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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Industry Sector Results

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ACRONYMS

ADB	Asian Development Bank
AWD	Alternate wetting and drying
BRT	Bus Rapid Transit
B-LEADERS	Building Low Emission Alternatives to Develop Economic Resilience and Sustainability
CBA	Cost-Benefit Analysis
CCC	Climate Change Commission
CEMAP	Cement Manufacturer's Association of the Philippines
CNG	Compressed Natural Gas
CO	Carbon Monoxide
COPD	Chronic obstructive pulmonary disease
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
CH_4	Methane
DENR	Department of Environment and Natural Resources
GDP	Gross Domestic Product
GHG	Greenhouse gas
GBD	Global Burden of Disease
GWP	Global Warming Potential
HFCs	Hydrofluorocarbons
ICCT	International Council on Clean Transportation
IEA	International Energy Agency
IER	Integrated Exposure-Response
IHD	Ischemic heart disease
IHME	Institute for Health Metrics and Evaluation
IIPIFC	Institute for Industrial Productivity and International Finance Corporation
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
LEAP	Long-range Energy Alternatives Planning tool
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
NAMA	Nationally Appropriate Mitigation Action
N_2O	Nitrous Oxide
NO_x	Nitrogen Oxides
NPV	Net Present Value
NREP	National Renewable Energy Program

ODS	Ozone depleting substances
O&M	Operation and Maintenance
PISI	Philippine Iron and Steel Institute
PPP GNI	Gross national income at purchasing power parity
PM	Particulate Matter
PSA	Philippine Statistics Authority
SO_2	Sulfur Dioxide
TC	Tricycle
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollars
US EPA	U.S. Environmental Protection Agency
VSL	Value per Statistical Life
WTP	Willingness to pay

VII. INDUSTRY

VII.1 EXECUTIVE SUMMARY

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

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

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

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

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

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

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

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

- A description of methods and 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
- A summary of next steps and specific areas for stakeholder involvement, including additional support for data sharing and review of proposed methodologies.

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 VII. 1 presents the direct costs and benefits of mitigation options in the industry sector. Results of the analysis show two industrial mitigation options (increased glass cullet use and cement clinker reduction) which have very low initial cost per ton estimates and therefore are the first two mitigation options to be listed in the retrospective analysis. 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.

The mitigation options all result in negative costs per ton, largely due to the use of lower-cost input materials or fuels which provide significant cost savings even before GHG mitigation is accounted for. In the increased glass cullet scenario, recycled glass is significantly less expensive than using raw materials according to a recent study (Ex Corporation, 2008). Therefore, while the overall emission reduction potential for increased glass cullet is low (0.2 MtCO$_2$e), it remains attractive because of the cost savings (-0.13 billion USD). The same is true for cement clinker reduction which results in cost savings from using lower-cost materials and reducing fuel input (-29.86 billion USD saved and 120.5 MtCO$_2$e mitigated), cement waste heat recovery (-0.56 billion USD saved and 10.5 MtCO$_2$e mitigated), biomass in cement (-2.35 billion USD saved and 115.6 MtCO$_2$e mitigated), and biomass co-firing (-0.48 billion USD saved and 70.6 MtCO$_2$e mitigated). Mitigation actions which provide cost-savings and emissions reductions are considered as “win-win” options.

Table VII. 1. Mitigation Options in the Industry Sector – Incremental Mitigation Potential and Net Costs

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$_2$e]	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*
1	Increase Glass Cullet Use	□	-0.13	-0.13	0.2	-564.5
2	Cement Clinker Reduction	-0.39	-29.48	-29.86	120.5	-247.8
9	Cement Waste Heat Recovery	-0.20	-0.36	-0.56	10.5	-53.9
11	Biomass in Cement	0.00	-2.35	-2.35	115.6	-20.4
13	Biomass Co-firing	1.05	-1.53	-0.48	70.6	-6.8

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.

Error! Reference source not found. 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 VII. 3.

Table VII. 2. Monetized Co-Benefits of Mitigation Options in the Industry Sector

Sequence Number of Mitigation Option	Mitigation Option	Incremental Co-benefits (Cumulative 2015-2050) [Billion 2010,USD] Discounted at 5%				Incremental Cost per Ton Mitigation (2015-2050) [2010,USD] *co-benefits only* [2]
		Health	Congestion	Income Generation	**Total Co-benefit**	
Symbol		*F*	*G*	*H*	*I*	*J*
Formula					*sum(F,G,H)=I*	*-I/D=J*
1	Increase Glass Cullet Use	□	□	□	0	0
2	Cement Clinker Reduction	0.038	□	□	0.038	-0.3
9	Cement Waste Heat Recovery	0.231	□	□	0.231	-21.9
11	Biomass in Cement	□	□	□	0	0
13	Biomass Co-firing	4.738	□	□	4.738	-67.1

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

Table VII. 3 summarizes the GHG abatement potential for each industry 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 net present value (NPV) excluding the value of GHG reduction (Column E).

Table VII. 3. Net Present Value of Mitigation Options in the Industry 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]			**Net Present Value Excluding Value of GHG Reduction (Billion 2010 USD)**[2]
			without co-benefits	co-benefits only[4]	with co-benefits[5]	
		A	*B*	*C*	*D = B+C*	*E = □D * A/1000*
1	Increase Glass Cullet Use	0.2	-564.5	0	-564.5	0.11
2	Cement Clinker Reduction	120.5	-247.8	-0.3	-248.1	29.9
9	Cement Waste Heat Recovery	10.5	-53.9	-21.9	-75.8	0.80
11	Biomass in Cement	115.6	-20.4	0	-20.4	2.36
13	Biomass Co-firing	70.6	-6.8	-67.1	-73.9	5.22

Sequence Number of Mitigation Option[1]	Mitigation Option	GHG Mitigation Potential ($MtCO_2e$)[3]	Cost per Ton CO_2e Mitigation (2010 USD)[2]			Net Present Value Excluding Value of GHG Reduction (Billion 2010 USD)[2]
			without co-benefits	co-benefits only[4]	with co-benefits[5]	
		A	*B*	*C*	*D = B+C*	*E = □D * A/1000*

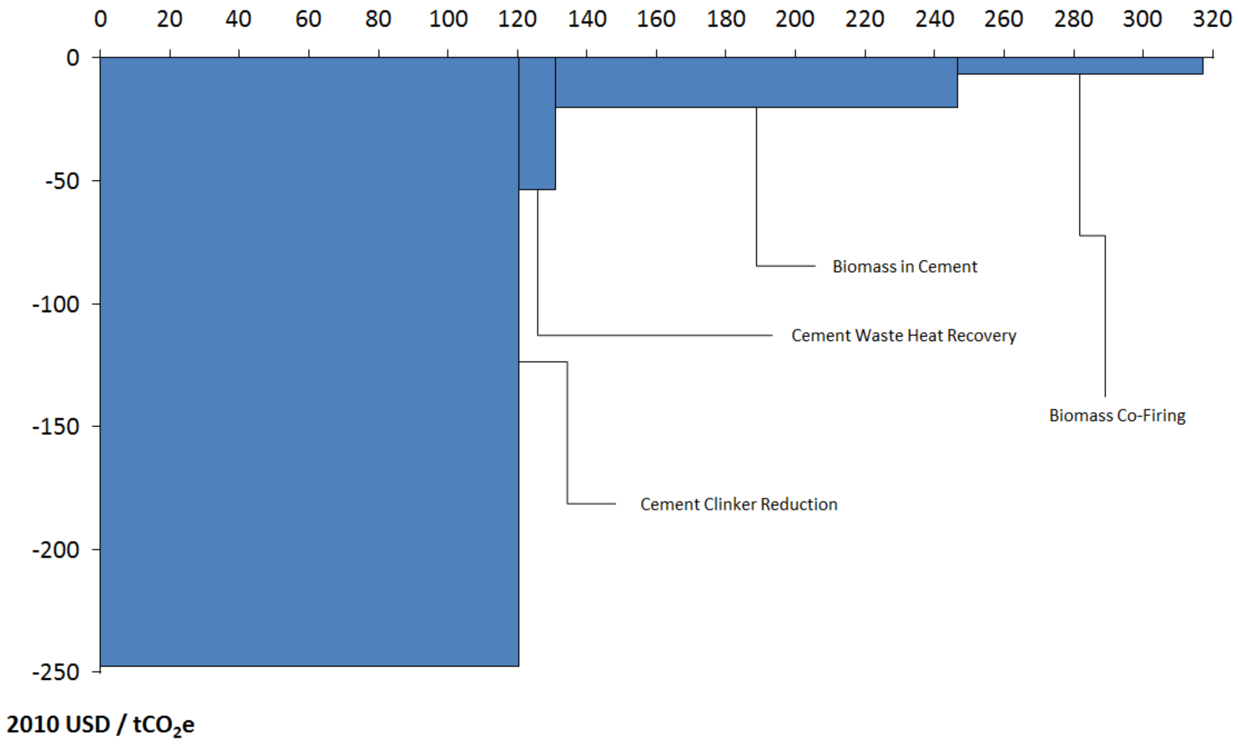
Abbreviations:
$MtCO_2e$ - Million metric tons of carbon dioxide equivalent
GHG – Greenhouse gas
USD – U.S. dollar
Notes:
[1] Refers to the sequential order in which the mitigation option is introduced in the retrospective analysis. In this analysis, mitigation options are compared to the baseline as stand-alone options, and then ranked according to their cost per ton mitigation (excluding co-benefits) from lowest cost per ton mitigation to highest cost per ton mitigation. The cost and GHG mitigation potential of a given mitigation option is calculated relative to a scenario that embeds all options with lower cost per ton mitigation.
[2] The costs and co-benefits expected to occur in years other than 2015 were expressed in terms of their present (i.e., 2015) value using a discount rate of 5%.
[3] The GHG mitigation potential is a total reduction in GHG emissions that is expected to be achieved by the option during 2015-2050.
[4] The co-benefits for the industry 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.

Figure VII. 1 shows the MACC for the industry mitigation options which indicates a total cumulative abatement potential of 317 $MtCO_2e$ if all five mitigation options are implemented. As discussed above, all of the mitigation options in the industry sector have negative costs per ton of emission reduction. The cement clinker reduction mitigation option is particularly attractive, with the potential to reduce up to 120 $MtCO_2e$ at a cost of approximately -250 USD per ton CO_2e. However, in order to reach the full abatement potential of this mitigation option, the standards for blended cement would likely need to be revised to enable increased use of low clinker materials.

Note that even though the increased glass cullet use mitigation option has the lowest cost per ton, it is not shown in the MACC because it has a very small mitigation potential, of less than 1 $MtCO_2e$.

Figure VII. 1. Marginal Abatement Cost Curve for Industry Mitigation Options

Cumulative $MtCO_2e$ Abated by 2050



Note: The increased glass cullet use mitigation option is not shown in the marginal abatement cost curve due to its small mitigation potential.

VII.2 BASE YEAR GHG EMISSIONS

This section describes the methods and assumptions used for developing the 2010 Base Year estimate of non-energy process emissions from industry, as well as the results. In the Philippines, the relevant emission source categories are minerals production, metal production, chemicals, and the use of substitutes for ODS in refrigerants (Table VII. 4. Emission Source Categories: Industry Process Emissions). The relevant GHGs for these source categories are CO_2, CH_4, and HFCs.

This report does not directly address the GHG emissions that result from energy use in industry. For more information on these emissions, see the report on the energy sector (B-LEADERS, 2015) which describes the process and results for using LEAP to conduct the CBA for energy.

Table VII. 4. Emission Source Categories: Industry Process Emissions

Sector	Activity	GHG
Minerals	Cement Production Lime Production Glass Production	CO_2

	Limestone and Dolomite Use Soda Ash Production and Use	
Chemicals	Carbide Production Carbon Black Production Fluorinated Compound Production and Use	CO_2, CH_4
ODS	Use of substitutes for ODS for refrigeration and air conditioning	Hydrofluorocarbons
Metals	Iron and Steel Production	CO_2

VII.2.1 Methods and Assumptions

Similar to the year 2000 GHG inventory for the Philippines, the Study Team used the 2006 IPCC Guidelines for National GHG Inventories Tier 1 approachto estimate industrial process emissions.

B-LEADERS collected activity data from the largest source categories representing more than 98 percent of the total 2010 GHG emissions, including:

- Production of cement from the Cement Manufacturer's Association of the Philippines (CEMAP) (2015);
- Lime production and use from the UN Statistics Division (2015);
- Iron and steel production from the Philippine Iron and Steel Institute (PISI) (2015);
- Flat glass production from flat glass manufacturers;
- Container glass production from Ex Corporation (Ex Corporation, 2008); and
- Use of substitutes for ODS from DENR-EMB, Philippine Ozone Desk (2015).

The only industry subsectors with GHG emissions unavailable to the Study Team was the 2010 activity data on soda ash use, calcium carbide production, and carbon black production. For these source categories, the Study Team extrapolated 2010 GHG emissions based on the change in economic activity during 2000-2010. Specifically, for each individual subcategory, the Study Team obtained the historical change in value added from 2000-2010 from PSA (2015) and applied this rate of change to the 2000 GHG inventory (Manila Observatory, 2010) in order to extrapolate emissions to 2010. The share of emissions that were extrapolated using this approach represent less than 2 percent of the overall 2010 process emissions from industry.

VII.2.2 Results

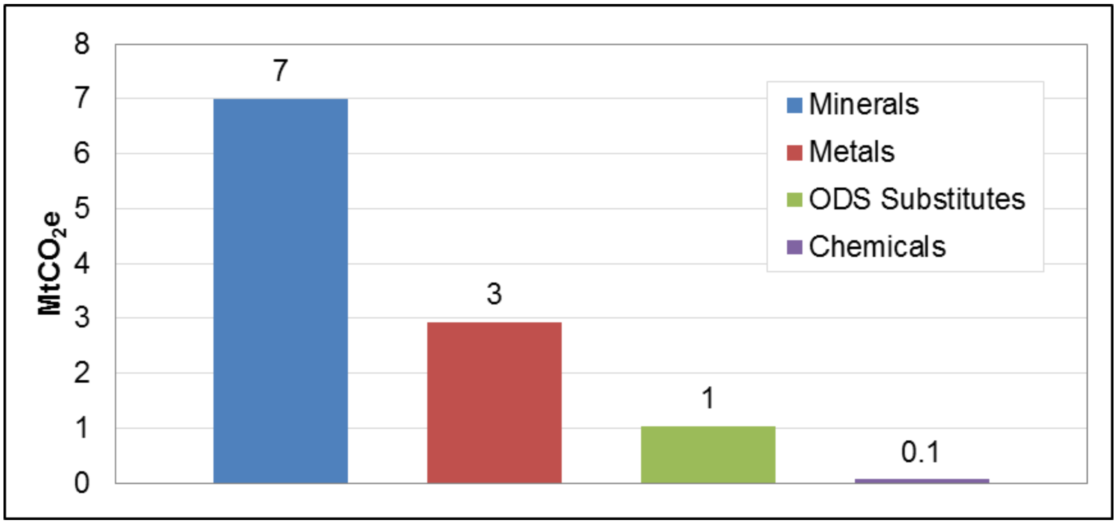
This section summarizes the results for the 2010 base year industry process emissions profile and includes graphical presentation of the results.

The production and use of minerals is responsible for a majority of process-related GHG emissions from industry, with nearly 7 million $MtCO_2e$ in 2010. In particular, cement production results in emissions of over 5.7 $MtCO_2e$ which accounts for more than 80 percent of the emissions from the minerals industry and more than 50 percent of all industrial emissions (Table VII. 5 and Figure VII. 2). The metals industry is responsible for nearly 3 $MtCO_2e$ of emissions, all of which come from the iron and steel industry. Substitutes for ODS contributed 1 $MtCO_2e$, while chemicals were responsible for 0.1 $MtCO_2e$ emissions.

Table VII. 5. Base Year GHG Emissions from Industry by Source Category ($MtCO_2e$)

Industry	Sector	Emissions ($MtCO_2e$)	% of Total
Minerals	Cement production	5.7	51.8
	Lime production	0.1	0.9
	Glass production	0.06	0.5
	Other uses of carbonates	1.1	10.0
Metals	Iron and steel production	2.9	26.4
Substitutes for Ozone Depleting Substances	Refrigeration and air conditioning	1.0	9.1
Chemicals	Carbide production	0.05	0.5
	Petrochemical and carbon black production	0.008	0.1
TOTAL		**10.9**	**99.3**

Figure VII. 2. Base Year GHG Emissions from Industry ($MtCO_2e$)



VII.3 BASELINE PROJECTION TO 2050

This subsection describes the estimated annual GHG emissions for the 2010 to 2050 industry baseline, including the data and key assumptions used for developing this baseline. The baseline describes projected GHG emissions under "business as usual" economic activity. As such, it serves as a standard against which the impacts of current and planned mitigation actions can be measured.

VII.3.1 Methods and Assumptions

The Study Team developed the 2010-2050 baseline for industry process emissions based on projections of sectoral value added. These projections were developed using a two-step process. First, the Study Team developed projections of GDP)using historical GDP data for 2010-2014 from PSA (2015). The Study Team used similar assumptions for the GDP projections as those used by an ADB study in 2015 on Low-Carbon Scenario and Development Pathways for the Philippines . The Study Team also used historical data from PSA (2015) on sector-specific value added to determine the share of GDP attributable to each industry sector (Error! Reference source not found. **and Figure Figure VII. 6. General Framework for Health Co-Benefits Calculation**

). These economic sector-specific value added shares were then extrapolated to 2050 using their historical annual average growth rates from 1998 to2014.

The use of historical value added by economic sector for extrapolation of the baseline, allows GHG emissions for different industry sectors to grow at different rates depending on expected market activity. For example, the chemicals industry has experienced rapid growth in recent years. As shown in Table Table VII. 6, if current growth trends continue, the chemicals sector is expected to see an 11-fold increase in value added by 2050 compared with 2010. The minerals sector, which is experiencing much lower growth, is expected to grow by approximately 50 percent by 2050. Based on an extrapolation of historical value added of "other manufacturing," the use of ODS substitutes is projected to increase by approximately 50 percent by 2050. Meanwhile the iron and steel industry, on the the basis of which emissions from the metals industry were determined, may contract by 40 percent by 2050.

Table VII. 6. Sectoral Value Added in 2010 and Projected to 2050[1]

Industry	Value Added (Billion 2010 USD)				
	2010	2020	2030	2040	2050
Chemical and Petrochemical	2.6	7.4	12.1	19.7	31.8
Other Manufacturing	7.9	7.6	8.9	10.1	11.4
Non-Metallic Minerals	1.1	1.3	1.5	1.6	1.7
Iron and Steel	1.0	0.8	0.7	0.7	0.6

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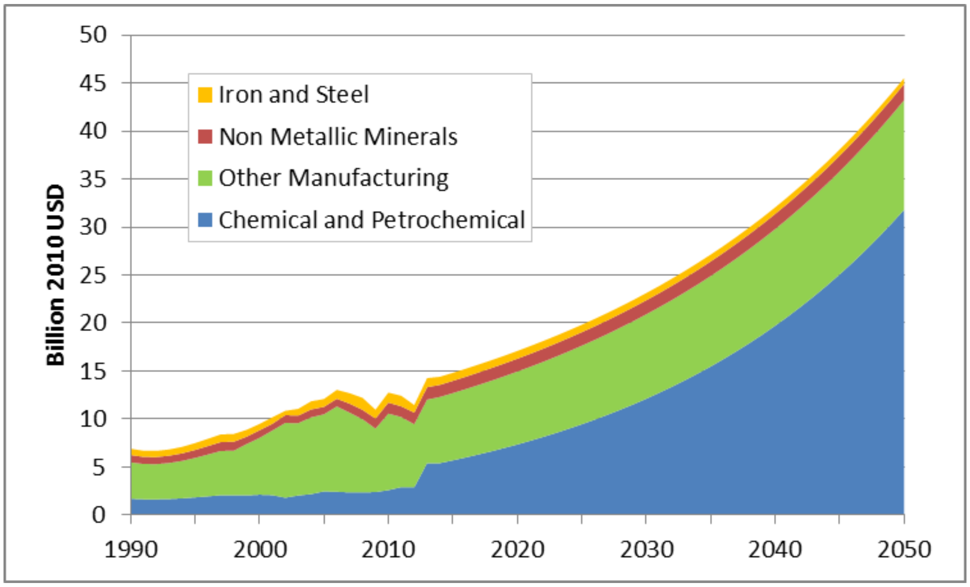
[1] Source: Philippine Statistics Authority, 2015

Figure VII. 3. Historical and Projected Sectoral Value Added



Source: Philippine Statistics Authority, 2015

VII.3.2 Results

As presented in Figure VII. 4 and Table VII. 7, the minerals sector continues to be the dominant source of process emissions through 2050, representing more than 80 percent of CO_2e emissions by 2050, with emissions of 20.8 $MtCO_2$e. In line with the projected contraction in the iron and steel industry, emissions from the metals sector are projected to decline by 40 percent between 2010 and 2050 from 2.9 to 1.8 $MtCO_2$e.

Although the chemical industry is projected to see an 11-fold increase in value added and therefore a proportionate increase in emissions, the 2010 base year process emissions from the chemical industry are relatively small. Therefore, even with a significant increase, the overall projected process emissions from the chemical industry in 2050 still represent only about 3 percent of the total industrial process emissions, and are driven mostly by carbide production. Emissions from ODS substitutes are projected to increase by more than 50 percent between 2010 and 2050, from 1.0 to 1.6 $MtCO_2$e.

Figure VII. 4. 2010-2050 Baseline for Process Emissions from Industry by Source Category ($MtCO_2e$)

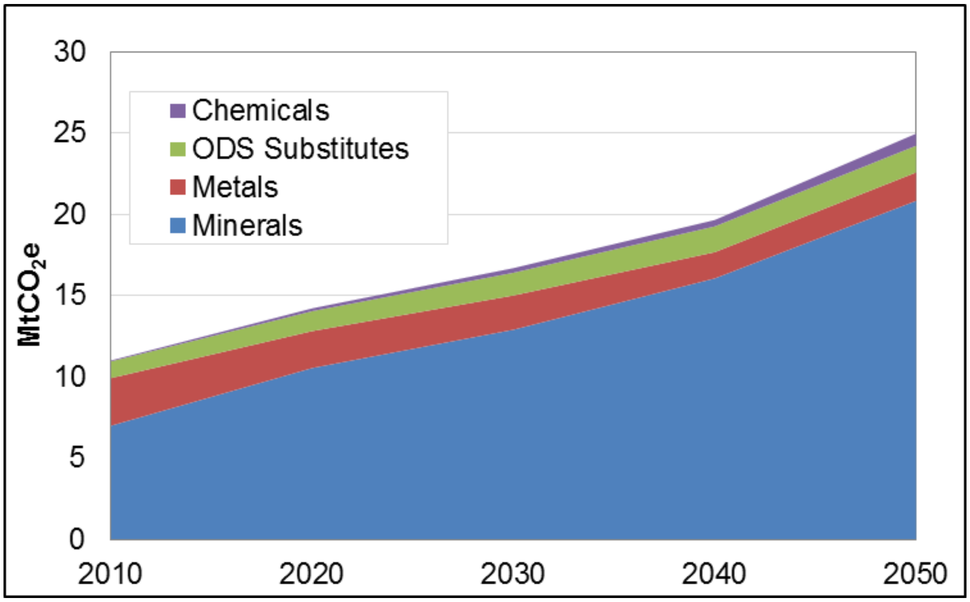


Table VII. 7. 2010-2050 Baseline for Process Emissions from Industry by Source Category ($MtCO_2e$)

Industry	Sector	Emissions ($MtCO_2e$) 2010	2020	2030	2050
Minerals	Cement production	5.72	9.06	11.28	18.95
	Lime production	0.10	0.12	0.13	0.15
	Glass production	0.06	0.07	0.07	0.09
	Other uses of carbonates	1.12	1.31	1.43	1.65
Metals	Iron and steel production	2.93	2.27	2.11	1.61
ODS Substitutes	Refrigeration and air conditioning	1.03	1.23	1.40	1.59
Chemicals	Carbide production	0.05	0.15	0.25	0.65
	Petrochemical and carbon black production	0.01	0.02	0.04	0.10
TOTAL		**11.02**	**14.23**	**16.71**	**24.79**

VII.4 MITIGATION COST-BENEFIT ANALYSIS

VII.4.1 Methods

In order to develop a set of mitigation options for consideration for the industry, B-LEADERS conducted a review of national-level plans for industry, reviewed existing mitigation studies for the Philippines, and consulted with relevant stakeholders. The Study Team also drew on the list of mitigation options that were included in the UNDP study of potential NAMAs for the Philippines (Berkman International, Inc., 2015).

The proposed mitigation options, and the associated assumptions, were confirmed during several stakeholder consultation workshops organized by the CCC during February-July 2015. The key criteria for the selection of the final list of mitigation options include applicability to the national development context and the potential for introducing win-win opportunities, which result in both GHG reductions and cost savings to industry.

The five industry mitigation options analyzed in the CBA include:

- Increased cullet use in glass manufacturing, which reduces process emissions by avoiding the production and use of virgin materials;
- Decreased clinker use in cement manufacturing which reduces the amount of fossil fuel combusted for clinker production and the amount of process emissions associated with the production of clinker;
- Waste heat recovery in cement manufacturing, which replaces the demand for on-grid power;
- Biomass energy in cement manufacturing which replaces the use of coal for process heat in cement manufacturing; and
- Biomass co-firing in coal fired power plants which replaces the use of coal for power generation.

For each mitigation option, the Study Team projected costs and emission reduction benefits, as well as potential co-benefits. Table VII. 8 presents a detailed description of each mitigation option and the assumptions used to model them.

Table VII. 8. Mitigation Options in the Industry Sector

Mitigation Option	Description	Assumptions
Increase Cullet Use in Glass	This mitigation option assumes an increase in the amount of cullet (recycled glass) used in container glass manufacturing, resulting in a decrease in CO_2 process emissions from glass production.	**General:** Cullet use in container class production is estimated to be approximately 60% in 2010. This mitigation option assumes that the use of cullet will increase to 65% in 2020, 70% in 2030, and 75% in 2050. **Capital Cost:** No changes in capital cost. **O&M Cost:** No changes in maintenance cost. **Input Cost:** Cullet is significantly less expensive than virgin materials in glass manufacturing, at approximately US$38 per ton for cullet compared with US$344 per ton for virgin materials (Ex Corporation, 2008).
Cement Clinker Reduction	Clinker is an important but highly energy and GHG intensive input to cement production, where it is used as a binding compound. Currently, cement manufactured in the Philippines is about 80% clinker by mass on average (World Business Council for Sustainable Development Cement Sustainability Initiative, 2015). This option	**General:** Thirty-five percent of national cement production is assumed to be lower-clinker by 2020, 50% by 2030, and 70% by 2050 (The targets were developed by the Study Team in consultation with industry stakeholders). Producing a metric ton of clinker is estimated to result in 0.43 $MtCO_2$ of process emissions (IPCC, 2006) and is assumed to require 3,510 MJ of heat and 74.1 kWh of electricity (World Business Council for Sustainable

Mitigation Option	Description	Assumptions
	considers the introduction of lower-clinker cement—60% clinker by mass. This option results in the decrease of direct process emissions of CO_2 from the production of clinker, as well as the reduction of emissions from the energy required to produce the clinker.	Development Cement Sustainability Initiative 2015). The heat saved by producing less clinker is assumed to come from coal and biomass in proportion to their usage in the cement industry in the absence of this mitigation option. Any incremental energy demand associated with producing and using clinker substitutes (e.g., coal fly ash, volcanic ash) is assumed to be negligible. The method for estimating energy-related emission reductions from this option are described further in the Energy Report of CBA (B-LEADERS, 2015). **Capital Cost:** No changes in capital cost. **O&M Cost:** No changes in maintenance cost. **Input Cost:** Data is not published on the cost of either clinker or replacement material, such as fly ash or volcanic ash. In some cases the replacement materials may be available at no cost (Muga et al. 2005). In this mitigation scenario it was assumed that the replacement material would be approximately half as costly as clinker, although there is significant uncertainty of the estimate. Energy-related costs depend on the change in demand for electricity, coal, and biomass, which are described in the Energy Report of the CBA (B-LEADERS, 2015).
Cement Waste Heat Recovery	Cement manufacturing is heat intensive and creates substantial amounts of waste heat. In some instances, this energy can be reclaimed and used for productive purposes such as electricity generation. This option examines deploying waste heat-to-power technology in the cement industry, taking current waste heat recovery initiatives as examples. Based on the Institute for Industrial Productivity and International Finance Corporation (IIPIFC) (2014), it evaluates adding 60 MW of new heat-to-power capacity during 2016-2025. After 2025, installed heat-to-power capacity is assumed to grow at the same rate as national cement production.	**General:** Introduction of heat-to-power capacity begins in 2015, growing linearly to 60 MW in 2025. The technology is assigned a capacity factor of 74%. Electricity generated is assumed to reduce the demand for on-grid power in the cement manufacturing industry. **Capital Cost:** Heat-to-power generation costs 2,983,633 2010 USD/MW, which is annualized over 25 years using the model's discount rate of 5%. Estimates are taken from IIPIFC I (2014). **O&M Cost:** Annual O&M costs (fixed and variable costs combined) are estimated at 2.5% of the total capital cost (ibid). **Implementation Cost:** No other costs or benefits are included.
Biomass for Cement Production	Coal is the dominant fuel used in the Philippine cement industry, primarily for process heat. Cement industry stakeholders consulted by B-LEADERS estimate that by 2020, 35% of coal inputs to cement production could be replaced with	**General:** Beginning in 2013, rice hull biomass gradually displaces baseline coal consumption in the cement industry, reaching 35% of the baseline coal consumption that would otherwise occur in 2020. **Capital Cost:** None reported. **O&M Cost:** None reported. **Implementation Cost:** Stakeholders do not foresee any

Mitigation Option	Description	Assumptions
	biomass without modifying existing kilns or production processes. This option analyzes such a substitution using rice hull waste from agriculture.	additional cost for biomass feedstock mixtures of less than 35%.
Biomass Co-firing in Power Generation	This option explores the potential for biomass co-firing in existing coal plants, building on assessments of biomass availability that are being carried out under the agriculture and forestry components of the CBA Study (B-LEADERS, 2015). It models replacing 5% of coal used in subcritical pulverized coal plants with biomass by 2020 (the percentage remains constant through 2050).	**General:** The measure is assumed to only affect shares of feedstock fuels for existing subcritical coal plants. The increased use of biomass co-firing begins in 2015 and gradually increases over time, with shares of biomass fuels in the input mix reaching 5% by 2020. 25% of the biomass is expected to come from coconut residues while the remainder is taken up by rice hull waste. **Costs:** The incremental costs for retrofitting plants are obtained from the International Renewable Energy Agency and IEA Energy Technology Systems Analysis Programme (2013). See the Energy Report for more information (B-LEADERS, 2015).

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, in the transport sector, some mitigation options address the same GHG emission source categories (i.e., Euro 4 and Euro 6 emission standards), leading to a potential overestimation of total GHG emission reductions if all the mitigation options analyzed in this report are simply summed up.

The CBA addressed this issue by following the retrospective systems approach in Sathaye and Meyers (1995). In this approach, the GHG emission reduction potential and cost per ton of CO_2e for a given mitigation option were calculated relative to a scenario that reflects 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 are implemented together. In brief, this method involves four steps:

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

combined scenario. Thus, the first option is evaluated in comparison to the 2010-2050 baseline only, the second option in comparison to the baseline plus the first option, and so forth.

The retrospective analysis spans all mitigation options across all sectors analyzed in the CBA. Industry mitigation options are initiated within the overall set or sequence of options analyzed. **Error! Reference source not found.** shows the sequence, in which the mitigation options are initiated in the retrospective analysis for this study. The sequence order of the industry mitigation options is specifically noted.

The results presented below in Section VII.4.2 Results focus only on the incremental impacts of the five industry mitigation options. However, it is important to understand that those results occur within and are dependent on where an option sits in the overall sequence of the 37 options summarized previously in Table Table VII. 9 The further down the list a mitigation option is placed, the less GHG-intensive the economy will be, thus reducing the potential for achieving additional abatement at a low cost.

Table VII. 9. Sequential Order of All Mitigation Options in the Retrospective Analysis

Sector	Mitigation Option Sequence	Mitigation Option Name
Industry	**1**	**Increase Glass Cullet Use**
Industry and Energy	**2**	**Cement Clinker Reduction**
Transport	3	MVIS
Transport	4	Electric Jeepney
Transport	5	Congestion Charging
Energy	6	Home Lighting Improvements
Transport	7	Driver Training
Energy	8	Home Appliance Standards
Industry and Energy	**9**	**Cement Waste Heat Recovery**
Energy	10	Efficient LED Lighting
Industry and Energy	**11**	**Biomass in Cement**
Energy	12	NREP Biomass
Industry and Energy	**13**	**Biomass Co-firing**
Waste and Energy	14	MSW Digestion
Energy	15	Nuclear Power
Energy	16	NREP Solar
Energy	17	Gas for Coal
Agriculture	18	Organic Fertilizers
Energy	19	NREP Wind
Waste and Energy	20	Methane Recovery from SLF
Agriculture	21	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	NREP Ocean
Energy	27	NREP Large Hydro
Waste	28	Composting
Waste	29	Eco-Efficient Cover

Sector	Mitigation Option Sequence	Mitigation Option Name
Energy	30	NREP Small Hydro
Energy	31	NREP Geothermal
Transport	32	Biofuels
Energy	33	Biodiesel Target
Transport	34	BRT
Agriculture and Energy	35	Biodigesters
Transport	36	Rail
Waste and Energy	37	MSW Incineration

VII.4.2 Results

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

Table VII. 10 provides a description of each of the variables given in the subsequent results tables. Each variable is assigned a symbol (e.g., "A") to allow efficient referencing in the row of formulas provided for each table. These formulas explain the process for calculating variables such as "Total Incremental Cost" or "Cost per Ton of Mitigation without Co-benefits."

Table VII. 10. 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 VII. 11 presents the direct costs and benefits of mitigation options in the industry sector. Results of the analysis show two industrial mitigation options (increased glass cullet use and cement clinker reduction) which have very low initial cost per ton estimates and therefore are the first two mitigation options to be listed in the retrospective analysis. The cement waste heat recovery mitigation option, the biomass in cement option, and the biomass co-firing option are reported as number 9, 11, and 13 on the sequencing list, respectively. This means that all five options are relatively cost effective compared to all the other mitigation options analyzed in the CBA. It also means that, if introduced according to the sequencing outlined in Table VII. 9, they would be implemented while the economy is still fairly carbon intensive and therefore have a greater potential to reduce emissions than some of the other mitigation options that are introduced later. This is particularly the case for those industry options that have an impact on energy consumption, since the system still relies on coal for a large share of the energy supplied. The impacts of these mitigation options on the energy sector are described further in the Energy Report for the CBA (B-LEADERS, 2015).

The mitigation options all result in negative costs per ton, largely due to the use of lower-cost input materials or fuels which provide significant cost savings even before GHG mitigation is accounted for. In the increased glass cullet scenario, recycled glass is significantly less expensive than using raw materials according to a recent study (Ex Corporation, 2008). Therefore, while the overall emission reduction potential for increased glass cullet is low (0.2 $MtCO_2e$), it remains attractive because of the cost savings (-0.13 billion USD). The same is true for cement clinker reduction which results in cost savings from using lower-cost materials and reducing fuel input (-29.86 billion USD saved and 120.5 $MtCO_2e$ mitigated), cement waste heat recovery (-0.56 billion USD saved and 10.5 $MtCO_2e$ mitigated), biomass in cement (-2.35 billion USD saved and 115.6 $MtCO_2e$ mitigated), and biomass co-firing (-0.48 billion USD saved and 70.6 $MtCO_2e$ mitigated). Mitigation actions which provide cost-savings and emissions reductions are considered as “win-win” options.

Table VII. 11. Mitigation Options in the Industry Sector – Incremental Mitigation Potential and Net Costs

Sequence Number of Mitigation Option*	Mitigation Option	Incremental Cost (Cumulative 2015-2050) [Billion 2010 USD] Discounted at 5%			Incremental GHG Mitigation potential (2015-2050) [$MtCO_2e$]	Incremental Cost per Ton Mitigation (2015-2050) [2010 USD] *without co-benefits*
		Capital, O&M, Implementation Costs	**Cost of Fuel and Other Inputs**	**Total Net Cost**		
Symbol				**A**	*B*	*C*
Formula						*(A*1000)/B=C*
1	Increase Glass Cullet Use	□	-0.13	-0.13	0.2	-564.5
2	Cement Clinker Reduction	-0.39	-29.48	-29.86	120.5	-247.8
9	Cement Waste Heat Recovery	-0.20	-0.36	-0.56	10.5	-53.9
11	Biomass in Cement	0.00	-2.35	-2.35	115.6	-20.4
13	Biomass Co-firing	1.05	-1.53	-0.48	70.6	-6.8

Table VII. 12. Monetized Co-Benefits of Mitigation Options in the Industry Sector

Sequence Number of Mitigation Option	Mitigation Option	Incremental Co-benefits (Cumulative 2015-2050) [Billion 2010,USD] Discounted at 5%				Incremental Cost per Ton Mitigation (2015-2050) [2010,USD] *co-benefits only* [2]
		Health	Congestion	Income Generation	**Total Co-benefit**	

Symbol		F	G	H	I	J
Formula					sum(F,G,H)=I	-I/D=J
1	Increase Glass Cullet Use	□	□	□	0	0
2	Cement Clinker Reduction	0.038	□	□	0.038	-0.3
9	Cement Waste Heat Recovery	0.231	□	□	0.231	-21.9
11	Biomass in Cement	□	□	□	0	0
13	Biomass Co-firing	4.738	□	□	4.738	-67.1

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

Table VII. 13. Net Present Value of Mitigation Options in the Industry 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]			Net Present Value Excluding Value of GHG Reduction (Billion 2010 USD)[2]
			without co-benefits	co-benefits only[4]	with co-benefits[5]	
		A	*B*	*C*	*D = B+C*	*E = □D * A/1000*
1	Increase Glass Cullet Use	0.2	-564.5	0	-564.5	0.11
2	Cement Clinker Reduction	120.5	-247.8	-0.3	-248.1	29.9
9	Cement Waste Heat Recovery	10.5	-53.9	-21.9	-75.8	0.80
11	Biomass in Cement	115.6	-20.4	0	-20.4	2.36
13	Biomass Co-firing	70.6	-6.8	-67.1	-73.9	5.22

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

Notes:

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

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

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

[4] The co-benefits for the industry sector include human health benefits due to reduced air pollution from electricity generation.

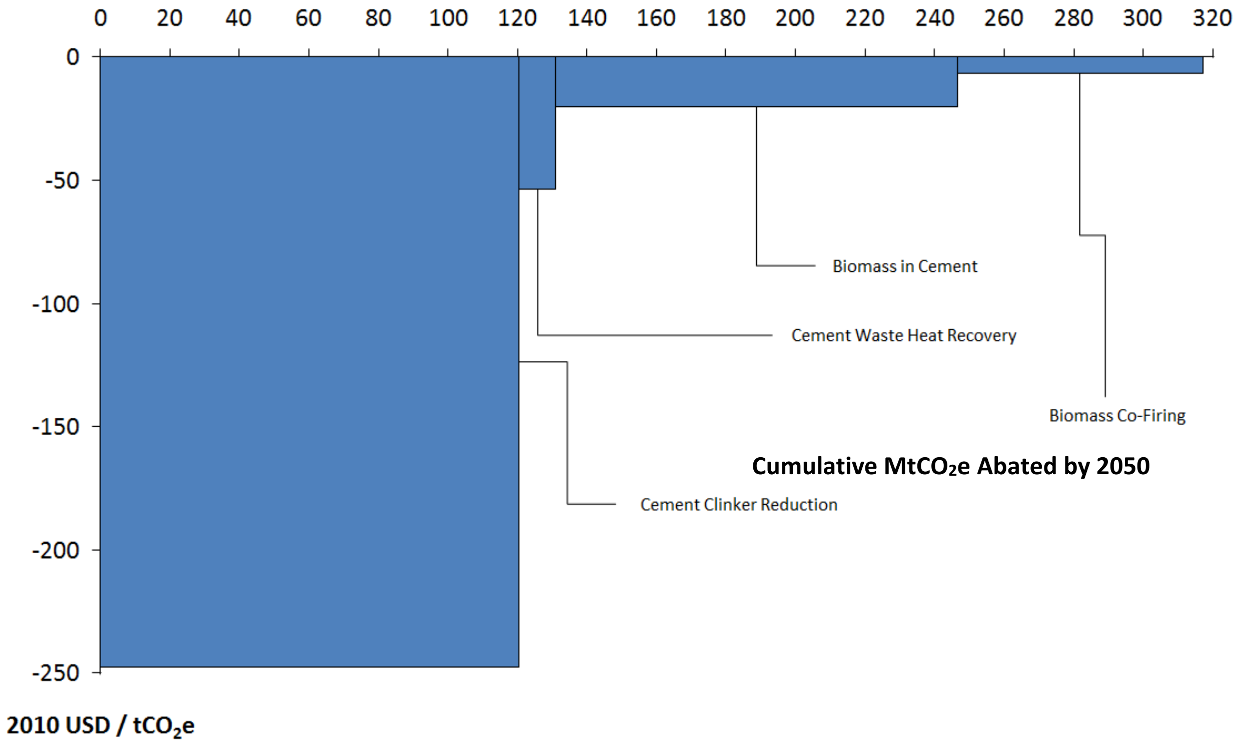
[5] Negative value indicates net benefits per ton mitigation. This excludes the non-monetized benefits of GHG reductions.

VII.4.2.1 Marginal Abatement Cost Curve for Industry Sector Mitigation Options

Figure VII. 5 shows the MACC for the industry mitigation options which indicates a total cumulative abatement potential of 317 $MtCO_2e$ if all five mitigation options are implemented. As discussed above, all of the mitigation options in the industry sector have negative costs per ton of emission reduction. The cement clinker reduction mitigation option is particularly attractive, with the potential to reduce up to 120 $MtCO_2e$ at a cost of approximately -250 USD per ton CO_2e. However, in order to reach the full abatement potential of this mitigation option, the standards for blended cement would likely need to be revised to enable increased use of low clinker materials.

Note that even though the increased glass cullet use mitigation option has the lowest cost per ton, it is not shown in the MACC because it has a very small mitigation potential, of less than 1 $MtCO_2e$.

Figure VII. 5. Marginal Abatement Cost Curve for Industry Mitigation Options



Note: The increased glass cullet use mitigation option is not shown in the marginal abatement cost curve due to its small mitigation potential.

VII.4.2.2 Co-Benefits

In this section, the general approaches are described including the steps taken to calculate human health, energy security, and employment impacts related to the mitigation optionswhich have an impact on the energy sector. A discussion of the results is provided. The relevant industry mitigation options include:

- Decreased clinker use in cement manufacturing which reduces the amount of electricity used for clinker production;
- Waste heat recovery in cement manufacturing, which replaces the demand for on-grid electricity;
- Biomass energy in cement manufacturing which replaces the use of coal for process heat in cement manufacturing; and
- Biomass co-firing in coal fired power plants which replaces the use of coal for power generation.

Consistent with all the sectoral analyses, the co-benefits have been calculated using the retrospective systems approach. Thus, the first option is evaluated in comparison to the baseline scenario only, the second option is evaluated in comparison to the baseline plus the first option, and so forth. Consistent with this, the marginal impact of a mitigation option is determined based on its impact relative to the prior mitigation option. Table VII. 9 summarizes the mitigation options considered, while identifying the sequence in which the options have been implemented for the retrospective analysis.

Within the industry sector, the CBA assessed air quality-related human health impacts, energy security impacts, and power sector employment impacts. 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.

VII.4.2.3 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 VII. 14 presents the incremental human health impacts calculated for the industry sector mitigation options.

Table VII. 14. 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 Avoided Premature Deaths	Incremental Cases of Avoided Premature Deaths (Females)
Industry	1	Increase Glass Cullet Use	No impact on energy sector emissions by design.		
Industry and Energy	2	Cement Clinker Reduction	38	50	18

Sector	Mitigation Option Sequence	Mitigation Option Name	Incremental Present Discounted Value (Million 2010 USD, 5% Discount Rate)	Incremental Cases of Avoided Premature Deaths	Incremental Cases of Avoided Premature Deaths (Females)
Industry and Energy	9	Cement Waste Heat Recovery	231	243	95
Industry and Energy	11	Biomass in Cement	No impact on energy sector emissions by design.		
Industry and Energy	13	Biomass Co-firing	4,738	4,865	1,891

The specific results in Table VII. 14 are affected by the sequence of options and details of the assumptions incorporated in the LEAP model regarding level of energy demand and dispatch within the electrical system (B-LEADERS, 2015). However, the following general observations can be made:

- Energy efficiency measures, such as the cement waste heat recovery mitigation option result in lower demand for on-grid electricity, which translates into reduced air pollutant emissions (all else equal);
- Females are expected to experience slightly less than 50% of the total health benefit 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.

VII.4.2.4 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 the LEAP model using the same retrospective analysis as the one used to assess the mitigation options. Table VII. 15 presents the average annual incremental impact of each mitigation option on the four energy security indicators for the period 2015-2050.

Table VII. 15. Incremental Changes in Energy Security Indicators due to the Proposed Mitigation Options, Average Annual Incremental Impact during 2015-2050

Sector	Mitigation Option Name	Mitigation Option Sequence	Average Annual Incremental Impact 2015-2050 [1]			
			Change in GHG Intensity of GDP (g CO_2e/ 2010 USD) [2]	Change in Share of Renewables (%) [3]	Change in Share of imports (%) [4]	Change in Energy Intensity of GDP (MJ/2010 USD) [5]
Industry	Increase Glass Cullet Use	1	-0.01	0	0	0.00
Industry and Energy	Cement Clinker Reduction	2	-4.11	9	-11	-0.02
Industry and Energy	Cement Waste Heat Recovery	9	-0.40	1	-2	-0.01
Industry and Energy	Biomass in Cement	11	-4.39	78	-69	0.00
Industry and Energy	Biomass Co-firing	13	-2.90	49	-42	0.00

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 VII. 15, it is critical to remember the incremental nature of the analysis, where results for any mitigation option are relative to the suite of those which are assumed to have already been implemented (i.e., all previously listed and lower numbered options). Within Table VII. 15 a number of general conclusions can be drawn including:

- All of the mitigation options in the industry sector reduce GHG intensity;
- With the exception of the increased glass cullet mitigation option, which does not result in changes in energy use, all of the other mitigation options:
    - Increase the share of renewables; and
    - Reduce the share of imports.
- Mitigation options that address energy generation outside of the formal electricity grid still have a positive impact on energy security by reducing energy demand (e.g., cement waste heat recovery).

VII.4.2.5 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 VII. 16.

Table VII. 16. 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 VII. 16 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 VII. 17 presents our estimates of the incremental change in the power sector employment indicator for each mitigation option.

Table VII. 17. Incremental Changes in Power Sector Job-Years for Proposed Mitigation Options, Cumulative Impact from 2015-2050

Sector	Mitigation Option Name	Mitigation Option Sequence	**Incremental Job-Years Impact (Unrounded Cumulative Job-**

			Years 2015-2050)
Industry	Increase Glass Cullet Use	1	**no change[1]**
Industry and Energy	Cement Clinker Reduction	2	**-1,582**
Industry and Energy	Cement Waste Heat Recovery	9	**-2,304**
Industry and Energy	Biomass in Cement	11	**no change[1]**
Industry and Energy	Biomass Co-firing	13	**0**
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 VII. 17 have a number of important caveats that need to be kept in mind in order to place these results in the proper context. These caveats include:

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

VII.4.2.6 Net Present Value

Table VII. 18 summarizes the GHG abatement potential for each industry 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 net present value (NPV) excluding the value of GHG reduction (Column E).

The cement clinker reduction, cement waste heat recovery, and biomass co-firing mitigation options all result in positive health co-benefits (i.e. negative costs) from improved air quality. Therefore the overall costs per ton of CO_2e mitigated becomes even lower (more negative) when accounting for co-benefits for these mitigation options. The NPV for all mitigation options is positive, indicating that these are “win-win” and provide social welfare gains even without accounting for the benefits of GHG abatement.

Table VII. 18. Net Present Value of Mitigation Options in the Industry 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]			Net Present Value Excluding Value of GHG Reduction (Billion 2010 USD)[2]
			without co-benefits	*co-benefits only*[4]	*with co-benefits*[5]	
		A	*B*	*C*	*D = B+C*	*E = □D * A/1000*
1	Increase Glass Cullet Use	0.2	-564.5	0	-564.5	0.11
2	Cement Clinker Reduction	120.5	-247.8	-0.3	-248.1	29.9
9	Cement Waste Heat Recovery	10.5	-53.9	-21.9	-75.8	0.80
11	Biomass in Cement	115.6	-20.4	0	-20.4	2.36
13	Biomass Co-firing	70.6	-6.8	-67.1	-73.9	5.22

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 industry 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 VII.5 CROSS-CUTTING ECONOMIC ASSUMPTIONS

The sector-specific baseline projections are based on the common set of projections for the Philippine economy characteristics. **Error! Reference source not found.** shows the data sources and assumptions used to generate these projections, while Table VII. 20 presents historical and projected values in select years that were used in the analysis. Table VII. 21 lists historical exchange rates and inflation rates used for inter-temporal and cross-country currency conversions.

Table VII. 19. 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 VII. 20. 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

	Historical Data				Baseline								
Year	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 VII. 21. 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 VII.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 VII. 6. General Framework for Health Co-Benefits Calculation

:

- 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.[2]
- 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.[3]
- 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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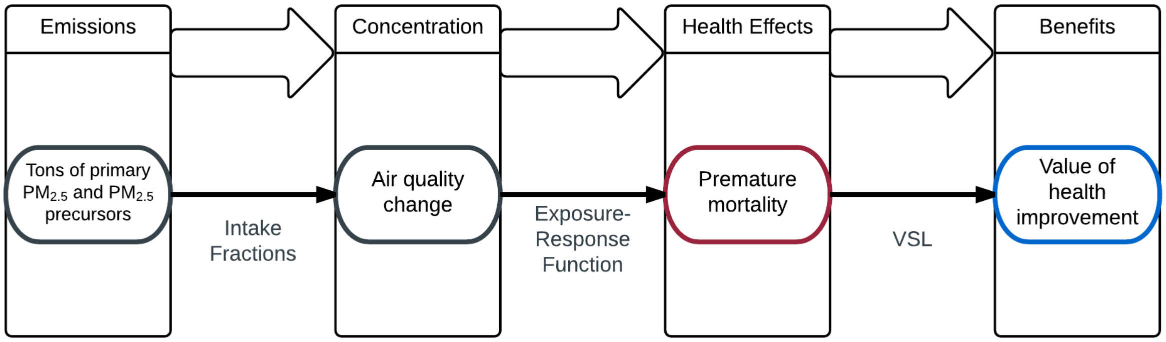
[2] Ozone is another important pollutant, but modeling ozone levels is outside of the scope of this analysis. Furthermore, the Global Burden of Disease Study found that deaths attributable to ambient ozone levels were less than 5% the number of deaths attributable to ambient $PM_{2.5}$ levels (Lim et al., 2013).

[3] 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 VII. 6. General Framework for Health Co-Benefits Calculation



ANNEX VII.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 VII. 22.

Table VII. 22. 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 VII.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 VII. 23) 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. $$C_y = C_{Background} + C_{Transport,y} + C_{Energyy}$$

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 VII. 23 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 VII. 23. 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.[4]

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 VII. 24. 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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[4] 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 VII. 24. 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 VII. 25. The concentration change is assumed to occur throughout the country.

Table VII. 25. 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 VII. 26. $Share_{UR-M}$ is further subdivided across each of the 17 cities based on population.

Table VII. 26. 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 VII.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 VII.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.

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U.S. Agency for International Development
1300 Pennsylvania Avenue, NW
Washington, DC 20523
Tel: (202) 712-0000
Fax: (202) 216-3524
www.usaid.gov