Estimating the Health & Economic Cost of Air Pollution in the Philippines

Exposure to ambient air pollutants has serious impacts on human health. In the Philippines, air pollution is the third highest risk factor driving death and disability as a result of non-communicable diseases (NCDs), and is also the leading environmental risk to health (IHME 2020). Dangerous pollutants such as fine particulate matter ($PM_{2.5}$) are of particular public health concern. When inhaled, $PM_{2.5}$ is capable of penetrating deep into the lungs onto the bloodstream. This increases the risk of cardiovascular and respiratory diseases and affects the health of other organs in the body. Such impacts are particularly severe for those with preexisting health conditions, as well as the young and the elderly. Its costs are not limited to the individual or community level, but also nationally, as air pollution-related health impacts yield corresponding financial and economic costs, which are often unaccounted for in policymaking.

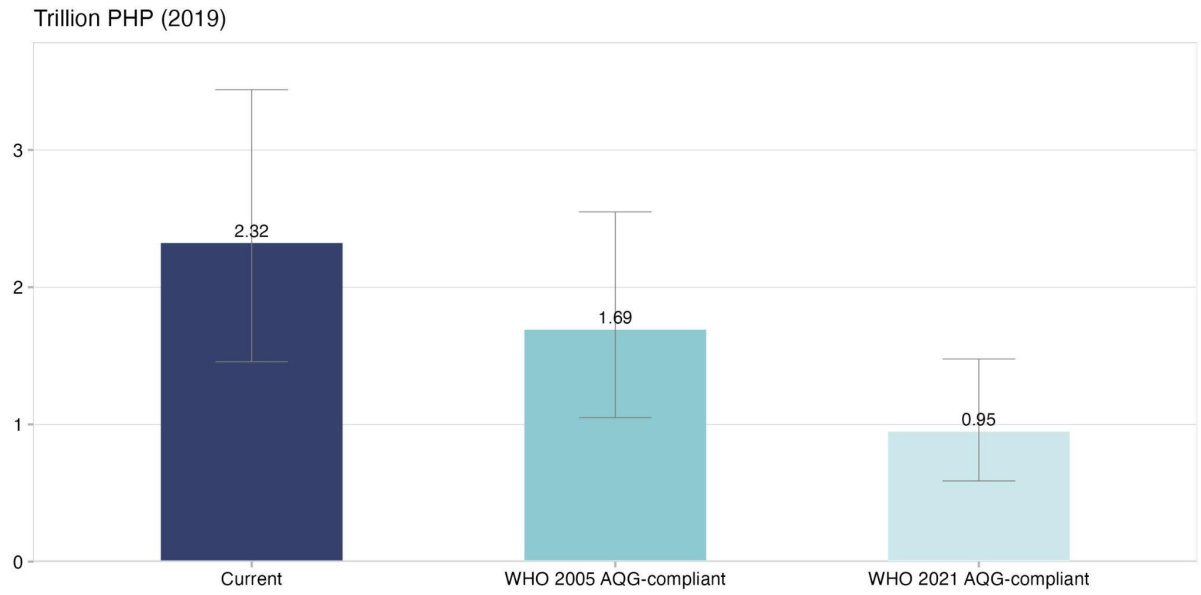
To add urgency to the issue, a growing body of scientific studies and literature are finding that air pollution is more dangerous to human health than previously thought. The World Health Organization updated its National Ambient Air Quality Guidelines (AQG) in September 2021, tightening the guidelines of annual average air pollution exposure to 5µg/m^3 from 10µg/m^3 for $PM_{2.5}$ and to 10µg/m^3 from 40µg/m^3 for nitrogen dioxide (NO_2).

Quantifying the impacts of air pollution has on human health and the economy is important, especially in countries like the Philippines, where air pollution levels are increasing due to a growing number of fossil fuel pollution sources across various sectors.

Our research found that **air pollution was responsible for 66,230 deaths in the Philippines in 2019,** of which **64,920 deaths** were estimated to be adults and 1,310 children. This is significantly higher than previous estimates made for the country, aligning the impact with the most recent literature.

The corresponding total economic cost of exposure to air pollution is estimated at **PHP 2.32 trillion (US$ 44.8 billion) in 2019**, or a GDP equivalent of 11.9% of the country's GDP in 2019. Premature deaths account for the majority of the estimated economic cost at PHP 2.2 trillion (US$ 42.8 billion).

Figure 1: *Estimated economic cost of air pollution in the Philippines.*



The error bars correspond to the 95% confidence intervals of the concentration-response functions, as detailed in Table 1.

This report covers the methodology and results of estimating the health and economic cost of air pollution in the Philippines under three scenarios: a baseline scenario, a WHO 2005 AQG-compliant scenario, and a WHO 2021 AQG-compliant scenario.

Methodology

CREA has developed a detailed globally implementable health and economic impact assessment framework based on the latest literature.

This framework includes as comprehensive a set of health outcomes as possible on the basis of peer-reviewed literature. The emphasis is on outcomes for which incidence data are available at the national level from global datasets, as well as outcomes that have high relevance for healthcare costs and labor productivity. These health endpoints were selected and quantified in a way that enables economic valuation, adjusted by levels of economic output and income in different countries.

Concentration base maps

Our health impact assessment begins with estimating the population exposure to NO_2 and $PM_{2.5}$. We built global concentration maps by combining widely used baseline maps (namely Larkin et al. 2017 for NO2 and Hammer et al. 2020 for $PM_{2.5}$) and measured PM_{10} and $PM_{2.5}$ concentration data in 2019 from the Philippine Environmental Monitoring Bureau (EMB), IQAir, and various academic papers. Where only PM_{10} measurements were available, we converted them into $PM_{2.5}$ using the average ratio of $PM_{2.5}$ to PM_{10} at all stations for which both parameters were available.

These measurements were applied to update Van Donkelaar et al. (2021) $PM_{2.5}$ exposure map with a geospatial regression model, using generalized additive models, including a spatial smoothing term. To prevent single stations from affecting large areas, we only retain stations located within 0.26 degrees of urban areas in the latitude-longitude grid, as 95% of the monitoring stations with available data were located in urban areas. Finally, we only update the base maps where the estimated deviation has a 90% confidence level.

Health impacts

We quantify the health burden of air pollution for nine different health outcomes (*Table 1*). For each evaluated health outcome, we selected a concentration-response relationship from peer-reviewed literature, which has already been used to quantify air pollution-related health burdens at the global level. This indicates the evidence is mature enough to be applied across geographies and exposure levels.

The calculation of health impacts follows a standard epidemiological calculation:

$$\Delta cases = Pop \times \sum_{age} \left[Frac_{age} \times Incidence_{age} \times \frac{RR_{conc,age} - 1}{RR_{conc,age}} \right]$$

where *Pop* is the total population in the grid location, *age* is the analyzed age group (in the case of age-dependent concentration-response functions, a 5-year age segment; in other cases, the total age range to which the function is applicable), $Frac_{age}$ is the fraction of the population belonging to the analyzed age group, *Incidence* is the baseline incidence of the analyzed health condition, and c is the pollutant concentration, with c_{base} referring to the baseline concentration (current ambient concentration). $RR_{(c,\ age)}$ is the function giving the risk ratio of the analyzed health outcome at the given concentration for the given age group compared with clean air. In the case of a log-linear, non-age-specific concentration-response function, the RR function becomes $RR(c) = RR_0\ c{-}c_0\ \Delta c_0$ $when\ c > c_0,\ 1\ otherwise$, where RR_0 is the risk ratio found in epidemiological research, Δc_0 is the concentration change that RR_0 refers to, and c_0 is the assumed no-harm concentration (i.e. the lowest concentration found in study data).

Data on the total population and population age structure for the Philippines were taken from the Global Burden of Disease results 2019 (IHME 2020). The spatial distribution of population within each city, as projected for 2020, was based on the Gridded Population of the World v4 (CIESIN 2018). For all health outcomes, we used national-level average incidences per 100,000 from the sources given in Table 1.

Cause-specific risk functions

Adult deaths and years of life lost from $PM_{2.5}$ exposure were estimated using the risk functions developed by Burnett et al. (2018), as applied by Lelieveld et al. (2019). For deaths, the Global Exposure Mortality Model (GEMM) risk model from Burnett et al. 2018 was chosen rather than the more widely-used Global Burden of Disease model because the latter incorporates highly conservative assumptions about health risks at low and high ends of the concentration range. At the extreme, the model indicates no reduction in risk when air pollutant concentrations are reduced by a small amount within these low and high concentrations. The GEMM is based on the latest evidence and focuses on outdoor air pollution, which is the subject of this study.

Deaths of small children (under 5 years old) from lower respiratory infections linked to $PM_{2.5}$ pollution were assessed using the Global Burden of Disease risk function for lower respiratory diseases (IHME 2020) since GEMM does not cover infant deaths.

In addition to $PM_{2.5}$, the mortality risk function for deaths related to NO_2 is included, based on the findings of Faustini et al. 2014 meta-analysis. Faustini et al. 2014 paid particular attention to the combined impacts of $PM_{2.5}$ and NO_2 in multi-pollutant risk models and included impacts down to 4 $\mu g/m^3$, the lowest concentration level in studies that found increased mortality risk. The concentration-response relationship (odds ratio of 1.04) also aligns closely with recommendations from the WHO HRAPIE project (WHO 2013), which recommended an odds ratio of 1.057 but indicated that up to one-third of the deaths attributed to NO_2 exposure could overlap with deaths attributed to $PM_{2.5}$. The assumed no-harm concentration was adopted from Stieb et al. (2021).

Concentration-response relationships for emergency room visits for asthma, and work absences were based on studies that evaluated daily variations in pollutant concentrations and health outcomes (*Table 1*); these relationships were applied to changes in annual average concentrations.

Table 1: *Input parameters and data used in estimating physical health impacts*

Age group	Effect	Pollutant	Concentration-response function	Concentration change	No-risk threshold	Reference	Incidence data
1–18	New asthma cases	NO_2	1.26 (1.10 – 1.37)	10 ppb	2 ppb	Khreis et al. 2017	Achakulwisut et al. 2019
0–17	Asthma emergency room visits	$PM_{2.5}$	1.025 (1.013 – 1.037)	10 µg/m3	6 µg/m3	Zheng 2015	Anenberg et al. 2018
18–99	Asthma emergency room visits	$PM_{2.5}$	1.023 (1.015 – 1.031)	10 µg/m3	6 µg/m3	Zheng 2015	Anenberg et al. 2018
Newborn	Preterm birth	$PM_{2.5}$	1.15 (1.07 – 1.16)	10 µg/m3	8.8 µg/m^3	Sapkota et al. 2012	Chawanpaiboon et al. 2019
20–65 economically active	Work absence	$PM_{2.5}$	1.046 (1.039 – 1.053)	10 µg/m3	N/A	WHO 2013	EEA 2014; labor participation from ILO 2022
0–4	Deaths from lower respiratory infections	$PM_{2.5}$	IHME 2020		5.8 µg/m^3	IHME 2020	IHME 2020
25–99	Deaths from NCDs, disaggregated by cause, and from lower respiratory infections	$PM_{2.5}$	Burnett et al. 2018		2.4 µg/m^3	Burnett et al. 2018	IHME 2020
25–99	Disability caused by diabetes, stroke and chronic respiratory disease	$PM_{2.5}$	IHME 2020		2.4 µg/m^3	Burnett et al. 2018	IHME 2020
25–99	Premature deaths	NO_2	1.04 (1.02 – 1.06)	10 µg/m^3	4.5 µg/m^3	Faustini et al. 2014; NRT from Stieb et al. 2021	IHME 2020

Numeric values in the column “Concentration-response function” refer to odds ratio corresponding to the increase in concentrations given in the column “concentration change”, with the 95% confidence intervals in parentheses. Literature references indicate the use of a non-linear concentration-response function. No-harm threshold refers to a concentration below which the health impact is not quantified, generally because the studies on which the function is based did not include people with lower exposure levels. Data on concentration-response relationships do not exist for all geographies, so a global risk model is applied to all cities. Incidence data are generally unavailable at the city level so national averages have to be applied.

Economic valuation

The economic cost estimates were based on the total health impacts attributed to air pollution exposure in 2019, namely: premature deaths of adults and children, absences, asthma emergency room visits, years lived with asthma, preterm births, and years lived with disability. Table 2 presents our estimates of the economic cost of these health outcomes for the Philippines in 2019.

Table 2: *Economic cost of different health outcomes (95% confidence intervals in parentheses).*

					Valuation for Philippines	
Outcome	Reference Valuation	Unit	Source	Reference income level	2019 $	2019 PHP
Absences (Lost workday)	130 EUR	workday	EEA, 2014	EU 2010	**18.3**	**948**
Number of children living with exacerbated asthma	3,914 US$	case	Brandt et al 2012	California, 2010	**231**	**11,950**
Asthma emergency room visits	844 US$	visit	Brandt et al 2012	California, 2010	**49.7**	**2,577**
Preterm birth	321,989 US$	birth	Trasande, et al. 2016	U.S. 2010	**23,067**	**1,194,792**
Deaths, adults	9,631,000 US$	death	Viscusi and Masterman, 2017	U.S. 2015	**634,648**	**32,872,093**
Deaths, children	19,262,000 US$	death	OECD 2012	U.S. 2015	**1,269,296**	**65,744,186**
Year lived with disability	62,800 GBP	year lived with disability	Birchby 2019	UK 2018	**6,855**	**355,039**

The methodology adopted to obtain these numbers are further detailed below. We first discuss the basis for the economic valuations of morbidity and mortality. We then detail the health outcome valuations adopted in this report. Finally, we elaborate on the valuation transfer between the reference locations and years to the Philippines in 2019.

The basis for morbidity and mortality valuations

The health impacts of air pollution affect the economy in numerous and different ways, including social cost, welfare cost, and welfare loss. Death and disability compose the vast majority of the total estimated economic cost, and they are valued on a willingness-to-pay basis. Willingness-to-pay estimates are, however, not available for many types of health impacts of air pollution that we have assessed. To give a picture of the total costs of air pollution, we have used other available methods to assign a cost to these impacts, such as the cost of treating or mitigating the effect. This requires some consideration of whether the different impacts can be summed together. The assessment of economic costs also requires a coherent view of to whom the costs are assessed, which we clarify below.

First, the increased risk of death or disability from cardiovascular diseases, lung cancer, chronic respiratory diseases, diabetes and other causes is a welfare cost valued on the basis of the willingness of individuals to pay (i.e. forgo higher income) in order to avoid such a risk or adverse outcome. Insofar as the government's interest is the welfare of citizens, the government's willingness to pay to avoid a higher risk of death and disability should align with that of citizens.

The second consideration is the impact on economic productivity. Lost working days due to illness or taking care of a sick child or dependents have a direct impact on productivity and the ability to earn an income. Missed school days affect children's future economic productivity and income. Other productivity impacts include the impact of preterm birth on lifetime economic productivity. Presumably, individuals' willingness-to-pay to avoid lower income should be at least equal to the lost income. Lost income does not capture non-monetary welfare loss and, therefore, likely represents only a portion of the willingness-to-pay. From the government's perspective, productivity losses represent a reduction in potential economic output. The government has the power to direct economic resources to the mitigation of air pollution (e.g. through regulation or public expenditure). Doing so would be a net benefit to the economy when the required resources are smaller than the avoided productivity impacts of air pollution, and therefore the government's willingness-to-pay should also be at least equal to the value of productivity losses.

The third type of cost included in our estimates is direct healthcare cost. These costs represent a diversion of real economic resources, both labour and capital, from other uses towards the treatment of the effects of air pollution. These costs are borne, in part, by affected individuals and households, employers and the government. However, government expenditures are eventually borne by the taxpayer, and employers are owned either by individuals or the government, so this distinction is not consequential. As with productivity impacts, direct healthcare costs capture only a part of the total welfare impact of air pollution, as individuals would presumably prefer to avoid hospital visits or medication use even if there was no cash cost involved.

For these reasons, we view the sum of the three types of economic cost as the lower bound for a willingness-to-pay-based valuation for the health impacts of air pollution. The aggregated cost is an estimate of the willingness of the citizens as a whole to pay to avoid the impacts. This should also reflect the willingness of the government to pay or direct resources to mitigate air pollution.

The decision to sum up these different types of costs into an aggregate cost to society, which also reflects the willingness-to-pay of the government to mitigate air pollution, is in line with the approaches taken by the U.S. EPA (2011) and the World Health Organization.

Estimating the economic impacts of health outcomes

Millions of people around the world are living with **diabetes** and **chronic respiratory diseases**, as well as disabilities caused by **stroke**, because exposure to air pollution increases the risk of developing these diseases and their complications. The Global Burden of Disease project has quantified the degree of disability caused by each disease into a "disability weight" that can be used to compare the costs of different illnesses. The economic cost of disability and reduced quality of life caused by diabetes and chronic bronchitis is assessed based on these disability weights, combined with the economic valuation of disability used by the UK environmental regulator DEFRA (Birchby et al. 2019).

The economic cost of air pollution-related **asthma** was assessed based on two indicators: new cases of asthma linked to NO_2 exposure and emergency room visits related to $PM_{2.5}$ and ozone exposure. The incidence and prevalence of asthma in children were taken from Global Burden of Disease (IHME 2020). The cost of new asthma cases was estimated assuming that an increase there means an equal increase in the prevalence of childhood asthma. This implies that a new case of child asthma results in 4 years of living with childhood asthma on a global average basis, with variation across countries. Brandt et al. (2012) assessed the direct and indirect costs per year of childhood asthma, including medical costs and loss of income to the child's caregiver, estimating a cost of \$3800 and \$4000 in two communities in California. The midpoint of these two valuations was used for the estimates, adjusted by the ratio of California's Gross Regional Product to the U.S. national average. Exposure to $PM_{2.5}$ is possibly linked to an even larger number of new asthma cases globally than exposure to NO_2, but uncertainty in the estimates is large (Anenberg et al. 2018). Thus, this effect was not included. Instead, we included the economic cost of **emergency room visits** for asthma linked to $PM_{2.5}$ exposure, which is only a small part of the overall cost of the burden of asthma linked to $PM_{2.5}$. We estimated the cost of these visits based on costs reported by Brandt et al. in California, with the cost per visit for each country in the world.

$PM_{2.5}$ exposure in pregnant women increases the likelihood of **preterm birth and low birth weight**, which consequently increase the risk of many health and development issues throughout the baby's life. A U.S. study (Trasande et al. 2016) estimated the economic costs of preterm birth, primarily lower economic productivity and increased healthcare costs, at \$300,000 per birth.

Exposure to $PM_{2.5}$ air pollution leads to increased **sick leaves (work absence)**, quantified based on the WHO HRAPIE recommendations (WHO 2013). The economic cost of these sick leaves was evaluated at EUR 130 per day (\$160 at 2005 exchange rate) in the European Union, according to EEA (2014). This value was taken to represent the valuation at the EU average GDP per capita.

Viscusi & Masterman 2017 provides a valuation of the **risk of death** from air pollution on a large meta-analysis of the value of statistical life derived from labor market data based on observed wage differentials between professions with different mortality risks (i.e., revealed preferences). It is valued at \$9,631,000 in the USA in 2015. In accordance with the recommendations of the OECD (2012), child deaths are valued at twice the value of adult deaths.

Valuation transfer

The cost of each outcome is derived from the reference valuation using either GNI PPP or GDP PPP expressed in constant 2017 international \$ as follows:

$$Valuation_{\;PH,\ 2019\ (2017\ \$)} = Valuation_{\;US,\ 2015\ (2017\ \$)} \times \left(\frac{GNI|GDP\ per\ capita,\ PPP_{\;PH,\ 2019\ (2017\ \$)}}{GNI|GDP\ per\ capita,\ PPP_{\;US,\ 2015\ (2017\ \$)}} \right)^{\eta}$$

The valuation is then converted to the current local current international \$ using the ratio of GNI expressed in both current international \$ and constant international \$ as indicated by the World

Bank. Results were then converted to local currency using the World Bank PPP LCU conversion factor, and finally to US dollars using market exchange rates. Data on GDP and GNI per capita were obtained from the World Bank (undated, as of 1 February 2023).

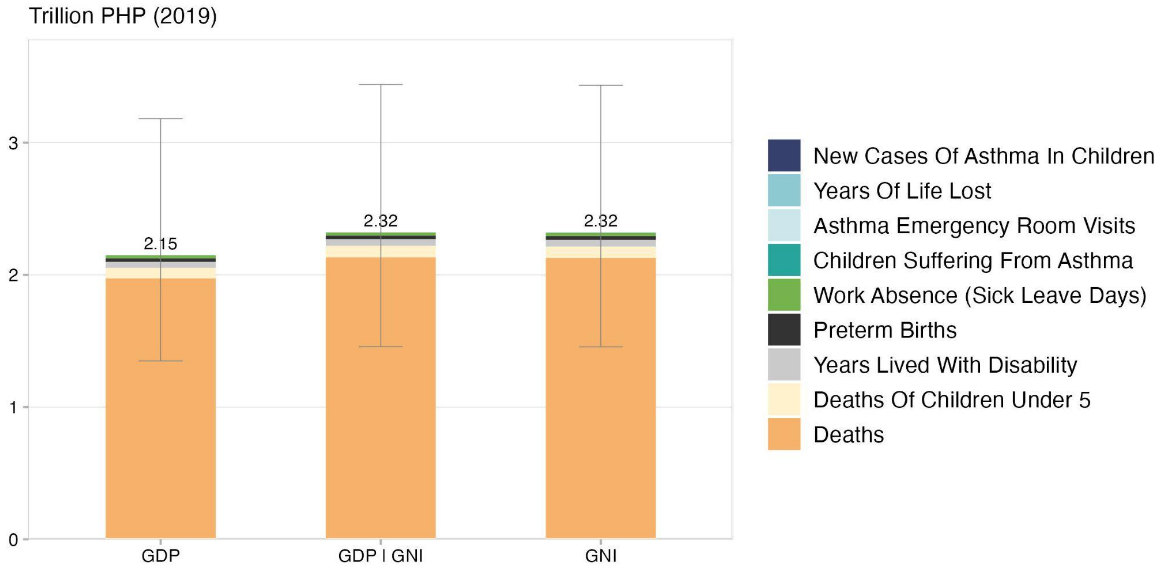
The economic losses of the outcomes related to productivity are adjusted by GDP, while the value transfer for deaths and YLDs were carried out using Gross National Income (GNI) expressed in Purchasing Power Parity (PPP) at 2017 prices, in line with a large meta-analysis of the VSL derived from Viscusi&Masterman (2017).

The authors find that the valuation of the risk of death between countries is closely proportional to average income (income elasticity close to unity). This also lends support to adjusting the valuation of other health impacts than deaths (morbidity impacts) proportionally by GDP or GNI per capita. GNI is related to income lost from death or disability and is the measure used by Viscusi & Masterman (2017) for value transfer for the value of statistical life. Our choice of using GNI for the value transfer for Viscusi&Masterman (2017) value of statistical life, and relating these costs to the GDP of the study country, is aligned, for example, with the approach taken by Alkire et al. (2018).

Sensitivity analysis

There is no consensus on whether one should use GNI or GDP to transfer from the reference country to the country of interest. In this report, we combine both GDP and GNI, based on whether the basis for the valuation is more closely related to productivity or income, respectively. To assess the impact of this choice, we conducted a sensitivity analysis to compare the results obtained using the three different methods. The results are shown in Figure 2.

Figure 2: *Economic valuation using either GDP, GNI or a combination of both to transfer reference values to the Philippines.*



The error bars correspond to the 95% confidence intervals of the concentration-response functions, as detailed in Table 1.

Results & Findings

Health Impacts

Our analysis revealed that ambient air pollution in the Philippines is responsible for approximately 66,230 premature deaths a year. Such impacts could be greatly reduced with cleaner air quality in the Philippines (Table 3), demonstrating that any reduction in air pollution is important. Meeting the WHO's 2005 guideline values would decrease annual premature deaths by 26%, reduce emergency room visits related to asthma by 63%, and reduce sick days by 35%.

If annual $PM_{2.5}$ and NO_2 concentrations met the 2021 WHO Guidelines, premature deaths would decrease by 58%. Years Filipinos may have had to live with disabilities such as COPD, diabetes, or the after-effects of stroke would also be reduced by 71%. Forced work absences due to air pollution-linked illnesses would also drop by 62% if air quality met the WHO Guidelines.

Table 3. *Central estimate of annual premature deaths as a result of exposure to air pollution by scenarios*

Pollutant	Cause	Observed	2005 WHO Guidelines	2021 WHO Guidelines
NO_2	**All causes**	**5,874**	**5,874**	**3,756**
	Cardiovascular diseases	6,788	6,788	4,358
	Respiratory diseases	262	262	167
$PM_{2.5}$	**Non-communicable diseases and lower respiratory infections**	**59,046**	**39,167**	**83,773**
	Chronic obstructive pulmonary disease (COPD)	2,932	1,818	830
	Diabetes	6,788	5,637	2,044
	Ischaemic heart disease	25,338	17,541	9,485
	Lung cancer	2,179	1,323	598
	Stroke	7,819	4,513	1,982
	Lower respiratory infections in children	**1,310**	**780**	**216**
Total Premature Deaths *(Sum of NO_2 All Causes, $PM_{2.5}$ NCD+LRI, $PM_{2.5}$ LRI in children)*		**66,230**	**48,899**	**27,877**

Table 4. *Central estimate of health impacts as a result of exposure to air pollution under three scenarios*

Cause	Observed	2005 WHO Guidelines	2021 WHO Guidelines
Work absence (sick leave days)	24,175,452	15,664,548	9,181,928
New cases of asthma in children	25,955	25,955	17,955
Number of children suffering from asthma due to pollution exposure	114,653	114,653	79,312
Asthma emergency room visits, adults	11,882	4,400	-
Asthma emergency room visits, children	17,718	6,563	-
Low birthweight births	38,503	18,941	3,742
Preterm births	22,547	3,272	-
Years of lives lost			
Cardiovascular diseases from NO_2 exposure	160,990	160,990	103,367
Respiratory diseases from NO_2 exposure	5,706	5,706	3,647
Lower respiratory infections in children from $PM_{2.5}$ exposure	115,141	68,474	18,959
Noncommunicable diseases and lower respiratory infections from $PM_{2.5}$ exposure	1,517,540	1,084,227	612,765
Years lived with disability			
Chronic obstructive pulmonary disease	30,649	19,011	8,676
Diabetes	82,499	68,508	24,837
Stroke	28,623	16,441	7,203

These mortality estimates are significantly higher in comparison to some previous efforts to estimate the health impacts of air pollution in the Philippines. For example, the State of Global Air report by the Health Effects Institute estimated 32,000 air pollution-related premature deaths in the Philippines in 2019 (HEI, 2020).

The most significant contributor to the difference in CREA and the HEI/IHME's estimates is the use of concentration-response functions (CRFs) derived from GEMM. The Global Burden of Disease CRFs in the HEI/IHME study follows an Integrated Exposure (IER) model, which has several limitations (Burnett, et al. 2018). Most notably, the incorporation of exposure and health-risk data from multiple PM2.5 sources — outdoor and indoor air pollution from solid fuel use, as well as secondhand and active smoking — leads to a highly conservative estimate of disease burden from ambient $PM_{2.5}$ exposure.

GEMM includes cause-specific risk functions for chronic obstructive pulmonary disease (COPD), diabetes, ischaemic heart disease, lower respiratory infections, lung cancer and stroke. There is also a combined risk function for total deaths from all non-communicable diseases and lower respiratory infections (NCD+LRI), which yields slightly higher estimates than the sum of the cause-specific risk functions. Burnett et al. 2018 also observed that excess deaths based on NCD+LRI risk factors were 30% higher than that of the five specific causes in total. They suggest that $PM_{2.5}$ exposure contributes to mortality from other diseases not yet included in most impact analyses, which other emerging evidence supports.

The use of more sensitive CRFs for exposure to ambient air pollution is supported by newer air pollution mortality estimates. WHO recently estimated 63,020 (95% confidence interval: 47,718 – 78,481) premature deaths in 2019 due to ambient $PM_{2.5}$ exposure (WHO, 2022).

Other factors contributing to the higher mortality estimates are the adjusted concentration data and the inclusion of impacts from exposure to NO_2. We estimate that exposure to NO_2 was responsible for nearly 6,000 premature deaths in 2019.

The Often-Excluded Economic Burden of Air Pollution

The deterioration of health as a result of short- and long-term exposure to poor air quality has associated economic costs that are often excluded from decision-making. These costs are incurred from healthcare spending, from loss of income, labor, and productivity, as well as from loss of well-being as a result of air pollution-related disabilities or death.

We estimate that the health impacts of observed ambient air pollution in the Philippines result in an annual economic cost of **PHP 2.3 trillion (US$ 44.8 billion)** — 11.9% of the country's GDP in 2019. Mortality is by far the largest component of the cost of air pollution, accounting for approximately 96% of the total economic cost estimated, or PHP 2.1 trillion (US$ 41.2 billion).

In addition to premature deaths, years lived with disabilities such as diabetes, chronic respiratory diseases, and stroke contributed to PHP 50.3 billion (US$ 972 million) in healthcare costs.

Table 5: *Estimate of economic costs by outcome (95% confidence intervals in parentheses)*

Outcome	Revised Cost, PHP mln (2019 PHP)	Revised Cost, US$ mln (2019 US$, current)	Share of GDP
Mortality			
Deaths	2,134,028 (1,369,727 – 3,089,214)	41,201 (26,445 – 59,642)	10.9% (7.0% – 15.8%)
Deaths of children under 5	86,213 (37,991 – 183,888)	1,664 (733 – 3,550)	0.4% (0.2% – 0.9%)
Years lived with disability	50,334 (16,030 – 108,544)	972 (309 – 2,096)	0.3% (0.1% – 0.6%)
Morbidity			
Preterm births	26,939 (13,288 – 28,544)	520 (257 – 551)	0.1% (0.1% – 0.1%)
Work absence (sick leave days)	22,907 (19,569 – 26,195)	442 (378 – 506)	0.1% (0.1% – 0.1%)
Children suffering from asthma (increased prevalence)*	1,370 (382 – 2,697)	26 (7 – 52)	0.0% (0.0% – 0.0%)
Asthma emergency room visits	76 (44 – 108)	1 (1 – 2)	0.0% (0.0% – 0.0%)
Total Economic Cost	**2,321,867** (1,457,032– 3,439,190)	**44,827** (28,130 – 66,399)	**11.9%** (7.5% – 17.6%)

Morbidity costs, or impacts felt as a result of shorter or nearer-term exposure to air pollution, are also notable despite accounting for a smaller share in total economic cost. The economic cost of forced absence from work is estimated at PHP 22.9 billion (US$ 442 million), as it affects the ability of individuals to earn a salary and support their families. The estimate of forced absence is based on the labor force participation rate estimated by the ILO for the Philippines (ILO 2022). Such costs could be higher if informal work were included more fully.

The direct and indirect cost associated with the increased prevalence of childhood asthma, including medical costs and loss of income of children's caregivers, is valued at approximately PHP 1.4 billion (US$ 26 million) in 2019. Additionally, we estimate the cost of emergency room visits as a result of asthma episodes among adults and children at PHP 76 million (US$ 1 billion). Preterm births result in the need for additional maternal and neonatal care, as well as reductions in lifetime economic productivity, which were estimated to cost PHP 26.7 billion (US$ 520 million).

Table 6: *The estimated economic cost of air pollution under WHO AGT-compliant scenarios (95% confidence intervals in parentheses), in PHP Millions*

Cause	WHO 2005 Guideline scenario	WHO 2021 Guideline scenario
Mortality		
Deaths	1,581,764 (1,007,922 – 2,295,905)	909,269 (578,609 – 1,319,249)
Deaths of children under 5	51,271 (15,945 – 140,681)	14,196 (0 – 84,791)
Years lived with disability	36,910 (10,361 – 88,634)	14,456 (1,958 – 61,070)
Morbidity		
Work absence (sick leave days)*	14,843 (12,661 – 16,998)	8,700 (7,413 – 9,975)
Preterm births*	3,909 (1,897 – 4,150)	–
Children suffering from asthma (increased prevalence)*	1,370 (382 – 2,697)	948 (263 – 1,870)
Asthma emergency room visits*	28 (16 – 40)	–
Total Estimated Economic Cost	**1,690,095** (1,049,185 – 2,549,106)	**947,568** (588,243 – 1,476,953)

Improved air quality would save millions of lives and trillions of pesos. If annual $PM_{2.5}$ and NO_2 ambient concentrations were improved to meet the 2005 WHO guidelines, the economic cost of air pollution would decrease by 30% (PHP 630 billion) to an estimated PHP 1.69 trillion at 2019 prices. Further improving air quality to the 2021 WHO guidelines would lessen the economic cost of air pollution by an additional 47% (PHP 740 billion) annually, or 60% compared to the current situation. These estimates only include the health and economic costs of ambient $PM_{2.5}$ and NO_2 in the country and therefore represent only a subset of the impacts.

Limitations

Modeling involves uncertainties. Results should be considered as reasonable estimates rather than absolute truth. Ground-level concentration data for $PM_{2.5}$ and PM_{10} are unavailable for many parts of the country. We have worked to improve existing pollutant concentration estimates by incorporating all available ground-level measurement data. Additional uncertainty is introduced by the conversion of PM_{10} measurements to $PM_{2.5}$ for locations in which $PM_{2.5}$ measurements aren't available. The effects of these limitations are expected to be within the overall margin of error for this type of air quality modeling.

While the valuation of mortality risk is based on a comprehensive international dataset, the cost estimates for other health outcomes are generally based on a single study and extrapolated to other income levels. We follow this approach because studies at different income levels and in different geographies are insufficient to establish a complex relationship. However, the directly proportional relationship between the value of mortality risk and income found in a large meta-analysis lends credence to the extrapolation.

Based on Faustini et al. (2014) risk functions, the total deaths from 'all causes' are smaller than deaths estimated using specific risk functions for cardiovascular and respiratory diseases, suggesting that exposure to NO_2 can suppress deaths from other causes. In addition, there remains uncertainty on the interaction between $PM_{2.5}$ and NO_2 exposure, making it possible that the deaths attributed to the two pollutants overlap. To avoid the inclusion of the potential overlap, we sum the 'all cause' mortality, NCD+LRI from $PM_{2.5}$ and LRI in children to get the total premature deaths value of 66,230.

Healthcare costs are likely to be low in areas with poor healthcare coverage. However, the overall economic cost of care needed but not provided is likely to be higher than the cost of delivering the care. Similarly, if workers are not entitled to sick leaves, the number of lost working days is likely to be lower, but the overall economic cost of employees working when ill or sending their children to school with illness is likely to be higher than the cost of the sick leaves.

Annex

Table A-1: *Total premature deaths by cause and scenario (95% confidence intervals in parentheses)*

	Cause	observed scenario	WHO 2005 scenario	WHO 2021 scenario
NO_2	all causes	5,874 (2,501 – 10,204)	5,874 (2,501 – 10,204)	3,756 (1,598 – 6,531)
	cardiovascular diseases	6,788 (3,885 – 10,823)	6,788 (3,885 – 10,823)	4,358 (2,490 – 6,964)
	respiratory diseases	262 (143 – 333)	262 (143 – 333)	167 (91 – 213)
$PM_{2.5}$	chronic obstructive pulmonary disease	2,932 (1,032 – 6,143)	1,818 (654 – 3726)	830 (303 – 1,674)
	diabetes	6,788 (2,557 – 13,330)	5,637 (1,718 – 12,886)	2,044 (0 – 10,117)
	ischaemic heart disease	25,338 (18,165 – 33,692)	17,541 (12,651 – 23,181)	9,485 (6,876 – 12,471)
	lower respiratory infections	15,896 (4,857 – 32,678)	7,521 (2,461 – 14,352)	2,702 (913 – 4,989)
	lower respiratory infections in children	1,311 (578 – 2,797)	780 (243 – 2,140)	216 (0 – 1,290)
	lung cancer	2,179 (978 – 3,966)	1,323 (605 – 2,359)	598 (277 – 1,053)
	stroke	7,819 (2,826 – 14,881)	4,513 (1,667 – 8,395)	1,982 (741 – 3,641)
Total premature deaths		**66,230 (42,246 – 96,774)**	**48,899 (30,904 – 71,983)**	**27,877 (17,602 – 41,422)**

Table A-2: *Total Health Impacts by cause and scenario (95% confidence intervals in parentheses)*

	Cause	observed scenario	WHO 2005 scenario	WHO 2021 scenario
NO_2	new cases of asthma in children	25,955 (6,354 – 54,754)	25,955 (6,354 – 54,754)	17,955 (4,380 – 37,959)
	number of children suffering from asthma due to pollution exposure (increased prevalence)	114,653 (31,979 – 225,704)	114,653 (31,979 – 225,704)	79,312 (22,043 – 156,471)
$PM_{2.5}$	low birthweight births	38,503 (12,285 – 64,888)	18,941 (5,955 – 32,416)	3,742 (1,164 – 6,480)
	preterm births	22,547 (11,122 – 23,890)	3,272 (1,588 – 3,473)	
	work absence (sick leave days)	24,175,452 (20,652,346 – 27,645,694)	15,664,548 (13,361,766 – 17,939,640)	9,181,928 (7,823,331 – 10,527,227)
	asthma emergency room visits, adults	11,882 (7,801 – 15,908)	4,400 (2,884 – 5,901)	
	asthma emergency room visits, children	17,718 (9,307 – 25,962)	6,563 (3,439 – 9,642)	
years of life lives with disability				
$PM_{2.5}$	chronic obstructive pulmonary disease	30,649 (10,829 – 58,955)	19,011 (6,865 – 35,752)	8,676 (3,181 – 16,067)
	diabetes	82,499 (25,399 – 186,143)	68,508 (17,068 – 179,950)	24,837 (0 – 141,279)
	stroke	28,623 (8,920 – 60,628)	16,441 (5,251 – 33,944)	7,203 (2,333 – 14,662)
years of life lives lost				
NO_2	all causes	149,652 (62,832 – 263,578)	149,652 (62,832 – 263,578)	95,698 (40,141 – 168,707)
	cardiovascular diseases	160,990 (89,553 – 260,297)	160,990 (89,553 – 260,297)	103,367 (57,398 – 167,483)
	respiratory diseases	5,706 (3,076 – 7,115)	5,706 (3,076 – 7,115)	3,647 (1,965 – 4,548)
$PM_{2.5}$	lower respiratory infections in children	115,141 (50,759 – 245,709)	68,474 (21,304 – 187,976)	18,959 (0 – 113,296)
	non–communicable diseases and lower respiratory infections	1,517,540 (998,733 – 2,180,594)	1,084,227 (717,263 – 1,549,806)	612,765 (407,216 – 871,898)

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