The Health & Economic Impacts of Ambient Air Quality in Malaysia

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Content

About the Authors

The **Centre for Research on Energy and Clean Air (CREA)** is an independent research organisation focused on understanding the trends, causes, health impacts and solutions to air pollution. CREA uses scientific data, research and evidence to support the efforts of governments, companies and organizations worldwide in their efforts to move towards clean energy and clean air, believing that effective research and communication are the key to successful policies, investment decisions and advocacy efforts. CREA was founded in December 2019 in Helsinki and has staff in several Asian and European countries. www.energyandcleanair.org

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01 Introduction

Air pollution is the fourth leading risk factor of premature death globally and the greatest environmental threat to human health.[1] Long-term exposure to air pollution can lead to severe adverse health effects, including premature death from respiratory and cardiovascular diseases.[2] Every year, more than 4 million people worldwide die due to long-term exposure to outdoor (ambient) air pollution alone.[3] A significant number of these occur in Asia, where air quality has deteriorated alongside rapid fossil-fueled expansion and population growth.

In Malaysia, respiratory illnesses were the second leading cause of death (14.8%) in 2019, while cardiovascular diseases were the underlying cause of 7.9% of deaths in hospitals.[4] The increasing number of stationary, mobile and area sources that emit particulate pollutants and toxic gases are the main contributors to this worsening health threat. Research suggested that Malaysian citizens would live on average 1.8 years longer if annual average fine particulate matter ($PM_{2.5}$) concentrations were reduced to 10 µg/m^3 — a 65% reduction from the current average levels of air pollution in the country.[5]

According to the State of Global Air 2020 report, deaths attributed to $PM_{2.5}$ in Malaysia increased by nearly 30% in the last 10 years.[6] In 2019, as many as 10,600 people in the country were estimated to have died as a result of air pollution.[7]

While the government has deployed a number of policies to control pollution, more aggressive action is needed. In 2021, the World Health Organization (WHO) tightened its Ambient Air Quality Guidelines — the recommended 'safe levels' of exposure to air pollution that serve as a benchmark for countries. The update was based on scientific evidence that air pollution is more dangerous to human health than originally estimated. This has significant implications for Malaysia, whose ambient air quality standards for most pollutants remain above both the 2005 and 2021 guidelines of the WHO.[8] Such health risks and outcomes have a corresponding cost in healthcare spending and losses in productivity, a significant economic burden of disease from air pollution.

To contribute to the assessment of the current impacts of outdoor air pollution on the Malaysian population, this report provides the most comprehensive estimates of the

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[1] HEI, 2020
[2] HRAPIE, 2013
[3] World Health Organization (WHO), 2021a. The WHO estimates that an additional 3.8 million die from indoor air pollution; such impacts are not covered by the scope of this report.
[4] Malaysia Ministry of Health, Fact Sheet 2020.
[5] Lee and Greenstone, 2021
[6] State of Global Air 2020
[7] IHME, 2020
[8] Malaysia's annual PM2.5 mean Guideline is 15 µg/m^3, WHO 2021 Guidelines recommend 5 µg/m^3 and 2005 is 10 µg/m^3.

health and economic impact of ambient air pollution in the country using the latest publicly available data and concentration-response functions (CRFs). To assess the benefits of cleaner air, we also calculate the impact of exposure to air quality under three different scenarios. First, under the currently observed air quality levels in Malaysia; second, with air quality in compliance with 2005 WHO guidelines; and lastly, air quality in compliance with the safest air quality for human health as presented in the 2021 WHO guidelines.

Links between Air Pollution and COVID-19

The importance of citizen health and the risks of ignoring factors that contribute to it, like exposure to air pollution, have been all the more urgent amidst the COVID-19 pandemic. Air pollution-related health problems like cancer, asthma, stroke, diabetes and high blood pressure are pre-existing medical conditions that raise the chances of serious COVID-19 symptoms and even death. At the end of May 2022, the total COVID-19 deaths in Malaysia reached 35,656.[9] Studies suggest that the pandemic's death toll could be even higher than official counts.[10]

A Harvard Chan study found an association between air pollution exposure over many years with an 11% increase in mortality from COVID-19 infection in regions where the long-term average PM2.5 increased by 1 microgram/cubic meter (µg/m^3).[11] While the study does not show that air pollution directly affects an individual's likelihood of death from COVID-19, it shows an association between long term exposure to air pollution and higher COVID-19 mortality rates. Another study analyzing 120 cities in China also found a significant relationship between air pollution and COVID-19 infection.[12] Across 66 regions in Italy, Spain, France and Germany: 78% of COVID-19 deaths occurred in five of the most polluted regions during the first months of the pandemic.[13]

The Global Burden of Disease estimates that for COVID-19 comorbidities such as ischemic heart disease, stroke and diabetes, approximately 13% of deaths in Malaysia were a result of long-term exposure to ambient PM pollution, for lung cancer and COPD it is approximately 12%.[14] This is estimated based on risk factors of deaths, which are mathematical functions that measure the relationship between exposure to pollution as a cause and specific outcomes as an effect. The number of deaths due to such risk factors could be decreased if the population's exposure to dangerous air pollution would be

[9] COVIDNow, Ministry of Health Malaysia. https://covidnow.moh.gov.my/
[10] Adam, David. The pandemic's true death toll: millions more than official counts. 18 January 2022. Nature.
[11] Wu, et al. November 2020
[12] Yongjian Zhu, et al. July 2020
[13] Yaron Ogen. July 2020
[14] Global Burden of Disease 2020

eliminated; the number of people at risk of severe cases or death from COVID-19 would also be reduced.

Table 1: *Risk factors of deaths as a result of ambient particulate matter pollution in Malaysia, and which are COVID-19 comorbidities*

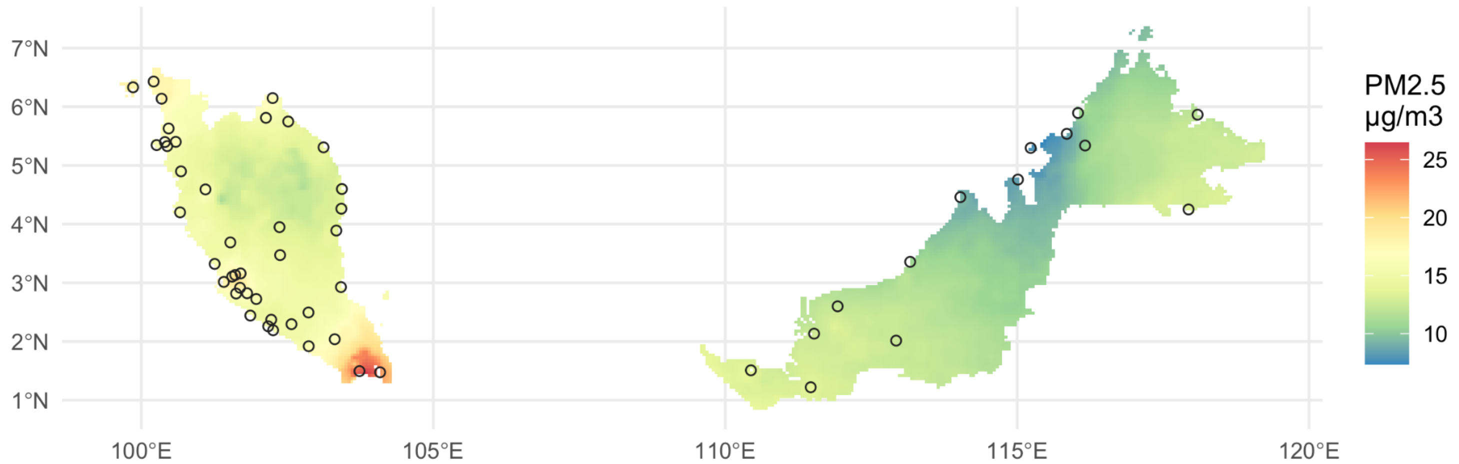
Cause (Covid-19 Comorbidities)	Risk Factor
Ischemic heart disease	13%
Stroke	13%
Tracheal, bronchus, and lung cancer	12%
Diabetes mellitus	13%
Cardiovascular diseases	6%
Chronic obstructive pulmonary disease	12%
Chronic respiratory diseases	11%

SOURCE: Global Burden of Disease, 2019

02 The State of Air Quality in Malaysia

The Malaysian Department of Environment (DOE), under the purview of the Ministry of Environment and Water, develops and implements air pollution policies at the national level. Over the past few years, efforts to address pollution have resulted in better overall air quality and an improved understanding of its sources and the extent of its threat.[15]

Figure 1. *Distribution of Monitoring Sensors in Malaysia in 2021*



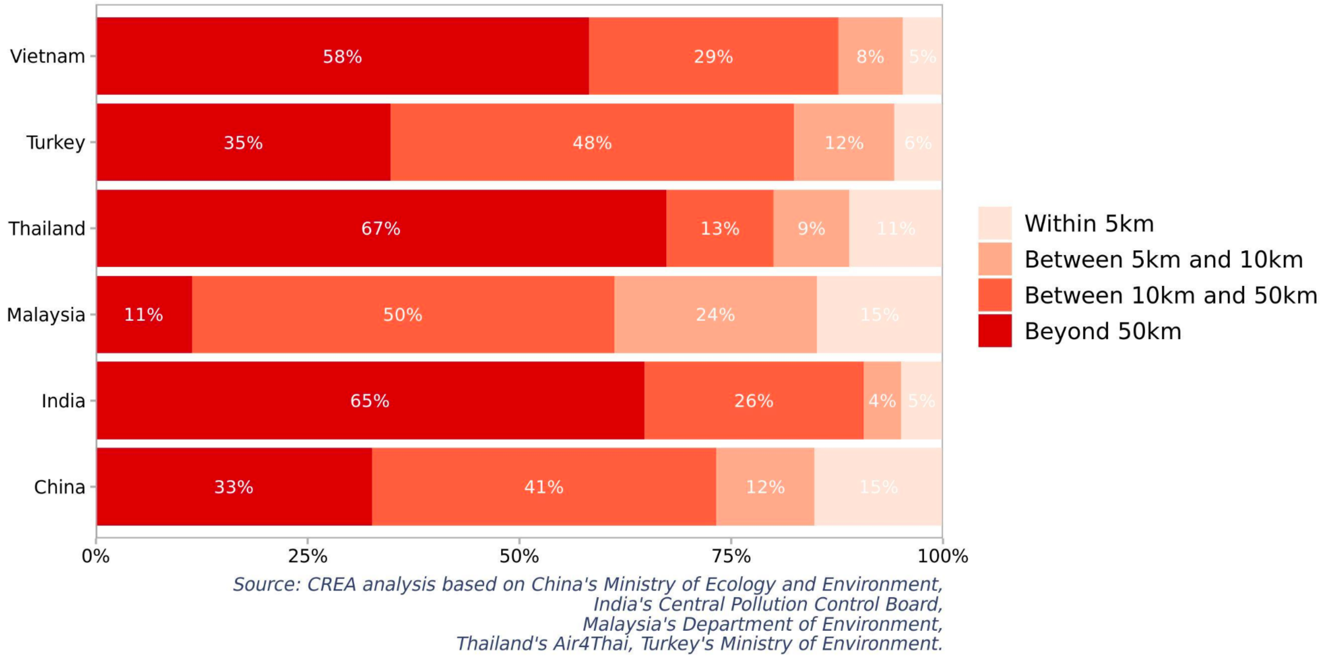
SOURCE: CREA Analysis of Annual $PM_{2.5}$ based on averaging from several sources, including Malaysia's DOE Monitoring Locations from DOE, 2021

For instance, the availability of data has improved with the expansion of the country's air monitoring network — an important tool in assessing the state of air and the effectiveness of interventions in real-time or near-real-time. At present, the DOE maintains and operates 58 ambient air quality monitoring stations across the country.

Real-time measurements are most widely available and published for PM_{10} and $PM_{2.5}$. The coverage of monitoring devices is also commendable, especially in cities. Nearly 40% of the population lives within 10 km of a $PM_{2.5}$ monitoring station. While ground-level monitoring capacity from harmful gases is still nascent and should be increased, available PM data has been crucial in improving air pollution regulations and public health interventions, and developing emission registries to track pollution from large emitting sources in Malaysia.

[15] Department of Environment (DOE). Malaysia Environmental Quality Report 2020.

Figure 2. *Share of Population with PM2.5 monitoring station within a certain distance*



The National Malaysian Ambient Air Quality Standards (NMAAQS) and the current average pollutant concentrations in the country remain far beyond the Air Quality Guidelines recommended by the WHO. The existing NMAAQS was established in 2015. It stipulated limits of pollutants such as particulate matter (PM, including PM_{10} and $PM_{2.5}$), carbon monoxide (CO), NO_2, sulfur dioxide (SO_2), and Ozone (O_3), which were pursued over a three-phased period with full implementation in 2020. Further refinement is needed as the existing NMAAQS meet neither the WHO 2005 nor the 2021 Guidelines (*Table 2*). According to these standards, dangerous pollutants like $PM_{2.5}$ and PM_{10} have allowable annual concentrations that are almost 3 times higher than the WHO Guidelines.

Table 2. *National Ambient Air Quality Standards in µg/m³*

Pollutant	Averaging Time	Malaysian Ambient Air Quality Standards (2020)	WHO, 2005 Guidelines	WHO, 2021 Guidelines
Fine Particles ($PM_{2.5}$)	24-hour	**35**	25	15
	Annual	**15**	10	5
Coarse Particles (PM_{10})	24-hour	**100**	50	45
	Annual	**40**	20	15
Ozone (O_3)	1-hour	**180**	-	-
	8-hour	**100**	100	100
Nitrogen Dioxide (NO_2)	1-hour	**280**	200	200
	24-hour	**70**	-	25
	Annual	**-**	40	10
Sulfur Dioxide (SO_2)	24-hour	**80**	20	40
	1-hour	**250**	-	-

Sources of Pollution

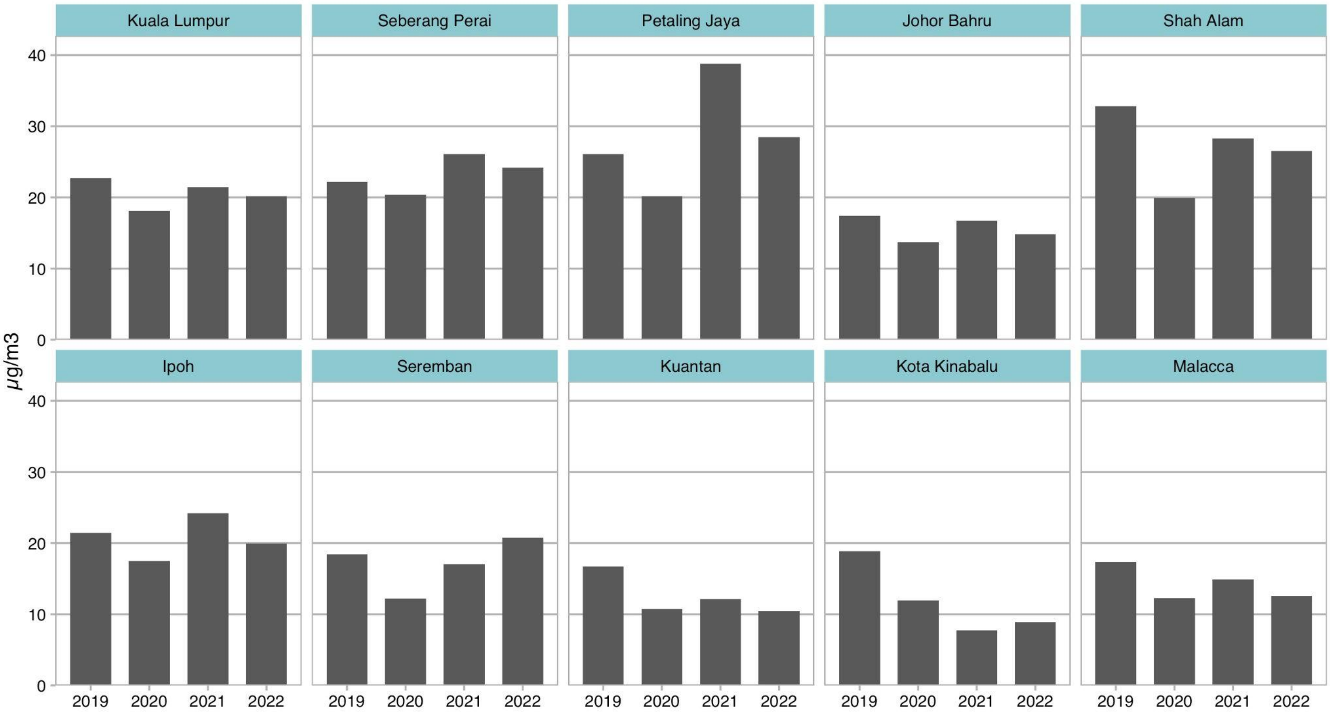
Air pollution in Malaysia is caused by emissions from a growing number of sources from industrial manufacturing, power generation, vehicles, and open burning activities. According to Department of Environment (DOE) data,[16] power plants represent 39% of PM emissions and approximately 62% of both NO_2 and SO_2 emissions. Industrial activities, like the processing of chemicals, rubber and metals as well as manufacturing, are a significant 29% of the PM emissions load. Residential, commercial, and agricultural combustion (open burning) represent another 20%. Finally, motor vehicles account for just 12% of PM emissions, but they represent 24% of NO_2 emissions.

While emissions from large sources such as power plants and industry saw an increase in their air pollutant emission load in 2020,[17] overall air pollution decreased in Malaysia in 2020. The Movement Control Order (MCO) to contain the spread of the COVID-19 virus reduced emissions in other polluting sectors, specifically from mobile road sources and biomass burning. PM_{10} averaged 20 µg/m³ — the lowest recorded in Malaysia since 2010. Overall $PM_{2.5}$ concentrations, which the DOE started tracking in 2017, averaged just 12 µg/m³ in 2020. While this is a 40% decrease from 2019, this is still more than double the WHO's recommended annual average $PM_{2.5}$ concentration.

[16] *Malaysia Department of Environment 2021*, ENVIRONMENTAL QUALITY REPORT 2020
[17] *Malaysia Department of Environment 2021*, ENVIRONMENTAL QUALITY REPORT 2020

The reason for the decrease in air pollution in 2020 was two-fold according to the DOE. Humid weather conditions and a reduction of biomass burning and forest fires in the country and in neighbouring countries minimized the seasonal transboundary haze incidents that often cause a spike in air pollution from July to October.

Figure 3: *Annual Average PM2.5 Concentrations in the ten largest cities of Malaysia for which measurements are available, 2019-2022*[18]



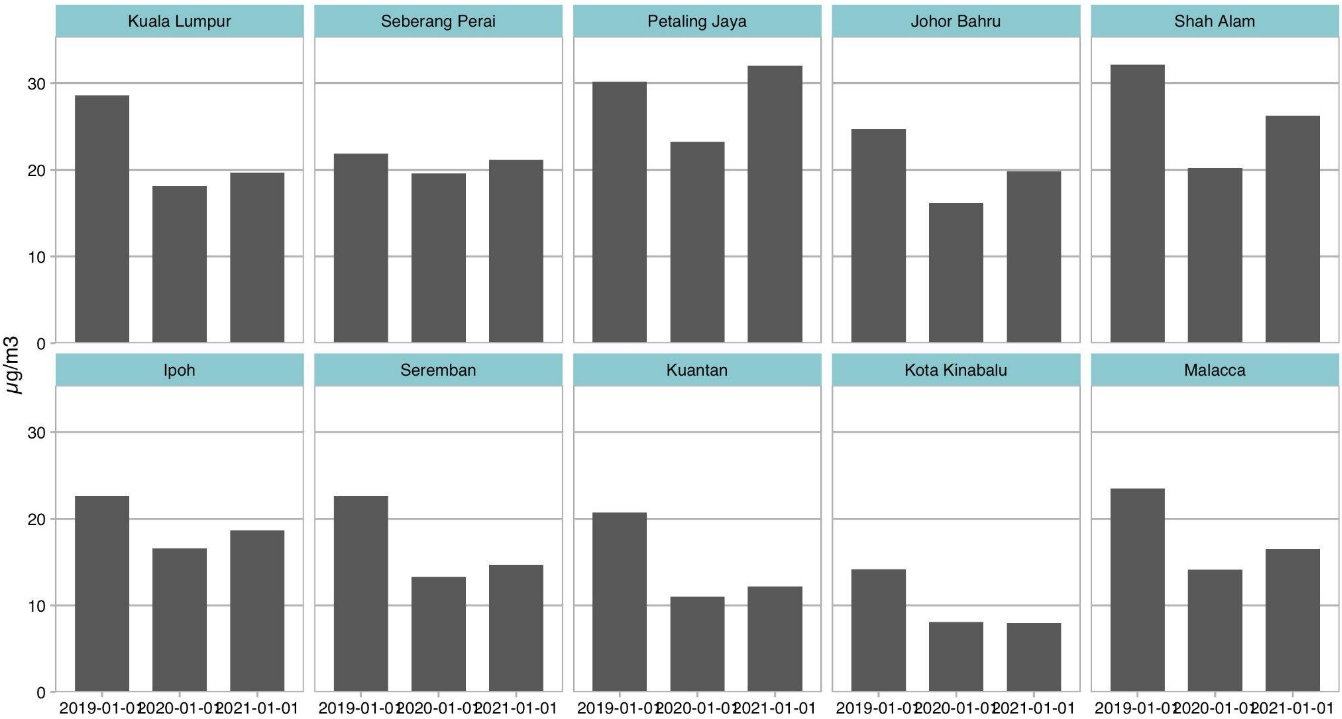
Note: Ten largest cities for which PM2.5 measurements are available.

Source: CREA based on Malaysia Ministry of Environment and Water

However, with COVID recovery efforts and a return to activity, air pollution in 2021 rebounded to pre-pandemic levels in many major cities across the country (*Figure 3*). Furthermore, the average air quality from January to March 2022 shows air pollution reached above 2020 levels in most major cities, despite a slow start to the year with the surge in cases of the COVID-19 Omicron variant (*Figure 4*).

[18] Of the top 10 most populated cities in Malaysia, only Kampung Baru Subang and Subang Jaya did not have PM2.5 data available.

Figure 4: *Average January-March PM2.5 Concentrations in the ten largest cities of Malaysia for which measurements are available, 2019-2022*



Note: Ten largest cities for which PM2.5 measurements are available.

Source: CREA based on Malaysia Ministry of Environment and Water

NO_2 concentrations have been on a downward trend in Malaysia as better fuel standards for motor vehicles were introduced. In 2015, the government published regulations for Euro 5 fuel quality, which were set to come into force in phases between September 2020 to 2022 for diesel fuel and 2025 to 2027 for gasoline fuel. Due to Covid-19, the implementation of Euro 5 diesel was delayed until April 2021.[19]

The MCO directive also resulted in a decrease in average NO_2 concentrations - recorded at 0.018 ppm in 2020 - due to a decrease in movement restrictions and vehicular activity; vehicles account for 25% of the NO_2 emissions load in Malaysia. This is significantly lower than the NMAAQS for annual NO_2 at 0.16 ppm, indicating that more stringent standards for NO_2 can likely be put in place. It is important to note; however, that Malaysia currently has a limited number of NO_2 monitoring stations across the country.

The transition to zero-emission vehicles, active transport and better urban planning to ensure sustainable development in cities and transportation systems are the crucial next steps for vehicular emissions reduction. Still, and more importantly, further emissions

[19] TheStar News Article. Euro 5 diesel to replace Euro 2M from Thursday (April 1), says Environment Minister. 31 Mar 2021

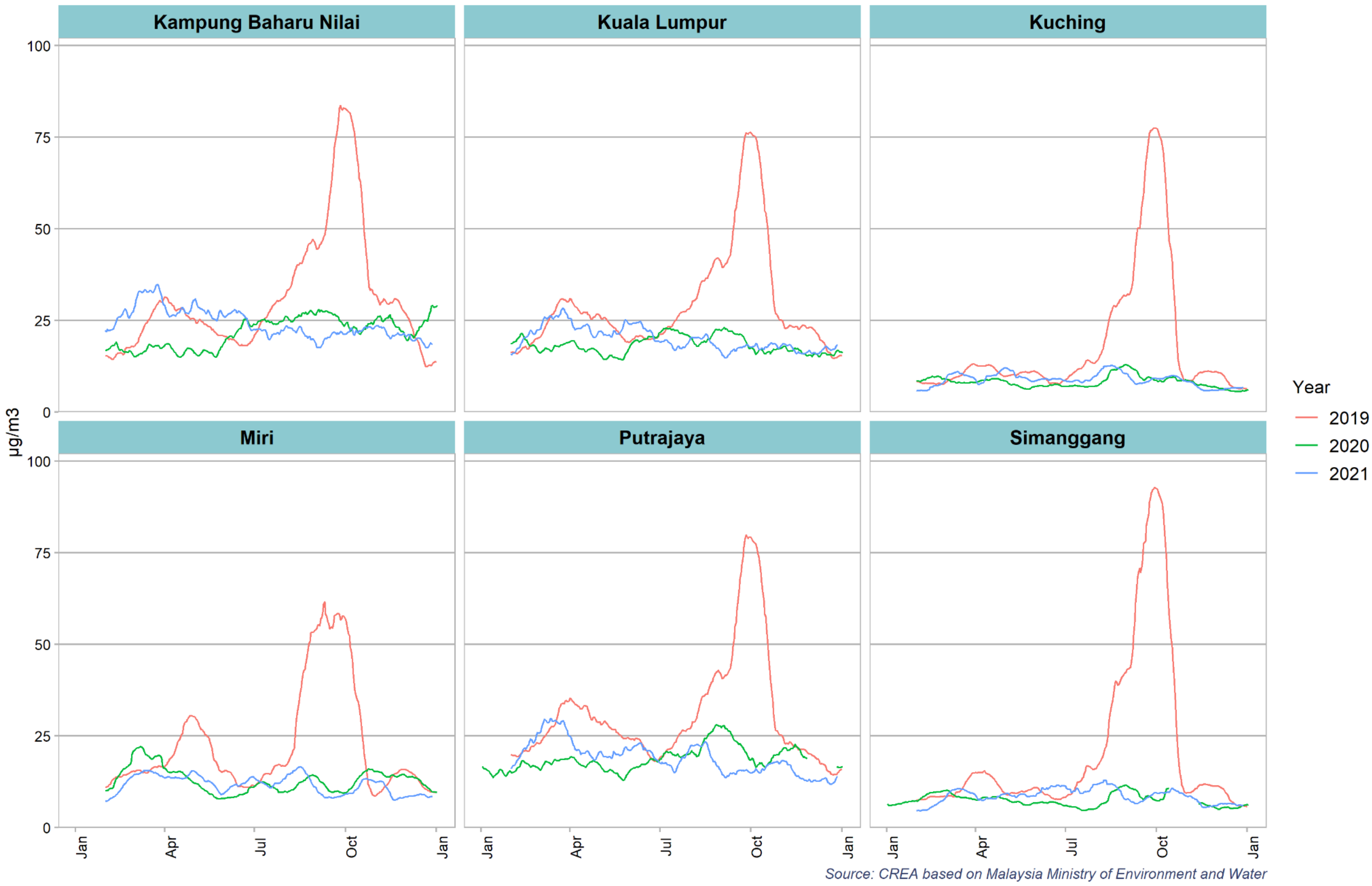
reductions will need to come from power plants and industries, which account for 66% and 7% of the 2020 NO_2 emissions load respectively.

Controlling emissions from a variety of sources is the most effective strategy to rapidly decrease pollution and avoid prolonged exposure to poor air quality.

Seasonal Pollution Spikes

In addition to local sources, Malaysia is heavily impacted by seasonal haze episodes during the dry season when weather conditions bring particulate pollution from large-scale forest fires from the Sumatra and Kalimantan regions of Indonesia into Malaysia. The southwest monsoons that characterize May to August allow low-level southwestern winds to carry massive concentrations of PM. Such transboundary pollution contributes to the formation of haze, as reflected in the spike in air pollution across the country for several months in 2019 (*Figure 3*).

Figure 5: *30-day Running Average of PM2.5 in cities most affected by seasonal Haze*



There is a direct and outsized impact on health during these months. A study conducted by the Universiti Teknologi Malaysia in Johor, one of the regions most severely and frequently affected by haze, found an uptick in cases of upper respiratory tract infections which was directly proportional to PM concentrations in the haze months of 2014 and 2015.[20]

Haze has been relatively controlled since 2020, as a result of COVID restrictions (*Figure 5*). However, the phenomenon is one whose root cause — peatland burning in Indonesia, for which Malaysian companies contribute and benefit— has not been sufficiently addressed.

[20] Hanafi et al. 2018

03 Quantifying the Domestic Health Impacts of Ambient Air Pollution

Our analysis revealed that approximately 32,000 deaths per year could be avoided in Malaysia with clean air quality, which is notably higher than previous estimates but in line with existing literature detailing that air pollution is more dangerous to human health than originally estimated. This estimate also includes health impacts from NO_2 pollution. The full methodology and sources, as well as its considerations and limitations are provided in the Appendix section of this report.

If annual $PM_{2.5}$ and NO_2 concentrations met the 2021 WHO Guidelines, premature deaths resulting from non-communicable diseases and lower respiratory infections linked to air pollution would save approximately 22,000 lives per year — a 67% decrease in estimated annual premature deaths (*Table 3*). Sick days taken due to air pollution-linked illnesses would also drop by 75% if air quality met the 2021 WHO Guidelines and virtually reduce low birth weights and preterm births by more than 90%. The number of years many have had to live with disabilities such as COPD, diabetes, or the after-effects of stroke would also be reduced by 78% (*Table 4*).

Interim targets, like those pursued by Malaysia in 2018, will be an important stepping stone to achieving fully protective standards that are in line with the WHO 2021 Guidelines. Meeting the WHO's 2005 guideline values would already decrease premature deaths by 38% annually, saving 12,200 lives per year in comparison to air pollution at the current, observed levels (*Table 3*). Improved air quality in line with WHO's 2005 guidelines would also reduce years lived with disabilities by 38%, decrease cases of low birthweight by 50%, and lessen sick days taken due to air pollution-related illness by 51% (*Table 4*).

Table 3: *Estimated Annual Premature Deaths in Malaysia as a result of exposure to poor air quality by cause vs. lives saved with air quality in compliance with WHO Guidelines*

		Annual Premature deaths by Scenario		
Cause	**Pollutant**	**Observed Air Quality in 2019**	**WHO, 2005**	**WHO, 2021**
Total Deaths		**32,531 (19,571 - 49,489)**	**20,294 (11,990 - 31,117)**	**10,689 (6,255 - 16,463)**
cardiovascular diseases	NO_2	4,121 (2,326 - 6,807)	4,121 (2,326 - 6,807)	2,620 (1,473 - 4,347)
respiratory diseases	NO_2	130 (66 - 176)	130 (66 - 176)	82 (42 - 111)
chronic obstructive pulmonary disease	$PM_{2.5}$	1,458 (461 - 3,302)	688 (225 - 1,504)	272 (91 - 585)
diabetes	$PM_{2.5}$	1,215 (450 - 2,303)	926 (270 - 2,176)	294 (- - 1,620)
ischaemic heart disease	$PM_{2.5}$	13,525 (9,233 - 19,173)	7,430 (5,118 -	3,561 (2,466 - 4,976)

			10,439)	
lower respiratory infections		13,945 (3,462 - 33,113)	4,604 (1,265 - 9,804)	1,401 (399 - 2,877)
lower respiratory infections in children		46 (19 - 97)	21 (6 - 62)	5 (- - 34)
lung cancer		1,412 (544 - 2,921)	643 (256 - 1,289)	252 (102 - 498)
non-communicable diseases and lower respiratory infections		28,707 (17,973 - 42,654)	16,471 (10,392 - 24,282)	8,280 (5,250 - 12,148)
stroke		3,417 (1,141 - 7,236)	1,449 (499 - 2,971)	551 (192 - 1,115)

Table 3: *Estimated Health Impacts as a result of exposure to air pollution in Malaysia, by cause and scenario*

Cause	Observed, 2019	WHO, 2005	WHO, 2021
new cases of asthma in children	**NA**	**3,534 (791 - 7,706)**	**2,384 (531 - 5,210)**
number of children suffering from asthma due to pollution exposure	**NA**	**15,451 (3,977 - 32,974)**	**10,421 (2,672 - 22,292)**
asthma emergency room visits, adults	**9,017 (5,939 - 12,037)**	**2,367 (1,553 - 3,174)**	**NA**
asthma emergency room visits, children	**6,655 (3,512 - 9,708)**	**1,749 (917 - 2,568)**	**NA**
low birthweight births	**9,869 (3,234 - 16,182)**	**3,601 (1,139 - 6,128)**	**625 (195 - 1,083)**
preterm births	**9,508 (4,806 - 10,045)**	**946 (460 - 1,004)**	**NA**
work absence (sick leave days)	**14,000,330 (11,993,114 - 15,966,324)**	**6,756,786 (5,766,968 - 7,733,515)**	**3,452,897 (2,942,287 - 3,958,406)**
Years Lived with Disabilities	**92,498 (30,190 - 185,062)**	**59,737 (16,532 - 139,552)**	**19,932 (1,868 - 93,541)**
COPD	*13,541 (4,578 - 26,921)*	*6,322 (2,212 - 12,131)*	*2,500 (890 - 4,716)*
diabetes	*59,980 (19,692 - 117,963)*	*45,553 (11,772 - 111,396)*	*14,460 (0 - 82,869)*
stroke	*18,977 (5,920 - 40,178)*	*7,862 (2,548 - 15,995)*	*2,972 (978 - 5,956)*
Years of Lives Lost	**779,209 (477,284 - 1,187,664)**	**463,541 (284,217 - 706,074)**	**238,368 (146,567 - 363,696)**
LRI in children	*4,390 (1,866 - 9,209)*	*2,013 (568 - 5,872)*	*478 (0 - 3,222)*
non-communicable diseases & LRI	*725,000 (447,993 - 1,094,813)*	*411,709 (256,224 - 616,560)*	*206,468 (129,302 - 307,598)*
cardiovascular diseases	*48,483 (26,752 - 81,813)*	*48,483 (26,752 - 81,813)*	*30,584 (16,843 - 51,728)*
respiratory diseases	*1,336 (673 - 1,829)*	*1,336 (673 - 1,829)*	*838 (422 - 1,148)*

The estimates above highlight that every incremental improvement in air quality makes a difference in the pursuit of the lowest levels of exposure to air pollution.

WHO-recommended concentration-response functions for $PM_{2.5}$ are based on a 6% increase in the risk of death from all causes per 10 µg/m^3 increase in average concentration levels, and studies show an approximately 4% increase in the risk of death per 10 µg/m^3 increase of annual NO_2 concentrations.[21] Such sensitivities are the reason why the estimated number of avoidable deaths is so significantly reduced under the three different scenarios presented in Tables 3 and 4 above. Any effort to reduce air pollution and improve air quality saves lives.

These estimates are in line with a newly developed risk model for $PM_{2.5}$ -related deaths built on the latest population studies, which found that the risk of death from air pollution-related diseases increases sharply above a concentration of 2.4 µg/m^3, which is one-quarter of the WHO guideline of 10 µg/m^3.[22]

[21] Faustini et al, 2014.
[22] Burnett et al, 2018.

04 The Annual Economic Cost 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, as well as loss of income, labor, and productivity as a result of air pollution-related disabilities or death.

We estimate that the health impacts of observed ambient air pollution in Malaysia result in an annual economic cost of **MYR 303 billion (US$ 73 billion) — or 20% of the country's GDP in 2019.** This amounts to approximately MYR 9,250 (US$ 2,200) per capita, as a result of healthcare and medical spending due to increased prevalence of diseases or disabilities related to air pollution, forced absence from work that affects individual ability to earn a salary, as well as the cost of lost livelihoods and economic productivity as a result of premature death.

Table 5: *Estimated Economic Cost of air pollution annually in Malaysia, by cause and scenario in USD millions*

	Economic Cost in USD millions		
Cause	Observed Scenario	WHO 2005 Scenario	WHO 2021 Scenario
Work absence (sick leave days)	904 (774 - 1,031)	436 (372 - 499)	223 (190 - 256)
Number of children suffering from asthma due to pollution exposure (increased prevalence)	14 (3.5 - 29)	14 (3.5 - 29)	9 (2.4 - 19.9)
Asthma emergency room visits	3.0 (1.8 - 4.1)	0.8 (0.5 - 1.1)	NA
Preterm births	766 (387 - 810)	76 (37 - 81)	NA
Years lived with disability	2,184 (713 - 4,370)	1,411 (390 - 3,295)	471 (44 - 2,209)
Premature deaths	9,084 (4,475 - 15,610)	9,084 (4,475 - 15,610)	5,718 (2,813 - 9,841)
	144,035 (75,166 - 250,668)	72,167 (40,367 - 117,599)	32,694 (19,009 - 53,354)
Total Economic Cost	**73,044 (44,266 - 110,410)**	**43,139 (25,867 - 66,075)**	**21,919 (13,096 - 34,549**

Improved air quality would save millions of lives and trillions of Ringgit. If annual $PM_{2.5}$ and NO_2 ambient concentrations were improved to meet 2005 WHO guidelines, the economic savings would amount to **MYR 124 billion** (US$ 30 Billion) per year. Improving air pollution to meet the recommended 2021 WHO guidelines would save an additional **MYR 87.9 billion** (US$ 21 Billion) every year — cutting the economic cost for Malaysians to a third of what was lost as a result of air pollution in 2019, or saving **MYR 212 billion** (US$ 51 Billion) annually.

These estimates only include the health and economic cost of ambient $PM_{2.5}$ and NO_2 in the country and therefore represent only a portion of the impacts. Health impacts such as Alzheimer's, depression, and poor sleep quality which can be impacted by poor air quality do not have enough evidence in the literature to quantify using cost-response functions; these impacts are not accounted for in our results. Additionally, the impacts of SO_2 and heavy metals like mercury are not covered in this report.

05 Conclusion and Recommendations

While significant progress has been made, coordinated and collaborative action from responsible bodies and stakeholders is necessary to create enforcement mechanisms and develop incentives to act on air pollution. Action and reform must be undertaken at the national and subnational levels in both the legislative branch and executive branch.

Key Recommendations to the Malaysian government:

1. Require that the Malaysian Ministry of Environment and Water explicitly makes public health and ecosystem health the main objectives of its air quality governance framework
2. Make ambient air quality standards legally binding, time-bound and enforceable. This means legally mandated ambient air quality standards must be embedded in Malaysia's primary air quality legislation, so that these standards are institutionalized and accorded appropriate importance in balancing socio-economic priorities.
3. Strengthen the governance of ambient air quality standards through transparency, access to information, public participation and accountability.

Furthermore, Malaysia's primary air quality legislation should include:

4. Strong public health and environmental objectives, as well as consideration of the economic cost of inadequate air quality standards
5. A clear timeframe and plan for implementation and enforcement
6. A requirement for interdisciplinary assessment and expert public health input in setting and updating standards
7. A regular review process that updates standards to align with global guidance and the latest scientific knowledge

More specifically, we recommend the following immediate actions be taken to align the country's national air quality with international standards and the recommended 2021 WHO Guidelines.

Revise Ambient Air Quality Standards and Set Binding Targets
A target year for meeting fully protective ambient National Air Quality Guideline Values (NAAQGVs) should be established in national legislation. An Air Quality Management Plan should include a phased multi-year schedule and intermediate targets that cover specific, achievable goals and objectives to meet the target year in national legislation. Clear mechanisms to coordinate policy and regulations and to create accountability must be established to ensure that air quality standards are met, which should include stringent standards and criteria for each pollution source.

Timely progression toward the adoption of the 2021 WHO air quality guidelines should be set, particularly in relation to PM2.5, where protection against unsafe levels of PM2.5 is urgently required for public health.

Ensure Broad and Coordinated Action

Given the collective nature of air pollution, national and local governments are jointly responsible for attaining legislative AAQS, including through duties to develop ambitious, resourced, and coordinated air quality policy plans. Additionally, action must be taken across sectors and sources, from power and industrial emissions to agricultural and forest fire emissions, and should include both urban centers and rural or industrial locations. An Air Quality Management Plan should prioritize the most polluting sectors but emissions standards should be applied broadly to all sectors.

Measures to tackle air pollution are also tied to sustainable development efforts. These should be based on scientific research identifying impactful and targeted methods for tackling air pollution, climate, and development challenges. Measures with the greatest co-benefits for climate and air pollution should be prioritized.

Tighten Emission Standards for Mobile and Stationary Sources and Expedite the Transition away from Fossil-fuel based sources

Given the growing number of pollution sources and the lax standards currently in place, a thorough review of emissions standards is highly recommended. In addition to ambient air quality targets, an Air Quality Management Plan should include goals and objectives for improving the emission control performance of existing emissions sources and highly polluting sectors.

More stringent standards and a set of criteria should also be established around permitting new emissions sources. Such standards should be improved to a level that would require the best-available emissions controls to be installed from the start, to ensure that pollution sources are mitigating their emissions and the health and economic impacts that have often been excluded from the equation.

06 Appendix

Methods & Materials

The health impact assessment begins with estimating the population exposure to NO_2 and $PM_{2.5}$. We built global concentration maps leveraging widely used baseline maps (namely Larkin et al. for NO2 and Hammer et al. for $PM_{2.5}$).

The PM2.5 concentration baseline map was updated using actual, historical ground-level measurements collected from the Ministry of Environment and Water of Malaysia. The update was made using a generalized additive model, including a spatial smoothing term. Different regressors were considered, including elevation, land use, distance to urban area, distance to coast etc. The formula leading to the best-generalized cross-validation was picked and only statistically significant differences were added to the baselines (diff > 1.96 * predicting error).

Health impact

CREA has developed a detailed globally implementable health impact assessment framework based on latest science. This framework includes a set of health outcomes that is as complete as possible without obvious overlaps.

The emphasis is on outcomes for which incidence data are available at the national level from global datasets and outcomes that have a high relevance for health care 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 jurisdictions.

For each evaluated health outcome, we have selected a concentration-response relationship that has already been used to quantify the health burden of air pollution at the global level in peer-reviewed literature. 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. $RR_{conc, age}$ 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 *RR0* is the risk ratio found in epidemiological research, Δ*c0* is the concentration change that *RR0* refers to, and *c0* is the assumed no-harm concentration (in general, the lowest concentration found in study data). Here, *c* is the pollutant concentration. Health impacts for a c_{base}, or the baseline concentration (current ambient concentration) as well as for an ideal scenario (WHO standards), are calculated this way.

Data on total population and population age structure were taken from Oxford Economics (Oxford economics, 2021). Cause-specific response functions and other health related factors for Malaysia are from the Global Burden of Disease results for 2019 (IHME 2020). The spatial distribution of population within each city and country, as projected for 2020, was based on the Gridded Population of the World v4 (CIESIN 2018).

Following the update of WHO Air Quality Guidelines, which now recognize health harm from NO_2 at low concentrations, we have updated the mortality risk function for NO_2 based on the findings of Faustini et al. 2014, including impacts down to 4.5 µg/m3, the lowest concentration level in studies that found increased mortality risk.

Adult deaths and years of life lost from $PM_{2.5}$ exposure were estimated using risk functions developed by Burnett et al. (2018), as applied by Lelieveld et al. (2019). For deaths, the GEMM (Burnett et al. 2018) risk model was chosen rather than the Global Burden of Disease model, which includes indoor air pollution and smoking in addition to outdoor air pollution. Although the GBD model is more widely used, it incorporates excessively 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 at low and high concentrations, as it would be applied here for reduction from the energy sector only. The GEMM is based on the latest evidence and focuses on outdoor air pollution, which is the subject of this study.

Deaths from long-term NO_2 exposure were quantified by applying the findings of Faustini et al. (2014) meta-analysis, which paid particular attention to the combined impacts of $PM_{2.5}$ and NO_2 in multi-pollutant risk models. The concentration-response relationship (odds ratio of 1.04) also aligns closely with the 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 NO2 exposure could overlap with deaths attributed to $PM_{2.5}$. As Faustini et al. did not document the lowest concentrations found in the included studies, the assumed no-harm concentration was adopted from Stieb et al. (2021).

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). For all mortality results, city-specific data on crude death rate by age group were obtained from Oxford Economics (Oxford economics, 2021). Overall death rates were disaggregated into cause-specific rates assuming that the relative share of different causes in different age groups is the same as that at the national level. The required cause-specific data were taken from the Global Burden of Disease project results for 2019 (IHME 2020).

For other health outcomes, national-level incidence data were used.

Health impact modeling projects the effects of pollutant exposure during the study year. Some health impacts are immediate, such as exacerbation of asthma symptoms and lost working days, whereas other chronic impacts may have a latency of several years. 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; these relationships were applied to changes in annual average concentrations. The annual average baseline concentrations of $PM_{2.5}$ and NO_2 were taken from van Donkelaar et al. (2016) and Larkin et al. (2017), respectively.

Table A-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 ug/m3	6 ug/m3	Zheng 2015	Anenberg et al. 2018
18-99	Asthma emergency room visits	$PM_{2.5}$	1.023 (1.015, 1.031)	10 ug/m3	6 ug/m3	Zheng 2015	Anenberg et al. 2018
Newborn	Preterm birth	$PM_{2.5}$	1.15 (1.07, 1.16)	10 ug/m3	8.8 ug/m3	Sapkota et al. 2012	Chawanpaiboon et al. 2019
20-65	Work absence	$PM_{2.5}$	1.046 (1.039-1.053)	10 ug/m3	N/A	WHO 2013	EEA 2014
0-4	Deaths from lower respiratory infections	$PM_{2.5}$			5.8 ug/m3	IHME 2020	IHME 2020
25-99	Deaths from non-communicable diseases, disaggregated by cause, and from lower respiratory infections	$PM_{2.5}$			2.4 ug/m3	Burnett et al. 2018	IHME 2020
25-99	Disability caused by diabetes, stroke and chronic respiratory disease	$PM_{2.5}$			2.4 ug/m3	Burnett et al. 2018	IHME 2020
25-99	Premature deaths	NO_2	1.04 (1.02-1.06)	10 ug/m3	4.5 ug/m3	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." 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 Impact

The economic impacts were assessed following the methodology of the CREA publication ["Quantifying the Economic Costs of Air Pollution from Fossil Fuels"]

Mortality and cost estimates are based on the total impact attributable to $PM_{2.5}$ in 2019. Daily figures were calculated by apportioning the annual costs daily to each day's recorded pollutant levels.

The economic losses from air pollution-related deaths were assessed based on the 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 (Viscusi & Masterman 2017). Labor market data has the strength that the findings are based on observed wage differentials between professions with different mortality risks, i.e., revealed preferences, rather than survey responses. 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. Health care costs and the value of lost working time are also proportional to GNI per capita because both depend closely on hourly wage or labor costs. In accordance with the recommendations of OECD (2012), child deaths are valued at twice the value of adult deaths.

Millions of people around the world are living with diabetes and chronic respiratory diseases, as well as disabilities caused by stroke, because of exposure to air pollution. 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), and adjusted by GNI PPP for other countries.

The economic cost of asthma related to air pollution 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. NO_2 pollution is linked to the annual occurrence of 4 million new cases of asthma in children worldwide (Achakulwisut et al. 2019). Incidence and prevalence of asthma in children were taken from Global Burden of Disease (2017).

The economic cost of new asthma cases was estimated assuming that an increase there means an equal increase in the prevalence of childhood asthma. This finding led to the assumption that a new case of child asthma results in 4 years living with childhood asthma on a global average basis. 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 midpoints of these two valuations were used for the estimates, adjusted by the ratio of California’s Gross Regional Product to the U.S. national average, and by GNI PPP for Malaysia.

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 adjusted to GDP at PPP.

$PM_{2.5}$ exposure to 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 a preterm birth, primarily lower economic productivity and increased health care costs, at $300,000 per birth. This valuation is used globally, adjusted using GDP at PPP for each country.

Exposure to $PM_{2.5}$ air pollution leads to increased sick leaves (work absence), quantified based on the WHO HRAPIE (2013) recommendations. The economic cost of these sick leaves was evaluated at EUR130 per day ($160 at 2005 exchange rate) in the European Union, according to EEA (2014). This value was taken to represent the valuation at EU average GDP per capita and adjusted for Malaysia based on GDP at PPP.

Each cost was converted to purchasing power adjusted international dollars at 2011 prices, and then the unit cost was calculated based on country-specific GDP or GNI as indicated. Results were then converted to US dollars and to local currency at 2019 prices and exchange rates. Impacts related to productivity were adjusted by GDP, whereas those related to income or welfare loss were adjusted by GNI.

Data on GDP and GNI per capita in dollars, at constant and current prices in US dollars and in local currency in 2019, were obtained from the World Bank (undated).

Table A-7: *Economic cost of different health outcomes.*

Outcome	Valuation	Currency	Year	Source	Reference income level	Valuation at world 2019 average GDP, US dollars
Year lived with asthma	3,914	USD	2010	Brandt et al 2012	California	1,240
Asthma emergency room visits	844	USD	2010	Brandt et al 2012	California	268
Preterm birth	321,989	USD	2010	Trasande et al 2016	U.S.	112,000
Deaths, adults	9,631,000	USD	2015	Viscusi and Masterman 2017	U.S.	2,910,000
Deaths, children	19,262,000	USD	2015	OECD 2012	U.S.	5,820,000
Year lived with disability	62,800	GBP	2018	Birchby 2019	UK	32,900
Lost workday	130	EUR	2010	EEA 2014	EU	90

Limitations

Modeling always 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. Where only PM_{10} is available, $PM_{2.5}$ is calculated as a ratio of PM_{10} based on the proportion of available PM_{10} and $PM_{2.5}$ — total ambient pollutant concentrations may be over or under-estimated. Additionally, the impacts of pollutants and heavy metals like SO_2 and mercury are not quantified. However, the effects of these limitations are expected to be within the overall margin of error for this type of air quality modeling.

The causes included in the study are ones with established cause-specific risk factors and response functions from exposure to a certain level of air pollution provided in the scientific literature; there are health impacts that are known and established as linked to air pollution exposure but not quantified in the study, as a result.

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.

Healthcare costs are likely to be low in cities 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 amount 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.

07 References

Achakulwisut P, Brauer M, Hystad P, Anenberg SC. 2019. Global, national, and urban burdens of paediatric asthma incidence attributable to ambient NO2 pollution: estimates from global datasets. Lancet 3(4):E166-E178.

Anenberg SC, Henze DK, Tinney V, Kinney PL, Raich W, Fann N, Malley CS, et al. 2018. Estimates of the Global Burden of Ambient PM2.5, Ozone, and NO2 on Asthma Incidence and Emergency Room Visits. Environmental Health Perspectives 126:10. https://doi.org/10.1289/EHP3766 .

Birchby D, Stedman J, Whiting S, Vedrenne M. 2019. Air Quality damage cost update 2019. Report for Defra. AQ0650. Ricardo Energy & Environment, United Kingdom. https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1902271109_Damage_cost_update_20 18_FINAL_Issue_2_publication.pdf.

Burnett, R.T. Chen, H. Szyszkowicz, M. Fann, N. Hubbell, B. Pope, C.A. et al. 2018. Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. Proc. Natl. Acad. Sci., 115, pp. 9592-9597

Hanafi NH, Hassim MH, Noor ZZ, Security W, Bahru J. 2018. Overview of health impacts due to haze pollution in Johor, Malaysia. J Eng Technol Sci 50(6): 818–831. https://doi.org/10.5614/j.eng.technol.sci.2018.50.6.5

Health Effects Institute, 2020. State of Global Air 2020. Data source: Global Burden of Disease Study 2019. IHME, 2020. https://www.healthdata.org/news-release/health-effects-institute-two-new-reports-offer-insights-global-air-quality-and-air

Lee, Han and Greenstone, Michael. September 2021. Air Quality of Life Index. “2021 Annual Update.” Appendix Table. https://aqli.epic.uchicago.edu/reports

Malaysia Department of Environment. 2016. Malaysian Ambient Air Quality Guidelines (MAAQS) 2013. https://enviro2.doe.gov.my/ekmc/wp-content/uploads/2018/07/PIL-Existing-AQM-SNA-Amended-5-August-2016.pdf

Malaysia Department of Environment, 2021. Malaysia Environmental Quality Report 2020. https://stagingportal.doe.gov.my/en/environmental-quality-report/

Myllyvirta, Lauri. 2020. Quantifying the Economic Costs of Air Pollution from Fossil Fuels. Centre for Research on Energy and Clean Air. https://energyandcleanair.org/publications /costs-of-air-pollution-from-fossil-fuels/

Suarez, Isabella and Vince Carlo Garcia. December 2021. Aiming Higher: Benchmarking the Philippine Clean Air Act. ICSC and CREA. https://icsc.ngo/wp-content/uploads/2021/11/AimingHigher_BenchmarkingthePhilippineCleanAirAct_CREA_ICSC_v4_10Nov2021.pdf

WHO, 2021a. World Health Organization – Fact Sheet: Ambient (outdoor) air pollution. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health (accessed 2022-03-08)

Wu, X., Nethery, R.C., Sabath, M.B., Braun, D., and Dominici, F. September 2020. Air pollution and COVID-19 mortality in the United States: Strengths and limitations of an ecological regression analysis. Sci. Adv. 6(45). DOI: 10.1126/sciadv.abd4049

Yaron Ogen. July 2020. Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality. Science of The Total Environment, Volume 726, 2020, 138605, ISSN 0048-9697. https://doi.org/10.1016/j.scitotenv.2020.138605.

Yongjian Zhu, Jingui Xie, Fengming Huang, Liqing Cao. July 2020. Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China, Science of The Total Environment, Volume 727, 2020, 138704, ISSN 0048-9697. https://doi.org/10.1016/j.scitotenv.2020.138704.