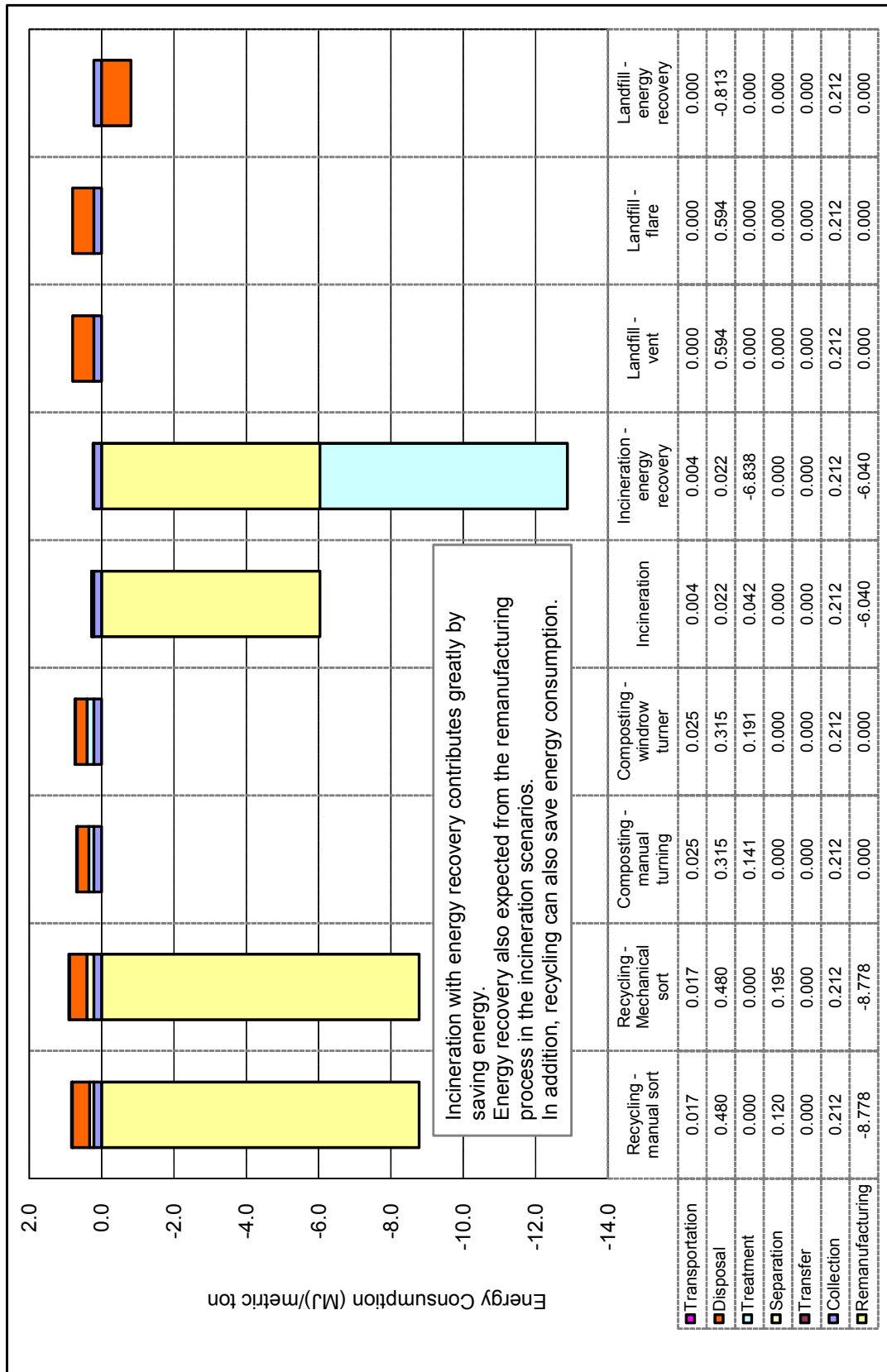


Figure 3.4-67 Energy Recovery Results of Simulation Scenarios (Atlanta)

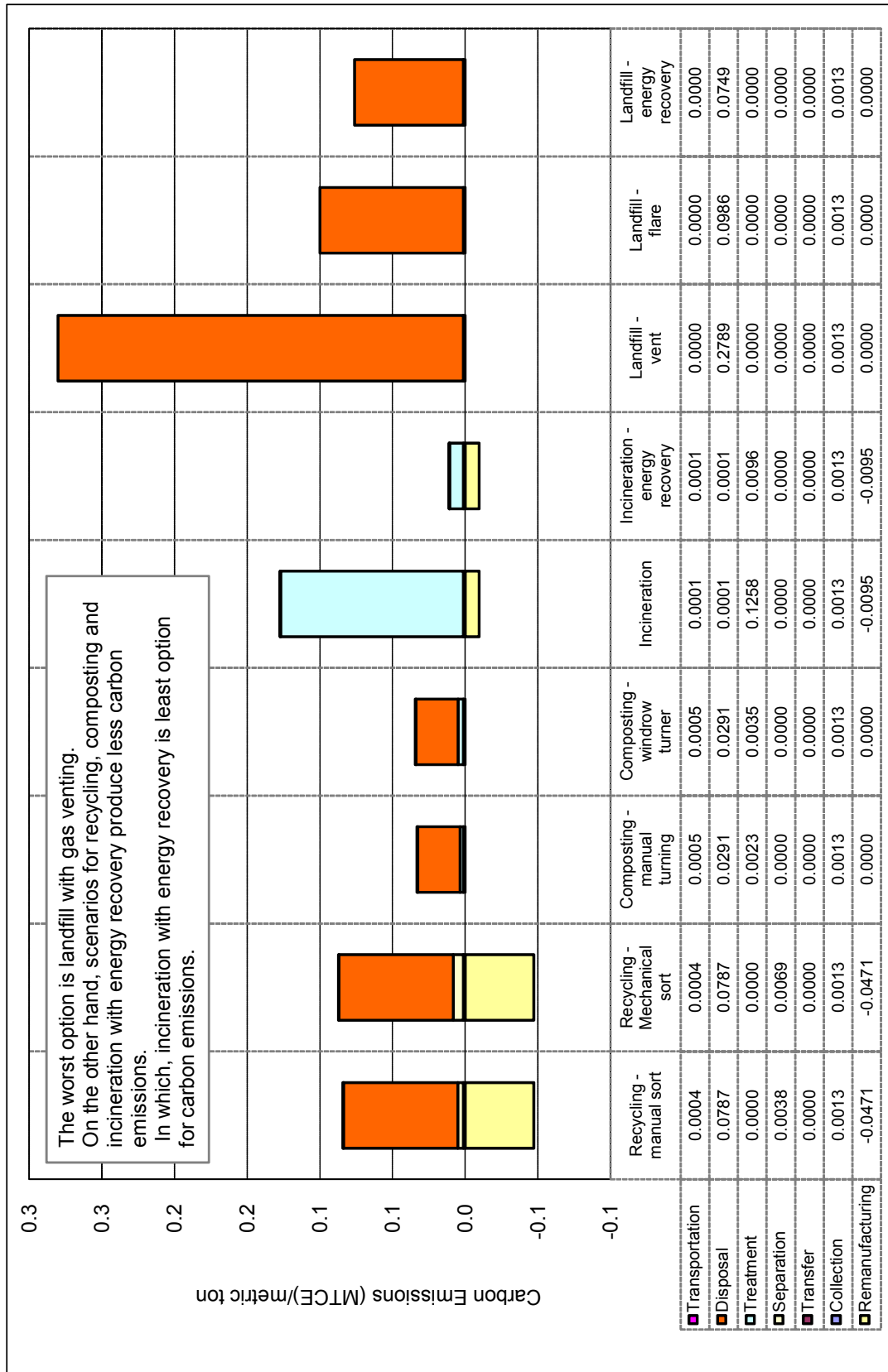


Figure 3.4-68 Carbon Emissions Results of Simulation Scenarios (Atlanta)

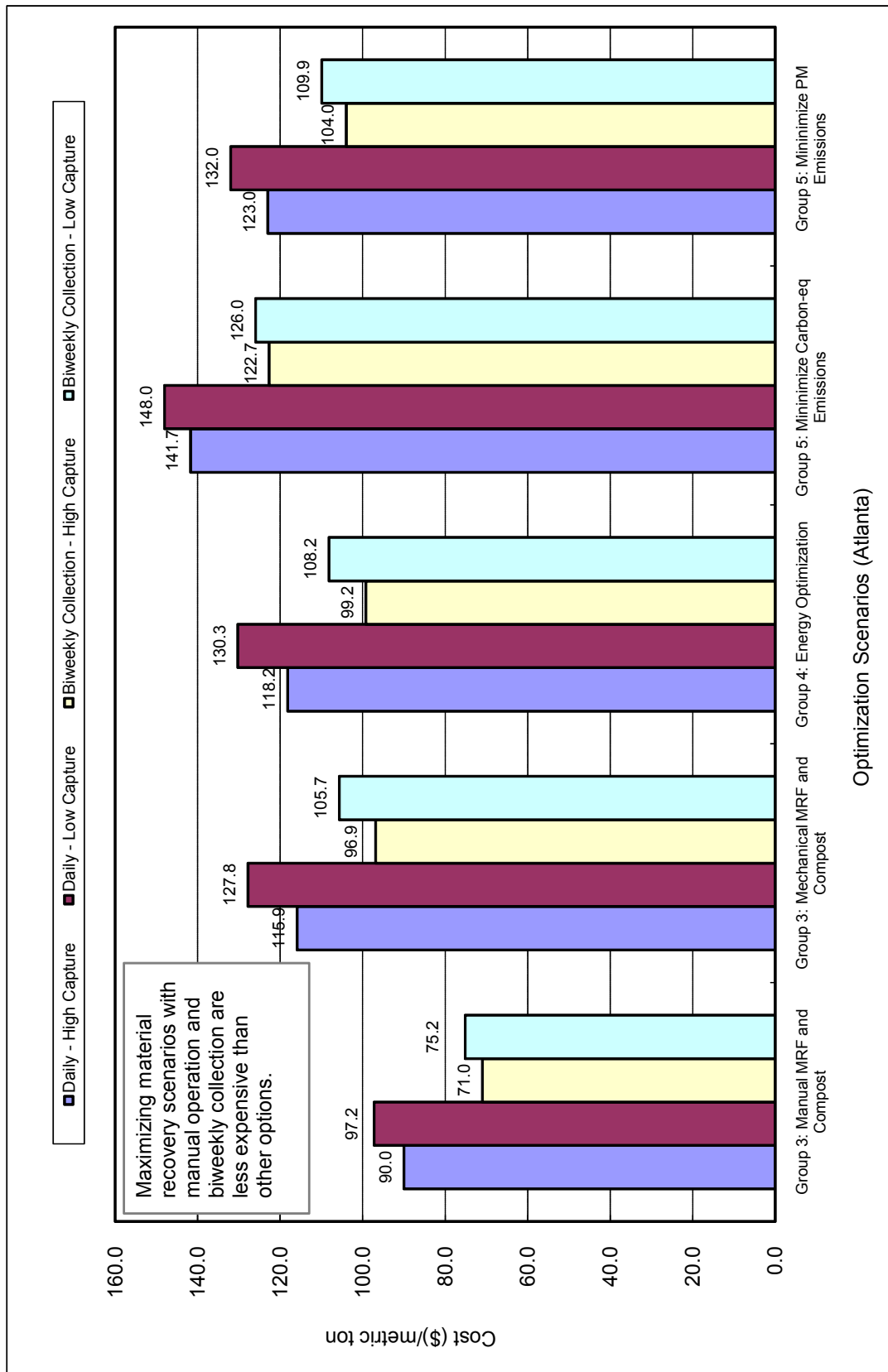


Figure 3.4-69 Cost Results of Optimizations Scenarios (Atlanta: with Land Price)

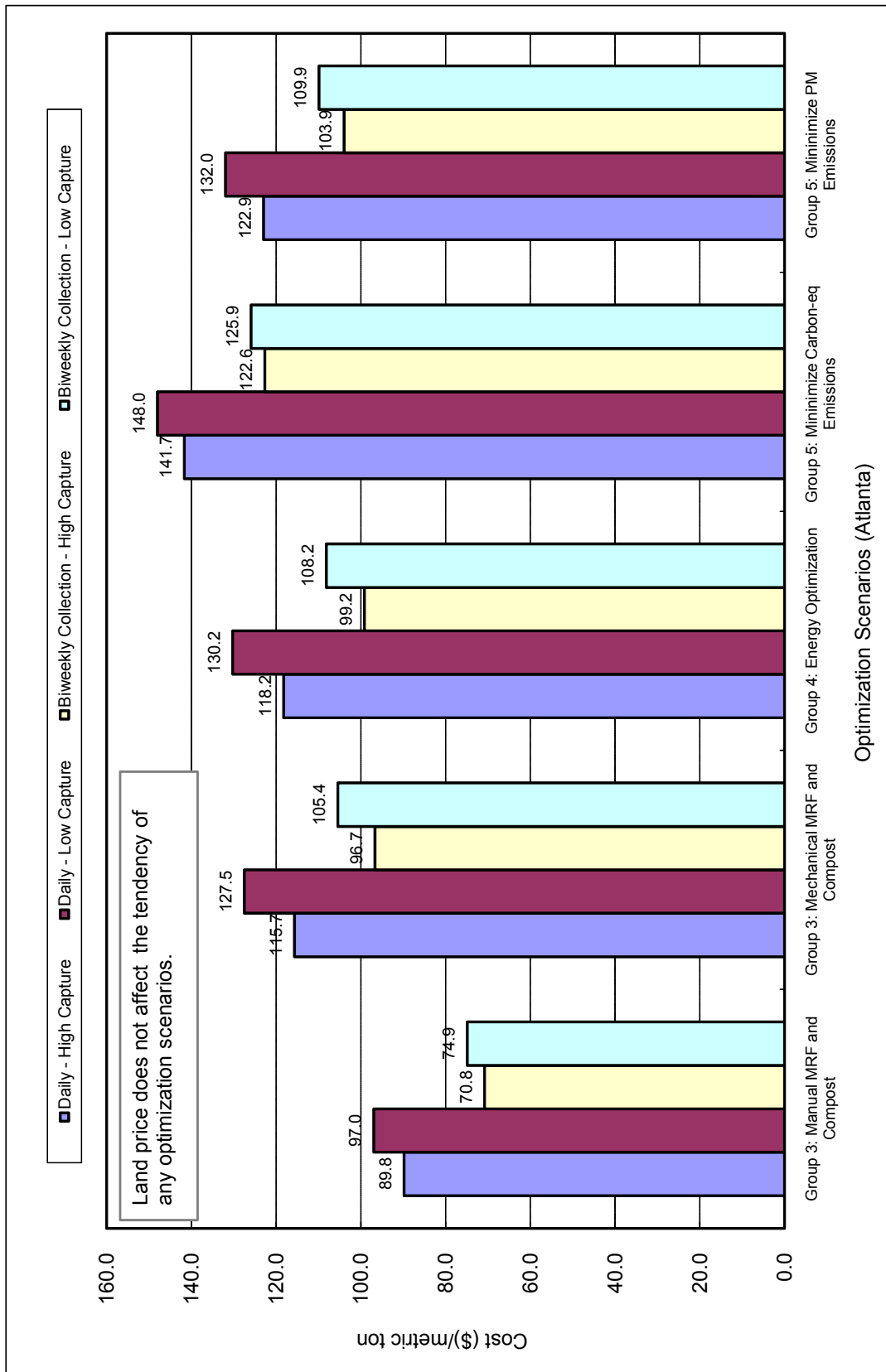


Figure 3.4-70 Cost Results of Optimizations Scenarios (Atlanta: without Land Price)

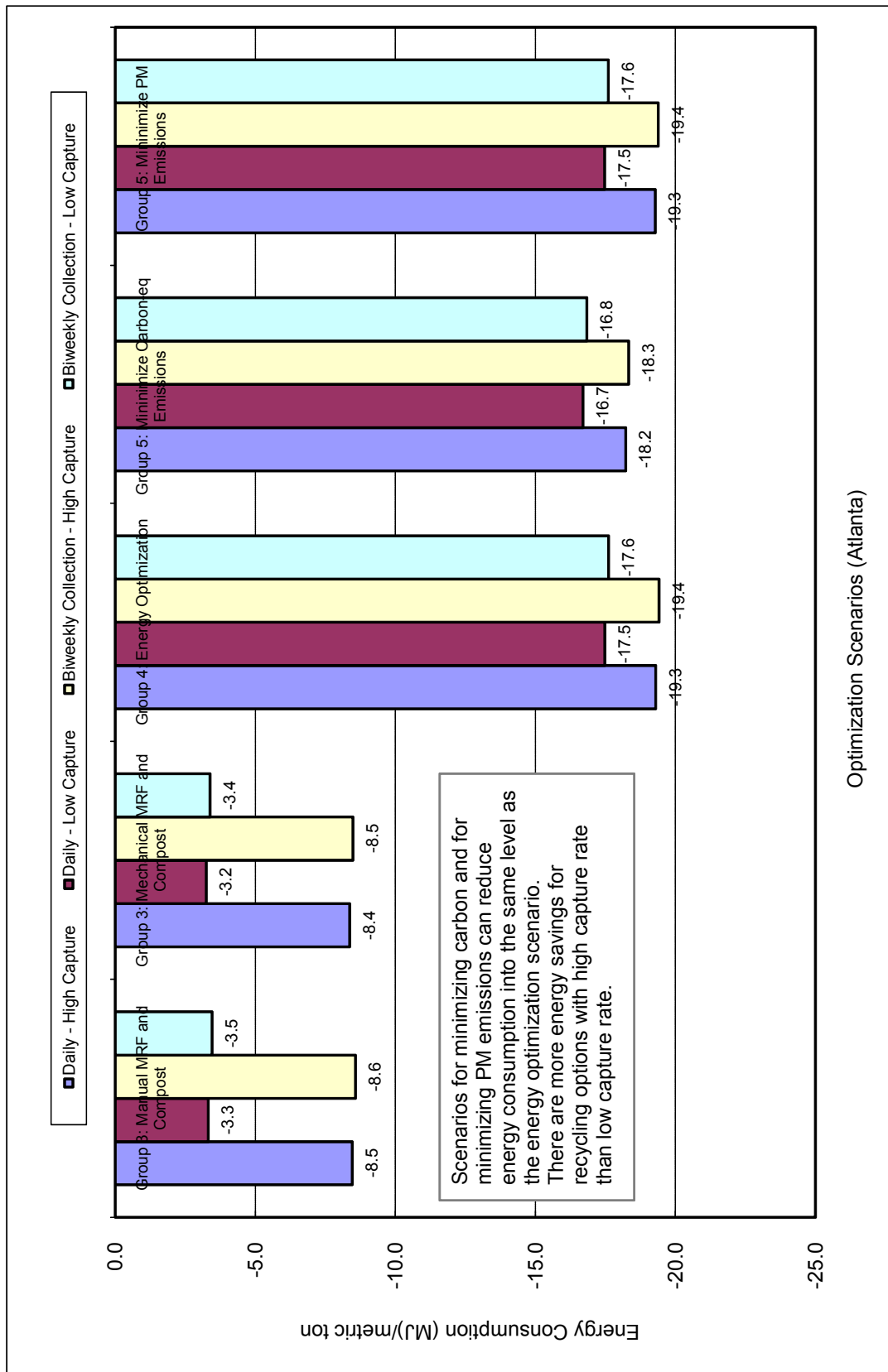


Figure 3.4-71 Energy Recovery Results of Optimizations Results (Atlanta)

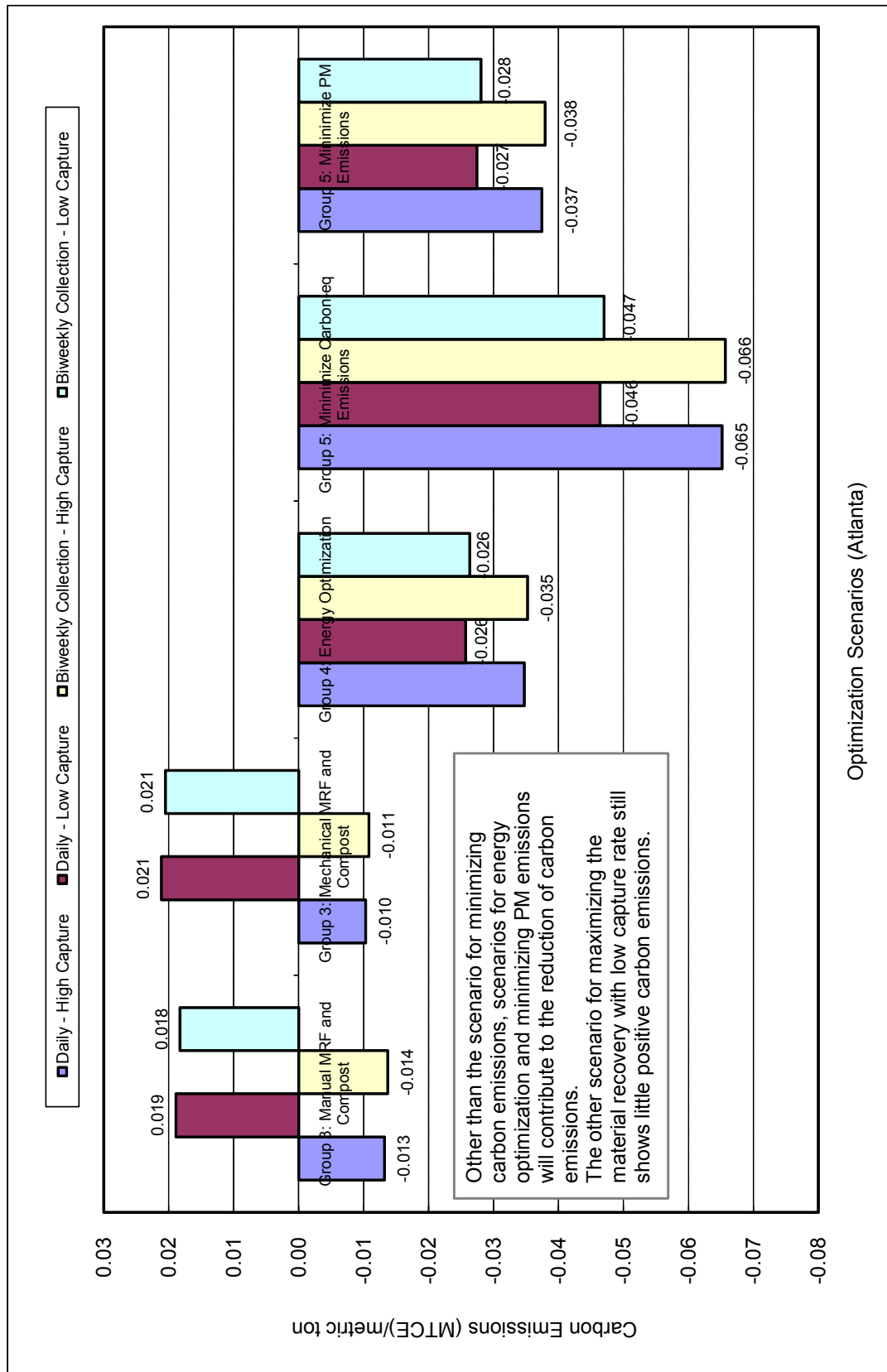


Figure 3.4-72 Carbon Emissions Results of Optimizations Results (Atlanta)

CHAPTER 4 CONCLUSIONS

4.1 Key Findings of the Scenario Modeling Exercise

As discussed in Section 2.5, there is a considerable amount of data and assumptions that were used to model the MSW management scenarios for each city in this study. Key data and assumptions used include a mixture of city-specific data that was collected through site visits and default data and assumptions that are built into the MSW DST. Table 2.5-1 presented a summary of the most important input parameters and whether they represent actual city data or MSW DST defaults. Cost data in particular were lacking in availability. Therefore, cost results may not be an accurate reflection of actual costs in a given city. The city of Lahore is one of the cities with least data availability, including cost and energy related data. The city of Atlanta is one of the cities with the best data availability. These city-specific data are carefully reviewed and some of them which are considered to be unreliable are modified into the model. For example, the cost for equipment and maintenance for landfill disposal in Conakry is not applied for the model because its value collected at the field is quite expensive than others. Operation and maintenance cost for the incineration plant in Shanghai is replaced to the MSW DST default because its value collected is much less than usual cost for incineration.

In addition, we compare the landfill cost with and without the land price in the cost analysis because usually the government does not pay for land in case the land is the government land.

As a modeling exercise, we were able to successfully input the city-specific data into the MSW DST and run both simulation and optimization type scenarios as presented in Section 3 of this report. In general, the following trends were observed through the scenario modeling exercise and examination of scenario results:

Cost:

- The lowest cost MSW management strategy appears to be landfill disposal. The highest cost MSW management strategy appears to be incineration without energy recovery.
- High land prices in some cities (e.g., Kawasaki) can significantly increase the cost of MSW management operations.
- Capital, labor and energy prices are keys in determining cost tradeoffs between manual and mechanical operations. For example, composting manual operations are more cost-effective than mechanical operations since those do not require any equipment, and labor is cheaper than energy in most cities. Should labor prices increase, this tradeoff can be minimized or reversed. Manual MRF operations are

less cost effective than mechanical MRF operations (Manual operations are 2- 4% more expensive), which seems to contradict previous statements. However, the cost difference is very small and due to manual operations being very labor intensive and still requiring equipment.

- Potential cost savings associated with materials and energy recovery are large and can significantly reduce the total cost of MSW management. Modeled revenues from the sale of recyclables ranged from US\$66- 197 per metric ton of recyclables. Modeled revenues from the sale of electrical energy, for example in case of incineration with energy recovery, ranged from US\$3- 59 per ton of waste incinerated.
- Markets for and market prices obtained for recyclables varies by city and causes significant variation in recycling costs among cities. For recycling, the revenue obtained from the sale of recyclables is dependent on available markets for recyclables. This is important because the revenue stream from the sale of recyclables can significantly lower the net cost of the recycling scenarios. If price data were not found a US\$0 market value was used for the recyclables that has no market in the surveyed area, and defaults or prices for similar materials are used for the recyclables which have the market. Conakry is the city with the least recyclable price data available.
- Scenarios with high or low capture of recyclables will vary in cost depending on the amount of waste going to each of the selected management scenarios. In general, scenarios with higher capture of recyclables are less expensive since this increases the revenues from material recovery and reduces landfill costs. However, this behavior can be reversed by the lack of revenues/markets from recycling and/or very low landfill disposal costs.

Energy:

- The strategies that appeared to be more effective minimizing net total energy consumption included recycling of key materials (e.g., metals) and incineration with energy recovery.
- The quantity and composition of recyclables in the MSW stream is key in determining energy savings associated with recycling. For example, metals production is very energy intensive so recycling metals achieves large energy savings. A city that has a larger percentage of metals, and other energy intensive materials, in its MSW stream can thus achieve higher levels of energy savings from recycling.
- As expected, manual labor-based operations (MRF and compost) generally consume less energy than mechanical-based operations.
- The amount of energy that can be recovered via incineration depends on the MSW composition and characteristics, and higher income countries and major urban areas within countries of higher income have more plastic, paper, cardboard, and textile wastes that drive up calorific values of the wastes. For many of the Bank member

cities (i.e., excluding Atlanta and Kawasaki), the MSW stream generally has a low average BTU/ton value due to high levels of food waste and other wet organics waste, as well as inerts (ash and soil) in some cases. In general, incineration needs to be more than 1500 kcal/kg of lower calorific value to sustain combustion, and few cities in developing countries have wet, as received, waste that reaches this calorific value.

- Energy offsets by virtue of incineration with energy recovery can be significant and are directly dependent on the electricity grid mix used for each city. A city that relies on fossil-based electricity production will achieve higher levels of energy savings than a city with hydroelectricity or other renewable electricity production systems.

Emissions:

- The waste management strategies that appeared to be most effective minimizing emissions included recycling of key materials (e.g., metals) and incineration with energy recovery.
- The life cycle environmental burdens associated with electricity consumption are highly variable between the cities studied and dependent on city-specific electricity grid mixes of fuels. For example, a city that relies on fossil-fuel based electricity production will have higher emissions associated with electricity use than a city that relies on renewable electricity production (e.g., hydroelectricity).
- Energy consumption (fuels and electricity) is a key indicator for criteria type air emissions and emission savings or offsets by virtue of materials and/or energy recovery. Some cities (e.g., Katmandu) have high percentages of hydroelectricity production and thus in these cities, electricity-related emissions are zero.
- Cities with high amounts of plastics in their waste stream will have higher GHG emissions from any waste management strategy involving combustion.
- Landfill gas management can greatly reduce landfill-related GHG emissions. This can be observed by comparing the results of landfill disposal with gas venting to the results of landfill disposal with gas flaring or gas-to-energy.
- Landfill diversion (via recycling, composting, incineration) of organics can greatly reduce net GHG emissions by avoiding landfill disposal and subsequent production of landfill gas.

4.2 Discussion of Sensitivity for Parameters of Interest

Up-front in the scoping phase of the study, several parameters were identified as parameters of interest in regards to their overall impact on the total MSW management system results. The sensitivity of the total results to these parameters were evaluated using the scenario results and are discussed below.

- **Landfill gas collection efficiency:** For this study a landfill gas collection efficiency of 70% was used. Landfill gas emissions (for cases where landfill gas is managed via flaring or energy recovery systems) are highly dependent on gas collection efficiency. A lower efficiency would directly increase landfill gas emissions and a higher efficiency would directly reduce landfill gas emissions.
- **Fuel Price:** Fuel prices will primarily affect the cost for waste collection and other operations that utilize fuel-burning equipment (e.g., compost windrow turner).
- **Electricity cost:** Electricity prices will primarily affect the cost for operations that use power-based equipment such as MRFs that are equipment (balers, screens, magnet, conveyor belts, etc.) intensive. Other operations, such as waste collection, will not be significantly impacted by electricity costs.
- **Price at which electricity can be sold back to the grid:** The price for electricity sale directly affects the net cost for landfill with gas-to-energy systems and incineration with energy recovery operations. The cost of these operations can be significantly reduced if a good sale price for electricity produced can be negotiated. In general, the results showed a 34- 43% decrease in cost for landfills and 15- 47% decrease in cost for incineration due to electricity sale revenues.
- **Labor costs:** Labor cost will primarily affect labor intensive operations such as waste collection and manual recycling/composting. In the cities analyzed, labor wages ranged from 0.08- 18\$US/hour.
- **Carbon Finance pricing:** The prices obtained for reduction of carbon emissions can significantly impact total costs for the waste treatment options. The results of this modeling exercise did not consider revenues from carbon pricing, which would be considered if comparing a given management strategy against a baseline strategy. For example, a simple exercise comparing the emissions from a worst case scenario in which all the waste is sent to a LF with gas venting vs. a best case carbon minimization scenario indicate that revenues from carbon pricing may range from US\$516,000- 2,323,000 among the studied cities using a carbon price of 12 \$US/MTCE.
- **Recyclables market price:** The availability of markets and prices obtained for the sale of recyclable varies by city and by the composition of recyclables in the MSW stream. For some cities, there are well established markets and good prices. In other cities, there are poor markets and low (or no) prices. Revenues obtained from

the sale of recyclables ranged from US\$66- 197 per metric ton of recyclables.

- **Compost market price:** The availability of markets and prices obtained for the sale of compost product varies by city. For some cities, there are well established markets and good prices. In other cities, there are poor markets and low prices. Revenues obtained from the sale of compost product ranged from US\$15- 60 per metric ton of the compost products.
- **Land price:** The land price impacts significantly on the overall cost of landfill disposal. For example, Kawasaki, which is the city with the highest land costs, has also the highest landfill overall cost even though its O&M costs are relatively low compared to other cities. Land price are usually not paid when the landfill is constructed at the government land. Therefore, we calculated the net total cost in all scenarios without land price for the landfill cost.

4.3 Appropriateness of Future Holistic analysis of Waste Management in Bank Member Countries

This study was a groundbreaking challenge that has tried to confirm whether or not the MSW-DST developed jointly by the US EPA and RTI and developed based on the SWM experiences and conditions in the US could be useful if applied to the cities in the developing countries.

In summary, the study confirmed that the MSW DST can play an important role for the decision making of the municipal solid waste management in those cities. However, it should be said that the existing MSW DST needs to be more tailored so as to conform with the actual conditions of those cities when preparing an individual detailed solid waste management plan.

In the development of this kind of simulation model, , there are often many gaps in the baseline data that a developer of the model does not know about the fields of solid waste management, and in these instances the developer has no option but to use the default settings, which can often be unsuitable to the city in question. In other words, the developer should understand the actual situation of the SWM practices at the target city, in addition to key aspects affecting cost and disposal techniques, such as waste composition, moisture content, fuel prices and so forth. Furthermore, users of the model, such as decision makers and SWM staff should similarly understand the essence of the model and the effects of using or overriding the default values contained within the model.

The result of the study should therefore be widely released to the concerned people, as the latest frontiers of SWM decision making, thus encouraging further additions to and verifications of default data. Good baseline data to override the US-based defaults is key to the accurate functioning of the model.

Needless to say, when planning the waste management system of a developing country, the information that is the most necessary for the decision-maker is cost. However the cheapest options such as open dumping or open burning cause severe environmental pollution and unsanitary conditions, and adoption of such scenarios is definitely not better choice for the decision makers who need to have the backing of their people because secure of the hygiene circumstances is one of the most important public services that is often committed by the decision makers.

Therefore, the present conditions in cities of many developing countries are such that the landfill option is the cheapest realistic alternative to open burning or dumping.

When preparing the solid waste disposal plan, in general, several disposal options are compared In order to assess the feasibility using cost benefit analysis for the final decision. Because it is usually difficult to estimate such benefits, especially when putting the currency

value on it, the proposed project might be given the green light to go ahead when the project is seen to be feasible by an economic analysis that considers some external cost as the benefit, even though it is not feasible financially.

In this regard, MSW DST can surely bring much considerable information, such as cost, energy consumption, carbon emissions and PM emissions by different disposal alternatives such as landfill, incineration, composting and material recovery, to the decision makers.

Three points that the decision makers who could take such information may be facing are;

Firstly, alternatives showing better results from the views of energy consumption, carbon emissions and PM emissions are not always the cheapest options. It is hard to the decision makers to adopt such costly options unless some financial policy will be put on such efforts to reduce of environmental impacts.

Secondly, sufficient capacity for the introduction and operation of the selected disposal options are needed. For example, in order to adopt the incineration with energy recovery option with the expectation of achieving a reduction of total net cost and total energy consumption via sales of the energy produced, a large amount of investment and advanced skills for the operation of the plant should be available.

Lastly, expected offsets by energy recovery or material recovery are not usually a direct benefit for the decision makers of the target city. In addition, a certain judgment for the economic perspectives should be also required because the oil price and sales price of recycled materials will always fluctuate.

It is also stressed that the reliability of SWM and associated data which are inputted to the model should be secured. Default values should be also tailored to reflect the actual situation of the city in the developing countries.

The consulting team collected as much data as possible from the field visits in about two weeks per city, with some follow-up communications, but these inputs were in practice insufficient to optimally fulfill the model run. A considerable limitation of data availability at the selected cities was encountered even though those cities are considered to be representative cities with better SWM management than others in the regions. Therefore, other data sources such as JICA, PAHO and METAP were also reviewed. Historical data availability is commonly difficult to obtain in developing cities, as the management authorities frequently have little capacity to gather and store accurate data, and so any further application of the model should initiate a data collection programme well in advance.

This study relied on available data in the target cities. While the level of detail of analysis is adequate to indicate how technologies and scenarios compare, more detail would normally be required for deciding on the most cost-effective technology that addresses local preferences to optimize energy security, land use minimization, carbon reduction, particulate reduction, materials recovery, etc. For future use of the model beyond this study, when a city would like to compare the disposal options of the waste in detail using MSW DST, more detailed data will be recommended.. For example, as clearly understood from the

experiences of JICA development studies, a certain amount of input of human resources, time and money are necessary to conduct the waste quantity and composition survey.

Though it is clear that even the basic surveys required for the detailed planning of solid waste disposal needs a large sum of investment, the general guidance utilizing the result of this study can be considered a useful tool for many cities to grasp the general perspectives of appropriate waste disposal options.