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

PHILIPPINES MITIGATION COST-BENEFIT ANALYSIS

November 2015

This document was produced for review by the United States Agency for International Development (USAID). It was prepared by the Building Low Emission Alternatives to Develop Economic Resilience and Sustainability (B-LEADERS) Project implemented by International Resources Group for USAID Philippines.

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Agriculture Sector Results

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ACRONYMS

ADB	Asian Development Bank
ALU	Agriculture and Land Use
ALU Software	Agriculture and Land Use Greenhouse Gas Inventory Software
AWD	Alternate wetting and drying
B-LEADERS	Building Low Emission Alternatives to Development, Economic Resilience, and Sustainability
BRT	Bus Rapid Transit
BSWM	Bureau of Soil and Water Management
CBA	Cost-Benefit Analysis
CCC	Climate Change Commission
CFBC	Circulating Fluidized Bed Combustion
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COPD	Chronic obstructive pulmonary disease
CH_4	Methane
DA	Department of Agriculture
DENR	Department of Environment and Natural Resources
DS	Dry Season
GBD	Global Burden of Disease
GDP	Gross Domestic Product
GHG	Greenhouse Gas
gWh	Gigawatt hour
GWP	Global Warming Potential
ICCT	International Council on Clean Transportation
IEA	International Energy Agency
IER	Integrated Exposure-Response
iF	Intake fraction
INDC	Intended Nationally Determined Contribution
IHD	Ischemic heart disease
IPCC	Intergovernmental Panel on Climate Change
LEAP	Long-range Energy Alternatives Planning tool
LECB	Low Emissions Capacity Building (UNDP Program)
LED	Light-Emitting Diode
LDV	Light-Duty Vehicle
LULUCF	Land Use, Land-Use Change, and Forestry
MAC	Marginal Abatement Cost
MACC	Marginal Abatement Cost Curve
MC	Motorcycle
MCTC	Motorcycle/Tricycle
MSW	Municipal Solid Waste
$MtCO_2e$	Million metric tons of carbon dioxide equivalent

MVIS	Motor Vehicle Inspection System
N	Nitrogen
NAMA	Nationally Appropriate Mitigation Action
NAMRIA	National Mapping and Resource Information Authority
NPV	Net Present Value
NREP	National Renewable Energy Program
N_2O	Nitrous Oxide
NO_x	Nitrogen Oxides
NOAP	National Organic Agriculture Program
O&M	Operation and Maintenance
PFPA	Philippines Fertilizer and Pesticide Authority
PhP	Philippine Peso
PM	Particulate Matter
PSA	Philippines Statistics Authority
RE	Renewable Energy
SO_2	Sulfur Dioxide
TC	Tricycle
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USD	United States Dollars
US EPA	United States Environmental Protection Agency
VSL	Value per Statistical Life
WS	Wet Season

VIII. AGRICULTURE

VIII.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 .

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

- A description of methods and sector-specific GHG emissions for the base year of 2010 and for the baseline projection spanning 2010-2050;
- A description of mitigation options evaluated for each sector;
- Estimates of the option/activity-specific direct benefits (i.e., the amount of GHG emissions reduced) as well as costs and economic co-benefits of the mitigation options for 2015-2050 time period, for which the Study Team already obtained data;
- Where relevant, estimates of indirect economic impacts (i.e., power sector impacts from mitigation activities in other sectors) and non-market co-benefits (congestion and public health) for those mitigation options where data are available;
- Where relevant, estimates of quantifiable energy security, employment, and public health-related gender impacts for the analyzed mitigation options;
- The development of a marginal abatement cost curve (MACC), which illustrates the cumulative abatement potential and costs per tonne of the mitigation options analyzed in this report; and

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 VIII. 1 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.

Table VIII. 1 Mitigation Options in the Agriculture Sector – Potential and Net Cost

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) [MtCO₂e]	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*
Agriculture	18	Organic fertilizers	–	-1.0	-1.0	48.1	-2.0
	21	AWD	0.1	–	0.1	91.2	0.1
	24	Crop diversification	–	0.4	0.4	8.5	4.6
	35	Bio-digesters	2.51	-1.16	1.35	1.1	1,287.2

*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.

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 VIII. 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 VIII. 3.

Table VIII. 2. Monetized Co-Benefits of Mitigation Options in the Agriculture 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/B=J*
18	Organic fertilizers	–	–	–	0.0	0.0
21	AWD	–	–	–	0.0	0.0
24	Crop diversification	–	–	–	0.0	0.0

35	Bio-digesters	-0.364	–	–	-0.364	348.0

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

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

Finally, Column E indicates the net present value of costs (including fuel savings) and co-benefits for health and traffic congestion. A positive value indicates a mitigation option has net benefits to society in addition to its potential to mitigate GHG emissions. Two mitigation options (Biofuels and Two-Stroke Replacement) would have costs that outweigh their (non-climate) benefits, indicating that society's willingness-to-pay for GHG mitigation would have to exceed the Cost per Ton Mitigation with Co-benefits (Column D) for these measures to be considered cost effective[1].

Table VIII. 3. Net Present Value of Mitigation Options in the Agriculture Sector during 2015-2050

Sequence Number of Mitigation Option[1]	Mitigation Option	GHG Mitigation Potential (MtCO$_2$e)[3]	Cost per Ton CO$_2$e Mitigation (2010 USD)[2]			Net Present Value Excluding Value of GHG Reduction (Billion 2010 USD)[2,6]
			without co-benefits	co-benefits only[4]	with co-benefits[5]	
		A	*B*	*C*	*D = B+C*	*E = –D * A/1000*
18	Organic fertilizers	48.1	-2.0	0.0	-2.0	0.10
21	AWD	91.2	0.1	0.0	0.1	-0.01
24	Crop diversification	8.5	4.6	0.0	4.6	-0.04
35	Bio-digesters	1.1	1,287.2	348.0	1,635.2	-1.71

Abbreviations:
MtCO$_2$e - 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 agriculture sector include human health benefits due to reduced air pollution from electricity generation.
[5] Negative value indicates net benefits per ton mitigation. This excludes the non-monetized benefits of GHG reductions.

Error! Reference source not found. shows the MACC for the agriculture mitigation options, which indicates a total cumulative abatement potential of 149 MtCO$_2$e if all four mitigation options are implemented. As discussed above, the organic fertilizers mitigation option results in a negative cost per

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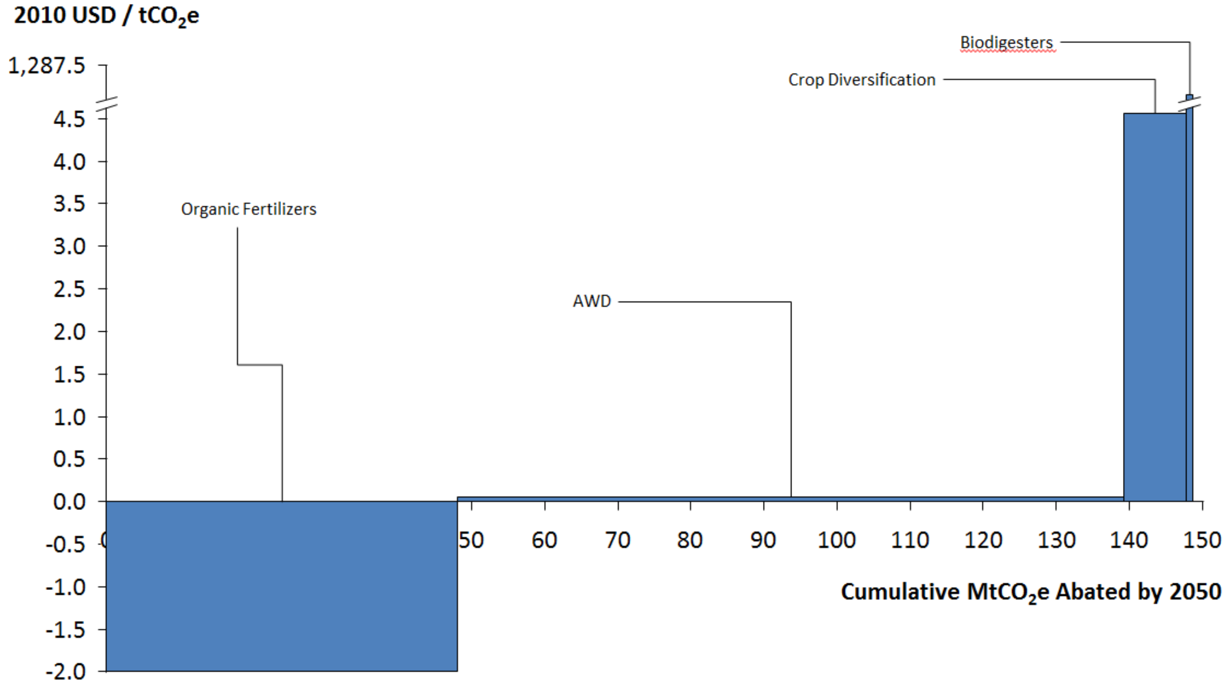
[1] Other mitigation options would still be considered cost effective even if the social cost of carbon-equivalent (expressed in USD per tonne) were zero.

ton and has significant abatement potential. The AWD mitigation option has the greatest mitigation potential with more than 90 $MtCO_2e$ for less than 1 USD per ton of mitigation. The other two mitigation options are smaller in terms of GHG abatement and are less cost effective, with the crop diversification option providing relatively lower mitigation potential for a relatively higher cost, and the bio-digester option providing very little mitigation potential for an extremely high price.

Figure VIII. 1 Marginal Abatement Cost Curve for Agriculture Mitigation Options



VIII.2 BASE YEAR GHG EMISSIONS

This section describes the methods and assumptions used for developing the 2010 Base Year estimate of GHG emissions from agriculture, as well as the results. In the Philippines, the relevant emission source categories are rice cultivation, agricultural soils, liming soils, livestock, and burning of agricultural residues, silvipasture, and grasslands (

Table VIII.4). The relevant GHGs for these source categories are carbon dioxide (CO_2), methande (CH_4), and nitrous oxide (N_2O). The Study Team used the ALU software to estimate emissions from all of these source categories. ALU uses the IPCC GHG inventory guidelines and emission factors for estimating GHG emissions. Consistent with the year 2000 GHG inventory in the Second National Communication (CCC, 2014), the Study Team used the IPCC Tier 1 approach for estimating emissions from all source categories, except for rice cultivation, where more detailed country-specific emission factors allowed for the use of a Tier 2 method.

There are key methodological differences in the analysis that make it difficult to compare the 2010 results presented in this report with the Philippines' year 2000 GHG inventory. Specifically, the 2000 inventory was based on the 1996 IPCC methods and classification. ALU uses the IPCC's 2000 Uncertainty Guidance (IPCC, 2000) and the 2003 Good Practice Guidance for emissions accounting methods and classification for the agriculture sector (IPCC, 2003).

Table VIII.4. Emission Source Categories: Agriculture

Category	Activity	Greenhouse Gases
Rice Cultivation	Decomposition of organic materials in flooded rice fields	Methane (CH_4)
Agricultural soils	Synthetic fertilizer application	Nitrous Oxide (N_2O)
Livestock	Enteric fermentation Decomposition of animal manure	Methane(CH_4), CH_4 and N_2O
Agricultural residues	Burning of residues	N_2O
Liming soils	Decomposition of lime added to the soil to neutralize soil acidity	CO_2
Silvipasture	Burning of silvipasture	CO_2, CH_4, and N_2O
Grasslands	Burning of grasslands	CO_2, CH_4, and N_2O

VIII.2.1 Methods and Assumptions

The information used to estimate 2010 base year GHG emissions from livestock and rice cultivation included data on the number of livestock (Table VIII. 5), assumptions made by the CBA Study Team regarding the type of livestock management systems used (

Table VIII. 6), and the number of hectares of rice planted (Table VIII. 7) (PSA, 2015). In particular, data was obtained from the CountrySTAT website[2] and supplemented with Philippine Statistics Authority data from Annual Industry Performance Reports.

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[2] Source: http://countrystat.bas.gov.ph/

Table VIII. 5. Livestock Populations Used to Estimate Emissions from Enteric Fermentation and Manure Management (PSA, 2015).

Livestock	Population
Buffalo	3,270,406
Dairy Cows	16,949
Goats	4,176,519
Horses	230,000
Non-Dairy Cattle	2,570,879
Poultry	169,252,300
Swine	13,397,790

Table VIII. 6. Livestock Management System, Percent Share of Each Livestock Category

Livestock Category	Manure Management System (percent share)
Dairy Cattle	Solid Storage (5%) Pasture/range (95%)
Non-dairy Cattle	Solid Storage (5%) Pasture/range (95%)
Non-dairy Buffalo	Solid Storage (2%) Pasture/range (98%)
Goat	Solid Storage (2%) Pasture/range (98%)
Horse	Solid Storage (50%) Pasture/range (50%)
Swine	Liquid/slurry (98%) Solid storage (0%) Anaerobic digester (2%)
Poultry (chicken, duck)	Liquid/slurry (0%) Solid storage (50%) Dry lot (50%)

Table VIII. 7. Harvested Area of Rice Used to Estimate CH_4 Emissions from Rice Production (PSA, 2015).

Crop	Harvested Area (ha)
Rice	4,305,984

Estimates of non-CO_2 emissions from land use were based on the amount of biomass or crop residue available for burning. The amount of crop residues burned was based on data from Mendoza and Samson (1999) (Table VIII. 8). Yield data for maize, pineapple, rice, root crops/tubers, sugarcane, and other general vegetables were converted to crop residues using yield-residue conversion factors developed by Koopmans and Koppejan (1997).

Table VIII. 8. Residues for Major Crops Used to Estimate Burning of Crop Residue and N_2O Emissions (PSA, 2015)

Crop	Crop Residues Burned (tons wet weight)	Crop Residues Retained (tons wet weight)
Maize	17,645,640	7,562,417
Pineapple	406,312	406,313
Rice, Wetland	24,690,850	2,743,429
Sugar Cane	3,401,336	1,913,252
Roots and Tubers	N/A	1,542,145
General Vegetable	N/A	18,347,290

Data on fertilizer use was obtained from the Philippines Fertilizer and Pesticide Authority (PFPA) (2015) (Table VIII. 9). These data were used with IPCC Tier 1 emission factors to determine N_2O emissions from agricultural soils due to synthetic fertilizer application (IPCC, 2006).

Table VIII. 9. Synthetic Fertilizer Application Used to Estimate N_2O Emissions from Soils. (PFPA, 2015).

Fertilizer Type	Amount (tons N)
Ammonium Phosphate	16.415
Ammonium Sulphate	106.108
Complete Fertilizer	6.749
Diammonium Phosphate	24.702
Urea	425.833

To estimate emissions from grasslands and silvipasture, the Study Team looked firstly at the land area available for each of these categories. In collaboration with stakeholders from the agriculture and forestry sectors, the Study Team used the 2010 Land Cover Statistics (NAMRIA, 2014) to develop consistent representation of Philippine land uses, using the IPCC's six land use categories: forest land, cropland, grassland, wetlands, settlements, and other lands (Table VIII. 10). The cropland and grassland (including silvipasture) categories are relevant for the agriculture sector. Emissions and removals from the other land use categories are covered in the Forestry Report of the CBA (B-LEADERS, 2015).

Table VIII. 10. Land Use Allocation in 2010, by IPCC Category (NAMRIA 2014; DENR).

IPCC Category	Total Area (ha)	% Total
Forest Land	7,175,888	24.3
Grassland	8,286,646	28.0
Cropland	12,444,352	42.1
Wetlands	857,888	2.9

Settlement	692,079	2.4
Other Land	97,303	0.3
Total	29,554,156	100

Estimates of emissions from grassland burning were based on assumptions that grassland burning occurs only in regions 1, 2, 3, 4A, and 10, and that 20 percent of the grasslands in these regions are burned annually, or approximately 480,000 ha per year. The 2000 GHG inventory assumed 5 percent of grasslands were burned that year (Manila Observatory, 2010). Emissions from liming of soil were based on data on lime application (PSA, 2015) and Tier 1 emission factors (IPCC, 2006).

VIII.2.2 Results

This section summarizes the results for the estimation of the 2010 base year emissions from the agriculture sector.

As shown in Table VIII. 11 and Figure VIII. 2, the agriculture sector emitted a total of 49.2 MtCO$_2$e in 2010. Rice cultivation represents the largest individual source of GHG emissions with 19.2 MtCO$_2$e (39.1 percent). This result reflecs the impact of CH$_4$ emissions, which is produced in the anaerobic conditions of continuously flooded rice fields. Given there are more than 4.7 million hectares of rice planted in the Philippines, more than any other crop, it is not surprising that rice cultivation is the agriculture sector's largest source of emissions (PSA, 2015).

The second largest source in the agriculture sector is N$_2$O emissions from agricultural soils, representing 10.4 MtCO$_2$e (21.2 percent) of emissions. These emissions result largely from the use of synthetic fertilizers.

Livestock represent a significant source of emissions, both through enteric fermentation, which are emissions of CH$_4$ directly from the animals themselves, as well as through emissions of CH$_4$ and N$_2$O from the decomposition of manure. Methane emissions from enteric fermentation are kept relatively low, given that Philippine livestock production is dominated by poultry and swine, which have no or low enteric fermentation emissions compared to other animals, such as cattle and buffalo (carabao).

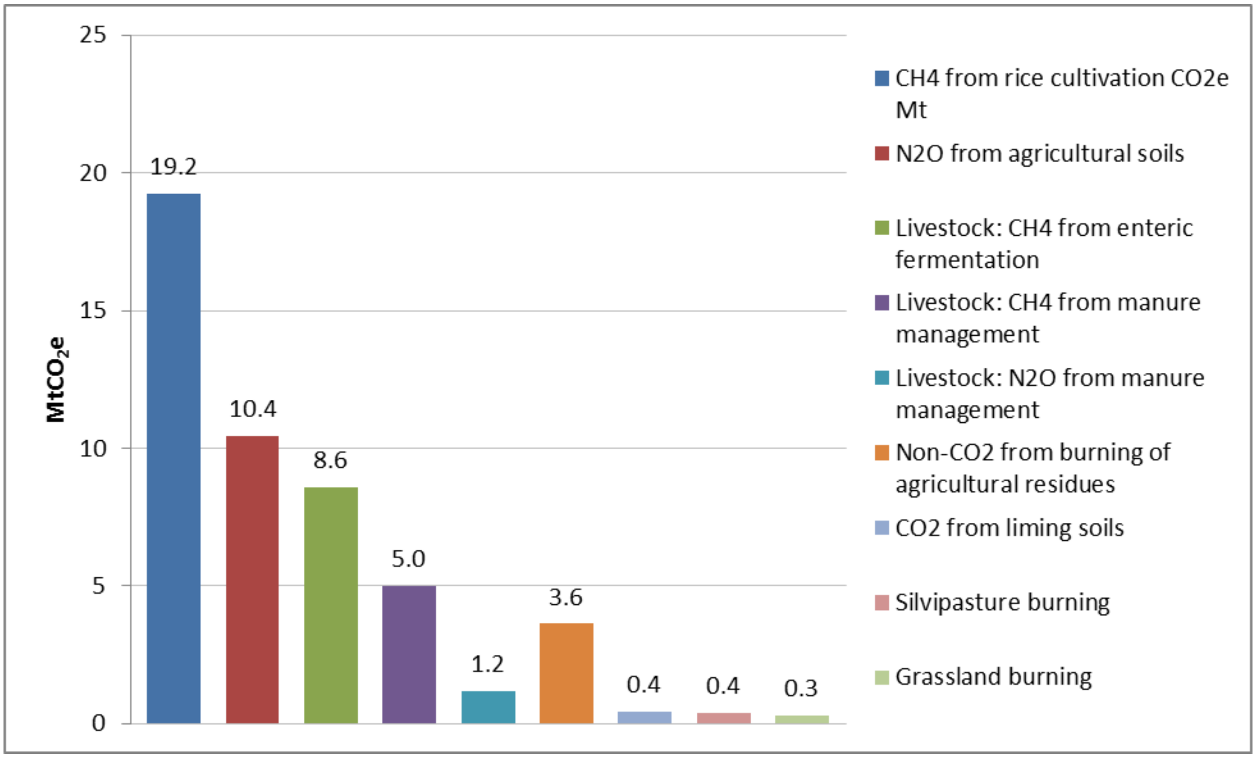
The 2010 base year estimate also includes CO$_2$ emissions from liming of agricultural soils, which was not included in the Philippines Second National Communication. These emissions make up less than 1 percent of the total emissions from the agriculture sector.

Table VIII. 11. 2010 Base Year GHG Emissions from the Agriculture Sector by Source Category (MtCO$_2$e)

Sub-Categories	Emissions (MtCO$_2$e)	% of Total
CH$_4$ from rice cultivation	19.2	39.1
N$_2$O from agricultural soils	10.4	21.2
Livestock: CH$_4$ from enteric fermentation	8.6	17.4
Livestock: CH$_4$ from manure management	5.0	10.1

Sub-Categories	Emissions ($MtCO_2e$)	% of Total
Livestock: N_2O from manure management	1.2	2.4
Non-CO_2 from burning of agricultural residues	3.6	7.4
CO_2 from liming soils	0.4	0.9
Silvipasture burning	0.4	0.8
Grassland burning	0.3	0.6
TOTAL	**49.2**	**100.0**

Figure VIII. 2. 2010 Base Year GHG Emissions from the Agriculture Sector by Source Category ($MtCO_2e$)



VIII.3 BASELINE PROJECTION TO 2050

This subsection describes the estimated annual GHG emissions for 2010 to 2050 for the agriculture sector, including the data and key assumptions used for developing this baseline. The baseline describes projected GHG emissions under “business as usual” economic activity. It also serves as a standard 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, the baseline for the agriculture sector excludes NOAP even though it has already been passed into law. Instead, NOAP is analyzed as part of the organic fertilizer and crop diversification mitigation options in order to determine the abatement potential and cost-effectiveness of this program.

VIII.3.1 Methods

The Study Team developed the agriculture baseline to 2050 based primarily on information on historical trends in crop, livestock and various land use practices, which were then used to extrapolate agricultural activity through 2050.

In the case of livestock and crop production, the Study Team obtained historical data from PSA (2015, Figure VIII. 3 and Figure VIII. 4) and used ordinary least squares regression analyzes to assess the historical rate of change in the production of crops and livestock. The results are shown in Table VIII. 12 and Table VIII. 13. The Study Team used these historical rates of change to extrapolate growth in livestock and crop production through 2050 and then used this information to estimate emissions in ALU andholding constant values for other factors such as the type of manure management systems used for livestock. The historical data shows a steady increase in the number of livestock over time; a trend which the Study Team assumed will continue through 2050, thereby resulting in an increase in emissions from this source category.

Figure VIII. 3. Historical Livestock Production (PSA, 2015)

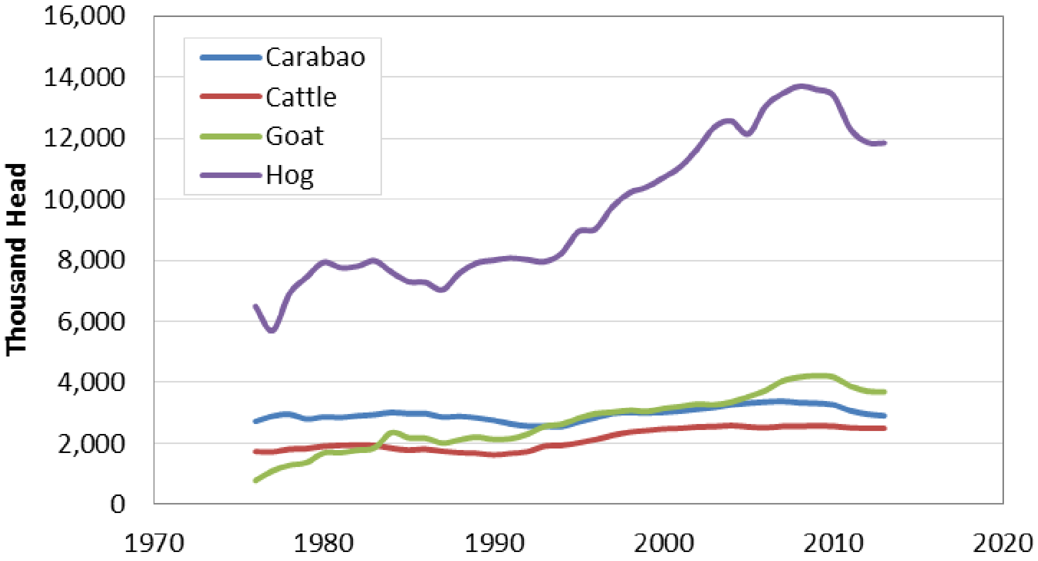


Figure VIII. 4. Production of Major Crops (Million Metric Tons) Used to Project Trends in Crop Residues, 1987 – 2013 (PSA, 2015)

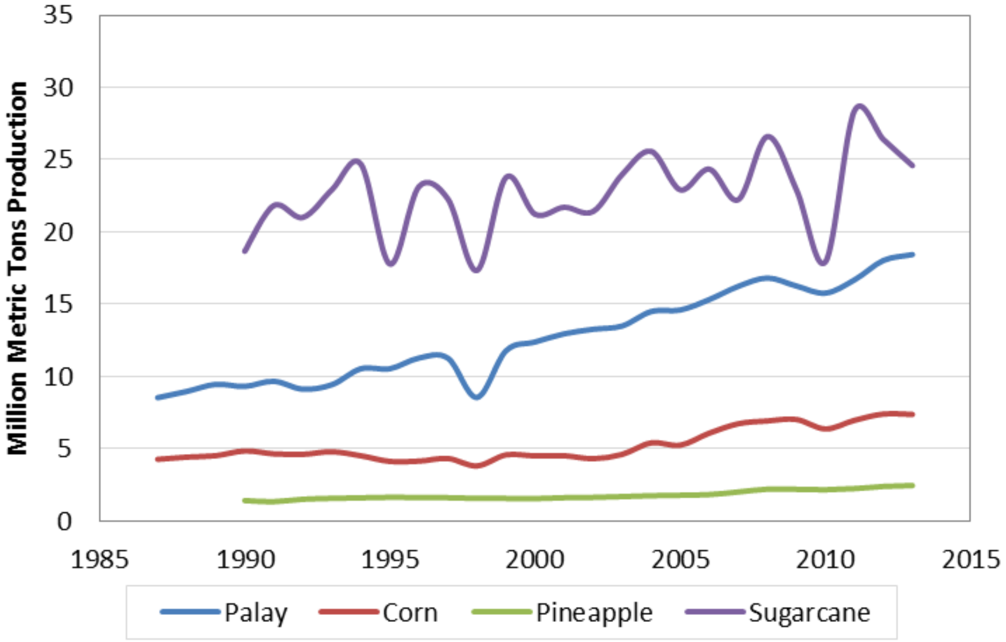


Table VIII. 12. Results of Linear Regression Analysis of Livestock Production Data.

Slope Indicates Increase in 1000 Head Per Year.

Livestock	Slope	R^2	P-Value
Carabao	11.64	0.33	< 0.05
Cattle	27.98	0.76	< 0.05
Goat	81.02	0.95	< 0.05
Hog	200.78	0.87	< 0.05
Poultry	3728.45	0.94	< 0.05

Table VIII. 13. Results of Linear Regression Analysis of Production of Major Crops.

Slope Indicates Increase in Metric Tons of Production Per Year.

Crop	Slope	R^2	P-Value
Palay	384,067.97	0.93	< 0.05
Corn	118,129.81	0.67	< 0.05
Pineapple	41,358.54	0.84	< 0.05
Sugarcane	191,504.15	0.23	< 0.05
General Vegetable	850,747.60	0.90	< 0.05

An analysis of the historical data on the rate of fertilizer use per hectare cultivated shows no significant increase over time (PSA, 2015). As a result, the Study Team assumed a constant rate of fertilizer application per unit of land cultivated. However, because there is a projected increase in the area for crops other than rice, total fertilizer use increases through 2050 in the baseline projection. Similarly, the increase in non-rice crop land results in an increase in N_2O emissions from soils as well as the biomass residue available for agricultural burning. The increase in non-rice crop land is driven by expected conversions of grassland into crop land. The rate of conversion was extrapolated based on the historical rate of change from grassland to crop land and confirmed by stakeholders during consultations in June 2015. For this version of the CBA, the Study Team assumed that no forest land will be converted to crop land. However, based on comments received from the stakeholders after July 2015, future versions of the CBA may change this approach by assuming that a small share of forest land is converted to crop land or grassland in the baseline.

The literature suggests no significant increase in the area cultivated for rice in the Philippines (Roy and Misra, 2002, Wailes and Chavez, 2012). The Study Team therefore held emissions from rice constant in the baseline based on the assumption that the area for rice will remain unchanged in the future.

While there is some conversion of grasslands to cropland, this conversion is relatively small and occurs largely in regions where grasslands are not assumed to be burned. Therefore, there is not significant change in grassland burning in the baseline. Furthermore, the area of silvipasture and the amount of lime added to soils have not changed significantly in the recent past and are therefore expected to remain unchanged in the baseline, leaving the resulting emissions constant through 2050.

VIII.3.2 Results

In 2050, rice cultivation will remain the largest source of GHG emissions from agriculture. Although the land area is planted with rice, and thus the resulting emissions, is assumed to be constant in the baseline (Figure VIII. 5). Meanwhile, the increase in non-rice cropland results in an increase in N_2O emissions from soils and non-CO_2 emissions from residue burning.

Emissions from livestock increase from enteric fermentation and from manure management. Much of the increase in livestock population is projected to be from swine. Because swine have a relatively low rate of emissions from enteric fermentation, but a relatively high rate of emissions from manure management, there is a larger increase in emissions from manure management compared to emissions from enteric fermentation.

In total, GHG emissions from the agriculture sector are projected to increase by more than 30 percent between 2010 and 2050 to about 68 $MtCO_2e$ (Table VIII. 14).

Figure VIII. 5. 2010-2015 GHG Emissions Baseline for the Agriculture Sector by Source Category (MtCO2e)

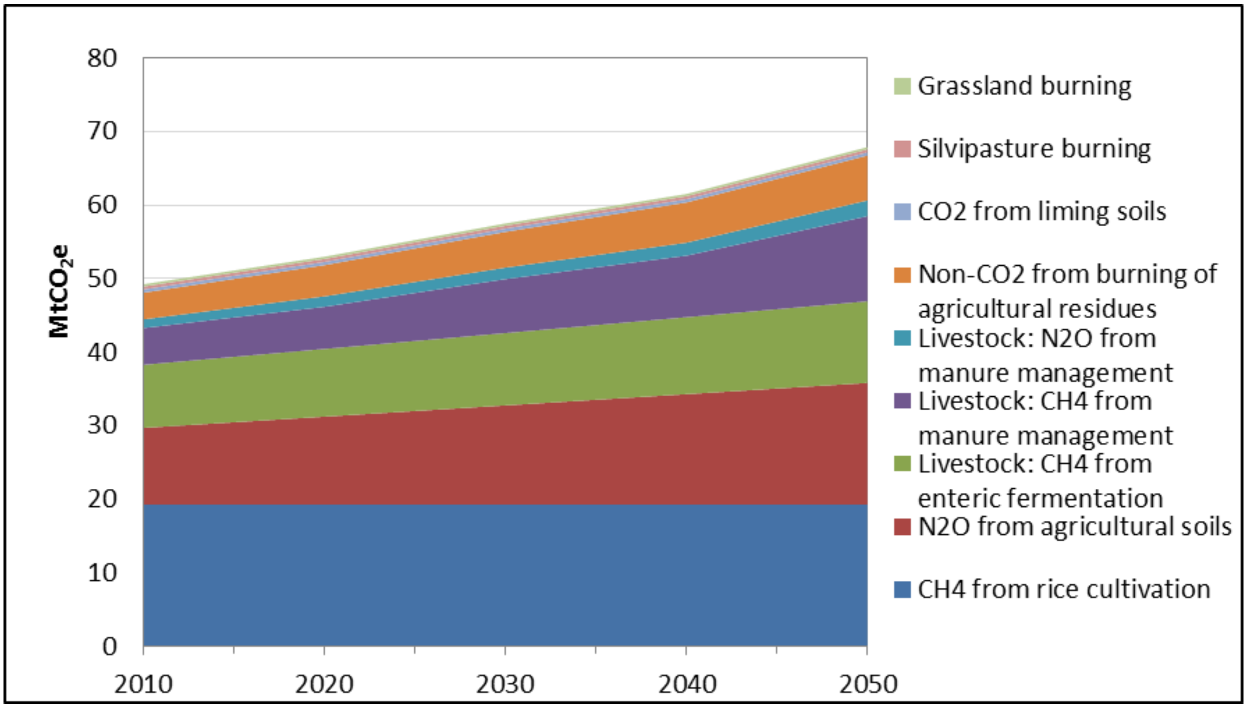


Table VIII. 14. 2010-2050 GHG Emissions Baseline for Agriculture by Source Category ($MtCO_2e$)

Source Category	Year ($MtCO_2e$)				
	2010	2020	2030	2040	2050
CH_4 from rice cultivation	19.24	19.24	19.24	19.24	19.24
N_2O from agricultural soils	10.44	11.97	13.50	15.03	16.56
Livestock: CH_4 from enteric fermentation	8.58	9.21	9.84	10.47	11.10
Livestock: CH_4 from manure management	4.99	5.72	7.34	8.37	11.58
Livestock: N_2O from manure management	1.19	1.43	1.56	1.76	2.15
Non-CO_2 from burning of agricultural residues	3.63	4.25	4.86	5.48	6.10
CO_2 from liming soils	0.44	0.44	0.44	0.44	0.44
Silvipasture burning	0.40	0.40	0.40	0.40	0.40
Grassland burning	0.31	0.31	0.31	0.31	0.31
TOTAL	**49.2**	**53.0**	**57.5**	**61.5**	**67.9**

VIII.4 MITIGATION COST-BENEFIT ANALYSIS

VIII.4.1 Methods

This section discusses the proposed mitigation options for the agriculture sector, which are also summarized in Table VIII. 15. The proposed mitigation options were developed based on a UNDP study on potential NAMAs for the Philippines (Berkman International Inc., 2015) and a review of existing and proposed policies, regulations, and programs targeting agriculture. The proposed mitigation options and the associated assumptions, were then confirmed during several stakeholders consultation workshops organized by CCC on February-July 2015. Key criteria for selection of mitigation options for agriculture include applicability to the national development context and the potential for introducing win-win opportunities, which result in both GHG abatement and cost savings.

There are four mitigation options analyzed for the agriculture sector:

- Increased organic fertilizer use, resulting in decreased synthetic fertilizer use;
- Crop diversification to include leguminous crops, resulting in decreased synthetic fertilizer use;
- AWD in rice production, which allows rice fields to periodically dry out, reducing CH_4 emissions; and
- Biodigesters in livestock production, which capture and destroy CH_4 and N_2O emissions from the decomposition of animal manure and produce renewable energy that replaces the use of traditional fuels.

For each mitigation option, the Study Team projected costs and emission reduction benefits, as well as potential co-benefits. Table VIII. 15 presents a detailed description of each mitigation option and the assumptions used to model them.

Table VIII. 15. Mitigation Options in the Agriculture Sector

CBA Mitigation Option	Description
Improved management of organic and inorganic fertilizers	This mitigation option involves a decrease in the amount of synthetic fertilizer use and an increase in organic fertilizer use for rice cultivation, which results in decreased N_2O emissions. In particular the option assumes: • A reduction in the use of synthetic fertilizers in rice production of 5%, 10%, and 20% in 2020, 2030, and 2050, respectively, compared to the 2010 level of fertilizer use. This is based on the 5% replacement target of the Department of Agriculture Bureau of Soil and Water Management (DA-BSWM) under the “Tipid-Abono” Fertilizer Program. • An increase in the amount of rice crop residue retained in the soil and a resulting reduction in rice crop residue burning. In 2010, 90% of rice crop residues are estimated to be burned. Under this scenario, 85% are burned in 2020, 75% in 2030, and 70% in 2050. • An increase in the amount of chicken manure composted starting with 0% in 2010, 5% in 2020, 10% in 2030, and 20% in 2050. • No change in rice crop yields.
Alternate wetting and	Rice grown in continuously flooded conditions can result in significant methane emissions from bacteria growing in the oxygen-free environment. This mitigation option assumes a

CBA Mitigation Option	Description
drying (AWD) in rice production	conversion of approximately 10,000 hectares per year to alternate wetting and drying to prevent conditions conducive to methane emissions from rice cultivation. Based on a review of the recent literature, this mitigation option assumes no significant change in net profit to farmers (Rejesus 2011).
Crop diversification	Planting nitrogen-fixing legume crops, such as mungbean, cowpea, or soybeans, in rotation with other cash crops will increase the amount of nitrogen in the soil and decrease the need for the use of synthetic fertilizers. This mitigation option assumes an increase in the planting of nitrogen-fixing crops, and a resulting decrease in synthetic fertilizer N use. In particular the option assumes: • A reduction in the use of synthetic fertilizers in rice production of 5%, 10%, and 20% in 2020, 2030, and 2050, respectively, compared to the 2010 level of fertilizer use. This is based on the 5% replacement target of the DA-BSWM under the "Tipid-Abono" Fertilizer Program. • An increase in the amount of leguminous crop area by 5% in 2020, 10% in 2030, and 20% in 2050.
Use of bio-digesters	Bio-digesters can be used to capture the methane generated from the decomposition of livestock manure. The captured methane can be used as a domestic energy source to provide fuel for electricity generation or other uses. This process converts the CH_4 to CO_2, which has a significantly lower global warming potential. This mitigation option also provides co-benefits in the form of improved local air quality and domestic energy production. The option assumes an increase in the amount of swine waste handled in bio-digesters from 2% in 2010 to 7% in 2020 to 12% in 2030 and 2050.

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 raise) 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 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, the method involved four steps:

1) Each mitigation option was first evaluated individually relative to the model's baseline scenario, following the first method of cost calculation (option a) as described above. An initial cost per ton for each is recorded;

2) The options were sorted according to their initial costs per ton in ascending order;

3) The options were added one at a time and in order of their initial cost-effectiveness to generate a new combined mitigation scenario, and emissions and costs for the combined scenario were recorded after each addition; and

4) The final abatement potential and cost per ton for each option were calculated using the marginal emission reductions and costs incurred after the option was added to the combined scenario. Thus, the first option was evaluated in comparison to the baseline scenario only, the second option in comparison to the baseline plus the first option, and so forth.

The retrospective analysis spans all mitigation options across all sectors analyzed in the CBA. Agriculture mitigation options were initiated within the overall set or sequence of options analyzed. Table VIII. 16 shows the sequence, in which the mitigation options are initiated in the retrospective analysis. The sequence order of the industry mitigation options is specifically noted.

Table VIII. 16. Sequential Order of All Mitigation Options in the Retrospective Analysis

Sector	Mitigation Option Sequence	Mitigation Option Name
Industry	1	Increased 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 Improvements
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 (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
Agriculture	**21**	**Alternative Wet-Dry (AWD)**
Waste	22	Methane Flaring
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

Sector	Mitigation Option Sequence	Mitigation Option Name
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**	**Bio-digesters**
Transport	36	Rail
Waste and Energy	37	Municipal Solid Waste (MSW) Incineration

The assumptions behind the analysis of the mitigation potential and cost of each of the four agriculture mitigation options are discussed in more detail in the following subsections.

Option 1: Improved Management of Organic and Inorganic Fertilizers

This mitigation option assumed a decrease in the amount of synthetic fertilizer used for rice cultivation, along with a decrease in crop residue burning and an increase in the application of poultry manure compost. The assumptions used to develop the mitigation analysis for this option, and estimated the potential GHG benefits in ALU, are listed in Table VIII. 17. In general, this option assumed a 5 percent reduction in synthetic fertilizer use compared with the 2010 level, every ten years. This was based on the 5 percent replacement target of the DA-BSWM under the “Tipid-Abono” Fertilizer Program. The nutrients from the synthetic fertilizers were assumed to be replaced with nutrients from crop residues and chicken manure.

The Study Team estimated the amount of crop residue to be retained in the field and the amount of chicken compost to be added to the field; to maintain yields based on the amount of nitrogen that would be needed to replace the nitrogen from synthetic fertilizers, as estimated in ALU.

Table VIII. 17. Assumptions for Analyzing the Mitigation Potential of Improved Management of Organic and Inorganic Fertilizers

Scenario	Parameter	2010	2020	2030	2050
Reference Scenario	Amount of synthetic fertilizer consumed in the country	Used 2010 synthetic N fertilizer data on production, import, and export	Assumed equal to the average quantity of domestic production, plus imports, minus exports of synthetic N fertilizer from year 2000 to 2010	Assumed equal to the average quantity of domestic production, plus imports, minus exports of synthetic N fertilizer from year 2000 to 2010	Assumed equal to the average quantity of domestic production, plus imports, minus exports of synthetic N fertilizer from year 2000 to 2010

Scenario	Parameter	2010	2020	2030	2050
	Crop residue management (mainly rice straw and leguminous crop)	For rice straw, 90% is burned and 10% retained in the field	Assumed to be the same as base year	Assumed to be the same as base year	Assumed to be the same as base year
	Manure management (chicken manure as organic fertilizer)	50% dry lot; 50% solid storage	Assumed to be the same as base year	Assumed to be the same as the base year	Assumed to be the same as base year
Mitigation Scenario	Amount of synthetic fertilizer consumed in the country		Assumed to decrease by 5% (of 2010 data) every 10 years)	10% decrease relative to 2010	20% decrease relative to 2010
	Crop residue management (mainly rice straw and legumes)	90% of rice straw is burned and 10% retained in the field	85% of rice straw is burned and 15% retained in the field	75% of rice straw is burned and 25% retained in the field	70% of rice straw is burned and 30% retained in the field
	Manure management (chicken manure as organic fertilizer)	50% dry lot; 50% solid storage	50% dry lot; 45% solid storage; 5% compost intensive	50% dry lot; 40% solid storage; 10% compost intensive	50% dry lot; 30% solid storage; 20% compost intensive

Synthetic fertilizer costs were estimated based on an exponential projection of historic fertilizer prices from PSA (2015), as shown in Figure VIII. 6. Chicken manure costs were based on the May 2015 price of chicken manure of 230 PhP per 50 kg sack. Because of lack of historic data on chicken manure costs, the projections for these costs were extrapolated based on historic chicken production.

The amount of fertilizer use per hectare cultivated for rice was based on an average of the 2003-2013 values from PSA (2015), as shown in Figure VIII. 7. Because the historic data on fertilizer use did not show a significant trend for any of the fertilizer types, it was assumed that the fertilizer use would remain constant in the baseline case.

Figure VIII. 6. Prices of Four Major Types of Fertilizers, 2010 PHP per 50 kg Bag (PSA 2015)

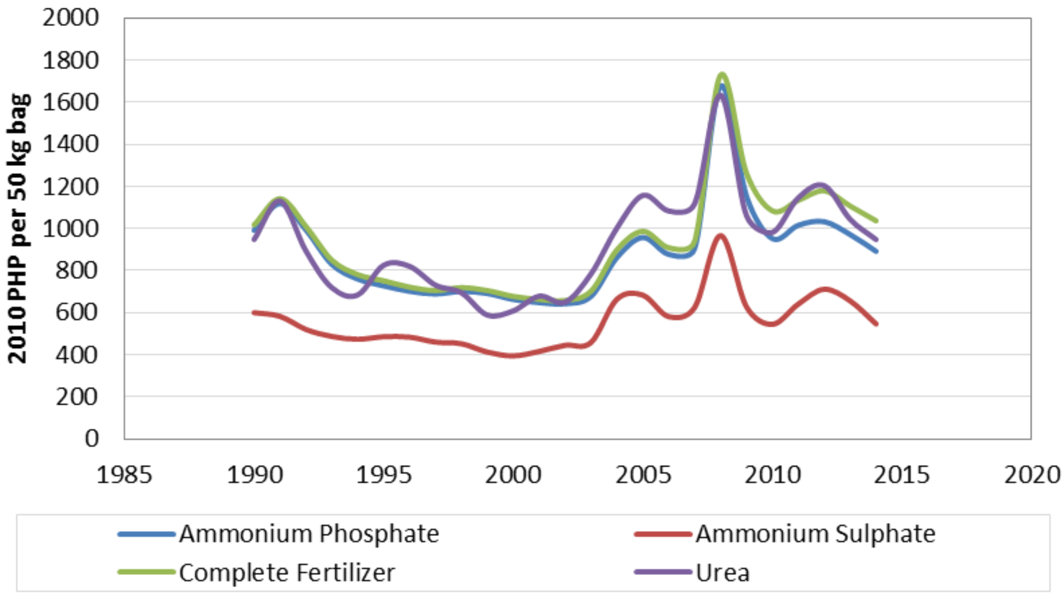
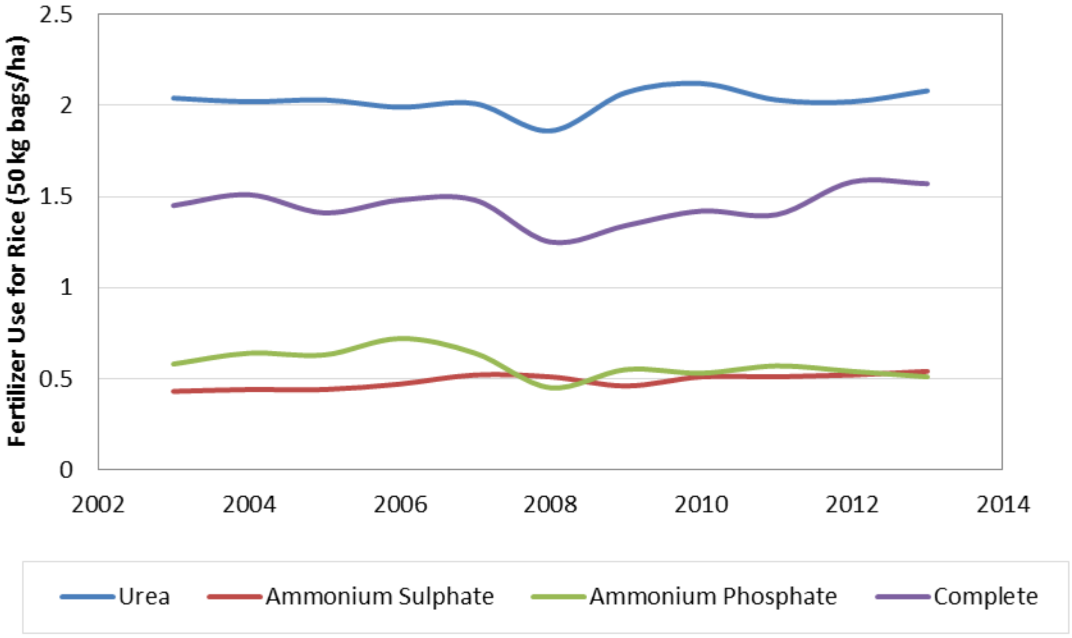


Figure VIII. 7. Fertilizer Use for Four Major Types of Fertilizers for Rice Cultivation, 50 kg bags/ha. (PSA 2015)



Option 2: Alternate Wetting and Drying

This mitigation option assumed an increase in the area that is converted from being continuously flooded to AWD to decrease CH_4 production.

Table VIII. 18 shows the assumptions used in ALU to model this option's mitigation potential. The results from the literature suggest that the area that is planted with rice in the Philippines will not increase significantly in the future (Roy and Misra, 2002, Wailes and Chavez, 2012). For this reason, the total area planted with rice is held constant for both the baseline case and the mitigation option. The mitigation option assumed an increase in the proportion of rice grown under AWD conditions.

Table VIII. 18. Assumptions for Analysing the Mitigation Potential of Alternate Wetting and Drying

Scenario	Water Management	2010		2020		2030		2050	
		DS	WS	DS	WS	DS	WS	DS	WS
Reference Scenario	Continuously flooded (poor irrigation to allow drainage)	40	50	Same as in 2010	Same as in 2010	Same as in 2010	Same as in 2010	Same as in 2010	Same as in 2010
	Intermittent flooding, single aeration (slightly better irrigation facilities to allow drainage)	20	15	Same as in 2010	Same as in 2010	Same as in 2010	Same as in 2010	Same as in 2010	Same as in 2010
	Intermittent flooding, multiple aeration (better irrigation facilities to allow frequent drainage)	10	5	Same as in 2010	Same as in 2010	Same as in 2010	Same as in 2010	Same as in 2010	Same as in 2010
	Rain fed (flood prone)	30	30	Same as in 2010	Same as in 2010	Same as in 2010	Same as in 2010	Same as in 2010	Same as in 2010
	Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Mitigation Scenario	Continuously flooded (poor irrigation to allow drainage)	40	50	38	48	36	46	32	42
	Intermittent flooding, single aeration (slightly better irrigation facilities to allow drainage)	20	15	21	16	22	17	24	19
	Intermittent flooding, multiple aeration (better irrigation facilities to allow frequent drainage)	10	5	11	6	12	7	14	9
	Rain fed (flood prone)	30	30	30	30	30	30	30	30
	Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Note: Values indicate percentage of total area planted in rice under continuously flooded, intermittently flooded (AWD), or rain fed conditions. DS = dry season, WS = wet season.

The literature indicates no significant change in net profit between continuously flooded and AWD in rice production (Rejesus 2011). For this reason, the cost analysis was based on implementation costs, as determined by UNDP (2014). The projections of lands converted to AWD in the UNDP report (750,000 ha by 2020) are significantly more optimistic than the mitigation presented here (approximately 110,000 ha by 2020), due to the expected contribution of international support to the mitigation scenario that was analyzed by UNDP.[3] Because of this, the total implementation costs presented in the UNDP report were scaled down for the CBA mitigation option by calculating an implementation cost of approximately 21.33 USD per hectare. The implementation costs include salaries and expenses of the agricultural extension workers who would help farmers with the transition to AWD.

Option 3: Crop Diversification

Similar to the organic fertilizer mitigation option, this mitigation option assumed a 5 percent reduction in synthetic fertilizer use compared with the 2010 level, every ten years. This was based on the 5 percent replacement target of the DA-BSWM under the “Tipid-Abono” Fertilizer Program. The nutrients from the synthetic fertilizers were assumed to be replaced by planting of mungbeans, which were nitrogen-fixing crops, in place of a portion of the rice crop. The assumptions used to develop the mitigation potential for this option are discussed in Table VIII. 19.

Table VIII. 19. Assumptions for Analyzing the Mitigation Potential of Crop Diversification

Scenario	Parameter	2010	2020	2030	2050
Reference Scenario	Amount of synthetic fertilizer consumed in the country	Use 2010 synthetic N fertilizer data of production, import, and export	Assumed equal to the average quantity of domestic production, plus imports, minus exports of synthetic N fertilizer from year 2000 to 2010	Assumed equal to the average quantity of domestic production, plus imports, minus exports of synthetic N fertilizer from year 2000 to 2010	Assumed equal to the average quantity of domestic production, plus imports, minus exports of synthetic N fertilizer from year 2000 to 2010
	Crop residue management (mainly rice straw and leguminous crop)	For legumes, 1.07% of total annual crop area is planted	Assumed the same as the base year	Assumed the same as the base year	Assumed the same as the base year
Mitigation Scenario	Amount of synthetic fertilizer consumed in the		Assume to decrease by 5% (relative to 2010)	10% decrease relative to 2010	20% decrease relative to 2010

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[3] The UNDP scenario was based on a larger conversion to AWD in part because the UNDP assumed that most of the implementation costs would be paid by donors.

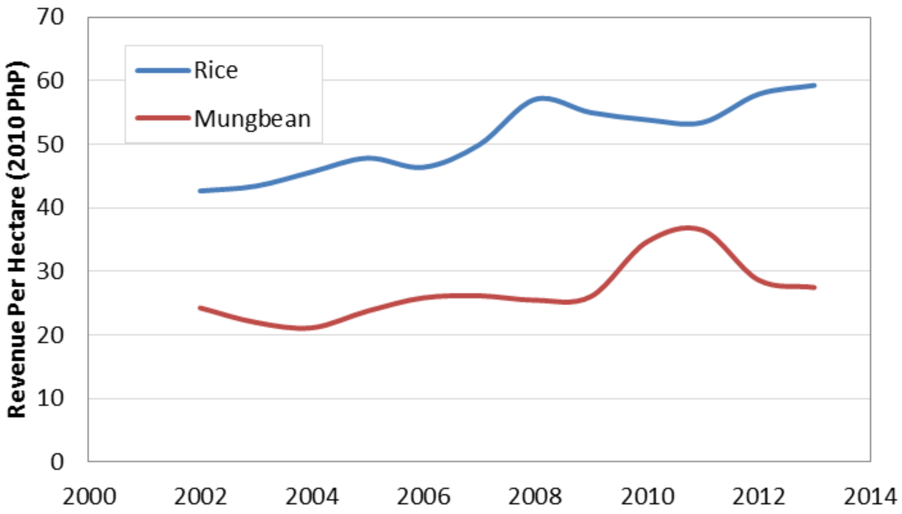
	country		every 10 years		
	Crop residue management (mainly rice straw and legumes)		Leguminous crop area increases by 5%	Leguminous crop area increases by 10%	Leguminous crop area increases by 20%

The cost analysis for this mitigation option was based on the difference in net profit from a hectare of mungbean production compared with a hectare of rice production.

As with the mitigation option on organic fertilizers, this mitigation option used information from PSA (2015) to project fertilizer prices. The cost analysis also used yield and price data from PSA (2015) to determine the gross revenue per hectare of rice and mungbeans. These were extrapolated to 2050 based on historical data (Figure VIII. 8). Net revenue was determined by subtracting the projected fertilizer costs, as discussed in the subsection for the organic fertilizer mitigation option, from the projected gross revenue.

Because mungbean production is not as profitable as rice on a per-hectare basis, this mitigation option results in positive total costs, even when accounting for the decrease in fertilizer costs.

Figure VIII. 8. Gross Revenue (2010 PhP) per Hectare of Land for Rice and Mungbean Production (PSA 2015)



Option 4: Bio-digesters

This mitigation option assumed an increase in the use of biodigesters for swine waste manure management. The assumptions used to develop the mitigation potential for this scenario in ALU are described in Table VIII. 20.

Table VIII. 20. Assumptions for Analyzing the Mitigation Potential of Bio-digesters

Scenario	Parameter	2010	2020	2030	2050
Reference Scenario	% of swine manure managed in liquid/slurry system	98	Same as in 2010 (except increase in animal population)	Same as in 2010 (except increase in animal population)	Same as in 2010 (except increase in animal population)
	% of swine manure managed using biodigester	2	Same as in 2010 (except increase in animal population)	Same as in 2010 (except increase in animal population)	Same as in 2010 (except increase in animal population)
	Total	100			
Mitigation Scenario	% of swine manure managed in liquid/slurry system	98	93	88	88
	% of swine manure managed using biodigester	2	7	12	12
	Total	**100**	**100**	**100**	**100**

The mitigation option assumed an increase in the percentage of swine waste managed in biodigesters from 2 percent in 2010, 7 percent in 2020, and 12 percent in 2030 and 2050, while the percentage of swine waste managed in biodigesters in the baseline case was held constant at 2 percent. This scenario assumed that only swine waste from commercial swine farms was available for biodigesters. This was based on a recent analysis of biodigester feasibility, which found that backyard swine populations in the Philippines tend to be too small to justify the expense of a biodigester (Teune et al. 2010).

In both the Baseline Scenario and the mitigation option, the total swine population is projected to increase over time (Table VIII. 21), based on historical production data from PSA (2015).

Table VIII. 21. Projected Swine Population in the Baseline and Mitigation Scenarios

Year	Swine Population (Head)
2010	13,397,790
2020	15,405,551
2030	20,022,831
2050	32,025,128

Note that this mitigation option may also result in decreased GHG emissions from displaced electricity from the national grid depending how it is sequenced in the retrospective analysis. The assumptions for the mitigation potential and the overall costs for this mitigation option are discussed in the CBA report for the Energy Sector (B-LEADERS, 2015).

VIII.4.2 Results

VIII.4.2.1 Direct Costs and Benefits

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 agriculture mitigation option included in the retrospective analysis.

Table VIII. 22 provides a description of each of the variables given in the subsequent results. . Each variable is assigned a symbol (e.g., "A") to allow efficient referencing in the row of formulas provided for each table. These formulas explain the process for calculating variables such as "Total Incremental Cost" or "Cost per Ton of Mitigation without Co-benefits."

Table VIII. 22. Description of Result Variables

Symbol	Variable	Description
-	Mitigation Option	Mitigation options, evaluated using the retrospective analysis approach.
A	Incremental Cost	Equal to the sum of capital, 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 VIII. 23 summarizes the direct costs and benefits of mitigation in the agriculture sector. As discussed above, the mitigation options were assessed using retrospective systems analysis, in which the mitigation options were sorted according to their initial cost per ton, then the mitigation options were added in that order to a new combined mitigation scenario. The results for each mitigation option in Table VIII. 23 are therefore incremental to the mitigation option that preceded it in the retrospective systems analysis.

The mitigation options from the agriculture sector have relatively high first-order costs per ton of mitigation potential compared to the mitigation options for the other sectors. As a result, the organic fertilizers, AWD, crop diversification, and biodigesters mitigation options are ranked 18, 21, 24, and 35, respectively, out of the 37 total mitigation options analyzed by the Study Team. Still, most of the mitigation options provide emission reductions at no or low cost (e.g., less than 5 USD per ton CO_2e), with the exception of the bio-digesters mitigation option.

Table VIII. 23. Mitigation Options in the Agriculture Sector – Potential and Net Cost

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*
Agriculture	18	Organic fertilizers	-1.0	48.1	-2.0
	21	AWD	0.1	91.2	0.1
	24	Crop diversification	0.4	8.5	4.6
	35	Biodigesters	13.5	1.1	1,287.2

*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. This approach takes into account the interdependence between a given mitigation option and every other previous option on the MACC.

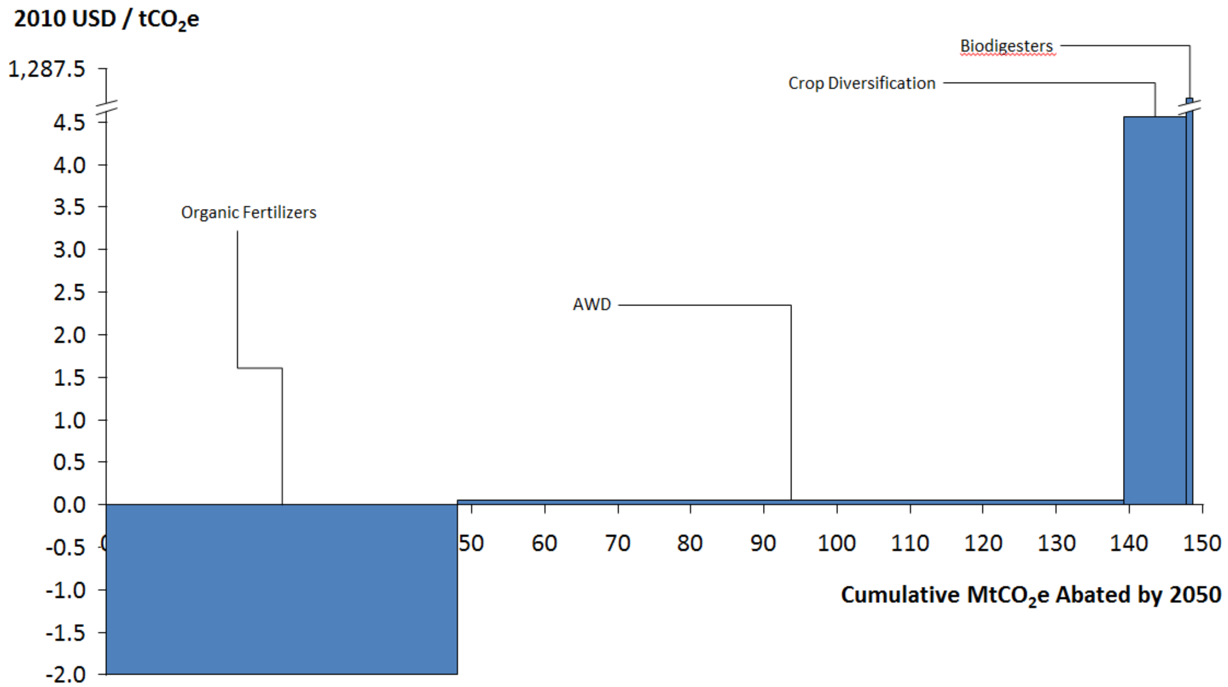
The organic fertilizer mitigation option results in negative total costs, due to the reduction in synthetic fertilizer use, which is replaced with less expensive organic fertilizers, such as composted chicken manure. The crop diversification mitigation option also results in reduced synthetic fertilizer use, but the total costs are positive for this option because the option assumes that a portion of the rice crop is replaced with mungbeans, which are not as profitable per hectare. The AWD mitigation option assumes no change in net profit from switching from continuously flooded to AWD, based on Rejesus et al. (2011). Therefore the costs for this option are based solely on implementation costs as described in UNDP (2014).

The biodigester mitigation option has a very high cost per ton of mitigation relative to the other agriculture sector mitigation options. This is due to its position in the retrospective systems analysis. Because its first-order cost per ton is relatively high, it is ranked 35th out of 37 mitigation options. As a result, it is added to the combined mitigation scenario after most of the other mitigation options have been introduced in the retrospective analysis, including after several mitigation options to de-carbonize the electricity grid (i.e. “gas for coal”, nuclear, and NREP biomass and solar). For this reason, the biodigester scenario adds relatively few emission reductions even though it increases the supply of renewable energy. While the biodigester scenario also results in abatement of non-energy emissions, these are relatively small compared to the potential energy benefits. In short, the combination of biodigesters with all the other options in the CBA reduces the cost-effectiveness of biodigesters as they result in less GHG emissions per unit cost than if the biodigesters were implemented by themselves.

VIII.4.2.2 Marginal Abatement Cost Curve

Figure VIII. 9 shows the marginal abatement cost curve (MACC) for the agriculture mitigation options, which indicates a total cumulative abatement potential of 149 $MtCO_2e$ if all four mitigation options are implemented. As discussed above, the organic fertilizers mitigation option results in a negative cost per ton and has significant abatement potential. The AWD mitigation option has the greatest mitigation potential with more than 90 $MtCO_2e$ for less than 1 USD per ton of mitigation. The other two mitigation options are smaller in terms of GHG abatement and are less cost effective, with the crop diversification option providing relatively lower mitigation potential for a relatively higher cost, and the biodigester option providing very little mitigation potential for an extremely high price.

Figure VIII. 9. Marginal Abatement Cost Curve for Agriculture Mitigation Options



VIII.4.2.3 Co-Benefits

In this section, the general approaches taken to calculate human health, energy security, and employment impacts related to the mitigation options for the agriculture sector and provide a discussion of the results are described. The co-benefits analyzed below 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.

Consistent with all the sectoral analyses, the co-benefits were calculated using the retrospective systems approach described in Sathaye and Meyers (1995), whereby the final emission reduction potential and cost per ton of CO_2e for each option were calculated using the marginal emission reductions and costs incurred after the option was added to a prior mitigation option. Table VIII. 16 summarizes the mitigation options considered, while identifying the sequence in which the options have been implemented for the retrospective analysis.

Within the agriculture sector, the CBA assessed air quality-related human health impacts, energy security impacts, and power sector employment impacts of those mitigation options with an impact on the energy sector (e.g., bio-digesters). The CBA calculated economic value (i.e., the co-benefit) only for human health impacts. The other impacts were characterized using a series of indicators as there was insufficient information to estimate their economic value. In subsections below, the methods and results for these impact assessments are described.

VIII.4.2.4 Air Quality-Related Human Health Impacts

The potential marginal impacts on human health associated with the mitigation options in the retrospective analysis is limited to a consideration of impacts on premature mortality associated with exposure to ambient fine $PM_{2.5}$. The potential human health impact of each mitigation option was based on LEAP-generated estimates of the option-specific $PM_{2.5}$ precursor emissions. 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 VIII. 24 presents the incremental human health impacts calculated for the agriculture sector mitigation options.

Table VIII. 24. Incremental Human Health Impact for Proposed Mitigation Options, Cumulative Impact during 2015-2050

Sector	Mitigation Option Sequence	Mitigation Option Name	Incremental Present Discounted Value (Million 2010 USD, 5% Discount Rate)	Incremental Cases of Premature Death	Incremental Cases of Premature Death (Females)
Agriculture	18	Organic Fertilizers	No impact on energy sector emissions by design.		

Sector	Mitigation Option Sequence	Mitigation Option Name	Incremental Present Discounted Value (Million 2010 USD, 5% Discount Rate)	Incremental Cases of Premature Death	Incremental Cases of Premature Death (Females)
Agriculture	21	AWD	No impact on energy sector emissions by design.		
Agriculture	24	Crop Diversification	No impact on energy sector emissions by design.		
Agriculture and Energy	35	Biodigesters	-364	-485	-157

The specific results in Table VIII. 24 are affected by the sequence of options and details of the assumptions incorporated in LEAP regarding level of energy demand and dispatch within the electric grid. These energy sector impacts are described in more detail in the Energy Report for the the CBA (B-LEADERS, 2015). However, the following general observations can be made:

- When the electricity grid impacts of RE generated by the bio-digesters are analyzed in the LEAP dispatch model (B-LEADERS, 2015), this option provides enough additional energy to result in a short delay of the closure of a coal plant. As a result, this mitigation option provides a slight health dis-benefit compared to the preceding mitigation option in the retrospective analysis, due to a small increase in air pollutant emissions from coal plants.
- Biodigesters are also less efficient than other energy conversion technologies, resulting in a combination of additional fuel use and higher local air pollutant emission rates than the preceding mitigation options;
- Females are expected to experience slightly less than 50% of the total health dis-benefit from the biodigester mitigation option because their baseline mortality rates are lower than the baseline mortality rates for males.

The Appendix presents additional caveats related to the health impact assessment methods that were used.

VIII.4.2.5 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. Table VIII. 25 presents the average annual incremental impact of each mitigation option on the four energy security indicators for the period 2015-2050.

Table VIII. 25. Incremental Changes in Energy Security Indicators due to the Proposed Mitigation Options, Average Annual Incremental Impact during 2015-2050

Sector	Mitigation Option Sequence	Mitigation Option Name	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]
Agriculture	18	Organic Fertilizers	-1.61	0	0	0.00
Agriculture	21	AWD	-3.47	0	0	0.00
Agriculture	24	Crop Diversification	-0.29	0	0	0.00
Agriculture and	35	Biodigesters	0.58	18	-19	0.02

Energy						
Notes: [1] All indicators are calculated in the LEAP model. 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 RE 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).						

In reviewing the results in Table VIII. 25 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. Within Table VIII. 25, a number of general conclusions can be drawn including:

- All of the mitigation options that are exclusively in the agriculture sector reduce GHG intensity;
- With the exception of the biodigester mitigation option, none of the other mitigation options results in changes in any of the other energy security indicators because they do not result in changes in energy demand or fuel mix;
- The biodigester mitigation option results in:
  - An increase in energy security by growing the share of RE and decreasing the share of imported energy; and
  - A slight increase in energy intensity, because biodigesters are assumed to be less efficient than preceding energy technologies.

VIII.4.2.6 Power Sector Employment Impacts

In this section, the general approach taken to assess power sector employment impacts and caveats to interpreting available option-specific results are described. 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 shown in Table VIII. 26.

Table VIII. 26. Average Job-Years/GWh in the Power Sector by Type of Power Generation

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

Source: Results based on Wei et al., 2010

Using the factors in Table VIII. 26 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 2015-2050 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 is considered that would result in the power sector. Employment changes in other sectors or elsewhere in the economy that are directly and indirectly affected with implementation are not accounted for as they are beyond the scope of the analysis. Table VIII. 27 presents our estimates of the incremental change in the power sector employment indicator for each mitigation option.

Table VIII. 27. Incremental Changes in Power Sector Job-Years for Proposed Mitigation Options, Cumulative Impact from 2015-2050

Sector	Mitigation Option Sequence	Mitigation Option Name	Incremental Job-Years Impact (Unrounded Cumulative Job-Years 2015-2050)
Agriculture	18	Organic Fertilizers	no change[1]
Agriculture	21	AWD	no change[1]
Agriculture	24	Crop Diversification	no change[1]
Agriculture and Energy	35	Biodigesters	3,587
Notes: [1] "no change" is indicated as there is no anticipated impact on energy sector by design of the mitigation option.			

The potential incremental power sector employment impacts presented in Table VIII. 27 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) focuses 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.

VIII.4.2.7 Net Present Value

Table VIII. 28 summarizes the GHG abatement potential for each agriculture mitigation option (Column A), cost per ton of CO_2e mitigation (Column B), and co-benefits per ton of CO_2e mitigation (Column C) for the 2015-2050 analysis period. In addition, for each option, the table presents the net cost per ton of CO_2e mitigation after incorporating the co-benefits (Column D) as well as the NPV excluding the value of GHG reduction (Column E).

The organic fertilizer, AWD, and crop diversification mitigation options do not provide quantifiable co-benefits as assessed using available information. The biodigester mitigation option provides a slight health dis-benefit as described above. As a result, this mitigation option becomes even more costly when considering the health impacts.

The NPV of the organic fertilizers mitigation option is positive, indicating that it provides a net benefit of 100 million 2010 USD to society over the period 2015-2050. All of the other mitigation options have positive costs, and therefore negative NPVs, indicating a net loss of social welfare from these mitigation options. As discussed above, the biodigesters have very high cost per ton of CO_2e mitigation, largely due to the fact that they are ranked toward the end of the mitigation options in the retrospective systems analysis and therefore have relatively f benefits. The non-energy mitigation benefits are not enough to outweigh the costs. When the health dis-benefit is factored in, this mitigation option results in a net loss of social welfare of 1.7 billion 2010 USD between 2015 and 2050.

Table VIII. 28. NPV of Mitigation Options in the Agriculture Sector during 2015-2050

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)[2,6]
			without co-benefits	*co-benefits only*[4]	*with co-benefits*[5]	
		A	*B*	*C*	*D = B+C*	*E = –D * A/1000*
18	Organic fertilizers	48.1	-2.0	0.0	-2.0	0.10
21	AWD	91.2	0.1	0.0	0.1	-0.01
24	Crop diversification	8.5	4.6	0.0	4.6	-0.04
35	Bio-digesters	1.1	1,287.2	348.0	1,635.2	-1.71

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 agriculture sector include human health benefits due to reduced air pollution from electricity generation.
[5] Negative value indicates net benefits per ton mitigation. This excludes the non-monetized benefits of GHG reductions.

ANNEX VIII.1 CROSS-CUTTING ECONOMIC ASSUMPTIONS

The sector-specific baseline projections are based on the common set of projections for the Philippine economy characteristics. Table VIII. 29 shows the data sources and assumptions used to generate these projections, while Table VIII. 30 presents historical and projected values in select years that were used in the analysis. lists historical exchange rates and inflation rates used for inter-temporal and cross-country currency conversions.

Table VIII. 29. 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 VIII. 30. 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
Mining	830	900	829	1972	2854	2493	3111	3868	4794	5923	7300	8976	11015

	Historical Data				Baseline								
Year	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
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
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

Year	Historical Data				Baseline								
	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
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 VIII. 31. 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 VIII.2 HEALTH CO-BENEFITS METHODS

B-LEADERS team estimated the human health co-benefits of the mitigation options according to the basic framework presented in Figure VIII. 10:

- 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.[4]
- 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.[5]
- 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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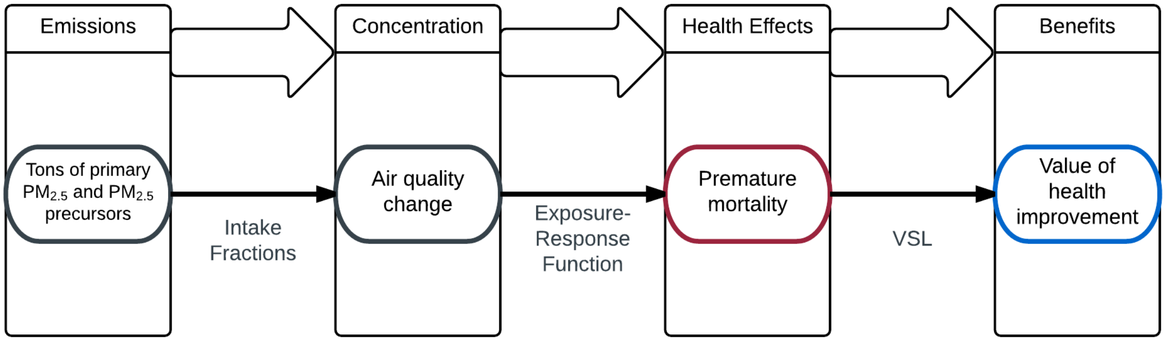
[4] Ozone is another important pollutant, but modeling ozone levels is outside of the scope of this analysis. Furthermore, the Global Burden of Disease Study found that deaths attributable to ambient ozone levels were less than 5% the number of deaths attributable to ambient $PM_{2.5}$ levels (Lim et al., 2013).

[5] 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 VIII. 10. General Framework for Health Co-Benefits Calculation



ANNEX VIII.2.1 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 $PM_{2.5}$.

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, we do 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 we do 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.

We followed the same general methods for calculating conventional pollutant emissions for on-road transportation as those described for GHG emissions. We 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. We 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 Table VIII. 32.

Table VIII. 32. 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.

Energy sector emissions

Within the energy sector, we model 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 we do 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).

ANNEX VIII.2.2 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. We do not conduct dispersion modeling, but instead apply the results of previous dispersion modeling studies using intake fractions.

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. We estimate 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 Table VIII. 33) 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.

We model 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 Table VIII. 33 and two additional studies provided supplementary measurements from previous years. A value of 35 μg/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 μg/m^3 was assumed. For rural areas, a $PM_{2.5}$ concentration of 9.5 μg/m^3 was taken from Oanh et al. (2012).

Table VIII. 33. Urban and rural measurements of $PM_{2.5}$ concentrations

City/station	Annual mean $PM_{2.5}$ (μg/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

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.

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

Equation 3.

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. We keep this ratio of unit of concentration per unit emissions fixed over time, and use it to calculate air pollution change for each mitigation option.[6]

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. We used these emission factors for the 18 largest cities in the Philippines, as we 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 VIII. 34. Variation in these values across 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.

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[6] 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.

Table VIII. 34. 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).

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 VIII. 35. The concentration change is assumed to occur throughout the country.

Table VIII. 35. 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

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 VIII. 36. $Share_{UR-M}$ is further subdivided across each of the 17 cities based on population.

Table VIII. 36. 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%

ANNEX VIII.2.3 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, we apply 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, we 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 we were 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.

ANNEX VIII.2.4 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 our 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.

ANNEX VIII.3 REFERENCES

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