BUILDING LOW EMISSION ALTERNATIVES TO DEVELOP ECONOMIC RESILIENCE AND SUSTAINABILITY PROJECT (B-LEADERS)

PHILIPPINES MITIGATION COST-BENEFIT ANALYSIS

November 2015

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Waste Sector Results

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ACRONYMS

ADB	Asian Development Bank
ALU Software	Agriculture and Land Use Greenhouse Gas Inventory Software
ASEAN	Association of Southeast Asian Nations
AWD	Alternate Wetting and Drying
B-LEADERS	Building Low Emission Alternatives to Development, Economic Resilience, and Sustainability
BOD	Biochemical Oxygen Demand
BOI	Board of Investments
BRT	Bus Rapid Transit
BSWM	Bureau of Soil and Water Management
CBA	Cost-Benefit Analysis
CCC	Climate Change Commission
CDF	Controlled Disposal Facility
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COD	Chemical Oxygen Demand
CH_4	Methane
CVD	Chemical Vapor Deposition
DOC	Degradable Organic Component
DOCf	Fraction of Degradable Organic Component
EMB	Environment Management Bureau
EO	Executive Order
FOD	First Order Decay
GBD	Global Burden of Disease
GDP	Gross Domestic Product
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GPH	Philippine Government
GWP	Global Warming Potential
HFCs	Hydrofluorocarbons
IEA	International Energy Agency
iF	Intake fraction
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IRG	International Resources Group
JICA	Japan International Cooperative Agency
LEAP	Long-range Energy Alternatives Planning tool
LECB	Low Emissions Capacity Building (UNDP Program)
LED	light emitting diode
LFG	landfill gas
LGU	Local Government Unit
LNG	Liquefied Natural Gas

LULUCF	Land Use, Land Use Change and Forestry
MAC	Marginal Abatement Cost
MACC	Marginal Abatement Cost Curve
MCF	Methane Correction Factor
MER	Market Exchange Rate
MRF	Material Recycling Facility
MSW	Municipal Solid Waste
MVIS	Motor Vehicle Inspection System
mW	megawatt
N	Nitrogen
NAMA	Nationally Appropriate Mitigation Action
NCSB	National Statistical Coordination Board
NEDA	National Economic and Development Authority
NF_3	Nitrogen Trifluoride
NGO	Non-governmental Organizations
NMVOC	Non-Methane Volatile Organic Compounds
N_2O	Nitrous Oxide
NO_x	Nitrogen Oxides
NPV	Net Present Value
NREP	National Renewable Energy Program
NSWMC	National Solid Waste Management Commission
OD	Open Dumpsite
OECD	Organization for Economic Cooperation and Development
O&M	Operation and Maintenance
OX	Oxidation factor
PDP	Philippine Development Plan
PFCs	Perfluorocarbons
PISI	Philippine Iron and Steel Institute
PM	Particulate Matter
PSA	Philippines Statistics Authority
RA	Republic Act
SLF	Sanitary Landfill Facility
SWDS	Solid Waste Disposal Site
SWM	Solid Waste Management
SO_2	Sulfur Dioxide
SF_6	Sulphur Hexaflouride
Ton	Metric ton, 1,000 kilograms
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollars
VSL	Value per Statistical Life
WEEE	waste electrical and electronic equipment
WtE	waste-to-energy
WW	waste water

V. WASTE

V.1 EXECUTIVE SUMMARY

As the Philippine economy continues to expand, the Government of the Philippines is working to address the sustainability and greenhouse gas (GHG) emission challenges related to sustaining this growth. As a part of this effort, the Climate Change Commission (CCC) partnered with the United States Agency for International Development (USAID) to develop the quantitative evidence base for prioritizing climate change mitigation by conducting a cost-benefit analysis (CBA) of climate change mitigation options. An economy-wide CBA is a systematic and transparent process that can be used to evaluate the impact of potential government interventions on the welfare of a country's citizens. Thus, the CBA is well-suited for the identification of socially-beneficial climate change mitigation opportunities in the Philippines.

The CBA Study is conducted under the USAID-funded Building Low Emission Alternatives to Develop Economic Resilience and Sustainability (B-LEADERS) Project managed by Engility Corporation. The scope of the CBA covers all GHG emitting sectors in the Philippines, including agriculture, energy, forestry, industry, transport, and waste. The assessment is carried out relative to a 2010-2050 baseline projection of the sector-specific GHG emissions levels. The evaluation of the mitigation options covers the period spanning 2015-2050, except for the forestry where costs are assessed starting in 2010.

For each sector, the CBA evaluates a collection of nationally-appropriate mitigation options. To this end, each option is characterized in terms of:

- **The direct benefits** that are measured by the expected amount of GHG emissions reduced via the option. These GHG emission benefits are quantified, but not monetized;
- **The costs** associated with the mitigation option that can be quantified and monetized; and
- **The co-benefits** associated with the mitigation option that can be quantified and monetized. Depending on the option, the co-benefits may include beneficial economic/market impacts and non-market impacts.

The CBA employs two tools that are already being used by stakeholders in the country:

- **The Long-range Energy Alternatives Planning (LEAP) Tool** – LEAP is a flexible, widely used software tool for optimizing energy demand and supply and for modeling mitigation technologies and policies across the energy and transport sectors, as well as other sectors.
- **The Agriculture and Land Use Greenhouse Gas Inventory (ALU)** Software which was developed to guide a GHG inventory compiler through the process of estimating GHG emissions and removals related to agriculture, land use, land-use change, and forestry (LULUCF) activities.

The CBA is performed predominantly in the LEAP tool. The estimates of the agriculture and forestry sector GHG emissions are computed in the ALU tool and subsequently fed to LEAP. For some of the mitigation options, the estimates of costs and benefits are developed externally, with the LEAP model linking to the relevant datasets.

This Report represents the second update on the CBA model development work. It contains:

- A description of methods and waste sector GHG emissions for the base year of 2010 and for the baseline projection spanning 2010-2050;
- A description of mitigation options evaluated for the waste sector;
- Estimates of the option/activity-specific direct benefits (i.e., the amount of GHG emissions reduced) as well as costs and co-benefits of the mitigation options for the 2015-2050 time period, for which the Study Team had already obtained the data;
- Where relevant, estimates of indirect economic impacts and non-market co-benefits (e.g., public health) of the analyzed mitigation options; and
- Where relevant, estimates of quantifiable energy security, employment, and public health-related gender impacts for the analyzed mitigation options.

This study builds on the output of the series of consultations conducted from February until July of 2015. The results of these consultations were vetted by CCC and stakeholders in each of the relevant sectors. As such, this does not include results of discussions, new assumptions and data collected after July 2015. An updated version of these report shall be done in consultation with the relevant national government agencies led by the CCC and hopefully wlll reflect outcome of the Conference of Parties (COP) in Paris where CCC played a key role in the Philippine Delegation.

Table V. 1. Direct Costs and Cost per Ton of Waste Sector Mitigation Options Excluding Co-benefits summarizes the direct costs and benefits of mitigation options, including changes in capital, operating and maintenance (O&M), implementation, and fueling costs as well as GHG emissions. An option's sequence number indicates its relative mitigation cost-effectiveness, accounting for direct costs and benefits only and assuming no interactions with other options. The lower the sequence number, the more cost-effective the option—i.e., the lower the direct cost per tonne of GHGs reduced. In the CBA, the ranking provided by sequence numbers is used in a separate assessment of interactions between options, called a retrospective systems analysis. This analysis assumes that options are implemented in the order given by the sequence numbers, and it defines the impacts of an option (costs and GHG abatement) as the marginal changes after the option is implemented.

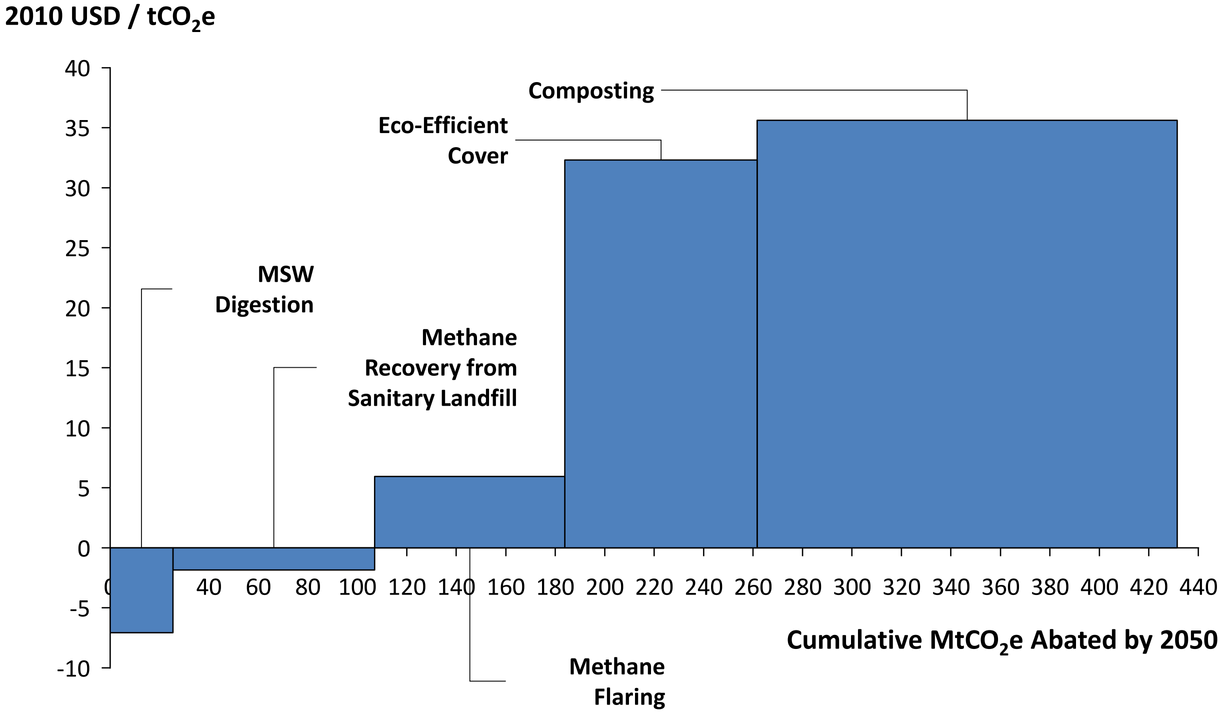
Figure V. 1 provides the MACC for the waste mitigation options analyzed in the CBA. The MACC visually illustrates the cumulative abatement potential and costs per ton if all the waste mitigation options are implemented. It is designed to take into account interactions between mitigation options. Implementing certain options together can lower (or increase) their total effectiveness. Figure V. 1 shows that implementation of all the waste mitigation options included in the retrospective analysis could result in total cumulative emission reductions of about 432 $MtCO_2e$ compared with the baseline projection from 2015 - 2050.

Table V. 1. Direct Costs and Cost per Ton of Waste Sector Mitigation Options Excluding Co-benefits

Sector	Sequence Number of Mitigation Option*	Mitigation Option	Incremental Cost (Cumulative 2015-2050) [Billion 2010 USD] Discounted at 5%			Incremental GHG Mitigation potential (2015-2050) [$MtCO_2e$]	Incremental Cost per Ton Mitigation (2015-2050) [2010 USD] *without co-benefits*
			Capital, O&M, Implementation Costs	**Cost of Fuel and Other Inputs**	**Total Net Cost**		
Symbol					**A**	*B*	*C*
Formula							*(A*1000)/B=C*
Waste	14	MSW Digestion	0.21	-0.39	-0.18	25.53	-7.08
	20	Methane Recovery from Sanitary Landfills	0.12	-0.27	-0.15	81.51	-1.85
	22	Methane Flaring	0.46	–	0.46	76.89	5.95
	28	Composting	6.05	–	6.05	169.88	35.60
	29	Eco-Efficient Cover	2.51	–	2.51	77.75	32.30

*Sequence Number of Mitigation Options refers to the sequential order in which individual mitigation options are initiated as described by the retrospective systems approach. In the retrospective systems approach, mitigation options are compared to the baseline as stand-alone options and then ranked or sequenced according to their cost per ton of mitigation (without co-benefits) from lowest cost per ton of mitigation to highest cost per ton of mitigation. Then the incremental cost and GHG mitigation potential of mitigation options is calculated as compared to the baseline and all prior sequenced mitigation options. The advantage of this approach is that the interdependence between a given mitigation option and every other previous option on the MACC is taken into account.

Figure V. 1. Marginal Abatement Cost Curve for Waste Sector



There are several non-market and market co-benefits which can add to the cost-effectiveness of a mitigation option. For this report the team have estimated the following co-benefits:

- Non-market co-benefits: the value of air quality-related improvements in public health as well as the value of congestion relief; and,
- Market co-benefits: the value of timber and agroforestry commodities obtainable from reforested areas (designated for production) as well as the income generated from recyclables and composting.

Table V. 2 summarizes the value of co-benefits that could be monetized for the energy mitigation options. Column J shows the value of these benefits, normalized per ton of GHG mitigation potential. These "co-benefits only" results exclude direct costs; they are combined with direct costs and benefits in Table V. 3.

Table V. 2. Monetized Co-Benefits of Mitigation Options in the Waste Sector

Sequence Number of Mitigation Option	Mitigation Option	Incremental Co-benefits (Cumulative 2015-2050) [Billion 2010,USD] Discounted at 5%				Incremental Cost per Ton Mitigation (2015-2050) [2010,USD] *co-benefits only* [2]
		Health	Congestion	Income Generation	**Total Co-benefit**	
Symbol		*F*	*G*	*H*	*I*	*J*
Formula					*sum(F,G,H)=I*	*-I/D=J*
14	MSW Digestion	0.183	–	–	0.183	-7.17

20	Methane Recovery from Sanitary Landfills	-0.127	–	–	-0.127	1.56
22	Methane Flaring	–	–	–	0.00	0.00
28	Composting	–	–	6.5	6.5	-38.26
14	MSW Digestion	–	–	–	0.00	0.00

Notes: – indicates inapplicability of a given co-benefits category

Table V. 3combines the cost per ton without co-benefits (Column E) with the cost per ton of co-benefits (Column J from Table V. 2).

Table V. 3. Monetized Co-Benefits of Mitigation Options in the Waste Sector

Sequence Number of Mitigation Option[1]	Mitigation Option	GHG Mitigation Potential ($MtCO_2e$)[3]	Cost per Ton CO_2e Mitigation (2010 USD)[2]			Net Present Value Excluding Value of GHG Reduction (Billion 2010 USD)[2]
			without co-benefits	co-benefits only[4]	with co-benefits[5]	
		A	*B*	*C*	*D = B+C*	*E = –D * A/1000*
14	MSW Digestion	25.53	-7.08	-7.17	-14.25	0.36
20	Methane Recovery from Sanitary Landfills	81.51	-1.85	1.56	-0.29	0.02
22	Methane Flaring	76.89	5.95	0.00	5.95	-0.46
28	Composting	169.88	35.60	-38.26	-2.66	0.45
29	Eco-Efficient Cover	77.75	32.30	0.00	32.30	-2.51

Abbreviations:
$MtCO_2e$ - Million metric tons of carbon dioxide equivalent
GHG – Greenhouse gas
USD – U.S. dollar

Notes:

[1] Refers to the sequential order in which the mitigation option is introduced in the retrospective analysis. In this analysis, mitigation options are compared to the baseline as stand-alone options, and then ranked according to their cost per ton mitigation (excluding co-benefits) from lowest cost per ton mitigation to highest cost per ton mitigation. The cost and GHG mitigation potential of a given mitigation option is calculated relative to a scenario that embeds all options with lower cost per ton mitigation.

[2] The costs and co-benefits expected to occur in years other than 2015 were expressed in terms of their present (i.e., 2015) value using a discount rate of 5%.

[3] The GHG mitigation potential is a total reduction in GHG emissions that is expected to be achieved by the option during 2015-2050.

[4] The co-benefits for the waste sector include income from composting activities and human health benefits due to reduced air pollution from the energy sector.

[5] Negative value indicates net benefits per ton mitigation. This excludes the non-monetized benefits of GHG reductions.

V.2 BASE YEAR GHG EMISSIONS

V.2.1 Methods and Assumptions

The 2010 base year emissions profile for the waste sector is divided into two primary sub-sectors: solid waste and wastewater. Solid waste and wastewater include residential, commercial, institutional, and industrial sources; excluding industrial wastewater treated on-site at industrial facilities.The Study Team developed an MS Excel spreadsheet-based model for estimating GHG emissions from solid waste and wastewater, which was calibrated based on the best and most recent available data on solid waste and wastewater generation, disposal, and treatment in the Philippines along with the IPCC guidelines for national GHG inventories (IPCC, 2006). Consistent with the IPCC guidance, the model incorporated the FOD method recommended by the IPCC for estimating CH_4 emissions from solid waste.

V.2.1.1 Solid Waste

In order to estimate emissions and abatement potential of various mitigation options for solid waste, a detailed characterization of solid waste management over the past 50 years is necessary as solid waste disposed in landfills continue to generate CH_4 over time at a rate determined by the type of landfill and the specific mix of waste landfilled. The Study Team developed a spreadsheet-based model to determine the solid waste profile for 2010 and prior years that can also be used for projecting emissions through 2050.

This historical solid waste profile developed by the Study Team includes a representation of: 1) solid waste generation, 2) solid waste segregation, and 3) solid waste disposal. Since there are no comprehensive data sources describing the annual national total quantity of solid waste generated by individual source categories in the Philippines, the CBA model was designed to estimate this information using data from available studies. The model further characterizes the amount of waste generated by type (e.g., biodegradable, recyclable, residual) and the mix of materials present in the waste (e.g., paper, plastic, metal, organics, etc.). It also describes the disposition of waste (i.e., waste segregation), by source category and material, in terms of the quantity of waste that is collected and recycled, composted, or disposed at a SWDS, or left uncollected.[1] Finally, the solid waste disposal model estimates the type and quantity of disposed waste that is disposed at different types of SWDS, including OD, CDF, and SLF.

A characterization of solid waste disposed at SWDS, both for the 2010 base year as well as prior decades, is required to support the emissions estimation methodology for solid waste. The Study Team based the methodology for estimating CH_4 emissions from SWDS on the FOD method. The FOD method requires data to be collected or estimated for historical disposals of waste over a time period of three to five half-lives (i.e., the amount of time required for half of a given quantity and type of waste to decompose) in order to achieve an acceptably accurate result. It is therefore good practice to use disposal data for at least 50 years as this time frame provides an acceptably accurate result for most typical disposal practices and conditions (IPCC, 2006). As described further below, the model developed for the CBA uses a combination of available data on waste generation and disposal rates and extrapolation to characterize waste disposal over the past 50 years.

V.2.1.1.2 Solid Waste Generation

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[1] This includes waste that is not accounted for in the waste stream. This waste may be disposed of in a variety of ways including disposal in rivers or creeks, buried, fed to animals, burned, and others (JICA, 2008).

Waste generation is defined in RA 9003 as the act or process of producing solid waste. For the furtherance of the objectives of RA 9003, DENR through its EMB, and in cooperation with NSWMC, prepared a six-year National Solid Waste Management Status Report to reflect the level of implementation of the law and to guide decision-makers and implementers on both the gains and challenges on solid waste management in the Philippines. This report, “Consolidated Regional Brown Environmental Reports 2008 – 2013” is a key data source for waste generation and other inputs required to support the solid waste analysis (NSWMC, 2014).

Waste generation rates are typically expressed as the daily generation rate on a kilograms-per-person basis. In 2010, it was reported that the Philippines generated between 0.10 and 0.79 kilograms of solid waste per-person, per-day, depending on the region. Metro Manila and other highly urbanized areas typically have the highest per-capita waste generation rates. The national, population-weighted average per-capita waste generation value was 0.40 kg/person/day for the entire Philippines in 2010 (NSWMC, 2014). Based on these figures, total national waste generation in 2010 is estimated at 36,935 tons per day in 2010, or about 13.48 million tons per year (NSWMC, 2014).

Historical estimates of solid waste generation were obtained from Kojima and Michida (2011) and NSWMC (2014) to develop a historical profile of solid waste generation.[2] Total waste generation per day for 2000 and 2005 was scaled based on the relationship between the 2010 estimate of 36,935 tons per day, and the prior 2010 forecast in Kojima and Michida to account for differences in the 2010 and older 2000 and 2005 estimates. Values for intervening years 2001 – 2004 and 2006 were linearly interpolated based on the 2000, 2005, and 2010 estimates. Values for 2007 – 2009 were obtained directly from NSWMC (2014). Finally, annual values from 1960 – 1999 were estimated working backwards from the 2000 estimate based on the annual percentage change in population.

Table V. 4. Historical Total Waste Generation Estimates, 1990-2010

Solid Waste Metric	1990	1995	2000	2005	2010
National Solid Waste Generation (tons/year)	7,257,620	8,229,059	9,197,614	11,232,762	13,481,326
Solid Waste Generation Rate (kg/person/day)	0.328	0.329	0.329	0.362	0.400

Waste generation in 2010 is attributed to four source categories – Residential, Commercial, Institutional, and Industrial – based on average data from 2008 – 2013 presented in NSWMC (2014).[3] These data describe the percentage of waste generated by each source category. The historical data are used directly for years 2003 – 2006. Year 2007 – 2010 assume the 2010 proportions across source sectors due to anomalies in the data during 2007 – 2009. The 2003 proportions by source sector are used for all

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[2] See Table 1 in Kojima and Michida (2011), which cites the National Solid Waste Status Report, December 2004; National Solid Waste Management Framework, Pre-final Draft, March 2005.

[3] Eight of the seventeen EMB Regional Offices (ROs) provided information on the sources of municipal solid waste within their respective jurisdictions that, together with supplementary references, is a sample that represents about 63% of the country’s population (NSWMC, 2014).

years prior to 2003. Figure V. 2 summarizes each sector's contribution to total waste generation for 2010.

The largest quantity of waste comes from households (56.7%). Commercial sources such as general merchandise stores and restaurants contribute 27.1%. About 12.1% of waste originates from institutional sources such as government offices, educational and medical institutions while the remaining 4.1% represents municipal wastes from the industrial or manufacturing sector (NSWMC, 2014).

Figure V. 2. Total Waste Generated by Source Sector, 2010 (Percent)

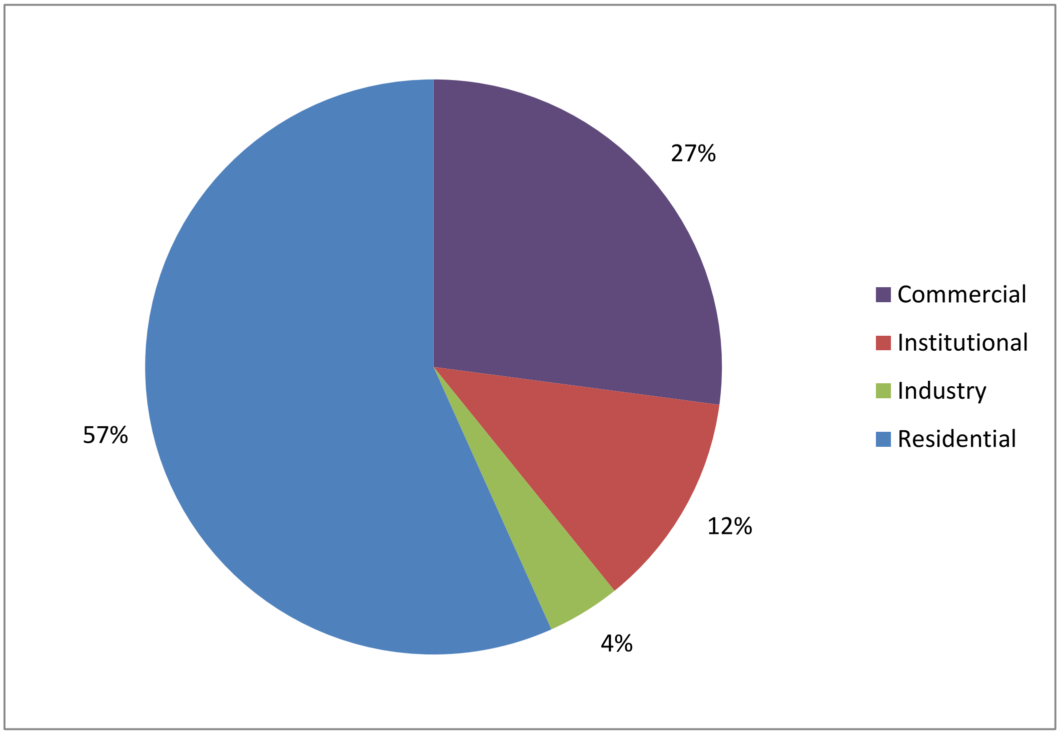
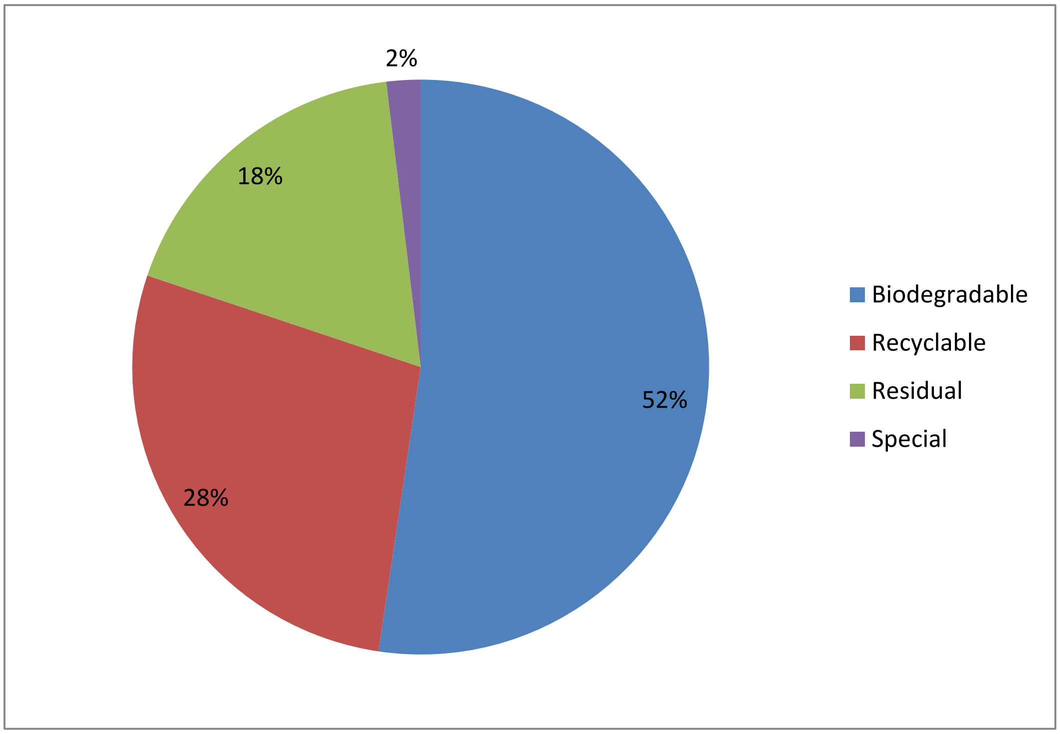


Figure V. 3 summarizes the overall composition of waste by type, nationally, in 2010. More than half of the solid waste generated in the country is biodegradable in nature. Typical bio-waste consists of kitchen or food waste and yard or garden waste. About 27.78% of the waste is classified by local government units (LGUs) as recyclable materials. Household healthcare waste, waste electrical and electronic equipment (WEEE), bulky waste and other hazardous materials that go along with the municipal waste stream are classified as special wastes and contribute around 1.93% by weight. Finally, residuals have been found to make up 17.98% of solid waste generated (NSWMC, 2014).

These data are generally consistent with other sources. For example, the waste analysis and characterization study of the municipality of Alabel in 2008 indicated 71% biodegradable, 15.6% recyclable, 13% residual, and 0.6% special (NSWMC, 2012). A study by ADB indicates that about 56% of the waste may be biodegradable waste or compostable, 28.4% as recyclable, and 15.6% as remaining materials that cannot be recycled and have to be disposed (ADB, 2003).

Figure V. 3. Total Waste Generated by Type, 2010 (Percent)



The Study Team disaggregated waste generation by source category and waste material based on data from the 2003 waste analysis and characterization study performed in 2003 for Makati, Muntinlupa, Pasig, Quezon, and Valenzuela (ADB, 2003). Based on the results of that study, the weighted average composition of waste, by sector, across the cities included in the study, weighted by their population was estimated. The resulting 2003 composition by sector and material was assumed for 2010 and all historical years (

Table V. 5. Total Solid Waste Generation by Material, 2010 (% Weight)). It is important to account for differences in the quantity and type of waste generated in different sectors because recycling, composting, and disposal practices can also vary by sector, and those factors ultimately determine the waste stream disposed of in SWDS.

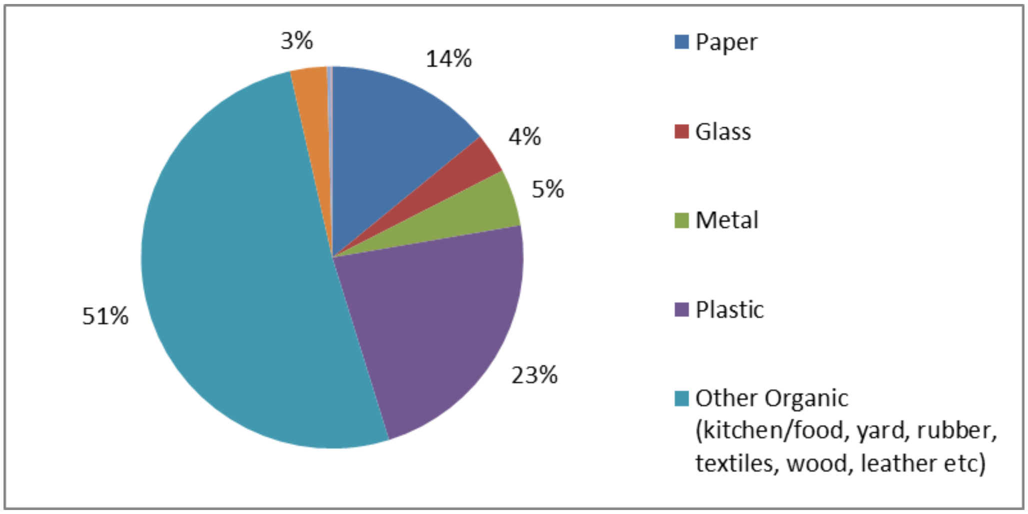
Table V. 5. Total Solid Waste Generation by Material, 2010 (% Weight)

Waste Material	Source Category			
	Residential	Commercial	Institutional	Industrial
Paper	11.5%	18.6%	30.8%	14.3%
Glass	3.8%	2.3%	2.1%	2.9%
Metal	5.6%	2.7%	2.3%	3.5%
Plastic	22.9%	21.4%	25.0%	29.5%
Other Organic (kitchen/food, yard, rubber, textiles, wood, leather etc.)	52.6%	52.7%	34.3%	35.8%
Other Inorganic (rock, concrete, soil, sand, ash etc.)	3.1%	2.0%	4.6%	11.7%
Hazardous	0.3%	0.3%	0.2%	1.9%
Special	0.1%	0.0%	0.6%	0.3%
Total	100.0%	100.0%	100.0%	100.0%
Source: ADB, 2003				

Figure V. 4 summarizes the overall composition of waste by material, nationally, in 2010. The overall percentage by material is estimated as the weighted average of each material across all sectors, weighted by each sector's percent contribution to total waste generation. Several other sources show consistent allocations across material categories in the overall waste stream. Kojima and Michida (2011) indicated 17% paper, 16% plastic, 3% glass, 5% metal, and a majority in the other organic category. A prior solid waste characterization of Metro Manila (JICA, 2001) indicated 19% paper, 17% plastic, 6% metal, and a majority organic. Lastly, the country presentation, presented by Emelita C. Aguinaldo

(Executive Director, NSWMC), as part of the Second Meeting of the Regional 3R Forum in Asia cited a composition consisting of 50% food/organics, 15% paper 25% plastics, and 5% metals by weight.

Figure V. 4. Total Waste Generated by Material, 2010 (% Weight)



V.2.1.1.2 Solid Waste Segregation

Next, the Study Team developed a waste segregation profile for the material-level characterization of waste generation in each source category. This module describes the proportion of each material in each sector that is: 1) recycled, 2) composted, 3) disposed of at a SWDS, or 4) uncollected (i.e., unaccounted-for waste).

Sections 32 and 33 of RA 9003 provide for the establishment of a Materials Recovery Facility (MRF) in every barangay or cluster of barangays. The MRF shall be designed to receive, sort, process and store compostable and recyclable material efficiently and in an environmentally sound manner. Compliance with the MRF provision of RA 9003 has been increasing over time and is a key element for achieving the mandatory 25% waste diversion goal under RA 9003. According to the NSWMC, the percentage of barangays served by an MRF increased from 6.4% in 2008 to 18.9% in 2010, and continued increasing to 21% by 2012 (NSWMC, 2014).

Recycling refers to the conversion of used or waste materials through a process that make it suitable for beneficial use and for other purposes, and includes any process by which solid waste materials are transformed into new products in such a manner that the original products may lose their identity, and which may be used as raw materials for the production of other goods or services. According to Section 20 of RA 9003, recycling could be an approach to achieve the mandatory waste diversion requirements. Recycling may either be a component of a MRF or established as a standalone processing facility (NSWMC, 2014).

Recycling rate estimates for households and businesses, by material, for 2008 were obtained from *The Study on Recycling Industry Development in the Republic of the Philippines* (JICA, 2008). The 2008 estimates are assumed to also apply for 2008 – 2010. To develop estimates of recycling rates prior to 2008, several data points describing historical recycling rates in Metro Manila were obtained, which were more readily available than national-level rates. Metro Manila recycling rates for 1997, 2007 and 2008 were obtained from JICA (2008), at 25% and 28%, respectively. A 2003 estimate of 11% was obtained from ADB (2003). National-level recycling rates from 1997 – 2007 were then estimated based on the initial 2008 values and the change in recycling over time based on the Metro Manila estimates. Rates for all years prior to 1997 were assumed. Household rates were assumed for the residential and institutional sector, and business rates were assumed for the commercial and industrial sectors.

Table V. 6. Recycling Rates by Sector and Material, 2001 - 2010[4] (% of Total Quantity of Material Waste Generated, by Weight)

Sector and Material	National Recycling Rates									
year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Households										
Paper	11.2%	12.2%	13.2%	17.4%	21.6%	25.8%	30.0%	33.6%	33.6%	33.6%
Aluminum	10.5%	11.5%	12.4%	16.3%	20.3%	24.2%	28.2%	31.6%	31.6%	31.6%
Other Metals	6.9%	7.5%	8.1%	10.7%	13.2%	15.8%	18.4%	20.6%	20.6%	20.6%
Plastics	7.8%	8.5%	9.2%	12.2%	15.1%	18.1%	21.0%	23.5%	23.5%	23.5%
Glass	9.6%	10.4%	11.3%	14.9%	18.5%	22.0%	25.6%	28.7%	28.7%	28.7%
Businesses										
Paper	12.7%	13.9%	15.0%	19.8%	24.6%	29.3%	34.1%	38.2%	38.2%	38.2%
Aluminum	15.4%	16.8%	18.2%	24.0%	29.8%	35.6%	41.4%	46.3%	46.3%	46.3%
Other Metals	16.3%	17.7%	19.2%	25.3%	31.4%	37.5%	43.6%	48.8%	48.8%	48.8%
Plastics	11.0%	12.0%	12.9%	17.0%	21.2%	25.3%	29.4%	32.9%	32.9%	32.9%
Glass	9.5%	10.4%	11.3%	14.8%	18.4%	22.0%	25.6%	28.6%	28.6%	28.6%

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[4] Source: JICA, 2008; ADB, 2003; and CBA model estimates.

Composting refers to the controlled decomposition of organic matter by micro-organisms, mainly bacteria and fungi, into a humus-like product. According to Section 20 of RA 9003, composting could be a means to achieve the mandatory waste diversion requirements. Composting may either be a component of an MRF or established as a standalone processing facility. Typical small-scale composting in the Philippines is done in compost pits, tire towers, coconut shell stack, bottomless bins, clay pots and plastic sacks. Meanwhile, large-scale composting is done in windrows (by turning, passive aeration, active aeration and static piles), in-vessel (e.g., agitated beds, composting silos and rotating drum bioreactors), and through vermi- or worm composting. Through composting, it is estimated that the weight of organic waste could be reduced by 50% or more (NSWMC, 2014).

The Study Team assumed an overall segregation rate for biodegradable waste of 5% for 2010 and all historical year, based on consultations with NSWMC experts. This composting rate is the percentage of biodegradable waste generated that is segregated for composting. The weight of the compost produced from that waste is a function of the biodegradable waste-to-compost conversion factor of 50%, cited above (NSWMC, 2014 and ADB, 2003).

The Study Team assumed that the percentage of waste that is uncollected/unmanaged in the waste system is 10% in 2010 and all historical years. This waste is not recycled, composted, or sent to a SWDS, and is therefore unaccounted for at all points downstream of segregation in the solid waste system. This fraction of waste was removed proportionally from each waste category (i.e., the model assumed the composition of the uncollected waste is the same as the overall composition of waste generated). No GHG emissions are produced for this fraction of waste, though it can be a significant cause of other environmental hazards such as water pollution and flooding.

Waste disposal refers to the discharge, deposit, dumping, spilling, leaking or placing of any solid waste into or in any land while disposal sites refer to areas where solid waste is finally discharged and deposited. Even though disposal is the least preferred method in the waste management hierarchy, it remains an important functional element of the SWM system specifically to take care of residual waste (NSWMC, 2014). The key outcome of interest in the segregation module is the quantity of waste, by source sector and material that is disposed of at SWDS, which is the source of CH_4 emissions from the solid waste sector. This quantity is estimated, annually, as all waste – by sector and material – that is not segregated for recycling or composting, or uncollected waste (Table V. 7. Quantity of Solid Waste Disposed at SWDS by Sector and Material, in 2010 (Tons)).

Table V. 7. Quantity of Solid Waste Disposed at SWDS by Sector and Material, in 2010 (Tons)

Waste Sector and Material	Waste Disposed at SWDS, 2010 (Tons)
Residential	
Organic (food waste, garden, wood/straw, nappies, textiles)	3,421,154
Paper	496,265
Plastics, Other Inert	1,830,228
Hazardous	21,664
Special	5,730
Total	**5,775,041**

Institutional	
Organic (food waste, garden, wood/straw, nappies, textiles)	461,491
Paper	283,310
Plastics, Other Inert	384,352
Hazardous	3,015
Special	8,482
Total	**1,140,651**
Commercial	
Organic (food waste, garden, wood/straw, nappies, textiles)	1,638,698
Paper	351,970
Plastics, Other Inert	604,201
Hazardous	8,760
Special	769
Total	**2,604,398**
Industrial	
Organic (food waste, garden, wood/straw, nappies, textiles)	163,661
Paper	41,017
Plastics, Other Inert	169,432
Hazardous	9,601
Special	1,481
Total	**385,193**
Grand Total	**9,905,282**
Source: CBA model estimates	

Table V. 8. National Solid Waste Generation and Segregation Summary, 2010 summarizes the detailed national waste characterization developed for the 2010 base year. The model estimates more than 13.4 million tons of solid waste generated in 2010. The overall national segregation rate (including recycling and composting) is estimated at 16.5%, and the rate of disposal at SWDS is 73.5%, by weight.

Table V. 8. National Solid Waste Generation and Segregation Summary, 2010[5]

Waste Model Parameter	2010 Base Year Value
Total Solid Waste Generated (tons)	13,481,326
Total Segregation of Recyclables (tons)	1,875,375
Total Segregation of Biodegradable (tons)	352,537
Overall segregation rate	*16.5%*
Total Uncollected (tons)	1,348,133
Percent uncollected	*10%*
Total Disposed at SWDS (tons)	9,905,282
SWDS disposal rate	*73.5%*

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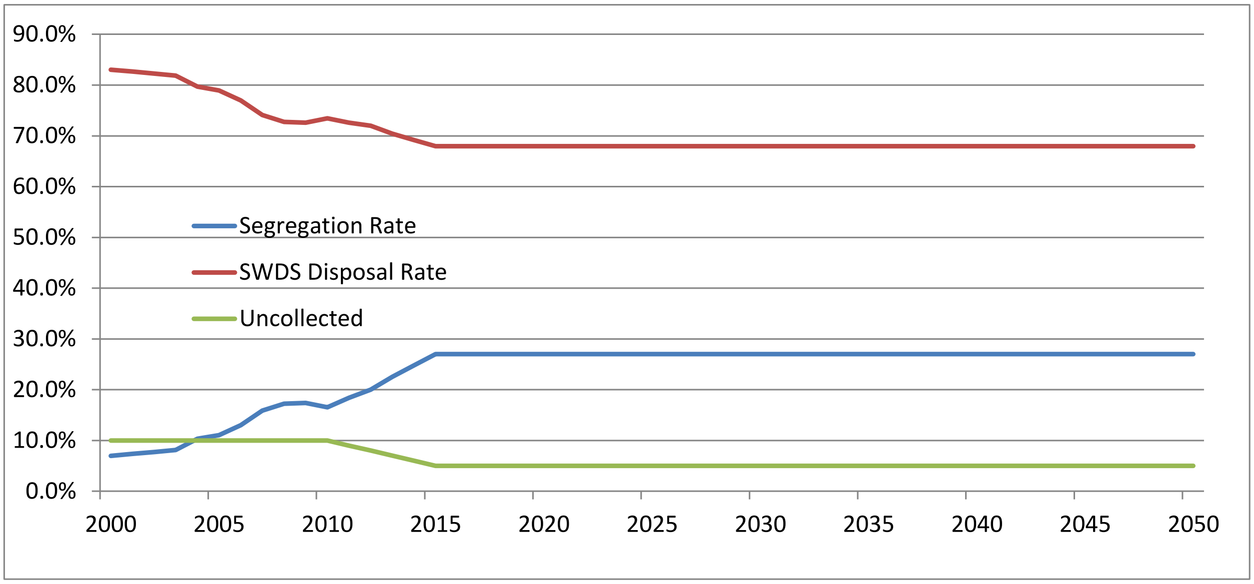
[5] Source: CBA model estimates

Figure V. 5 presents a portion of the historical time series developed above describing the overall SWDS disposal rate, recycling rate, and self-disposal rate. Notice that waste segregation for recycling and composting begins to increase significantly in 2002 – 2003 following initial implementation of the Ecological Solid Waste Management Act of 2000, with a corresponding decline in the rate of disposal at dumpsites.

Figure V. 5. Recycling Rate and Solid Waste Disposal Rate, 1995 - 2010 (% by Weight)



V.2.1.1.3 Solid Waste Disposal at SWDS

Before estimating the base year emissions associated with waste disposed at SWDS, an additional step is required to determine the quantity of waste disposed at *different types* of SWDS. Waste disposal practices vary in the control, placement of waste, and management of the site and therefore emissions vary based on differences in these practices. The emission estimation methodology includes an MCF, which accounts for the fact that unmanaged SWDS produce less CH_4 from a given amount of waste than anaerobic managed SWDS. In unmanaged SWDS, a larger fraction of waste decomposes aerobically in the top layer. Open and controlled dumpsites are assigned an MCF of 0.64 based on the weighted average MCF across DAO 2006-10 landfill categories reported in Gerstmayr and Krist (2012) (Table V. 9.

Weighted Average Methane Correction Factors for Open and Controlled Dumpsite Facilities). Sanitary landfill facilities are assigned an MCF of 1.0 based on the IPCC default value for an anaerobic, managed landfill (IPCC, 2006).

Table V. 9. Weighted Average Methane Correction Factors for Open and Controlled Dumpsite Facilities[6]

Landfill Size Category		Methane Correction Factor	Share of Category (Percent)
1	< 15 tons/day	0.4	47
2	15 – 75 tons/day	0.5	11
3	75 – 200 tons/day	0.8	12
4	> 200 tons/day	1.0	30
Weighted average MCF: 0.64			

Prior to the passage of RA 9003, almost all solid wastes were disposed at dumpsites. Dumpsites are mere open spaces hastily identified as local disposal areas without the proper engineering measures or pollution control systems. Even at present, majority of cities and municipalities maintain a 'collect and dump system,' where mixed wastes are brought to the dumpsites.

RA 9003 differentiates an OD to a CDF. An OD refers to a disposal area wherein the solid wastes are indiscriminately thrown or disposed of without due planning and consideration for environmental and health standards. Meanwhile, CDF refer to disposal sites at which solid waste is deposited in accordance with the minimum prescribed standards of site operation. RA 9003 mandates the closure and rehabilitation of all dumpsites and construction of SLFs instead. SLFs are disposal facilities with impermeable liners to prevent liquid discharges from polluting ground and surface waters (NSWMC, 2014).

The percentage of waste that is disposed at in each type of facility for 2010 was estimated based on consultations with the NSWMC and data provided in NSWMC (2014). The resulting estimates for 2010 are 34% CDF, 20% SLF, and 46% OD. NSWMC (2014) indicates that approximately 20% - 30% of the population had access to an SLF during 2010 – 2013. Also, the estimated full capacity of all SLFs in 2010 was 13,600 tons per day. Given the model estimate of 6,272 tons per day disposed at SLFs, this implies a 2010 SLF capacity utilization rate of about 46%, which is consistent with the fact that "only a few SLFs operate at capacity" (NSWMC, 2014).

To develop the historical time series, the model should account for the fact that CDF and SLF have only more recently emerged as a result of RA 9003. Prior to 2003, the Study Team assumes that 100% of waste disposed at SWDS goes to OD facilities. During 2004 – 2009, the proportion of waste served by SLFs is estimated based on the percentage change in the number of SLFs in the country over time,

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[6] Source: Gerstmayr and Krist, 2012 and feedback received during Focus Group Discussion on the Cost Benefit Analysis for Mitigation Options for the Solid Waste Sector, Diliman Quezon City, July 10, 2015

obtained from NSWMC (2012, Table XIX). The proportion of waste served by CDFs is linearly interpolated from 2004 – 2009, and the proportion served by OD facilities is the remainder in each year from 2004 – 2009. Also note that the Study Team assumed that industrial waste that is disposed at a SWDS is always disposed at a managed facility, and therefore is assigned an MCF of 1.0. The resulting historical profile of SWDS utilization is presented in Table V. 10. Estimated Utilization of SWDS by Type of Facility (Percent Share) below, and shows increasing use of SLFs and CDs over time, with a corresponding decrease in the use of OD facilities (although OD facilities still receive more waste than other types of facilities, at 46%, which reflects in part the challenges present in achieving full implementation of RA 9003).

Table V. 10. Estimated Utilization of SWDS by Type of Facility (Percent Share)

SWDS Type	**National SWDS Utilization by SWDS Type (% Share)**								
year	2002	2003	2004	2005	2006	2007	2008	2009	**2010**
Non-Industrial									
CDF	0.0%	4.3%	8.5%	12.8%	17.0%	21.3%	25.5%	29.8%	34%
SLF	0.0%	0.2%	0.7%	1.0%	2.4%	8.3%	10.7%	17.1%	20%
OD	100.0%	95.5%	90.8%	86.3%	80.6%	70.4%	63.8%	53.1%	46%
Source: NSWMC, 2014									

V.2.1.1.4 Solid Waste Emissions

CH_4 emissions were estimated for 2010 using the FOD method (IPCC, 2006). The FOD method assumes that DOC decays slowly throughout a few decades. If the conditions are constant the CH_4 released from the decomposition of wastes is proportional to the amount of carbon remaining in the waste. Thus, more CH_4 is released during the first few years after deposition because more degradable organic carbon is available for bacterial decay. The methodology is driven by annual estimates of the quantity and type of waste disposed at different types of SWDS (as described in prior sections), as well as a range of additional parameters in Table V. 11. Other Variables Required for Estimating Solid Waste Methane Emissions for which IPCC default values were adopted.

Table V. 11. Other Variables Required for Estimating Solid Waste Methane Emissions

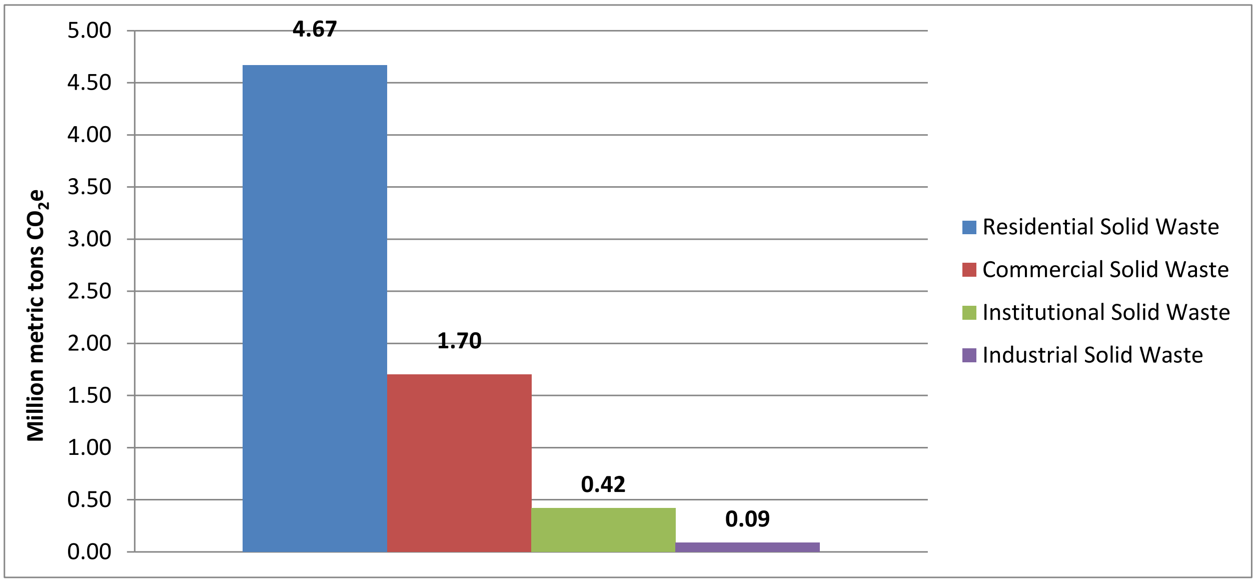
Methane Generation Rate Constant (k)	Variable
Organic (food waste, garden, wood/straw, nappies, textiles)	0.17
Paper	0.07
Plastics, Other Inert	0
Hazardous	0
Special	0
Sludge	0.4
Industrial Waste	0.17
Degradable Organic Carbon (DOC)	
Organic (food waste, garden, wood/straw, nappies, textiles)	0.252
Paper	0.4
Plastics, Other Inert	0
Hazardous	0
Special	0
Sludge	0.05
Industrial Waste	0.15
Other Parameters	
Delay time (months)	6
Fraction of DOC dissimilated (DOCf)	0.5
Fraction of methane in developed gas	0.5
Conversion factor, C to CH_4	1.33
Oxidation factor (OX)	0%
Source: IPCC, 2006; IPCC Waste Model.xls	

The base year analysis assumed 0.25 million metric tons of CO_2e of CH_4 recovery from SWDS in 2010 based on monitoring reports from the Montalban, Quezon City, and San Pedro disposal facilities (UNFCCC, 2009, 2011, 2012, and 2012b). The resulting estimate of total 2010 CH_4 emissions from solid waste is presented in Table V. 12. 2010 Base Year Emissions for Solid Waste by Source Category ($MtCO_2e$) and Figure V. 6, which shows a total of 6.88 million metric tons of CO_2e.

Table V. 12. 2010 Base Year Emissions for Solid Waste by Source Category ($MtCO_2e$)

Solid Waste Emission Source Category	2010
Residential Solid Waste	4.67
Commercial Solid Waste	1.70
Institutional Solid Waste	0.42
Industrial Solid Waste	0.09
Solid Waste Total Emissions	**6.88**

Figure V. 6. 2010 Base Year Emissions for Solid Waste by Source Category ($MtCO_2e$)



V.2.1.2 Wastewater

Wastewater can be a source of CH_4 when treated or disposed anaerobically. It can also be a source of N_2O emissions. Wastewater originates from a variety of residential, commercial and industrial sources and may be treated on site (uncollected), sewered to a centralized plant (collected), or disposed untreated nearby or via an outfall.

Wastewater as well as its sludge components can produce CH_4 if it degrades anaerobically. Key drivers of wastewater emissions include the quantity of degradable organic material in the wastewater and the type of treatment systems used. These characteristics in turn determine the emission factor that quantifies the extent to which the wastewater generates CH_4. Treatment systems or discharge pathways that provide anaerobic environments will generally produce CH_4 whereas systems that provide aerobic environments will normally produce little or no CH_4 (IPCC, 2006). BOD is used to measure the organic component of domestic wastewater. The total quantity of domestic BOD in the base year and subsequent years is driven by changes in population and per-capita BOD generation.

The current wastewater analysis focuses on domestic wastewater. Domestic wastewater refers to all residential, commercial, institutional, and industrial wastewater discharged to the wastewater system. The analysis does not include industrial wastewater treated on-site at industrial facilities due to a lack of available data on these facilities.

V.2.1.2.1 Domestic Wastewater

Key steps in estimating 2010 base year CH_4 emissions from domestic wastewater include:

- Estimate the total quantity of BOD generated and treated/discharged through each treatment/discharge approach;
- Assign CH_4 emission factors (and MCF) to each treatment/discharge approach to estimate total methane production; and
- Adjust the total CH_4 production estimate to account for sludge removal and methane recovery.

The wastewater treatment and discharge profile determines the fraction of wastewater treated or disposed of by a particular type of system (Table V. 13). In the absence of a detailed assessment of treatment and discharge profile in the Philippines, stakeholders recommended using the characterization outlined inTable V. 13.

Table V. 13. Domestic Wastewater Treatment and Discharge Profile, 2010[7]

Domestic WW Treatment & Discharge Pathway	2010 Value (Percent)
Collected	1.6
Treated	1.0
Anaerobic treatment	0.0
Aerobic treatment	1.0
Untreated	0.6
River discharge	**0.0**
Sewers (closed and underground)	**0.3**
Sewers (open)	**0.3**
Uncollected	98.4
Septic tanks	**74.0**
Open pits/latrines	**8.4**
River discharge	**16.0**

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[7] Source: CBA model assumptions and consultations with stakeholders on June 25-26, 2015, First Pacific Leadership Center, Antipolo City.

The Study Team estimated the total quantity of BOD associated with each treatment and discharge pathway based on the national population, an assumption of 14,600 kg-BOD/1000 people/year (IPCC, 2006), and the fraction of total wastewater handled by a given treatment/discharge pathway. The IPCC default BOD value falls in-between the 1994 GHG inventory value of 12,775 and the 2000 GHG inventory value of 19,345. For wastewater handled via pathways that fall under "Collected", a further 1.25 multiplicative adjustment factor is applied to account for the portion of industrial wastewater discharged into sewers (IPCC, 2006).

The domestic emission factor for a given wastewater treatment and discharge pathway and system is a function of the maximum CH_4 producing potential (kg CH_4 / kg BOD) and the MCF for the wastewater treatment and discharge system. In the absence of country-specific information on maximum CH_4 production, the Study Team adopted the IPCC default value of 0.6 kg CH_4 / kg BOD (IPCC, 2006). The Team also adopted default IPCC MCF values for each pathway, presented in Table V. 14, as well as IPCC default assumptions of 0% sludge removal and CH_4 recovery.

Table V. 14. Domestic Wastewater Methane Correction Factors, 2010

Wastewater Treatment/Discharge Pathway	2010 Value
Anaerobic treatment	0.6
Anaerobic digester for sludge	0.8
Anaerobic shallow lagoon	0.2
Anaerobic deep lagoon	0.8
Aerobic treatment	0
River discharge	0.1
Sewers (open)	0.5
Septic tanks	0.5
Open pits/latrines	0.7
Source: IPCC, 2006, Table 6.3	

V.2.1.2.2 Nitrous Oxide Emissions from Domestic Effluent

Nitrous oxide emissions can occur as direct emissions from treatment plants or from indirect emissions from wastewater after disposal of effluent into waterways, lakes or the sea. Direct emissions from nitrification and denitrification at wastewater treatment plants may be considered as a minor source. IPCC guidance suggests these emissions are much smaller than those from effluent and may only be of interest to countries that predominantly have advanced centralized wastewater treatment plants with nitrification and denitrification steps. Accordingly, the N_2O emissions inventory framework addresses indirect N_2O emissions from wastewater treatment effluent that is discharged into aquatic environments.

The emissions estimate is driven by the quantity of nitrogen in the effluent discharged to aquatic environments (kg N/year), and an emission factor for N_2O emissions from discharges (kg N_2O-N/kg N). The Study Team adopted the IPCC default emission factor of 0.005 kg N_2O-N/kg N (IPCC 2006). The quantity of nitrogen in discharged effluent is estimated based on the product of: population, annual per-capita protein consumption, the fraction of nitrogen in protein, and factors to account for non-consumed and industrial co-discharged protein added to wastewater (IPCC, 2006). A final adjustment is made to account for nitrogen removed with sludge, for which the default IPCC value of zero is used. Table V. 15 summarizes the key inputs to the N_2O emissions analysis.

Table V. 15. Key Inputs for N_2O Emissions Estimates from Domestic Effluent

Wastewater Treatment/Discharge Pathway	2010 Value	Source
Protein consumption (kg/person/year)	20.84	Household Food Consumption Dietary Survey (FNRI, 2008)
Fraction N in protein (kg N/kg protein)	16%	IPCC, 2006, Ch. 6.3.3
Fraction of non-consumption protein	110%	IPCC, 2006, Ch. 6.3.1.3
Fraction of industrial and commercial co-discharged protein	125%	IPCC, 2006, Ch. 6.3.1.3
N removed with sludge	0.00	IPCC, 2006, Ch. 6
Emission factor (kg N_2O/kg N)	0.005	IPCC, 2006, Ch. 6.3.1.2
Convert N_2O-N to N_2O	1.571	IPCC, 2006, Ch. 6

V.2.2 Results

Table V. 16 and

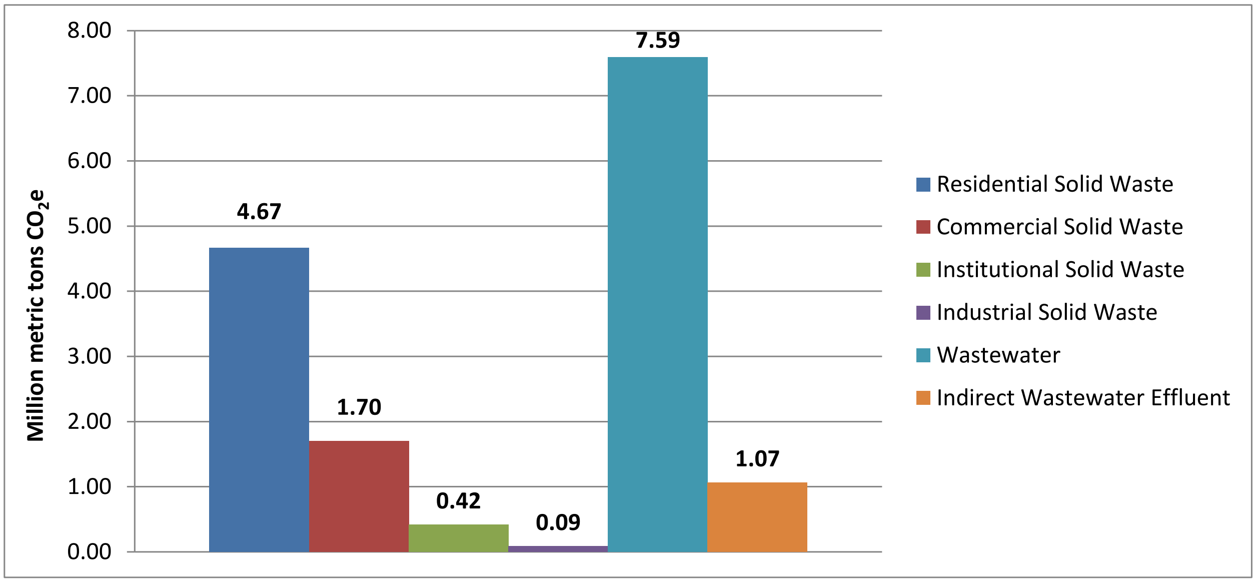
Figure V. 7 below summarize total 2010 base year emissions from the waste sector, which includes 6.88 $MtCO_2e$ from solid waste and 8.66 $MtCO_2e$ from wastewater, for a total contribution of 15.54 $MtCO_2e$.

The residential sector contributes the most to solid waste emissions because it is the largest source of solid waste generation in the Philippines (about 57% of solid waste generated (NSWMC, 2014)).

Table V. 16. 2010 Base Year Emissions for Waste by Source Category ($MtCO_2e$)

Source Category	2010
Residential Solid Waste	4.67
Commercial Solid Waste	1.70
Institutional Solid Waste	0.42
Industrial Solid Waste	0.09
Solid Waste Subtotal	***6.88***
Wastewater	7.59
Indirect Wastewater Effluent	1.07
Wastewater Subtotal	***8.66***
TOTAL	**15.54**

Figure V. 7. 2010 Base Year Emissions for Waste by Source Category ($MtCO_2e$)



V.3 BASELINE PROJECTION 2010 TO 2050

The 2010-2050 baseline projection describes expected GHG emissions under “business as usual” economic activity. It also serves as a reference against which the impacts of current and planned mitigation actions can be measured. The goal of this CBA is to quantify the GHG emissions impact, costs and benefits of *existing* and *proposed* mitigation actions, regulations, and policies in the Philippines. Therefore, the baseline excludes some of the existing policies that contribute to GHG mitigation, even though these policies have already been passed into law and are being implemented in the Philippines. Instead, these policies and measures are analyzed as sector-specific mitigation options. This approach enables stakeholders to assess the future GHG impact, costs and co-benefits of the many recent initiatives that are being implemented to reduce GHG emissions. Using this approach, several components of the Ecological Solid Waste Management Act of 2000 (RA 9003) are analyzed as mitigation even though the Act is already being implemented by the government and therefore could have been part of the baseline.

This subsection describes the estimated annual GHG emissions for 2010 to 2050 for the waste sector, including the data and key assumptions used for developing this baseline.

V.3.1 Methods and Assumptions

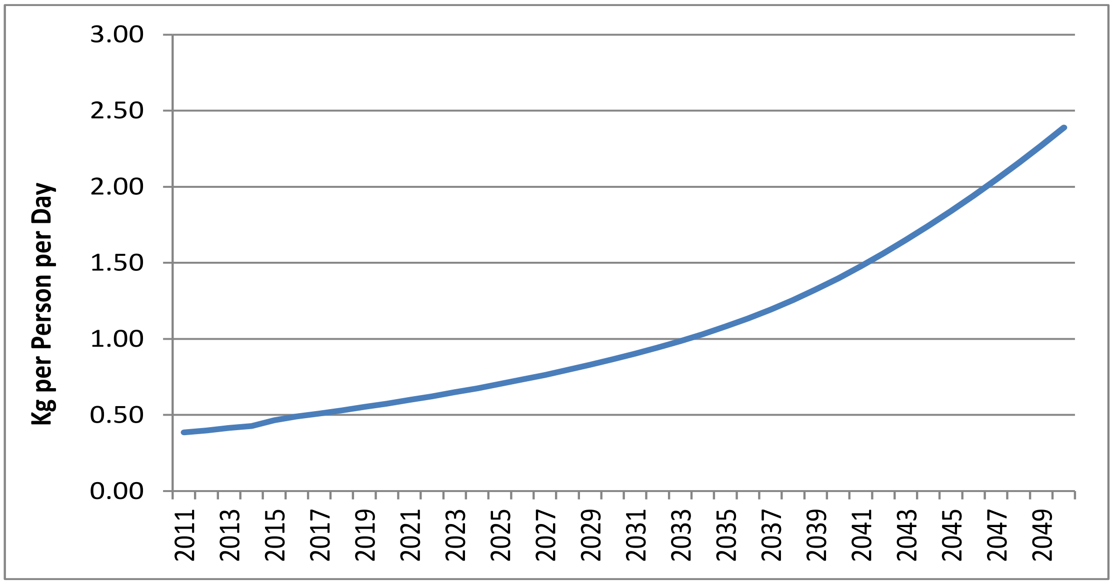
V.3.1.1 Solid Waste

The overall methodology for estimating the quantity and type of waste disposed at SWDS, as well as for estimating CH_4 emissions from disposal, is similar for each year from 2011 – 2050 as it is for the base year, 2010. That is, allocation parameters specified annually are used to characterize the generation, segregation, and disposal of the solid waste generated each year. Then, the FOD method is used to estimate annual CH_4 emissions.

V.3.1.1.1 Solid Waste Generation

The total quantity of solid waste generated annually from 2010 - 2050 is driven by population growth and growth in the 2010 base year per-capita waste generation value of 0.40 kg/person/day. We used historical population size estimate for 2010 and population size projections for 2011–2045 from Philippine Statistics Authority. For 2046–2050, population size was projected using annual average population size growth rate during 2035–2045. Per-capita solid waste generation is forecast annually from 2010 – 2050 based on the historical statistical relationship between per-capita waste generation and GDP from 2000 - 2010, combined with the GDP forecast to 2050. We used historical GDP data for 2010–2014 from Philippine Statistics Authority (PSA). For 2015–2050, GDP was projected using similar assumptions as those used by the Asian Development Bank in the study on Low-Carbon Scenario and Development Pathways for the Philippines (ADB, 2015). Based on this approach, per-capita waste generation is forecast to increase from 0.4 kg/person/day in 2010 to 2.39 kg/person/day in 2050 (Figure V. 8).

Figure V. 8. Forecast of Per-Capita Solid Waste Generation per Day, 2011-2050



V.3.1.1.2 Solid Waste Characterization

The allocation factors used to specify the type of waste generated by source category in the baseline to 2050 are summarized in Table V. 17 below.

Table V. 17. Baseline Solid Waste Characterization Parameter Values (% by Weight)

Solid Waste Baseline Parameter	2011 – 2050 Value		Source
Sector sources of Solid Waste	Residential = 56.7% Commercial = 27.1% Institutional = 12.1% Industrial = 4.1%		NSWMC, 2014
Composition of Solid Waste by Type			
Residential, Commercial, Institutional, and Industrial	Biodegradable = 52.3% Recyclable = 27.8% Residual = 17.9% Special = 1.9%		NSWMC, 2014
Composition of Solid Waste by Material			
Residential	Paper = 11.5% Glass = 3.8% Metal = 5.6% Plastic = 22.9%	Other Organic = 52.6% Other Inorganic = 3.1% Hazardous = 0.3% Special = 0.1%	ADB, 2003
Commercial	Paper = 18.6% Glass = 2.3% Metal = 2.7% Plastic = 21.4%	Other Organic = 52.7% Other Inorganic = 2.0% Hazardous = 0.3% Special = 0.0%	ADB, 2003
Institutional	Paper = 30.8% Glass = 2.1%	Other Organic = 34.3% Other Inorganic = 4.6%	ADB, 2003

Solid Waste Baseline Parameter	2011 – 2050 Value		Source
	Metal = 2.3% Plastic = 25.0%	Hazardous = 0.2% Special = 0.6%	
Industrial	Paper = 14.3% Glass = 2.9% Metal = 3.5% Plastic = 29.5%	Other Organic = 35.8% Other Inorganic = 11.7% Hazardous = 1.9 Special = 0.3%	ADB, 2003

V.3.1.1.3 Solid Waste Segregation and Disposal

To more accurately capture continued improvements in overall solid waste management and compliance with RA 9003 between 2010 and 2015, the baseline to 2050 incorporates a continuation of key trends regarding waste segregation and disposal through 2015, including:

- The baseline to 2050 assumes a 50% increase in 2010 baseline segregation rates for both recyclable waste and biodegradable waste from 2010 – 2015. These changes reflect NSWM adopted targets set forth under the Philippine Development Plan (PDP) for 2011 – 2016 (NSWMC, 2014);
- The baseline to 2050 assumes a 1% decrease in the uncollected/unmanaged portion of waste annually from 2010 – 2015; and
- The baseline to 2050 assumes that the percentage of waste that is disposed at SLFs continues to increase from 2010 – 2015, and the use of OD and CDF facilities continues to decline. Estimates of the increase in SLF utilization are based on the percentage change in total SLF capacity from 2010 – 2015 and an assumed 60% capacity utilization of SLF facilities. Total SLF capacity for 2010 and 2013 are obtained from the NSWMC (2014, Table 12), and values for 2011, 2012, 2014, and 2015 and interpolated based on these estimates.

The input values reflecting the above trends are summarized in Table V. 18, Table V. 19, and Table V. 20.

Table V. 18. Rate of Recyclable Material Segregation by Sector and Material, 2010 - 2015[8]

(% of Total Quantity of Material Waste Generated by weight)

Sector and Material	National Segregation Rates for Recyclable Materials					
year	2010	2011	2012	2013	2014	2015
Households						
Paper	34%	37%	40%	44%	47%	50%
Aluminum	32%	35%	38%	41%	44%	47%
Other Metals	21%	23%	25%	27%	29%	31%

Sector and Material	National Segregation Rates for Recyclable Materials					
year	2010	2011	2012	2013	2014	2015
Plastics	24%	26%	28%	31%	33%	35%
Glass	29%	32%	34%	37%	40%	43%
Businesses						
Paper	38%	42%	46%	50%	53%	57%
Aluminum	46%	51%	56%	60%	65%	69%
Other Metals	49%	54%	59%	63%	68%	73%
Plastics	33%	36%	40%	43%	46%	49%
Glass	29%	32%	34%	37%	40%	43%
Source: JICA, 2008; ADB, 2003; and CBA model estimates.						

Table V. 19. Rate of Biodegradable Material Segregation and Rate of Uncollected Waste, 2010 - 2015[9] (by Weight)

Waste Type	National Segregation Rates for Biodegradable Materials and Fraction of Waste that is Uncollected					
year	2010	2011	2012	2013	2014	2015
Biodegradable Waste Segregation Rate	5%	6%	7%	8%	9%	10%
Percentage of Waste Uncollected/Unmanaged	10%	9%	8%	7%	6%	5%
Source: CBA model estimates.						

Table V. 20. Percentage of Disposed Waste that is Disposed at Different SWDS[10] (by Weight)

SWDS Type	Percentage of Solid Waste Disposed by SWDS Type					
year	2010	2011	2012	2013	2014	2015
Open DumpsiteOD	46%	46%	46%	44%	43%	42%
Controlled Dumpsite FacilityCDF	34%	34%	34%	33%	32%	31%
Sanitary Landfill FacilitySLF	20%	20%	21%	23%	25%	28%
Total SLF Capacity per Day (tons)	*13,600*	*13,875*	*14,300*	*16,700*	*19,716*	*22,848*
Total SLF Disposal per Day (tons)	6,272	6,427	6,577	7,351	8,284	9,723
Source: NSWMC, 2014; CBA model estimates.						

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[11] Source: NSWMC, 2014; CBA model estimates.

V.3.1.1.4 Development of Additional Sanitary Landfill Facilities

The baseline from 2010 – 2050 accounts for the number and land area associated with the construction of new SLFs. The Study Team estimated the number of new SLFs required each year from 2016 – 2050 in the baseline by assuming that there are no additional changes in SLF utilization (on a percentage basis) for disposal beyond 2015. The analysis accounts for all SLFs that became operational annually from 2003 – 2015, the replacement of these existing SLFs as they eventually go offline – assuming a 15-year lifetime – and the SLF capacity requirements to absorb the continued increases in waste generation and disposal based on population growth and growth in the per-capita waste generation value. The analysis assumed an overall average of 116 tons per day capacity for new SLFs, which reflects weighted average SLF size requirement for LGUs across the four landfill size categories based on Gerstmayer and Krist (2012). The number of SLFs operational in each year from 2008 – 2013 was obtained from NSWMC (2014), along with data indicating that 53 SLFs were under construction in 2013. It was assumed that half of these 53 SLFs, each became operational during 2014 and 2015. The number of SLFs operational from 2004 – 2007 was linearly interpolated based on the 2003 value of 1 and the 2008 value of 21 (NSWMC, 2014). In addition, it was estimated that the land area of 7 hectares was required for each new SLF based on the total number of hectares per SLF reported for 2013 by NSWMC (2014). The results of this analysis for the baseline are summarized in Table V. 21 below.

Table V. 21. Requirements for Additional SLFs in the Baseline[11]

Sector and Material	Baseline SLF Requirements								
year	2010	2015	2020	2025	2030	2035	2040	2045	2050
Number of Operational SLFs	29	126	120	97	0	0	0	0	0
Annual SLF Capacity (million tons) (with no new construction after 2015)	4.9	8.3	7.2	3.4	0	0	0	0	0
Total Additional SLF Capacity Requirement (million tons)	0	0	0	2.9	8.1	10.7	14.5	19.6	26.5
Cumulative Number of New SLFs	**0**	**0**	**0**	**79**	**226**	**298**	**402**	**546**	**736**
Land Area (hectares)	**0**	**0**	**0**	**553**	**1,582**	**2,086**	**2,814**	**3,822**	**5,152**

V.3.1.1.5 Results of the Solid Waste Baseline to 2050

The figures below summarize the results for the solid waste baseline forecast. The figures show solid waste emissions rising from about 7 $MtCO_2e$ in 2010 to 59 $MtCO_2e$ in 2050. As seen in Figure V. 9, since the baseline forecast does not include any future waste management actions, the relative proportion of

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[11] Source: NSWMC, 2014; CBA model estimates.

waste that is disposed in a SWDS does not change over time, and continues to represent the largest share of overall waste disposition in 2050.

Figure V. 9. Figure 1. Solid Waste Generation by Disposition Method, 2000 - 2050

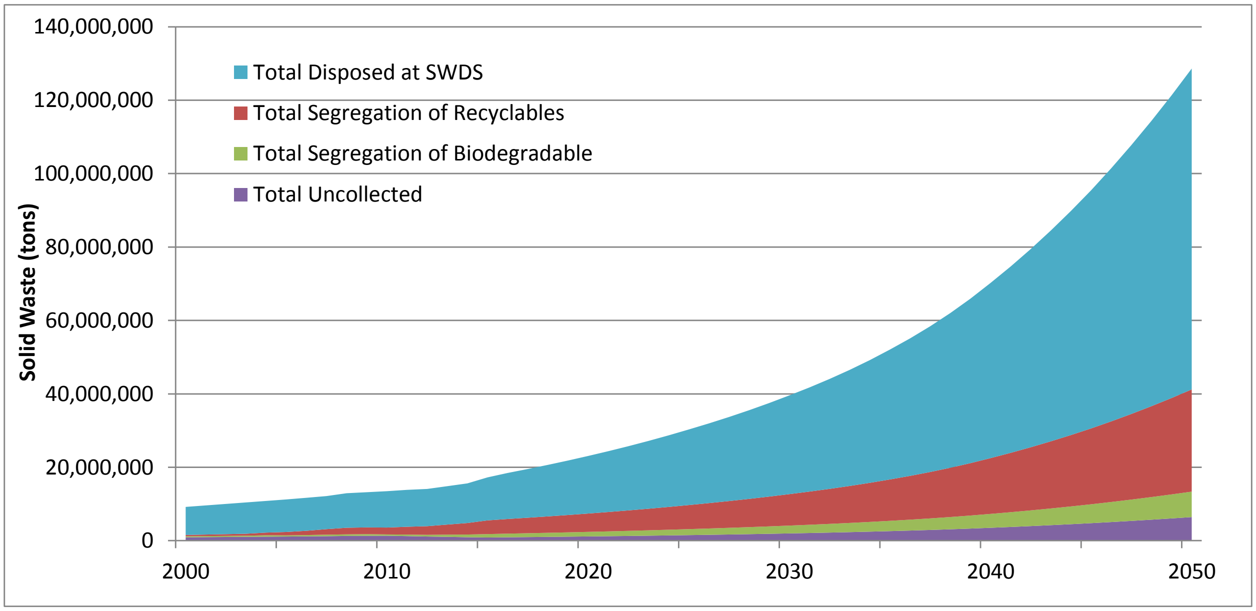
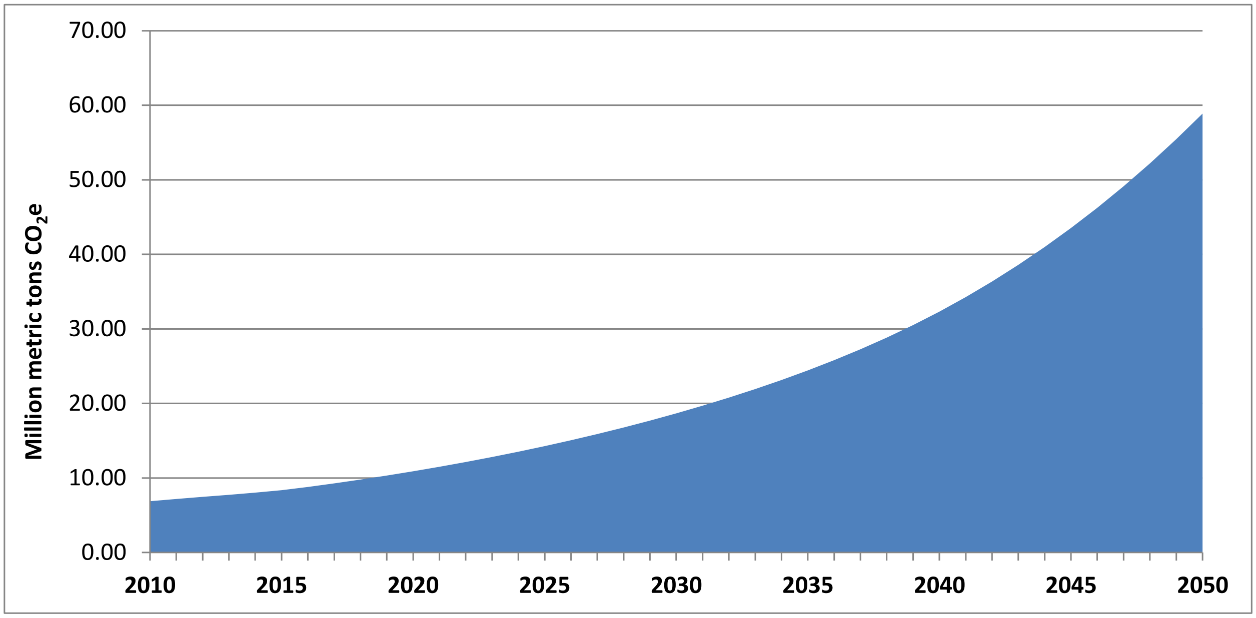


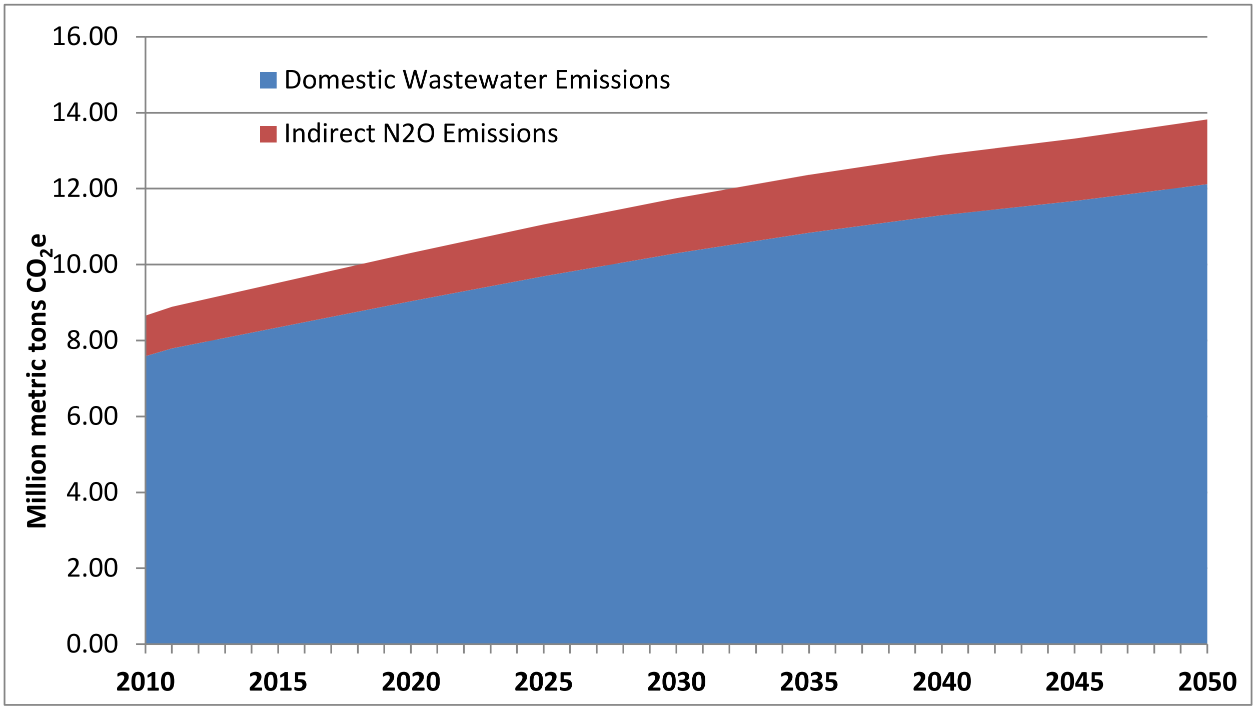
Figure V. 10. 2010-2050 GHG Emissions Baseline for Solid Waste ($MtCO_2e$)



V.3.1.2 Wastewater

Changes in domestic wastewater methane emissions as well as indirect N_2O emissions are driven by changes in national, urban, and rural population over time (see Figure V. 11). All other emissions estimation parameters described in the 2010 base year analysis are assumed to stay constant over the baseline time period, 2010 – 2050.

Figure V. 11. 2010-2050 GHG Emissions Baseline for Wastewater ($MtCO_2e$)



V.3.2 Results

Figure V. 12 and Table V. 22 summarize total waste sector emissions for the 2010 – 2050 baseline. While the emission contributions from solid waste and wastewater are comparable in magnitude in 2010, the solid waste sector constitutes a growing proportion of total waste emissions over time. By 2050, solid waste-related emissions are expected to represent about 90% of total waste emissions. This result is due to the activity forecast in each subsector – i.e., solid waste generation and wastewater generation. The quantity of wastewater generated over time is driven solely by population growth, whereas the rate of wastewater generation per-person does not change over time. In contrast, solid waste generation is driven both by population growth and growth in the per-capita rate of waste generation due to growth in GDP. As a result of the expected strong GDP-growth through 2050 in the Philippines, solid waste generation and the associated CH_4 emissions are forecast to grow at a much faster rate than that of wastewater.

Figure V. 12. 2010-2050 GHG Emissions Baseline for Waste by Subsector ($MtCO_2e$)

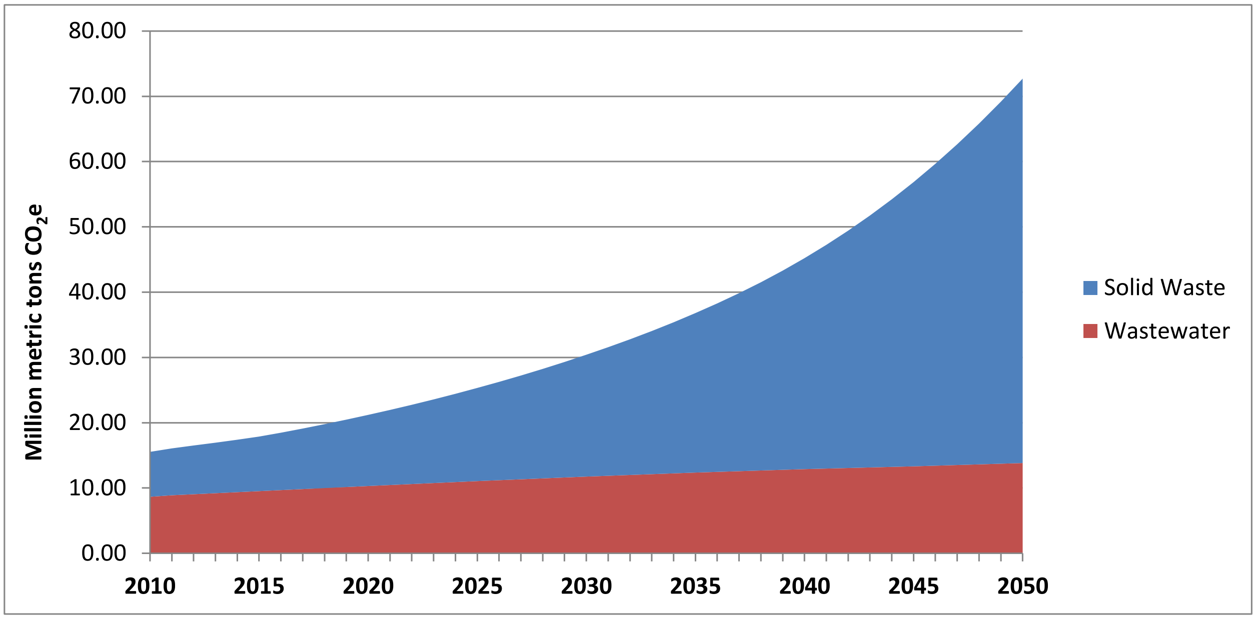


Table V. 22. 2010 - 2050 Baseline for Waste by Source Category ($MtCO_2e$)

Source Category	Year ($MtCO_2e$)				
	2010	2020	2030	2040	2050
Residential Solid Waste	4.67	6.47	10.86	18.73	34.12
Commercial Solid Waste	1.70	3.12	5.43	9.43	17.18
Institutional Solid Waste	0.42	1.07	1.95	3.42	6.23
Industrial Solid Waste	0.09	0.23	0.42	0.74	1.35
Solid Waste Subtotal	***6.88***	***10.90***	***18.67***	***32.31***	***58.88***
Wastewater	7.59	9.03	10.30	11.30	12.12
Indirect Wastewater Effluent	1.07	1.27	1.45	1.59	1.71
Wastewater Subtotal	***8.66***	***10.31***	***11.75***	***12.89***	***13.82***
TOTAL	**15.54**	**21.20**	**30.41**	**45.21**	**72.71**

Notes:

* Includes all emissions from wastewater except for industrial wastewater treated on-site at industrial facilities.

** Indirect wastewater effluent refers to nitrous oxide emissions from wastewater treatment effluent that is discharged into aquatic environments.

V.4 MITIGATION COST-BENEFIT ANALYSIS

V.4.1 Direct Cost and Benefits

B-LEADERS conducted a review of national-level requirements and plans that set priorities for GHG reductions in the waste sector, reviewed existing mitigation studies for the Philippines, and consulted with relevant stakeholders in order to develop a set of mitigation approaches for consideration in the analysis. In particular, this review included examination of RA 9003 (the Ecological Solid Waste Management Act of 2000) and related plans such as the National Solid Waste Management Strategy 2012 – 2016 (NSWMC, 2012). It also drew heavily on a 2014 UNDP study on potential NAMAs for the Philippines (Berkman International Inc., 2015). The proposed mitigation options, and the associated assumptions, were then confirmed during several stakeholder consultation workshops organized by the CCC during February-July 2015. Key criteria for selection of mitigation options for the waste sector included applicability to the national development context and the potential for introducing win-win opportunities for waste which result in both GHG reductions and cost savings.

The specific set of mitigation options included in the analysis supports compliance with RA 9003, and is based on a multi-criteria analysis of NAMA priorities supported by the NSWMC. RA 9003 is aimed at a systematic, comprehensive strategy for solid waste management that incorporates: 1) source reduction (avoidance) and minimization of waste generated at source; 2) reuse, recycling and resource recovery of wastes at the barangay level; 3) efficient collection, proper transfer, and transport of wastes by city/municipality; and 4) efficient management of residuals and of final disposal sites and/or any other related technologies for the destruction/reuse of residuals. The law includes several key waste management concepts that are considered in the mitigation analysis:

- **Establish Material Recovery Facilities (MRFs)** – The Act mandates that MRFs be established in every barangay or cluster of barangays. The MRF includes a solid waste transfer station or sorting station, drop-off center, a composting facility, and a recycling facility. MRFs serve to reduce the amount of wastes to be disposed of mainly through recycling, composting, and residual treatment (NSWMC, 2012).

- **Closure and Rehabilitation of Open and Controlled Dumpsites** – The Act mandates the closure and rehabilitation of all dumpsites. Section 37 of the law states that no open dumps shall be established and operated, nor any practice or disposal of solid waste by any person, including LGUs, which constitutes the use of open dumps for solid waste, be allowed. It also mandates that by 2004, every LGU shall convert its open dumps into controlled dumps, provided that by 2006 no controlled dumps shall anymore be allowed. In essence, the criteria for converting open to controlled dumpsites represent a set of remedial measures to limit the impacts of garbage that already exists in open dumps, but these facilities should ultimately be closed and rehabilitated (NSWMC, 2012).

- **Construction of Sanitary Landfill Facilities (SLFs)** – In concert with closing open and controlled dump sites, the Act that sanitary landfills be constructed instead. Sanitary landfill is defined as a waste disposal site that has been designed and engineered to accept municipal residual waste, while ensuring minimal negative impact on the environment; or a specially engineered site for disposing of solid waste on land, constructed in such a way as to reduce hazard to public health and safety. Some qualities of a sanitary landfill include natural impermeable lower layer to block the movement of leachate into ground water; a leachate collection system; gravel layers permitting the control of methane; and daily covering of garbage with soil (NSWMC, 2012).

In addition to these considerations, there are other essential components to account for in the mitigation analysis. The closure of existing dumpsites and construction of new sanitary landfills also creates opportunities for landfill gas recovery to generate electricity. For example, current facilities that utilize this technology, and which are included in the baseline, include the Quezon City Controlled Disposal Facility Biogas Emission Reduction Project (UNFCCC, 2011), the San Pedro Landfill Methane Recovery & Energy Generation Project (UNFCCC, 2009), and the Montalban Methane Capture to Electricity Project (UNFCCC, 2012b). The mitigation analysis therefore also considers opportunities for additional CH_4 recovery for the purpose of electricity generation as open and controlled dumpsites continue to be closed and sanitary landfills constructed.

Capturing landfill gas (LFG) and using it for power generation can have considerable climate and economic benefits. Though the precise CH_4 content of the gas may vary by landfill, it is assumed to be comprised of 50% CH_4 and 50% other gases, primarily CO2 and other organic compounds. This makes LFG both a potent source of GHG emissions and a valuable fuel for many energy applications - LFG power technology in particular is mature and widely used outside the Philippines (USEPA, 2015b). Building on the initial LFG power projects currently underway in the country, this option analyzes an expansion of LFG power at landfills where it is deemed economically viable [see the Energy Report for the CBA (B-LEADERS, 2015) for additional information on the analysis of the energy sector effects of electricity production from LFG].

Municipal solid waste (MSW) can also be used directly to generate electricity. It can be either incinerated or pyrolized directly as a fuel, or digested to produce biogas from which power can be generated. While each of these options is potentially controversial in the Philippines, it is commonly practiced in the U.S. and many European countries (USEPA, 2014a; European Environment Agency, 2013). Provided that waste-to-energy (WtE) plants include robust emission controls, these plants can be an effective way of reducing landfilling and related CH_4 emissions while contributing to energy security [see the Energy Report for the CBA (B-LEADERS, 2015) for additional information on the analysis of the energy sector effects of energy production from MSW]. The analysis therefore also considered MSW waste-to-energy options for both organic waste digestion and residual waste incineration.

In addition to the solid waste mitigation measures outlined above, at the request of the NSWMC, the Study Team began work on a mitigation option which looked at the emission benefits of more efficient waste truck collection. However, due to lack of cost data, the cost effectiveness of this mitigation option could not be fully assessed and is therefore not included in this report.

There is also potential to reduce GHG emissions from the wastewater sector, for example, by increasing the capacity for centralized wastewater collection and treatment, and septic tank desludging in stances without a sewer connection. However, the availability of data for analyzing the GHG abatement potential, costs, and benefits of these opportunities is limited. During consultations organized by CCC in

June and July 2015,[12] wastewater stakeholders provided several new data sources for the development of mitigation options in this sector. However, the analysis of these mitigation options was still on-going at the time the CCC settled on the numbers for the INDC in July of 2015. Accordingly, the results of the wastewater mitigation analysis are not included in this report. They may be added at a later stage pending direction from CCC and stakeholders.

V.4.1.1 Methods and Assumptions

Table V. 23 lays out the definition and key assumptions for each waste sector mitigation option analyzed.

Table V. 23. Definitions and Assumptions for Waste Sector Mitigation Options

Mitigation Option	Description	Assumptions
CDF and Substitute SLFs[1]	• The option assumes continued increases in the share disposed waste being handled by SLF, such that all landfill-disposed waste is handled by SLFs by 2030. Simultaneously, the option assumes closure of the approximately 923 open and controlled dumpsites that were still active in 2015 (NSWMC, 2014) by 2030 • In the absence of methane recovery and additional biodegradable waste diversion from SLFs, the switch from OD/CDFs to SLFs increases overall methane emissions.	• As SLF utilization increases there are corresponding decreases in the percentage of waste handled by open and controlled dumpsites. • The number of OD/CDF facilities that close each year is a function of the reduced disposal requirement at these facilities each year; similarly, the number of additional SLFs required to take disposed waste is a function of the increased disposal requirement for these facilities, compared to baseline. • A 100% shift to SLFs by 2030 requires construction of 1,693 additional SLFs (with 116 ton-per-day capacity on average) by 2050, compared to the baseline. Development of new SLFs would require approximately 12,000 additional hectares of land, compared to the baseline. • Closing ODs and CDFs: USD 345,410 per dumpsite (2010 USD) (NSWMC guidance); applied to number of OD/CDFs the close per year. • Construction of SLFs: USD 13.65/ton (2010 USD) (NEDA/NSWMC, 2008); applied to additional capacity requirement for SLFs per year.
CDF Only[2]	• The option assumes closure of the approximately 923 open and controlled	• Closing ODs and CDFs: USD 345,410 per dumpsite (2010 USD) (NSWMC guidance); applied to number of OD/CDFs that close per year.

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[12] Based on consultations with stakeholders on June 25-26, 2015, First Pacific Leadership Center, Antipolo City; meeting with Department of Public Works and Highways on July 8, 2015; meeting with Maynilad Water Services on July 9, 2015; and meeting with Manila Water Corporation on July 9, 2015.

Mitigation Option	Description	Assumptions
	dumpsites that were still active in 2015 (NSWMC, 2014) by 2030. - This option does not account for an alternate disposal method for this waste, unlike the prior option that included additional SLF utilization.	

Composting	- Option includes increasing the percentage of biodegradable waste that is composted from 10% in 2015 to 50% in 2050.
	- Increased composting results in additional biodegradable waste diversion from landfills, reducing CH4 emissions and overall disposal requirements.
		- 284 million tons of additional biodegradable waste is diverted for composting, compared to the baseline, cumulatively by 2050.
		- By 2050, the national waste diversion rate increases to 48.6% of all waste, compared to 27% in 2050 in the baseline.
		- The percentage of waste disposed in landfills drops in 2050 to 46.4%, compared to 68% in the baseline. This also means a lower requirement for new landfill construction compared to baseline.
		- MRF and Transfer Station Capital Costs: Requirement based on total additional quantity of biodegradable waste processed by composting facilities at MRFs; USD 0.31/ton (2010 USD) (NEDA/NSWMC 2008)
		- Composting Technology Capital and Operating Costs: Requirement to construct and operate composting facilities within or exclusive of MRFs; assume 70% bioreactor technology, 30% average cost of mix of box, windrow, and vermin composting:
		  ○ Bioreactor capital cost: USD 19,650 per 1-ton reactor (2010 USD) (ADB, 2003b)
		  ○ Bioreactor operating cost: USD 11,056 per reactor per year (2010 USD) (ADB, 2003b)
		  ○ Windrow, box, vermi capital cost: USD 75.79/ton (2010 USD) (Paul et. al., 2008)
		  ○ Windrow, box, vermin operating cost: USD 40.94/ton of compost product (2010 USD) (Paul et. al., 2008)
		- Implementation Costs:
		  ○ Separate collection of biodegradable waste: USD 38.55/ton (2010 USD) (Gerstmayer and Krist, 2012)
		  ○ Landfill disposal cost savings: USD 13.33/ton

Mitigation Option	Description	Assumptions
		(2010 USD) (ADB, 2003b)
Eco-Efficient Cover	• Option includes deployment of eco-efficient soil cover (methane oxidizing cover) at small OD and CDF by 2030.	• Eco-efficient cover is deployed at 50% of small dumpsites by 2030, with a phase-in beginning in 2018. • Small dumpsites are defined as category 1 and 2 sites. Gerstmayer and Krist (2012) indicate that approximately 58% of dumpsite capacity exists in category 1 and 2 dumpsites. • For the portion of small dumpsites that get eco-efficient cover in each year, we assume a 70% emission reduction is achieved (Gerstmayer and Krist 2012). • Cost of biocover per ton of CO_2e mitigated: USD 100 (2010 USD/tCO_2e) (IPCC, 2014) • Option assumes overall utilization of dumpsites for disposal remains the same as baseline (no additional dumpsite closures).
Methane Recovery from Dumpsites for Flaring	• Option includes deployment of methane recovery for flaring at large OD and CDFs by 2030.	• Assume methane recovery can occur at Category 4 ODs and CDFs. • The percentage of emissions subject to recovery (e.g., percentage of emissions from Category 4 facilities) is assumed to be the same as the overall disposal capacity present in Category 4 facilities. • Category 4 facilities are assumed to comprise 30% of OD/CDF capacity based on Gerstmayer and Krist (2012). • Assume 50% ofCH4 in LFG and a capture efficiency of 50% (IPCC, 2006). • Assume that implementation of potential methane recovery per year given the above assumptions is phased-in between 2018 – 2030, with achievement of the full potential (30% of dumpsites) in 2030. • Capital Cost for Methane Recovery: USD 17 per ton of capacity deploying methane recovery (2010 USD) (USEPA, 2013). Capital cost is applied to the additional dumpsite capacity getting methane recovery capabilities in each year from 2018 – 2030. • Operating Cost for Methane Recovery: USD 3 per ton of capacity deploying methane recovery (2010 USD) (USEPA, 2013). Operating costs are applied to the cumulative quantity of dumpsite capacity with methane recovery in each year (not just the incremental capacity added each year).
Methane	• Option includes	• Assume methane recovery can occur at Category 4

Mitigation Option	Description	Assumptions
Recovery from Dumpsites for Electricity[3]	deployment of methane recovery for electricity generation at large ODs and CDFs by 2030. • Option includes the costs of the same methane recovery and flaring system as in the prior option, plus construction and operation of an on-site generation facility as outlined in the CBA Energy Report (B-LEADERS, 2015).	ODs and CDFs. • The percentage of emissions subject to recovery (e.g., percentage of emissions from Category 4 facilities) is assumed to be the same as the overall disposal capacity present in Category 4 facilities. • Category 4 facilities are assumed to comprise 30% of OD/CDF capacity based on Gerstmayer and Krist (2012). • Assume 50% of methane in LFG and a capture efficiency of 50% (IPCC, 2006). • Assume that implementation of potential CH4 recovery per year given the above assumptions is phased-in between 2018 – 2030, with achievement of the full potential (30% of dumpsites) in 2030. • Capital Cost for Methane Recovery: USD 17 per ton of capacity deploying methane recovery (2010 USD) (USEPA, 2013). Capital cost is applied to the additional dumpsite capacity getting methane recovery capabilities in each year from 2018 – 2030. • Operating Cost for Methane Recovery: USD 3 per ton of capacity deploying methane recovery (2010 USD) (USEPA, 2013). Operating costs are applied to the cumulative quantity of dumpsite capacity with methane recovery in each year (not just the incremental capacity added each year).
Methane Recovery from SLFs for Electricity	• Option includes deployment of methane recovery for electricity generation at large sanitary landfills by 2030. • Option includes the costs of a methane recovery and flaring system, plus construction and operation of an on-site generation facility. For more information see the CBA Energy Report (B-LEADERS, 2015).	• Assume methane recovery can occur at Category 4 SLFs. • The percentage of emissions subject to recovery (e.g., percentage of emissions from Category 4 facilities) is assumed to be the same as the overall disposal capacity present in Category 4 SLF facilities. • Category 4 facilities are assumed to comprise 56% of SLF capacity based on Gerstmayer and Krist (2012). • Assume 50% of CH4 in LFG and a capture efficiency of 50% (IPCC, 2006). • Assume that implementation of potential methane recovery per year given the above assumptions is phased-in between 2018 – 2030, with achievement of the full potential (56% of SLFs) in 2030. • Capital Cost for Methane Recovery: USD 24.46 per ton of SLF capacity deploying methane recovery (2010 USD) (UNFCCC, 2012). Capital cost is applied

Mitigation Option	Description	Assumptions
		to the additional SLF capacity getting methane recovery capabilities in each year from 2018 – 2030. • Operating Cost for Methane Recovery: USD 0.0134 per cubic meter of LFG subject to recovery (2010 USD) (UNFCCC, 2012). Operating costs are applied to the cumulative quantity of LFG recovered in each year (not just the incremental quantity recovered each year). • Power Generation: New LFG generation capacity is constructed to utilize the additional fuel. Paralleling NREP, this capacity is deployed into the baseline power model displacing baseline generation and some endogenously built capacity. Electricity demand and total electricity production are not affected. Changes in requirements for fossil fuels impact upstream energy use and emissions from fossil fuel production in keeping with the supply-side model. Capital and O&M costs for LFG power generation can be found in the CBA Energy Report (B-LEADERS, 2015).
MSW Digestion	• Option includes diversion and collection of biodegradable waste for digestion and power generation. • Includes diversion of 1,000 tons per day of biodegradable waste from SLFs by 2025, with a phase-in beginning in 2018.	• This option comprises a limited deployment of MSW plants which are built to U.S. and European technical standards using electrostatic precipitator pollution control technology. • For the MSW Digestion option, sufficient MSW digestion capacity is constructed between 2018 and 2025 to consume 1,000 short tons of organic MSW per day (116 MW). • Each unit of organic solid waste which is consumed for power generation is expected to reduce landfill emissions of CH4 which would otherwise have occurred. • This capacity is deployed into the baseline power model, displacing baseline generation and some endogenously built capacity. Electricity demand and total electricity production are not affected. Capital and O&M costs for MSW Digestion power generation can be found in the CBA Energy Report (B-LEADERS, 2015).
MSW Incineration[4]	• Option includes diversion and collection of residual waste for incineration and power generation. • Includes diversion	• This option comprises a limited deployment of MSW plants which are built to U.S. and European technical standards using electrostatic precipitator pollution control technology. • Sufficient MSW combustion capacity is constructed between 2018 and 2025 to consume 1,000 short

Mitigation Option	Description	Assumptions
	1,000 tons per day of residual waste from SLFs by 2025, with a phase-in beginning in 2018.	tons of residual MSW per day (51 MW). • Each unit of organic solid waste which is consumed for power generation is expected to reduce landfill emissions of CH4 which would otherwise have occurred. • This capacity is deployed into the baseline power model, displacing baseline generation and some endogenously built capacity. Electricity demand and total electricity production are not affected. Capital and O&M costs for MSW Digestion power generation can be found in the CBA Energy Report (B-LEADERS, 2015).

[1] This option is excluded from the retrospective MACC analysis because it does not result in lower GHG emissions.

[2] This option is excluded from the retrospective MACC analysis because it does not account for an alternative disposal method for the waste that would have otherwise been disposed at dumpsites, and therefore overstates the mitigation potential.

[3] This option is excluded from the retrospective MACC analysis because it competes directly with methane recovery from dumpsites for flaring, which is more cost-effective that electricity generation from these sites.

[4] This option was included in the retrospective MACC analysis, but did not mitigate GHG emissions when analyzed within the retrospective option sequence. Therefore, we do not report results for this option.

A key issue in the estimation of mitigation potential and costs per ton is how to account for interactions between mitigation options. Implementing certain options together can lower (or increase) their total effectiveness—for example, an energy efficiency measure will result in greater abatement when the power system is carbon intensive, but less if a renewable power measure is deployed concurrently. Similarly, some mitigation options address the same GHG emission source categories, leading to a potential overestimation of total GHG emission reductions if all the mitigation options analyzed in this report are simply summed up.

The CBA addressed this issue by following the retrospective systems approach in Sathaye and Meyers (1995). In this approach, the GHG emission reduction potential and cost per ton of CO_2e for a given mitigation option were calculated relative to a scenario that reflected the cumulative effect of previously implemented (more cost effective) mitigation options. In the present analysis, the value of an option was represented by its cost per ton of CO_2e mitigation (*excluding* co-benefits), relative to the baseline scenario. Options with low cost per ton of CO_2e mitigation were most cost effective. The advantage of this approach is that it accounts for the interdependence between a given mitigation option and the preceding options analyzed in the CBA. This enables the development of a MACC that illustrates the potential emission reductions that can be achieved if all mitigation options analyzed in this CBA were implemented together. In brief, this method involves four steps:

- Each mitigation option is first evaluated individually (compared to the baseline scenario), and an initial cost per ton for each is recorded;
- The options are sorted according to their initial costs per ton in ascending order;
- The options are added one at a time and in order to a new combined mitigation scenario, and emissions and costs for the combined scenario are recorded after each addition; and
- The final abatement potential and cost per ton for each option are calculated using the marginal emission reductions and costs incurred after the option was added to the combined scenario. Thus, the first option is evaluated in comparison to the 2010-2050 baseline only, the second option in comparison to the baseline plus the first option, and so forth.

The retrospective approach, which ultimately determines the abatement potential and cost of an option, spans all mitigation options across all sectors. Waste mitigation options were initiated within the overall set or sequence of options based on the retrospective analysis approach, as summarized in Table V. 24. Across all sectors, 37 mitigation options were included in the retrospective analysis, including six of the nine waste options described above. In three instances, a waste option was excluded from the retrospective analysis:

- **CDFs and Substitute SLFs** – This option is excluded from the retrospective MACC analysis because it does not result in lower GHG emissions.
- **CDFs Only** – This option is excluded from the retrospective MACC analysis because it does not account for an alternative disposal method for the waste that would have otherwise been disposed at dumpsites, and therefore overstates the mitigation potential.
- **Methane Recovery from Dumpsites for Electricity** – This option is excluded from the retrospective MACC analysis because it competes directly with methane recovery from dumpsites for flaring, which is more cost-effective that electricity generation from these sites.

Furthermore, the retrospective analysis revealed that the MSW Incineration option does not mitigate GHG emissions when implemented in the sequence order of options in Table V. 24. Therefore, the results presented in this report focus only on the incremental impacts of the *five* waste mitigation options that: (i) were included in the retrospective analysis; and (ii) for which the analysis found GHG reduction benefits.

The results presented below in Section V.4.1.2 Results focus only on the incremental impacts of the *five* waste mitigation options. However, it is important to understand that those results occur within and are dependent on where an option sits in the overall sequence of 37 options in Table V. 24. The further down the list a mitigation option is placed, the less GHG-intensive the economy will be, thus reducing the potential for achieving additional abatement at a low cost. For example, this is the reason that the MSW Incineration option does not result in GHG emission reductions. At the time it comes online, the energy system is already very clean and the new electricity from the waste incineration replaces mostly renewables, natural gas, and nuclear power.

Table V. 24. Sequential Order of All Mitigation Options in the Retrospective Analysis Approach

Sector	Mitigation Option Sequence	Mitigation Option Name
Industry	1	Increase Glass Cullet Use
Industry and Energy	2	Cement Clinker Reduction
Transport	3	Motor Vehicle Inspection System (MVIS)
Transport	4	Electric Jeepney
Transport	5	Congestion Charging
Energy	6	Home Lighting Improvements
Transport	7	Driver Training
Energy	8	Home Appliance Standards
Industry and Energy	9	Cement Waste Heat Recovery
Energy	10	Efficient Light Emitting Diode (LED) Lighting
Industry and Energy	11	Biomass in Cement
Energy	12	National Renewable Energy Program (NREP) Biomass
Industry and Energy	13	Biomass Co-firing
Waste and Energy	**14**	**Municipal Solid Waste (MSW) Digestion**
Energy	15	Nuclear Power
Energy	16	National Renewable Energy Program (NREP) Solar
Energy	17	Gas for Coal
Agriculture	18	Organic Fertilizers
Energy	19	National Renewable Energy Program (NREP) Wind
Waste and Energy	**20**	**Methane Recovery from Sanitary Landfill for Electricity (SLFs)**
Agriculture	21	Alternate wetting and drying (AWD)
Waste	**22**	**Methane Flaring from Dumpsites**
Forestry and Energy	23	Forestry Mitigation 2 – Restoration and Reforestation
Agriculture	24	Crop Diversification
Forestry and Energy	25	Forestry Mitigation 1 – Forest Protection
Energy	26	National Renewable Energy Program (NREP) Ocean
Energy	27	National Renewable Energy Program (NREP) Large Hydro
Waste	**28**	**Composting**
Waste	**29**	**Eco-Efficient Cover**
Energy	30	National Renewable Energy Program (NREP) Small Hydro
Energy	31	National Renewable Energy Program (NREP) Geothermal
Transport	32	Biofuels
Energy	33	Biodiesel Target
Transport	34	Buses and Bus Rapid Transit (BRT)
Agriculture and Energy	35	Biodigesters
Transport	36	Rail
Waste and Energy	**37**	**Municipal Solid Waste (MSW) Incineration**

V.4.1.2 Results

The following section presents the results of the analysis of direct costs and benefits of mitigation options considering two primary questions: the mitigation potential (tons of CO_2e reduced) and the cost-effectiveness (cost per ton of CO_2e) of each discrete mitigation option included in the retrospective analysis.

Table V. 25 provides a description of each of the variables given in the subsequent results tables. Each variable is assigned a symbol (e.g. "A") to allow efficient referencing in the row of formulas provided for each table.

Table V. 25. Description of Result Variables

Symbol	Variable	Description
A	Incremental Cost	Equal to the sum of capital, operating and maintenance (O&M), implementation, fuel, and input costs compared to the mitigation option that preceded it in the retrospective analysis. Represents the net change in costs with implementation of the mitigation option. Negative costs indicate cost savings compared to the prior mitigation option analyzed (e.g., fuel savings).
B	Incremental GHG Mitigation Potential	Potential change in cumulative GHG emissions from 2015-2050 with implementation of the mitigation option relative to the preceding mitigation option. Positive values indicate GHG emission benefits.
C	Incremental Cost per Ton Mitigation without co-benefits	Equal to the total net cost divided by the mitigation potential. Represents the cumulative cost per ton of a mitigation option relative to the preceding mitigation option. Negative values indicate cost savings as well as GHG emission benefits.

Table V. 26 summarizes the direct costs and benefits of mitigation options, including changes in capital, O&M, implementation, and fueling costs as well as GHG emissions. The assessment is based on cumulative costs expected during the 2015-2050 time period. Two of the mitigation options – the MSW Digestion option and the Methane Recovery from SLFs option – have a negative cumulative net cost which means that they will be cost-effective to implement simply from a perspective of direct cost and GHG reduction potential. These two are therefore the most attractive options from the standpoint of direct costs and benefits. Both of these options include emissions mitigation through WtE concepts, but from different perspectives. The MSW Digestion option enables electricity generation through a waste diversion concept, which prevents organic material from being disposed in a landfill, and avoids the production of CH4. The SLF option considers electricity generation from the recovery of CH4 produced from organic material that is actually disposed in a landfill.

The Flaring of Recovered Methane option is less cost-effective than digestion and methane recovery for electricity production, highlighting the benefits achieved from on-site electricity production versus flaring. The use of eco-efficient covers at small landfills and composting are more expensive than the other options, but offer the largest mitigation potential. The composting option provides the greatest potential for future mitigation (e.g., since composting diverts organic waste from landfill disposal), but also at the highest cost per ton at USD 35/ton of CO_2e, based on direct costs only.

Table V. 26. Mitigation Options in the Waste Sector without Co-benefits

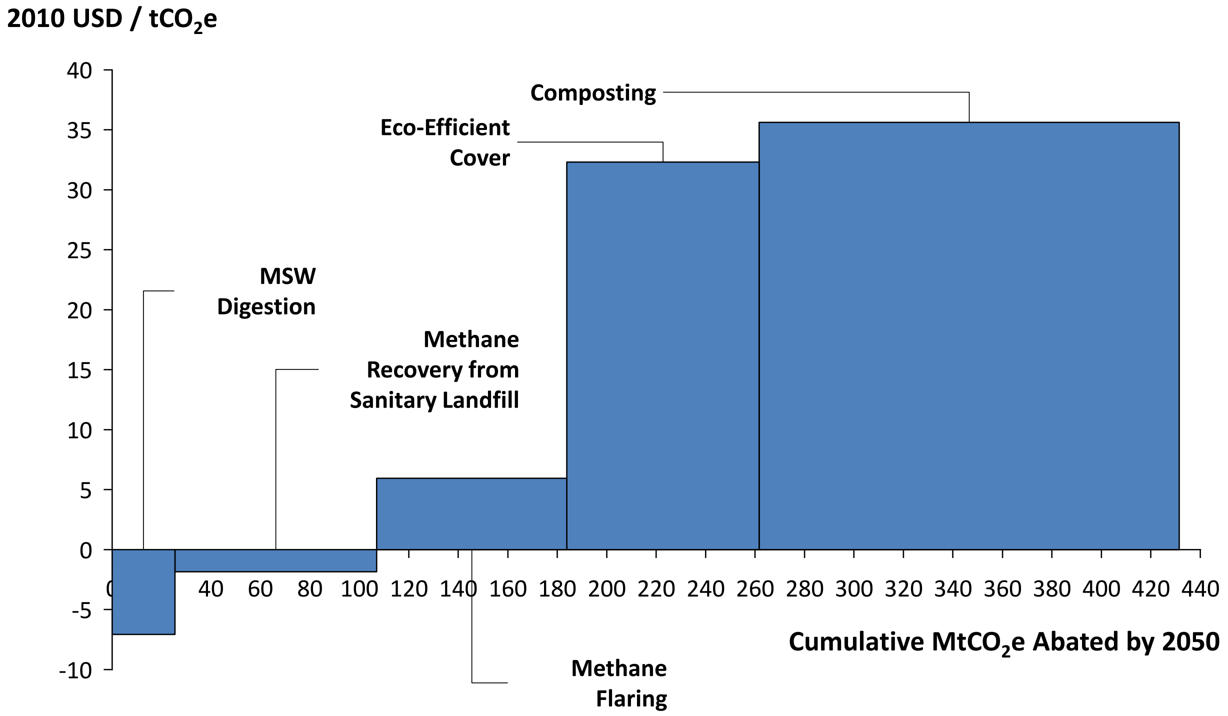
Sector	Sequence Number of Mitigation Option*	Mitigation Option	Incremental Cost (Cumulative 2015-2050) [Billion 2010 USD] Discounted at 5%	Incremental GHG Mitigation Potential (2015-2050) [$MtCO_2e$]	Incremental Cost per Ton Mitigation (2015-2050) [2010 USD] ***without co-benefits***
Symbol			*A*	*B*	*C*
Formula					*(A*1000)/B=C*
Waste	14	MSW Digestion	-0.18	25.53	-7.08
	20	Methane Recovery from Sanitary Landfills	-0.15	81.51	-1.85
	22	Methane Flaring	0.46	76.89	5.95
	28	Composting	6.05	169.88	35.60
	29	Eco-Efficient Cover	2.51	77.75	32.30

* Refers to the sequential order in which the mitigation option is introduced in the retrospective analysis. In this analysis, mitigation options are compared to the baseline as stand-alone options, and then ranked according to their cost per ton mitigation (excluding co-benefits) from lowest cost per ton mitigation to highest cost per ton mitigation. The impact of a given mitigation option is calculated relative to a scenario that embeds all options with lower cost per ton mitigation.

Figure V. 13 presents the same information in a MACC. The MACC visually illustrates the cumulative abatement potential and costs per ton of the waste sector mitigation options. It shows that implementation of all the waste mitigation options analyzed in the study could result in total cumulative emission reductions of approximately 432 $MtCO_2e$. The negative cost options include the MSW Digestion (waste-to-energy) option and the Methane Recovery from SLFs for Electricity Generation option. If the negative cost mitigation options are implemented (i.e., all those below the horizontal axis), the Philippines can achieve cumulative reductions of 100 $MtCO_2e$ by 2050. These options are especially important as the negative cost implies that a true cost saving to society would be realized by implementing the option as a result of avoided costs or direct benefits from the option.

The MACC presented in Figure V. 13 is based on the direct costs and benefits. It does not capture the indirect market effects highlighted in Section V.4.2 Co-Benefits on co-benefits.

Figure V. 13. 2015-2050 GHG Emissions Abatement Cost Curve for Waste ($MtCO_2e$)



V.4.2 Co-Benefits

In this section we describe the general approaches taken to calculate income generation, human health, energy security, and employment impacts related to the mitigation options for the waste sector and provide a discussion of the results. Consistent with all the sectoral analyses, these impacts have been calculated using the retrospective systems approach described in Sathaye and Meyers (1995). There are market and non-market co-benefits which can add to the cost-effectiveness of a mitigation option. In the waste sector, we have estimated the following co-benefits:

- *Market co-benefits*: the income generated by sales of the compost product (under the Composting option);
- *Non-market co-benefits*: the economic value of air quality-related improvements in human health (for the MSW Digestion option and the Methane Recovery from SLFs for Electricity option, because these options interact with the energy sector).

The co-benefits that were monetized in this report represent only a subset of the benefits that can be achieved by introducing the mitigation options. However, they are the only ones for which sufficient data were available to quantify and monetize their benefit within the timeframe of the CBA. In addition to the co-benefits listed above, several other impacts of mitigation, such as improvement in energy security, were characterized using a series of quantitative indicators as the available information to estimate their economic value was insufficient. In subsections below, we describe the methods and results for these impact assessments.

V.2.2.1 Income Generation

The Composting option includes increases in the segregation of biodegradable waste for the production of compost product, which has a market value. GHG mitigation strategies that result in additional compost materials provide an income co-benefit from the eventual sale of these materials into the marketplace.

The primary market for compost products are in the agricultural sector. By definition, the compost produced by the bioreactor or the composter is a pure organic fertilizer. It has both fertilizing and soil conditioning characteristics, and is highly recommended for enriching soil nutrients in a manner that also enhances soil texture conducive to plant development (ADB, 2003b). A key challenge in the compost market, however, is that agricultural activities, which offer various options to reuse or recycle organic wastes, occur in rural areas. Yet, in cities, the demand for compost products is limited. The pressure to intensify composting as a waste reduction strategy pursuant to RA 9003 is bound to create a situation where it might be challenging to match demand with supply. While enormity of the supply is unavoidable under the situation, the demand has certain limits among compost users (JICA, 2008; ADB, 2003b). In addition, a situation where there is an over-supply of compost is likely to lead to a significant decline in the market price of compost.

This analysis estimates the potential market value of the compost produced (compared to the baseline case), without attempting to characterize the distribution of that income across various involved parties. Further, the analysis does not account for the price changes that are likely to occur due to the shifts in supply of the compost product. To account for the limitations of the compost market size, it was assumed that only 50% of the compost produced can be sold into the market (whereas the remaining 50% of the compost product cannot be sold due to insufficient demand).

Compost is priced on a per-ton basis. The weight of the compost produced from segregated biodegradable waste is estimated based on the assumption that composting technologies can reduce the initial weight of the waste by 50% (NSWMC, 2014). Table V. 27 summarizes the market prices applied to the compost produced.

Table V. 27. Market Price of Compost Products

Compost Product Type	Market Price (2010 USD per Metric Ton)	Source
Bioreactor compost product	87.96	ADB, 2003b

Vermicast compost product	73.73	Paul et al., 2008

Based on the above assumptions, the CBA estimates an income co-benefit potential from compost production of approximately 6.5 billion 2010 USD, cumulative net present value over 2015 – 2050 at 5% discount rate. As noted above, realizing this potential requires significant increases in the diversion of organic waste as well as overcoming market challenges with respect to the overall supply and demand for compost.

V.2.2.2 Air Quality-Related Human Health Impacts

Waste mitigation options that result in the addition of new RE supply to the energy system have the potential to produce human health-related benefits if the new capacity replaces fossil fuel-based power generation that emits local air pollutants. The following subsection presents the method for assessing these impacts from the MSW Digestion option and the Methane Recovery from SLF option.

The human health impact assessment was limited to a consideration of impacts on premature mortality due to exposure to ambient fine particulate matter ($PM_{2.5}$). The potential human health impact of each mitigation option was based on LEAP-generated estimates of the option-specific $PM_{2.5}$ precursor emissions from power sector. To assess the premature mortality impact of the air pollutant emissions, the associated ambient $PM_{2.5}$ concentrations was computed and the epidemiological relationships was used to combine this information with estimates of the exposed population sizes and baseline mortality rates. The resulting option-specific impact was quantified in terms of the *incremental change* in the cumulative number of air pollution-related premature deaths (separately for males and females) expected to occur based on the *incremental change* in emissions of air pollutants during 2015-2050. In this framework, a negative value reflects the option resulting in *additional* projected premature deaths. The economic value of the changes in premature mortality was computed using an estimate of the VSL and the standard discounting procedures used throughout this assessment. Additional details on estimation of the human health co-benefits are presented in the Appendix.

Table V. 28 the incremental human health impacts calculated for the waste sector mitigation options. The specific results in Table V. 28 are affected by the sequence of options in the retrospective analysis and details of the assumptions incorporated in the LEAP model regarding level of energy demand and dispatch within the electrical system. However, the following observations can be made:

- The MSW Digestion option results in modest additions to electric generation capacity (without net additions to the power supply). The new capacity displaces additions of coal capacity that would have occurred in the absence of MSW digestion. Therefore, this option provides an improvement in the power sector air pollutant emissions profile, air quality, and human health;
- The Methane Recovery from SLFs option is similar to the MSW Digestion option in that it adds to the electric generation capacity without changing overall power supply. However, this option is implemented after the energy sector option that replaces new coal capacity with new natural gas capacity. Thus, the Methane Recovery from SLFs option primarily displaces natural gas generation and, thereby, results in higher emissions of air pollutants from the power sector and associated health dis-benefits; and

- Females are expected to experience slightly less than 50% of the total health benefit (or dis-benefit) because their baseline mortality rates are lower than the baseline mortality rates for males.

Important caveats to interpreting these results would include recognizing that the morbidity impacts of changes in ambient air pollution are not quantified. The direction/sign of any morbidity impact for an option would be the same as the premature mortality results. The Appendix presents additional caveats related to the health impact assessment methods that were used.

Table V. 28. Incremental Human Health Impact for Proposed Mitigation Options, Cumulative Impact during 2015-2050

Sector	Mitigation Option Sequence*	Mitigation Option Name	Incremental Present Discounted Value (Millions 2010 USD, 5% Discount Rate)	Incremental Cases of Premature Death [2015-2050]	Incremental Cases of Premature Death [2015-2050] (Females)
Waste and Energy	14	MSW Digestion	183	188	73
Waste and Energy	20	Methane Recovery from SLFs for Electricity	-127	-130	-42
Waste	22	Methane Flaring from Dumpsites	No impact on energy sector emissions by design.		
Waste	28	Composting	No impact on energy sector emissions by design.		
Waste	29	Eco-Efficient Cover	No impact on energy sector emissions by design.		

* Refers to the sequential order in which the mitigation option is introduced in the retrospective analysis. In this analysis, mitigation options are compared to the baseline as stand-alone options, and then ranked according to their cost per ton mitigation (excluding co-benefits) from lowest cost per ton mitigation to highest cost per ton mitigation. The impact of a given mitigation option is calculated relative to a scenario that embeds all options with lower cost per ton mitigation.

V.2.2.3 Energy Security Impacts

Increased energy security means that the country's energy system is more resilient to a variety of shocks (e.g., global economic crises, international conflicts, spikes in individual fuel costs). In practice, as energy security within a country's system increases, the adverse impacts from these shocks on the country's economy will be less pronounced. Improvements in energy security can result from several changes in the energy sector, such as increasing combinations of fuel diversity, transport diversity, import diversity, energy efficiency, and infrastructure reliability. For example:

- Energy generation portfolios that are heavily dependent on a limited number of fuel inputs or generation sources can be highly affected by shocks to a single fuel or generation source. In contrast, energy systems that incorporate a relatively diverse mix of fuel inputs and a number of generation sources with redundancy will be less affected by shocks to any single fuel or generation source. Energy security concerns can be alleviated by increasing the diversity of both the source of the fuels (i.e., domestic or imported, including the country of origin), the type of fuel (i.e., oil, gas, solar, renewables), and the mix of technologies used to generate the energy;
- Energy system security is also a function of available fuel supplies/reserves compared to demand. An increase in available fuel supply would increase energy security. Supply can be increased through increased exploration of fossil fuels, increasing investment in renewable fuels, or by encouraging energy efficiency measures to prolong the availability of known existing resources.

A number of indicators may be applied to assess whether a country is becoming more or less energy secure due to implementation of a mitigation option. For this evaluation, the following indicators were computed:

- Energy intensity (energy consumption per unit of GDP);
- GHG intensity (CO_2e emissions per unit of GDP);
- Percentage share of imports in total energy supply; and
- Percentage share of renewable energy in energy supply.

The Study Team calculated these indicators in LEAP using the same retrospective analysis as the one used to assess the mitigation options. gy intensity of GDP.

Table V. 29 presents the average annual incremental impact of each mitigation option on the four energy security indicators for the period 2015-2050. In reviewing the results it is critical to remember the incremental nature of the analysis, where results for any mitigation option are relative to the suite of those which are assumed to have already been implemented (i.e., all previously listed and lower numbered options). The various waste options generally tend to improve energy security by reducing GHG intensity, increasing the share of renewable energy, and reducing the share of imported fuel. These options have no impact on the energy intensity of GDP.

Table V. 29. Incremental Changes in Energy Security Indicators due to the Proposed Mitigation Options, Average Annual Incremental Impact during 2015-2050

Sector	Mitigation Option Name	Mitigation Option Sequence*	Average Annual Incremental Impact 2015-2050 [1]			
			Change in GHG Intensity of GDP (g CO_2e/2010 USD) [2]	Change in Share of Renewables (%) [3]	Change in Share of imports (%) [4]	Change in Energy Intensity of GDP (MJ/2010 USD) [5]
Waste and Energy	MSW Digestion	14	-0.92	8	-8	0
Waste and Energy	Methane Recovery from SLFs for Electricity	20	-2.22	8	-7	0
Waste	Methane Flaring from Dumpsites	22	-2.18	0	0	0
Waste	Composting	28	-4.07	0	0	0
Waste	Eco-Efficient Cover	29	-2.32	0	0	0

Notes:

* Refers to the sequential order in which the mitigation option is introduced in the retrospective analysis. In this analysis, mitigation options are compared to the baseline as stand-alone options, and then ranked according to their cost per ton mitigation (excluding co-benefits) from lowest cost per ton mitigation to highest cost per ton mitigation. The impact of a given mitigation option is calculated relative to a scenario that embeds all options with lower cost per ton mitigation.

[1] All indicators are calculated in LEAP. Results reflect the average of annual results from 2015-2050 that compare the indicator value for a given mitigation option relative to the value for the previous mitigation option.

[2] GHG intensity is measured as grams (g) of CO_2e emissions (economy-wide, including from energy and non-energy sources) per unit of GDP (2010 USD).

[3] Percentage share of renewable energy in total primary energy supply.

[4] Percentage share of imports in total primary energy supply.

[5] Energy intensity is measured as total megajoules of primary energy supply (indigenous production of primary

energy + energy imports - energy exports) divided by GDP (2010 USD).

V.2.2.4 Power Sector Employment Impacts

In this section, we describe the general approach taken to assess power sector employment impacts and caveats to interpreting available option-specific results. The basic indicator used to capture potential employment impacts is the *job-year,* defined as “full-time employment for one person for a duration of one year” (Wei et al., 2010 p. 7). Estimates of the net change in job-years associated with the mitigation options were calculated using results from Wei et al. (2010). Wei et al. conducted a literature review and synthesis of results that quantified the employment impacts of *new* power projects over a defined project lifetime. By accounting for the power generation potential and anticipated use of the project the Wei et al. (2010) results are expressed in terms of the average number of job-years per Gigawatt Hour (GWh). The CBA incorporates The Wei et al. (2010) results using the job-years/GWh factors in Table V. 30.

Table V. 30. Average Job-Years/GWh in the Power Sector by Type of Power Generation[13]

Power Generation Technology	Average Job-Years/GWh of Generation*
Solar Photovoltaics	0.87
Landfill Gas	0.72
Large Hydro	0.27
Small Hydro	0.27
Geothermal	0.25
Agricultural Waste Digestion	0.21
Biomass	0.21
MSW Digestion	0.21
MSW Incineration	0.21
Ocean Thermal	0.17
Wind	0.17
Nuclear	0.14
CFBC Coal	0.11
Natural Gas Combined Cycle	0.11
Subcritical Pulverized Coal	0.11
Supercritical Pulverized Coal	0.11
Ultrasupercritical Pulverized Coal	0.11

*** Assumptions:**

- Wei et al. (2010) provided job-years factor for *Small Hydro*. The same factor was assigned to *Large Hydro.*
- *MSW Incineration*, *MSW Digestion*, and *Agricultural Waste Digestion* use the *Biomass* job-years factor
- *Ocean Thermal* uses the *Wind* job-years factor
- All *Coal* types have the same job-years factor based on the belief they are a close match for each other

Using the factors in Table V. 30 and power generation projections by source and year calculated using LEAP, the employment in the power sector for the different mitigation options over the period 2015-

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[13] ***Source:*** Results based on Wei et al., 2010

2050 was calculated in terms of *job-years*. The incremental impact of each mitigation option on job-years was then calculated by subtracting the calculated job-years for the previous mitigation option from the result for the mitigation option under consideration.

The scope of this analysis is constrained. In quantifying potential employment impacts from implementing the mitigation options, only the net change that would result in the power sector was considered. Employment changes in other sectors or elsewhere in the economy that are directly and indirectly affected with implementation were not accounted for as they are beyond the scope of the analysis. Table V. 31 presents our estimates of the incremental change in the power sector employment indicator for each mitigation option.

Table V. 31. Incremental Changes in Power Sector Job-Years for proposed Mitigation Options, Cumulative Impact from 2015-2050

Sector	Mitigation Option Name	Mitigation Option Sequence*	Incremental Job-Years Impact (Cumulative Job-Years 2015-2050)
Waste and Energy	MSW Digestion	14	**1,974**
Waste and Energy	Methane Recovery from SLFs	20	**9,861**
Waste	Methane Flaring from Dumpsites	22	**No impact on power sector employment by design.**
Waste	Composting	28	**No impact on power sector employment by design.**
Waste	Eco-Efficient Cover	29	**No impact on power sector employment by design.**

*** Refers to the sequential order in which the mitigation option is introduced in the retrospective analysis. In this analysis, mitigation options are compared to the baseline as stand-alone options, and then ranked according to their cost per ton mitigation (excluding co-benefits) from lowest cost per ton mitigation to highest cost per ton mitigation. The impact of a given mitigation option is calculated relative to a scenario that embeds all options with lower cost per ton mitigation.**

The potential incremental power sector employment impacts presented in Table V. 31 have a number of important caveats that need to be kept in mind in order to place these results in the proper context. These caveats include:

- Wei et al. (2010) focus on results from the United States. The relevance of their results in the context of the Philippines cannot be assessed;
- The Wei et al., (2010) results focus on development of new generation facilities, their relevance when there is a change in the mix of generation among existing facilities is uncertain;
- The application of the job-year factors as a constant value over the period of the analysis assumes future changes in technology will not affect these values and that they can be used regardless of the cumulative scale of generation in the Philippine power sector; and

The estimated changes in the power sector job-years do not reflect changes in employment of the Philippine economy at large, because gains (losses) in power sector employment may be matched by losses (gains) in employment elsewhere in the economy.

V.4.3 NPV of Mitigation Options

The following section presents the NPV results of each mitigation option included in the retrospective analysis. Table V. 32 shows the cost per ton of CO_2e of each mitigation option with and without co-benefits. Column E of Table V. 32 indicates the present value of the net benefit stream, which is the difference between the discounted value of cumulative co-benefits and the discounted value of the cumulative costs of a mitigation option. A positive value indicates a mitigation option has net benefits to society in addition to its potential to mitigate GHG emissions.

It is interesting to note that the Composting option, which is the least attractive on the direct cost-per-ton basis (Table V. 26. Mitigation Options in the Waste Sector without Co-benefits and Figure V. 13), is the most cost-effective option when co-benefits are incorporated into the analysis. As noted above, there are significant challenges in achieving the full potential for composting, which make the potential income co-benefits from composting highly uncertain. Aside from the reversal observed in the composting option, the general ranking of the mitigation options when co-benefits is consistent with the ranking based on direct costs, though in some cases the differences between options are even greater. For example, the MSW digestion option is still the most cost-effective, but appears even more attractive compared to other options when co-benefits are included in the analysis (i.e., -7.08 USD/ton per Table V. 26. Mitigation Options in the Waste Sector without Co-benefits versus -14.25 USD/ton with co-benefits).

Table V. 32. Net Present Value of Mitigation Options in the Waste Sector

Sequence Number of Mitigation Option[1]	Mitigation Option	GHG Mitigation Potential ($MtCO_2e$)[3]	Cost per Ton CO_2e Mitigation (2010 USD)[2]			NPV Excluding Value of GHG Reduction (Billion 2010 USD)[2]
			without co-benefits	*co-benefits only*[4]	*with co-benefits*[5]	
		A	*B*	*C*	*D = B+C*	*E = –D * A/1000*
14	MSW Digestion	25.53	-7.08	-7.17	-14.25	0.36
20	Methane Recovery from Sanitary Landfills	81.51	-1.85	1.56	-0.29	0.02

Sequence Number of Mitigation Option[1]	Mitigation Option	GHG Mitigation Potential ($MtCO_2e$)[3]	Cost per Ton CO_2e Mitigation (2010 USD)[2]			NPV Excluding Value of GHG Reduction (Billion 2010 USD)[2]
			without co-benefits	*co-benefits only*[4]	*with co-benefits*[5]	
		A	*B*	*C*	*D = B+C*	*E = –D * A/1000*
22	Methane Flaring	76.89	5.95	0.00	5.95	-0.46
28	Composting	169.88	35.60	-38.26	-2.66	0.45
29	Eco-Efficient Cover	77.75	32.30	0.00	32.30	-2.51

Notes:

[1] Refers to the sequential order in which the mitigation option is introduced in the retrospective analysis. In this analysis, mitigation options are compared to the baseline as stand-alone options, and then ranked according to their cost per ton mitigation (excluding co-benefits) from lowest cost per ton mitigation to highest cost per ton mitigation. The cost and GHG mitigation potential of a given mitigation option is calculated relative to a scenario that embeds all options with lower cost per ton mitigation.

[2] The costs and co-benefits expected to occur in years other than 2015 were expressed in terms of their present (i.e., 2015) value using a discount rate of 5%.

[3] The GHG mitigation potential is a total reduction in GHG emissions that is expected to be achieved by the option during 2015-2050.

[4] The co-benefits for the waste sector include income from composting activities and human health benefits due to reduced air pollution from the energy sector.

[5] Negative value indicates net benefits per ton mitigation. This excludes the non-monetized benefits of GHG reductions.

ANNEX V.5 CROSS-CUTTING ECONOMIC ASSUMPTIONS

The sector-specific baseline projections are based on the common set of projections for the Philippine economy characteristics. Table V. 33 shows the data sources and assumptions used to generate these projections, while Table V. 34 presents historical and projected values in select years that were used in the analysis. Table V. 35 lists historical exchange rates and inflation rates used for inter-temporal and cross-country currency conversions.

Table V. 33. Data Sources and Assumptions Used for Projections of Population, GDP, Economic Sector-Specific Value Added, and Fuel Price

Characteristic	Data Sources for 2010-2014 Estimates	Projection Method for 2015-2050
Population	1990-2010: Philippine Statistics Authority, National Statistical Coordination Board (http://www.nscb.gov.ph/secstat/d_popn.asp). Accessed 13 March 2015. 2011-2020: Philippine Statistics Authority, National Statistics Office (http://web0.psa.gov.ph/sites/default/files/attachments/hsd/pressrelease/Table4_9.pdf). Accessed 13 March 2015.	2011-2020: Philippine Statistics Authority, National Statistics Office (http://web0.psa.gov.ph/sites/default/files/attachments/hsd/pressrelease/Table4_9.pdf). Accessed 13 March 2015. 2021-2045: Philippine Statistics Authority, National Statistics Office (http://web0.psa.gov.ph/sites/default/files/attachments/hsd/pressrelease/Table1_8.pdf). Accessed 13 March 2015 2045-2050: Population is assumed to grow at average annual rate during 2035-2045.
GDP	1990-2010: Philippine Statistics Authority, National Statistical Coordination Board (http://www.nscb.gov.ph/sna/Rev_Ann_Qtr/1946_2010_NAP_Linked_Series_NSIC.xls). Accessed 12 March 2015. 2011: Philippine Statistics Authority, National Statistical Coordination Board (http://www.nscb.gov.ph/sna/2013/4th2013_RevisedMay2014/Revised_Q1_to_Q4_2011_to%202013.rar). Accessed 12 March 2015. 2012-2014: Philippine Statistics Authority, National Statistical Coordination Board (http://www.nscb.gov.ph/sna/2014/4th2014/tables/1Q4-Rev_Summary_93SNA.pdf). Accessed 12 March 2015.	GDP assumed to grow at similar rate as that projected by ADB in *Low-Carbon Scenario and Development Pathways for the Philippines* (ADB, 2015)

Characteristic	Data Sources for 2010-2014 Estimates	Projection Method for 2015-2050
Value Added by Industrial Sectors	1998-2010: Philippine Statistics Authority, National Statistical Coordination Board (http://www.nscb.gov.ph/sna/revisedQuarterlyPSNA/Annual (revised,rebased%2098-2000.rar). Accessed 12 March 2015. 2011-2013: Philippine Statistics Authority, National Statistical Coordination Board (http://www.nscb.gov.ph/sna/2013/4th2013_RevisedMay2014/Revised_Q1_to_Q4_2011_to%202013.rar). Accessed 12 March 2015. 2014: Philippine Statistics Authority, National Statistical Coordination Board (http://www.nscb.gov.ph/sna/2014/4th2014/tables/10MFG_93SNA_Q4.pdf, http://www.nscb.gov.ph/sna/2014/4th2014/tables/9MAQ_93SNA_Q4.pdf, http://www.nscb.gov.ph/sna/2014/4th2014/tables/11CNS_93SNA_Q4.pdf, and http://www.nscb.gov.ph/sna/2014/4th2014/tables/12EGW_93SNA_Q4.pdf). Accessed 12 March 2015.	All value added variables projected based on trends in their historical share of GDP.
Value Added by Commercial Sector	1998-2010: Philippine Statistics Authority, National Statistical Coordination Board (http://www.nscb.gov.ph/sna/revisedQuarterlyPSNA/Annual(revised,rebased%2098-2000.rar). Accessed 12 March 2015. 2011-2013: Philippine Statistics Authority, National Statistical Coordination Board (http://www.nscb.gov.ph/sna/2013/4th2013_RevisedMay2014/Revised_Q1_to_Q4_2011_to%202013.rar). Accessed 12 March 2015. 2014: Philippine Statistics Authority, National Statistical Coordination Board (http://www.nscb.gov.ph/sna/2014/4th2014/tables/1Q4-Rev_Summary_93SNA.pdf). Accessed 12 March 2015.	All value added variables projected based on trends in their historical share of GDP.

Characteristic	Data Sources for 2010-2014 Estimates	Projection Method for 2015-2050
Value Added by Agriculture, Forestry, Fishing	1998-2010: Philippine Statistics Authority, National Statistical Coordination Board (http://www.nscb.gov.ph/sna/revisedQuarterlyPSNA/Annual(revised,rebased%2098-2000.rar). Accessed 12 March 2015. 2011-2013: Philippine Statistics Authority, National Statistical Coordination Board (http://www.nscb.gov.ph/sna/2013/4th2013_RevisedMay2014/Revised_Q1_to_Q4_2011_to%202013.rar). Accessed 12 March 2015. 2014: Philippine Statistics Authority, National Statistical Coordination Board (http://www.nscb.gov.ph/sna/2014/4th2014/tables/8AFF_93SNA_Q4.pdf). Accessed 12 March 2015.	All value added variables projected based on trends in their historical share of GDP
Biomass	Department of Environment and Natural Resources, 2013 Philippine Forestry Statistics, Table 4.10 MONTHLY RETAIL PRICES OF FUELWOOD AND CHARCOAL: 2013 (http://forestry.denr.gov.ph/PFS2013.pdf)	Assumed same as the constant price for 2010-2014
Coal Sub bituminous	Data gathered by B-LEADERS project, 2015 (Philippine Coal Importation.xlsx) and national energy balances. Note that prices are based on imported coal only.	IEA (2014), World Energy Outlook 2014, IEA, Paris. (Current Policies scenario)
Natural Gas	Fuel price data provided by DOE to B-LEADERS project, 2015 (USAID Request_historical prices-03.04.2015.xls)	IEA (2014), World Energy Outlook 2014, IEA, Paris. (Current Policies scenario)
Nuclear	IPCC AR5 WG3 Annex III	Assumed same as the constant price for 2010-2014
Crude Oil	Fuel price data provided by DOE to B-LEADERS project, 2015 (USAID Request_historical prices-03.04.2015.xls)	IEA (2014), World Energy Outlook 2014, IEA, Paris. (Current Policies scenario)
Avgas	Fuel price data provided by DOE to B-LEADERS project, 2015 (USAID Request_historical prices-03.04.2015.xls)	Grows at the rate of crude oil
Lubricants	Same as Residual Fuel Oil	Same as Residual Fuel Oil
Bitumen	Fuel price data provided by DOE to B-LEADERS project, 2015 (USAID Request_historical prices-03.04.2015.xls)	Grows at the rate of crude oil
Naphtha	Fuel price data provided by DOE to B-LEADERS project, 2015 (USAID Request_historical prices-03.04.2015.xls)	Grows at the rate of crude oil
Other Oil	Same as Residual Fuel Oil	Same as Residual Fuel Oil
LPG	Fuel price data provided by DOE to B-LEADERS project, 2015 (USAID Request_historical prices-03.04.2015.xls)	Grows at the rate of crude oil

Characteristic	Data Sources for 2010-2014 Estimates	Projection Method for 2015-2050
Residual Fuel Oil	Fuel price data provided by DOE to B-LEADERS project, 2015 (USAID Request_historical prices-03.04.2015.xls)	Grows at the rate of crude oil
Diesel	Fuel price data provided by DOE to B-LEADERS project, 2015 (USAID Request_historical prices-03.04.2015.xls)	Grows at the rate of crude oil
Kerosene	Fuel price data provided by DOE to B-LEADERS project, 2015 (USAID Request_historical prices-03.04.2015.xls)	Grows at the rate of crude oil
Jet Kerosene	Fuel price data provided by DOE to B-LEADERS project, 2015 (USAID Request_historical prices-03.04.2015.xls)	Grows at the rate of crude oil
Motor Gasoline	Fuel price data provided by DOE to B-LEADERS project, 2015 (USAID Request_historical prices-03.04.2015.xls)	Grows at the rate of crude oil
Biodiesel	Renewable Energy Management Bureau, DOE	Grows at the rate of crude oil
Ethanol	Fuel price data provided by DOE to B-LEADERS project, 2015 (USAID Request_historical prices-03.04.2015.xls)	Grows at the rate of crude oil
CNG	Department of Energy. “Compressed Natural Gas,” 2015. http://www.doe.gov.ph/programs-projects-alternative-fuels/297-compressed-natural-gas	CNG price held constant until 2016 per Velasco, Myrna. “DOE Admits Delayed Rollout of CNG Buses.” Manila Bulletin, 2014. http://www.mb.com.ph/doe-admits-delayed-rollout-of-cng-buses/. After 2016, CNG price based on price of natural gas plus cost adders for compression, distribution, refining, taxes, and retail mark-up shown in American Clean Skies Foundation. Driving on Natural Gas: Fuel Price and Demand Scenarios for Natural Gas Vehicles to 2025, 2013.

Table V. 34. Data and Projections of Population, GDP, Economic Sector-Specific Value Added, and Fuel Price in Select Historical and Baseline Years.

	Historical Data				Baseline								
Year	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Population (Millions)	61	69	77	85	92	102	110	118	125	132	138	142	147
GDP (Billions 2010 USD)	98	106	132	161	200	274	336	474	611	793	1,060	1,433	1,895
Value Added by Economic Sectors (Millions 2010 USD)													
Beverages	1094	1187	1413	1232	1573	2166	2392	2631	2884	3152	3437	3739	4059
Tobacco	515	558	725	364	169	129	119	110	100	92	83	76	69
Food Manufactures	7123	7725	10420	14346	18193	23711	30501	39089	49929	63590	80780	102383	129502
Textile and Leather	2785	3021	3314	3156	2508	2542	2343	2153	1971	1799	1638	1488	1349
Wood and Wood Products	819	888	954	1049	777	1006	965	923	879	835	792	748	706
Paper Pulp and Print	684	742	879	650	627	865	837	807	776	743	710	677	645
Chemical and Petrochemical	1694	1837	2126	2468	2595	5697	7351	9449	12106	15465	19705	25050	31782
Non Metallic Minerals	762	827	795	771	1146	1274	1338	1400	1460	1518	1575	1629	1683
Iron and Steel	661	717	650	819	1040	835	808	778	748	716	684	652	620
Machinery	1532	1662	2624	2668	2603	2469	2566	2657	2742	2821	2895	2965	3030
Rubber and Rubber Products	424	460	534	532	616	634	644	652	657	661	663	664	664
Petroleum and Other Fuel Products	1080	1171	1892	2616	2984	3126	3859	4746	5819	7112	8672	10548	12805
Other Manufacturing	3791	4112	5913	8029	7972	7010	7586	8177	8786	9413	10058	10724	11410

	Historical Data				Baseline								
Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Mining	830	900	829	1972	2854	2493	3111	3868	4794	5923	7300	8976	11015
Construction	6225	6752	7504	7625	12220	16201	19385	23107	27453	32522	38427	45302	53298
Electricity Gas Water Supply	3649	3958	4828	6139	7128	8200	9398	10729	12208	13851	15675	17699	19943
All Commercial	49783	53995	67958	86076	110009	145430	180027	222018	272898	334462	408861	498673	606984
Agri Crops Product	7201	7810	9214	10318	13304	16309	18733	21437	24449	27804	31537	35691	40310
Livestock and Poultry	3666	3976	4725	5177	5592	5882	6106	6313	6507	6687	6854	7009	7153
Agri Services	946	1026	1172	1314	1633	1907	2117	2341	2580	2836	3109	3400	3711
Forestry	94	102	192	129	54	91	84	77	70	64	58	53	48
Fishing	2544	2759	3100	3439	3995	3799	3860	3908	3943	3967	3981	3986	3982
Value Added by Economic Sectors (Millions 2010 USD)													
Biomass	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Coal Sub bituminous	1.77	1.77	1.77	2.75	4.27	4.39	5.14	5.37	5.62	5.78	5.95	6.13	6.31
Natural Gas	1.46	1.46	1.46	6.54	8.89	9.96	9.43	9.83	10.24	10.55	10.87	11.2	11.54
Nuclear	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
Crude Oil	5.13	5.13	5.13	8.67	12.49	15.68	16.73	18.31	20.05	21.18	22.37	23.63	24.96
Avgas	14.44	14.44	14.44	21.7	32.79	33.45	35.69	39.07	42.78	45.19	47.73	50.41	53.24
Lubricants	8.46	3.49	9.33	14.02	18.76	19.41	20.71	22.68	24.83	26.22	27.7	29.25	30.9
Bitumen	5.5	5.5	5.5	5.24	13.12	13.14	14.01	15.34	16.8	17.74	18.74	19.8	20.91
Naphtha	7.51	7.51	7.51	7.74	11.19	14.13	15.07	16.5	18.07	19.09	20.16	21.29	22.49
Other Oil	8.46	3.49	9.33	14.02	18.76	19.41	20.71	22.68	24.83	26.22	27.7	29.25	30.9

	Historical Data				Baseline								
Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
LPG	6.8	5.59	7.69	11.24	15.34	16.38	17.47	19.13	20.95	22.13	23.37	24.69	26.07
Residual Fuel Oil	8.46	3.49	9.33	14.02	18.76	19.41	20.71	22.68	24.83	26.22	27.7	29.25	30.9
Diesel	11.99	9.34	11.9	21.6	19.93	21.47	22.91	25.08	27.46	29	30.63	32.36	34.18
Kerosene	12.47	9.71	11.89	23.04	25.35	26.23	27.97	30.63	33.54	35.42	37.41	39.52	41.74
Jet Kerosene	21.72	18.65	15.47	25.57	29.52	30.04	32.04	35.08	38.41	40.57	42.85	45.26	47.81
Motor Gasoline	20.42	13.65	17.85	27.27	29.09	30.58	32.62	35.71	39.1	41.3	43.62	46.08	48.67
Biodiesel	28.59	28.59	28.59	28.59	28.59	31.3	33.39	36.56	40.03	42.28	44.66	47.17	49.82
Ethanol	19.08	19.08	19.08	19.08	33.89	29.71	31.69	34.7	38	40.13	42.39	44.77	47.29
CNG	9.07	9.07	9.07	9.07	9.07	9.07	19.16	19.56	19.97	20.28	20.61	20.94	21.28

Table V. 35. Historical Exchange Rates and Inflation Rates used to Build the Baseline

Year	Philippine Peso per US Dollar[1]	Philippine Peso Annual Inflation Rate (%)[2]	US Dollar Annual Inflation Rate (%) [3]
1990	24.31	12.30	3.71
1991	27.48	19.40	3.32
1992	25.51	8.60	2.28
1993	27.12	6.70	2.38
1994	26.42	10.50	2.12
1995	25.71	6.70	2.09
1996	26.22	7.50	1.82
1997	29.47	5.60	1.72
1998	40.89	9.30	1.08
1999	39.09	5.90	1.43
2000	44.19	4.00	2.28
2001	50.99	6.80	2.28
2002	51.60	3.00	1.53
2003	54.20	3.50	1.99
2004	56.04	6.00	2.75
2005	55.09	7.60	3.22
2006	51.31	6.20	3.07
2007	46.15	2.80	2.67
2008	44.47	9.30	1.93
2009	47.64	3.20	0.79
2010	45.11	3.80	1.23
2011	43.31	4.40	2.06
2012	42.23	3.20	1.80
2013	42.45	3.00	1.49
2014	44.40	4.10	1.25

Notes:
[1] Source: Bangko Sentral Ng Pilipinas (http://www.bsp.gov.ph/statistics/statistics_online.asp -> Online Statistical Interactive Database -> Exchange Rates -> Philippine Peso per US Dollar). Accessed 12 March 2015.
Bankers Association of the Philppines (BAP) reference rate from December 13,1984 to August 3,1992 weighted average rate. Philippine Dealing System (PDS) starting August 14,1992 From: Reference Exchange Rate Bulletin, TD-BSP
[2] Sources:
1990-2011: Bangko Sentral Ng Pilipinas (http://www.bsp.gov.ph/statistics/statistics_online.asp -> Online Statistical Interactive Database -> Prices -> Consumer Price Index, Inflation Rate, and Purchasing Power of the Peso). Accessed 12 March 2015.
2012-2014: http://web0.psa.gov.ph/statistics/survey/price/summary-inflation-report-consumer-price-index-2006100-february-2015. Accessed 12 March 2015.
[3] Sources:
1990-2013: World Bank World Development Indicators (http://data.worldbank.org/indicator/NY.GDP.DEFL.KD.ZG). Accessed 12 March 2015.
2014: US. Bureau of Economic Analysis, Gross Domestic Product: Implicit Price Deflator [GDPDEF], retrieved from

Year	Philippine Peso per US Dollar[1]	Philippine Peso Annual Inflation Rate (%)[2]	US Dollar Annual Inflation Rate (%) [3]
FRED, Federal Reserve Bank of St. Louis https://research.stlouisfed.org/fred2/series/GDPDEF/, March 25, 2015.			

ANNEX V.6 HEALTH CO-BENEFITS METHODS

B-LEADERS team estimated the human health co-benefits of the mitigation options according to the basic framework presented in **Error! Reference source not found.**:

- Emissions from the LEAP model are converted to outdoor air pollution concentrations. The emissions from the LEAP Baseline case inform the baseline concentration estimates and the predicted change in emissions in each mitigation scenario is translated to air quality change. We focus on concentrations of fine particulate matter ($PM_{2.5}$), which has dominated cost-benefit analyses of reduced air pollution.[14]
- The health benefits of reduced exposure to outdoor air pollution come from reduced risk of morbidity and premature mortality. The risk reductions are calculated using research literature-based epidemiological relationships known as "exposure-response functions". In this analysis, we estimate the co-benefits associated with reduced risk of premature mortality.[15]
- To express the social benefit of fewer premature deaths in monetary terms, we rely on the concept of the aggregate willingness to pay (WTP) for small reductions in annual mortality risk by a population of a given size. We estimate the WTP is as a product of the number of premature deaths avoided due to a mitigation option and the value per statistical life (VSL), a risk reduction-normalized WTP estimate derived from the research literature.

Each of these steps is described in depth below, and methodological differences between the transportation and energy sectors are explained.

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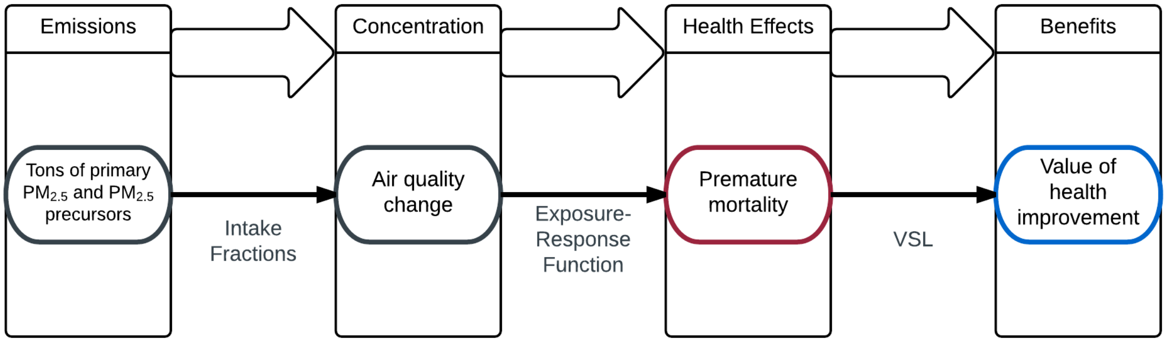
[14] Ozone is another important pollutant, but modeling ozone levels is outside of the scope of this analysis. Furthermore, the Global Burden of Disease Study found that deaths attributable to ambient ozone levels were less than 5% the number of deaths attributable to ambient $PM_{2.5}$ levels (Lim et al., 2013).

[15] We focus on all-cause mortality, since there may not be sufficient data to estimate cause-specific mortality. There are also associations between $PM_{2.5}$ and non-mortality (morbidity) health endpoints, but these tend to be smaller in cost benefit analysis.

Figure V. 14 General Framework for Health Co-Benefits Calculation



V.6.1 Emissions

The relevant emissions for the health co-benefits we consider are primary $PM_{2.5}$ and two gaseous precursors to secondary $PM_{2.5}$, NOx and SO_2. Primary $PM_{2.5}$ is the mass of particulates that is emitted directly from an emissions source, while secondary $PM_{2.5}$ forms from the oxidation of primary gases in the atmosphere. The LEAP model provides national-scale estimates of primary $PM_{2.5}$ and secondary $PM_{2.5}$ precursors for each sector and each mitigation scenario. For the transport sector, health co-benefits are estimated based on tank-to-wheel primary $PM_{2.5}$ emissions only. For the energy sector, health co-benefits are estimated based on emissions of NOx, SO_2, and primary $PM_{2.5}$.

V.6.1.1 Transportation sector emissions

For the transportation sector, the mitigation options focus on on-road vehicles. For these mitigation options, we only model the co-benefits of downstream (tank-to-wheel) reductions in primary $PM_{2.5}$ emissions. With one exception, the team does not estimate the additional upstream (well-to-tank) impacts that these policies may have by reducing refinery emissions or emissions elsewhere in the energy sector, as the team does not have sufficient information to characterize the resulting change in exposure. The exception is for vehicle electrification policy. For the three options that involve replacing a share of the fleet with electric vehicles, we account for the increased upstream emissions by on-grid power generation.

The team followed the same general methods for calculating conventional pollutant emissions for on-road transportation as those described for GHG emissions. The team used emission factors from the ICCT Roadmap Model (ICCT 2014). A report by the Asian Development Bank (1992) was the only resource providing emission factor information specific to the Philippines, and presents emission factors that do not likely apply to most vehicles currently on the road, and did not include emission factors for methane, nitrous oxide, or black carbon. The team used emission factors from the ICCT Roadmap Model, and used the ADB report as a reference to check against the emission factors for uncontrolled vehicles. Where there were large discrepancies between emission factors reported by ADB (1992) for a specific pollutant or mode and those used in the Roadmap, the emission factors were adjusted using a third source, the zero-mile emission rates used in the ICCT India Model (Bansal and Bandivadekar, 2013).

In some cases, additional adjustments were made to fill gaps for relevant pollutants and vehicle fuel types. Adjustments by mode, fuel type and pollutant are shown in **Error! Reference source not found.**.

Table V. 36 Selection of Road Vehicle Emission Factors

Vehicle - Fuel type	$PM_{2.5}$	CH_4	BC	N_2O	NO_X	CO
MC - diesel	-	* (4-6)	-	-	-	-
MC - gasoline	†	-	* (6)	-	-	-
TC - diesel	-	* (6)	-	-	-	-
TC - gasoline	†	-	* (6)	-	-	-
Bus - CNG	‡ (VI, diesel)	‡ (VI, diesel)	* (all)	* (all)	-	-
Bus - diesel	-	-	-	-	-	-
Bus - gasoline	-	-	-	-	-	-
Truck - diesel	* (6)	-	-	-	-	-
Truck - gasoline	-	-	-	-	-	-
LDV - diesel	-	* (4-6)	* (6)	* (uncontrolled)	-	-
LDV - gasoline	†	-	†	-	-	-
LDV - LPG	†	-	†	* (uncontrolled, 6)	-	-
UV - diesel	•	-	•	-	•	•
UV - gasoline	•	-	•	-	•	•

KEY:

Parentheses indicate Euro-equivalent emission standards/fuels. For example, (VI) indicates Euro VI.

- No change to ICCT Roadmap Model Emission Factors
* Missing emission factors for some control levels were filled in from ICCT India Model (emission control levels)

† India Model emission factors substituted for all control levels due to better match with ADB (1992)

‡ Emission factor for some control levels estimated to be reduced proportionally from EFs from earlier standards (emission control level, fuel type proportion was based on)

- Emission factor for uncontrolled vehicles taken from ADB (1992), emission factors for subsequent control levels calculated as a proportional reduction from uncontrolled level using reductions from Roadmap Model Emission Factors.

V.6.1.2 Energy sector emissions

Within the energy sector, the team models the health impacts of emissions from on grid power generation only. While on grid power generation produces the largest share of $PM_{2.5}$, NOx, and SO_2 emissions, other activities within the energy sector (grid electricity generation, oil production and transport, biofuel production, and charcoal production) also contribute to local air pollution and health impacts. As the team does not have sufficient information to characterize exposure to emissions from these sources, the impacts of other activities are not included in our health co-benefit estimates.

In general, Philippine sources were used for all pollutants except PM. As the available Philippine sources do not cover PM, factors for this pollutant were taken from international literature. International sources were also consulted to fill gaps in the Philippine sources relating to other pollutants and particular fuels or fuels and technologies (e.g., emissions from ultrasupercritical coal power plants). The $PM_{2.5}$ emission factors for on grid power generation are taken from U.S. EPA (2014) and IEA (2012); NOx emission factors are taken from DENR (2011), Manila Observatory (2010), IPCC (2015), U.S. EPA (2014), and IEA (2012); and SO_2 emission factors are taken from Manila Observatory (2010), U.S. EPA (2014), and IEA (2012).

V.6.2 Concentrations

The next step in estimating health co-benefits is to use the projected emissions from the LEAP model to estimate the baseline $PM_{2.5}$ concentration and the change in $PM_{2.5}$ concentration resulting from each of the mitigation options. Specifically, we estimate the annual average ambient $PM_{2.5}$ concentration in urban and rural areas. The team does not conduct dispersion modeling, but instead apply the results of previous dispersion modeling studies using intake fractions.

V.6.2.1 Baseline concentrations

The exposure-response function used to estimate the change in health requires an estimate of the baseline $PM_{2.5}$ concentration in addition to the change in concentration from each mitigation option. The team estimates the baseline ambient $PM_{2.5}$ concentrations using both measured data and modeled data, the latter using the previously discussed modeled emissions from the transportation and energy sectors as a key input. Since the annual average concentration of $PM_{2.5}$ varies significantly between rural areas and urban areas, we model concentrations separately for rural and urban areas. For rural areas, baseline exposure integrates measured concentrations (see **Error! Reference source not found.**)**Error! Reference source not found.Error! Reference source not found.** and changes from the power sector only. The effects of transportation in rural areas are minor and dominated by secondary $PM_{2.5}$ formation, which we are not modeling for transport. For urban areas, baseline exposure is informed by measured concentrations and the contribution of the transportation and power sectors. A single baseline urban exposure is assumed for energy sector impacts, while transportation impacts assume two baselines: one average concentration for major cities in the Philippines and a separate baseline concentration for Metro Manila.

The team models the urban baseline concentration in all years by estimating a background concentration, defined as the concentration without contributions from the transportation or energy sectors, and then adding the additional modeled concentration from the Baseline case transportation and energy sector emissions in a given year. This calculation is shown in Equation 1 and Equation 2 below:

Equation 1. $$C_{Background} = C_{Measured,2010} - (C_{Transport,2010} + C_{Energy,2010})$$

Equation 2. $$C_y = C_{Background} + C_{Transport,y} + C_{Energy,y}$$

The background concentration ($C_{Background}$) is calculated as the measured concentration in the year 2010 ($C_{Measured,2010}$) minus the modeled contribution from transportation ($C_{Transport,2010}$) and energy ($C_{Energy,2010}$) in the year 2010. The background concentration is held constant through 2050, and the baseline concentration in a given year ***y*** (C_y) is calculated as the sum of the background concentration and the modeled contribution from transportation ($C_{Transport,y}$) and energy ($C_{Energy,y}$) in the Baseline Scenario in the year ***y***. The rural baseline concentration is calculated using similar methods, but excluding $C_{Transport,2010}$ and $C_{Transport,y}$.

There are limited data reporting measurements of $PM_{2.5}$ in the Philippines for use as $C_{Measured,2010}$ in Equation 1 above. Three measurements were available monitoring sites for the year 2010 (Cities Act 2010), shown in **Error! Reference source not found.** and two additional studies provided supplementary measurements from previous years. A value of 35 $\mu g/m^3$ was assumed for Manila, an average of monitoring data and concentrations reported in supplementary studies (Cities Act 2010, Oanh et al. 2012). For urban areas where there was no measurement data, a default value of 15 $\mu g/m^3$ was assumed. For rural areas, a $PM_{2.5}$ concentration of 9.5 $\mu g/m^3$ was taken from Oanh et al. (2012).

Table V. 37. Urban and rural measurements of $PM_{2.5}$ concentrations

City/station	Annual mean $PM_{2.5}$ ($\mu g/m^3$)	Year(s) of measurement	Source
Baguio	49	2010	Cities Act 2010
Cebu	22	2010	Cities Act 2010
Manila	22	2010	Cities Act 2010
Manila	46	2001-2007	Cohen et al. 2009
Manila	45	2006-2008	Oanh et al. 2012
Rural background	9.5	2006-2008	Oanh et al. 2012

V.6.2.2 Converting emissions to concentrations using intake fractions

Estimates of $C_{Transport}$, C_{Energy}, and the change in concentrations from both sectors resulting from each of the mitigation options are produced using source-specific intake fractions. The relationship between emissions of $PM_{2.5}$ and $PM_{2.5}$ precursor species (including NOx and SO_2) to the change in ambient $PM_{2.5}$ concentrations is complex, and depends on numerous factors including local meteorological patterns (e.g. wind speed, temperature) and characteristics of the emissions source (location, plume height, exhaust temperature). Use of a chemical transport model would produce detailed, localized concentration estimates, but for our purposes would introduce undue complexity to the task of projecting the air quality impacts of many scenarios up to 35 years into the future, with little baseline information about local air quality. We use a set of factors called intake fractions (iFs) to estimate the contribution of emissions from transport and energy sectors to ambient $PM_{2.5}$ levels, separately for the Baseline Scenario and for the mitigation options under consideration. Because of the uncertainty associated with this simplified method, this analysis is useful to indicate the order of magnitude of the health benefits but does produce highly precise results. The iFs are derived from more complex air quality modeling using the equation shown in Equation 3. They are specific to a given emissions source, such as on-road vehicles, and to a given pollutant, such as primary $PM_{2.5}$ or NOx.

$$\begin{aligned}\text{intake fraction} &= \frac{\text{population intake}}{\text{total emissions}} \\ &= \frac{\int_{T_1}^{\infty} \left(\sum_{i=1}^{P} \left(C_i(t)Q_i(t)\right)\right)dt}{\int_{T_1}^{T_2} E(t)dt}\end{aligned}$$

Equation 3. Equation for calculating intake fraction (from Apte et al. 2012)

Equation 3 shows that intake fraction is specific to a population of size P, with breathing rate Q. Once the value of the intake fraction has been calculated, and the population and breathing rate are known, the equation can be re-arranged and solved to directly give the relationship between total emissions E and concentration C. The team keeps this ratio of unit of concentration per unit emissions fixed over time, and use it to calculate air pollution change for each mitigation option.[16]

V.6.2.3 Transport sector intake fractions

The set of intake fractions (iFs) used for on-road vehicles were developed for major urban areas worldwide, and include 30 specific to the Philippines (Apte et al. 2012). These intake fractions apply only to conserved pollutants like primary $PM_{2.5}$, not pollutants that undergo significant transformation in the atmosphere, like NOx and SO_2. The team used these emission factors for the 18 largest cities in the Philippines, as the team had reliable population projections for these cities. As described above, the intake fractions were divided by the relevant city populations (Angel et al. 2010, as cited in Apte et al. 2012) and a breathing rate of 5292.5 m^3/year to derive the ratio of unit concentration per unit emissions for each city, shown in Table V. 38**Error! Reference source not found.**. Variation in these values across

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[16] Rather than solving for the concentration-to-emissions ratio in a single year and holding that value constant, year-to-year change in city-specific intake fractions may be modeled using population projections and assumptions about linear population density (see Chambliss et al. 2013, Marshall 2007). The concentration-to-emissions ratio is then calculated separately for each year. This approach was not applied in this analysis due to maintain consistency in calculations across sectors.

cities occurs due to differences in city size, as well as meteorological factors such as average wind speed. In a city with a larger footprint, emissions are distributed over a larger area and so the ratio of concentration to emissions is lower. For example, the ratio is lowest in Metro Manila, which has a footprint of about 900 km^2 compared to an average of 100 km^2 across the other cities (Angel et al. 2010). However, a low ratio should not be understood to indicate a low impact; in fact, because of the large share of emissions and the large population in Manila, it is modeled to have the largest share of transportation-related health impacts.

Table V. 38. Concentration-to-emissions ratio used for 18 largest cities in the Philippines

City	Concentration-to-emissions ratio (ug/m^3 change per kiloton emitted)
Metro Manila	1.4
Lipa City	14.3
Butuan	19.8
Batangas City	9.5
Iligan	25.2
Cotabato	8.4
Baguio City	5.6
Angeles City	3.3
Mandaue City	11.2
Basilan City (including City of Isabela)	11.2
Lapu-Lapu City	11.2
Iloilo City	11.9
Bacolod	6.8
General Santos City	7.0
Cagayan de Oro City	10.5
Zamboanga City	17.4
Cebu City	2.5
Davao City	5.3

Although the intake fractions used for the transportation sector cover only contributions to ambient $PM_{2.5}$ from primary $PM_{2.5}$ emissions, on-road vehicles contribute to the formation of secondary $PM_{2.5}$ in the atmosphere from emissions of NOx and SO_2. The health impacts of secondary PM were not included in the assessment of health co-benefits from the transportation sector. An initial estimate was made that compared both the scale of reductions of NOx and SO_2 emissions expected from emission control policies and the intake fractions for secondary $PM_{2.5}$ from NOx and SO_2 (Humbert et al. 2011) to those for primary $PM_{2.5}$. This estimate found that the health impacts from secondary particulates would add roughly 25% to the health co-benefits of policies focused on conventional pollutant reduction (e.g. emission standards).

V.6.2.4 Energy sector iFs

For the energy sector, three iFs are used, one for primary $PM_{2.5}$ (6×10^{-7}), one for secondary $PM_{2.5}$ from SO_2 (2 x 10-7), and one for secondary $PM_{2.5}$ from NO_2 (6×10^{-8}). These iFs are based on a study of exposure to energy sector emissions in the US from (Levy et al. 2003). The resulting concentration-to-emissions ratios are shown in Table V. 39. The concentration change is assumed to occur throughout the country.

Table V. 39. Concentration-to-emissions ratio used for the energy sector

Concentration-to-emissions ratio (ug/m^3 change per kiloton emitted)		
$PM_{2.5}$	NOx	SO_2
0.91	0.09	0.30

V.6.2.5 Disaggregating national transportation emissions to urban areas

As the on-road intake fractions only apply to urban areas, the emissions outputs from the LEAP model must also be scaled to the urban level. The share of national emissions occurring in Metro Manila ($Share_{MM}$) was estimated for each mode based on the national share of vehicle registrations within the national capital region. Less information on registration share was available for the 17 remaining cities. The cumulative share of national emissions occurring in those cities and excluding Metro Manila (urban share without Manila, or $Share_{UR-M}$) was estimated from the share of population and highway infrastructure in urban areas following a methodology applied and described previously by Chambliss et al. (2013). The urban share for Metro Manila and the combined share across the other 17 cities are given in Table V. 40. $Share_{UR-M}$ is further subdivided across each of the 17 cities based on population.

Table V. 40. Share of national emissions in Metro Manila and aggregate of 17 largest cities in the Philippines (excluding Metro Manila)

Mode	Share of emissions in Metro Manila, $Share_{MM}$	Share of emissions aggregated across 17 largest cities excluding Metro Manila, $Share_{UR-M}$
Bus	44%	24%

LDV	52%	15%
MC	18%	32%
TC	18%	32%
Truck	22%	13%
UV	32%	16%

V.6.3 Health Impacts

Outdoor air pollution is associated with adverse health effects ranging from worsened asthma symptoms to early death from heart and lung disease. This study focuses on the fatal impacts of $PM_{2.5}$, and estimates impacts using Integrated Exposure-Response (IER) functions developed for the Global Burden of Disease 2010 study (Lim et al. 2012, Burnett et al. 2014).

The integrated exposure-response (IER) functions are described in depth in Burnett et al. 2014. The GBD 2010 study applied the IER functions to estimate the mortality attributed to $PM_{2.5}$ from ambient sources, as well as indoor sources, such as cook stoves and smoking (Lim et al. 2013). The IER functions combine the results of several types of epidemiological studies, including those conducted in high $PM_{2.5}$ exposure settings (e.g., exposure to tobacco smoke). Therefore, a health impact assessment based the IER functions is a better extrapolation of air pollution mortality risk for populations exposed to high ambient $PM_{2.5}$ levels, compared to extrapolations based on a single epidemiological study conducted in a population with low baseline $PM_{2.5}$ exposure (e.g., Anenberg et al. (2012)).

The IER functions were developed for five types of mortality: lung cancer (for all ages), ischemic heart disease (IHD, for ages 25 or older), stroke (for ages 25 or older), chronic obstructive pulmonary disease (COPD, for all ages), and acute lower respiratory infection (for children). In this assessment, we focus on the first four causes of death, i.e., lung cancer, IHD, stroke, and COPD.

Application of the IER functions required two inputs in addition to the change in exposure attributable to mitigation options:

- Cause-specific mortality rates, which were obtained at a national level from the Global Health Data Exchange catalog created by the Institute for Health Metrics and Evaluation (IHME 2013); and
- Ambient $PM_{2.5}$ exposure levels for urban and rural populations in the Philippines, the computation of which was described earlier.

The analysis also accounts for the impact of a potential lag in reductions of mortality risk following the reductions in $PM_{2.5}$ exposure. Specifically, the team applies a 20-year mortality lag consistent with that used by the EPA, which assumes that 30 percent of the total estimated mortality effects occur in the first year, 50 percent are distributed evenly among years 2 through 5, and the remaining 20 percent are distributed evenly among years 6 through 20 (USEPA SAB, 2004). However, there is uncertainty about the length and the structure of this lag.

The health impacts were computed using a Monte Carlo simulation. We characterized the statistical uncertainty in the risk estimates by taking 50 draws from the 1000 available IER curve parameter sets. In addition, the team also characterized the statistical uncertainty in the cause-specific mortality rates by sampling from lognormal distributions with that were consistent with the mean and the uncertainty bounds reported by IHME. We also represented the age- and sex-related variability in health impacts. To this end, we computed the health impacts for each cause separately for 12 age groups and two sexes, by combining: 1) our estimates of the age group- and sex-specific exposed population sizes (based on the national-level demographic data); 2) the age group-specific IER functions; and 3) the age group- and sex-specific mortality rates for each cause. Note that the team was unable to model the likely important spatial variability in the health impacts, because the information on cause-specific mortality rates did not have the sufficient spatial resolution.

V.6.4 Valuation

The value of a statistical life, or VSL, is a value that reflects the amount people are willing to pay for small reductions in risk of early death. The conceptual foundation and application of the VSL are described in detail elsewhere (OECD 2011, Hammit and Robinson 2011, Lindhjem and Navrud 2011). A range of values for VSL have been estimated worldwide based on stated preference (contingent valuation studies) and revealed preference (labor market studies) (OECD 2011). We use the benefit transfer approach to take a VSL value calculated for broad international application and adjust it for use in the Philippine context. This approach has been applied in numerous contexts, as discussed by Minjares et al. (2014) and Miller et al. (2014). The benefit transfer equation is shown in Equation 4.

$$VSL_b = VSL_a \; X \; \frac{PPP\ GNI\ per\ capita_b}{PPP\ GNI\ per\ capita_a}$$

Equation 4. Benefit transfer equation

VSL_a is taken from a recent meta-analysis of international studies that recommends a value of $2.9 million 2005 USD for OECD countries, adjusted to $3.2 million 2010 USD (OECD 2011). Values for gross national income at purchasing power parity (PPP GNI) in the year 2005 from the World Bank (2015) are used to transfer from the OECD to the Philippines. The value is transferred using the average per-capita PPP GNI across OECD countries and in the Philippines, resulting in a VSL of $0.76 million in 2015. Future increases in VSL are projected based on an average annual GDP growth rate consistent with LEAP model assumptions. The present value is calculated assuming a 5% discount rate.

Note that the team's calculations implicitly assume that the income elasticity of the WTP for mortality risk reductions is 1: That is, a 1% increase in income will result in a 1 % increase in the WTP (and, thus, the VSL). However, there is considerable uncertainty regarding the income elasticity appropriate for income-related VSL adjustments. A recent synthesis of the VSL studies conducted in high-income countries found the VSL income elasticity to be in the range of 0.25-0.63 (Doucouliagos et al. 2014). On the other hand, Hammitt and Robinson (2011) suggest that a VSL income elasticity value in the range of 1-2 would be more appropriate for transfers in low income countries, because mortality risk reductions in these settings are likely to be perceived as a luxury good. Given that the Philippines is a lower-middle-income country, we opted for a proportional scaling of the VSL using an elasticity value of 1. An elasticity of 1 has been used in other recent studies valuing health benefits in lower- and upper-middle-income economies, including India (Garg 2011), Colombia (Castillo 2010), China (Rabl 2011), Thailand (Sakulniyomporn et al. 2011), Mexico (Crawford-Brown et al. 2011), and Iran (Hoveidi 2013). The uncertainty in VSL elasticity warrants a sensitivity analysis exploring the results with different elasticity values (e.g. 0.5 – 1.5), but this was not within the scope of this analysis.

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