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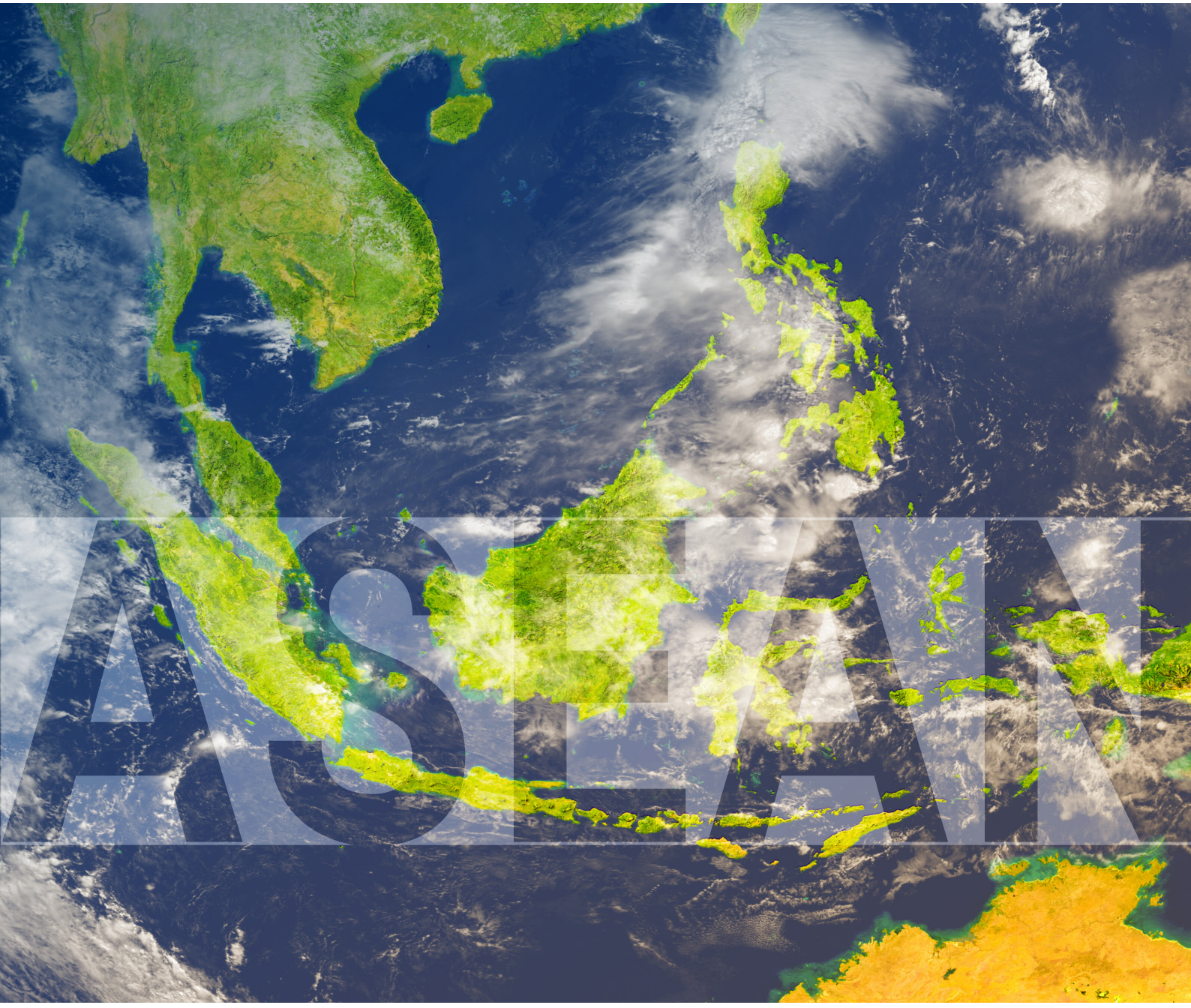
Clean Air and Climate Solutions for ASEAN



CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS
a UNEP convened initiative

asean

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Preface

As a member of the Association of Southeast Asian Nations (ASEAN) Working Group on Climate Change (AWGCC), I am delighted to provide the preface for this timely report. The report is the result of a proposal that the Philippine Government has put forward to the Climate and Clean Air Coalition (CCAC) for a science-based assessment that would identify air pollution and climate change solutions in Southeast Asia. The intent of the Philippine proposal was to come up with a report complementing the Asian-wide assessment report entitled Air Pollution in Asia and the Pacific: Science-based Solutions (Asia Solutions Report) which was published in 2019. We nonetheless envisioned that this report would offer a critical subregional perspective and deeper dive into solutions to air pollution and climate change in Southeast Asia. With this publication, I am happy to say that the report exceeds those expectations.

The report's messages are at a glance compelling but encouraging. It shows that there are 15 solutions that can bring clean air to over 100 million people in the ASEAN region. At the same time, the benefits from these solutions are not limited to improved air quality and health but would also bring climate co-benefits due to the reduction of short-lived climate pollutants (SLCPs) and of some greenhouse gases (GHGs). Just as encouraging, countries in Southeast Asia have encountered some indications of success with the implementation of many of the 15 solutions. In addition, countries in the region are willing to adopt enabling reforms such as enhancing multi-level governance and innovative financing arrangements to spread that success. Lastly, a coalition of champion ASEAN countries could work with the ASEAN secretariat, the CCAC, and other development partners to support the capacitation and institutional strengthening that could mainstream the 15 solutions across the region.

As a policymaker with considerable experience working on climate and other development issues, I am deeply aware that a report on paper is only as valuable as the actions that need to be implemented on the ground. Indeed, the next step will be for ASEAN member states to put forward the report's recommendations and translate them into meaningful changes in their countries' policies and practices. In the Philippines, I see considerable enabling environment to bring the report's recommendations to life. We also perceive similar opportunities in many of the other partner countries in the ASEAN. It is with this belief that I look forward to the widespread adoption of the report's recommendations for clearer skies, more stable climate, and healthier future for the ASEAN.

MARIA ANTONIA YULO LOYZAGA
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Executive Summary

The main objective of this report is to meet the growing demands from policymakers and other stakeholders for clean air solutions in the Association of Southeast Asian Nations (ASEAN) region. Toward that end, the report identifies a set of 15 priority measures that would more than triple the number of people in ASEAN countries breathing 'clean air'—from approximately 80 million in 2015 to over 250 million in 2030. The solutions also have the potential to reduce population weighted $PM_{2.5}$ mean concentrations across many countries by 50 per cent to over 70 per cent, allowing many countries in the region to improve compliance with the 2021 WHO air quality guidelines and virtually all countries could comply with the WHO Interim Target 1 by 2030. Implementation of the 15 solutions would also result in important climate co-benefits due to reductions of short-lived climate pollutants (SLCPs), including black carbon (-70 per cent), methane (-39 per cent), HFCs (-75 per cent), ozone as well as CO_2 (-25 per cent); all reductions refer to 2030 and are compared to a business-as-usual baseline. Importantly, nearly 40 per cent (20-60 per cent at the country level) of identified potential can be achieved by implementing existing legislation. This finding highlights the importance of continuing to strengthen implementation of existing air pollution, energy, climate, and other sectoral policies.

There is a growing demand for solutions to air pollution and climate change from policymakers in Southeast Asia. In 2019, following a regional meeting to share the key results from an assessment report titled *Air Pollution in Asia and the Pacific: Science-based Solutions (Asia Solutions Report)*, the Philippine Government requested the Climate and Clean Air Coalition (CCAC) to develop a project to identify air pollution and climate change solutions in Southeast Asia. The recently published *State of Climate Change Report in ASEAN* also underscores the strong regional interest in controlling air pollution while combating climate change.

The Opportunity

- **The 15 solutions can reduce population-weighted $PM_{2.5}$ average concentrations across the ASEAN region by 50 to 70 per cent by 2030**, allowing countries in the region to achieve compliance with the 2021 WHO air quality guidelines for over a third of population (and for about 70 per cent, i.e., about 500 million with 2005 WHO guidelines). This would also mean that most of the population would live in areas complying with both national legislation and WHO interim Target 1.

The 15 solutions offer significant mitigation potential across many sectors and there is a considerable experience with implementation of these options. Nearly 40 per cent (20-60 per cent at the country level) of identified potential is associated with existing environmental legislation. This highlights the importance of strengthening capacities to effectively implement existing legislation related to air quality, energy efficiency, and climate policies.

- **Implementing the 15 solutions would result in important climate co-benefits due to the reduction of SLCPs.** Emissions of black carbon would be reduced by about 70 per cent, methane by nearly 40 per cent, HFCs by 75 per cent, and CO_2 could decline by 25 per cent by 2030. Additional opportunities exist to reduce electricity consumption of stationary cooling technology when transitioning to low-Global Warming Potential (GWP) alternatives to comply with the Kigali Amendment to the Montreal Protocol – these could amount to 6-9 per cent of total electricity consumption in the region in 2030 translating into significant CO_2 reductions and further air quality benefits if fossil fuel electric generation capacity reduction is prioritized.

Why Act

- **Today over 85 per cent of the ASEAN population are exposed to levels of air pollution exceeding the 2021 WHO air quality guidelines for $PM_{2.5}$ (5 µg/m³), and 15 per cent to levels above the WHO Interim Target 1 levels (35 µg/m³)—levels that are higher than most national legislation in ASEAN (World Health Organization [WHO] 2021).** Currently observed and modelled concentrations of $PM_{2.5}$ across the ASEAN region are often significantly above the WHO Interim Target 1; in 2015, an estimated 100 million people were exposed to pollution levels above this target.
- **Continuing along the current development paths will jeopardize the health and well-being of much of ASEAN's population through 2030. It could also undermine the achievement of key Sustainable Development Goals (SDGs), including food security, water quality, gender empowerment and education.** Most of the population of ASEAN will ***not*** experience improvements in air quality over the next decade as expected levels of economic growth and increasing urbanization will offset gains from stronger energy efficiency, clean cooking as well as air pollution policies.
- **Air quality and resulting threats to public health and climate change could become worse in ASEAN by 2030.** The number of people exposed to levels above the WHO interim Target 1 could grow to nearly 170 million, representing about a quarter of the population in 2030. Considering the national air quality standards for $PM_{2.5}$ of between 12 and 35 µg/m³, in many countries 20 to 60 per cent of population will be exposed to higher pollution levels and less than 12 per cent will enjoy 'clean air' as defined in the 2021 WHO air quality guidelines (WHO 2021).

How To Do It

- **Much of the reduction of particulate matter (PM) exposure would come from measures targeting reductions in "usual suspect" sources such as transport, power, and industry.** Though these measures are well recognized, more stringent implementation is critical as these sources represent nearly two thirds of total potential to reduce PM exposure.
- **Sectors and sources that are often outside the purview of air pollution regulation have untapped potential and could deliver the widest range of sustainable development benefits.** This includes key measures that reduce emissions from solid fuel cooking (primarily biomass), waste management, and agriculture. Compared to previous pan-Asia assessments, these measures have increased the most in importance for Southeast Asia. These include measures promoting transformational changes to improve nitrogen use efficiency and enable lower meat protein diets, which result in important ammonia and methane mitigation. Finally, policies addressing forest fire management could improve air quality within and across countries.
- **The ASEAN region could yield significant benefits from strengthening regional cooperation and harmonization of policies promoting the implementation of the 15 solutions specifically as well as integrated air pollution and climate change planning generally.** Countries such as the Philippines, Thailand, Cambodia, Viet Nam, and Indonesia have taken some positive steps toward strengthening this cooperation. Moreover, regional cooperation could help to deepen and scale up these efforts in other countries where knowledge and action is limited.
- **Several organizations, initiatives, and networks are supporting efforts that contribute to regional cooperation in ASEAN.** ASEAN serves as the secretariat of the ASEAN Haze Agreement that could facilitate the sharing of good practices, enabling policies, and planning tools related to sustainable land use and fire prevention. Other notable examples that could help mainstream the report's recommendations include the Asian Pacific Clean Air Partnership (APCAP), the East Asia Acid Deposition Network (EANET), the Issue-based Coalition on Climate Change and Air Pollution (IBC), Clean Air Asia, and the Asian Co-benefits Partnership (ACP). The Asian Development Bank (ADB) has launched a new initiative called the Asia Clean Blue Skies Program (ACBSP) that could help strengthen air pollution planning and invest in the 15 solutions. Collectively these organizations could work together and with national governments, development partners, the private sector, and civil society toward a making an integrated approach to air pollution and climate planning common practice in ASEAN.
- **The ASEAN secretariat's Environment Division and Working Group on Climate Change could help support this coordination and harmonization.** Many of the above efforts are voluntary cooperative arrangements between countries; however, they focus chiefly on information sharing and capacity building. None has the same convening power and institutional standing to support policy coordination and harmonization on integrated climate change and air pollution planning like ASEAN.
- **The ASEAN secretariat will need the strong support of champion ASEAN countries to promote the adoption and spread of the recommended solutions.** Should this coalition of champion countries develop, it is likely to include the Philippines, Thailand, and Cambodia–with the possible near-term expansion to Viet Nam and Indonesia.
- **The Philippines, Thailand, and Cambodia are selected for the initial members of the champion countries because they have demonstrated a keen interest in integrating national-level air pollution and climate planning.** They also have engaged in training and co-design processes that can support integration and serve as models for other countries. Viet Nam and Indonesia are selected because they have accumulated experience with energy models that could support integrated air pollution and climate planning. This interest and experience make them natural choices to provide the leadership, guidance and drive for integrating air pollution, climate, and other development priorities.

- **The efforts to strengthen regional cooperation in ASEAN on policies that can promote the 15 solutions could address three sets of needs identified during project interviews: 1) integrated air pollution and climate planning; 2) demonstration projects; and 3) mobilizing finance.** In terms of planning, it will be important to equip countries with the tools and knowledge to implement priority solutions as well as integrating air pollution, climate change (including nationally determined contributions [NDCs]), and other relevant sectoral policies and strategies. Planning tools such as Low Emissions Analysis Platform – Integrated Benefits Calculator (LEAP-IBC) have a solid track record for enabling countries to own the work they do to enhance policies and strategies. In terms of demonstration project and finance, concrete examples of the implementation of the 15 solutions will be essential. This may be supported by financial institutions such as the ADB, World Bank or Japan International Cooperation Agency (JICA). They may also get support from a new project-based finance mechanism currently being discussed under EANET.
- **While much of this report is focused on ASEAN, other institutions and initiatives can play a key role to advance the objectives of this work. The CCAC is arguably best equipped to move quickly and take a lead in bringing together and showcasing the coalition of champion countries, continue to build capacity and enthusiasm to implement the 15 solutions, undertake integrated air quality and climate planning, and highlight the links between policies and demonstration projects.** It may begin by building on the stated interest of the Pollution Control Department of Thailand to help coordinate actions in the Mekong sub-region. By building up the demand for increased action and coordination this can then lead on to the development of a coordinated programme for and with ASEAN and its countries.

1 Bringing Clean Air, Better Health, A Stable Climate and Other Benefits to the ASEAN Region

Few environmental problems pose a greater threat to the health and well-being of the 660 million people living in the Association of Southeast Asian Nations (ASEAN) region than air pollution. Not only does air pollution contribute to a range of health problems, but efforts to control air pollution can help achieve multiple sustainable development goals (SDGs), including mitigating climate change (Haines et al. 2017). The growing realization of these benefits has motivated policymakers in the ASEAN region to express an interest in solutions to air pollution. Many of these solutions will also bring co-benefits for near- and long-term climate change and other development priorities.

The interest in these solutions was shared widely in 2019 when the Philippines hosted the ASEAN Regional Ministerial Dialogue on Clean Air, Health and Climate in Manila. The meeting reviewed the results of a high-profile report titled *Air Pollution in Asia and the Pacific: Science-based Solutions (hereafter the Solutions Report)* that identified 25 measures that could help 1 billion people across Asia enjoy air quality within the 2005 World Health Organization's air quality guidelines for ambient particulate matter (below 10 µg/m^3 $PM_{2.5}$) by 2030. The same measures could reduce carbon dioxide (CO_2) emissions by almost 20 per cent relative to baseline projections by 2050 (United Nations Environment Programme [UNEP] 2019). The Regional Ministerial Dialogue on Clean Air, Health and Climate further suggested the need to examine support policy and institutional reforms that could enable the adoption and scaling of those measures in ASEAN countries as well as at the subregional level. A similar message can be found in the recently published ASEAN State of Climate Change Report which underlines the importance of controlling air pollution and pursuing co-benefits (Association of South East Asian Nations [ASEAN] 2021).

1.1 Objectives and Methods

The main objective of this report is to meet the growing demands from policymakers and other stakeholders for clean air solutions in the ASEAN region. Toward that end, the report identifies a set of ***15 priority measures that would more than triple the number of people in ASEAN countries—from approximately 80 million to over 250 million—breathing 'clean air'***. The report also reviews some of the experiences implementing these measures as well as governance and financial arrangements that can enable their spread in the ASEAN region. Finally, the report outlines recommendations from a series of key informant interviews with policymakers and representatives from the development community that can help strengthen regional cooperation on the 15 priority solutions and integrated air pollution and climate planning more generally in ASEAN.

The methods used to identify the priority measures parallels the approach employed in the Asia wide *Solutions Report* (UNEP 2019) with a few modifications. The *Solutions Report* identified three groups of 25 measures for Asia and the Pacific; it further reported potential reduction in exposure to fine particulate matter ($PM_{2.5}$) for four country groups in Asia, i.e., East Asia, South Asia, Southeast Asia and the high-income countries. While information at this resolution is useful for the entire region, further work is required to identify which of these measures have the greatest potential to deliver multiple benefits at the subregional and national levels.

The three-step approach employed in this chapter follows the same principles as the *Solutions Report* (chiefly *Chapter 2: Scenarios and Solutions* (Amann et al. 2019), but with a subregional and national focus. That three-step process involves the following: (i) analysis of the historical trends and factors determining future development; (ii) assessment of the scope for further reductions; and (iii) assessment of the impacts of each measure/solution on population exposure to $PM_{2.5}$ at the regional (ASEAN and the national level. The analysis employs the Greenhouse gas – Air pollution Interactions and Synergies (GAINS) model (Amann et al. 2011) developed at the International Institute for Applied Systems Analysis (IIASA) see Box 1.

BOX 1: The GAINS model

The GAINS (Greenhouse gas-Air Pollution Interactions and Synergies) model explores cost-effective multi-pollutant emission control strategies that meet environmental objectives on air quality impacts (on human health and ecosystems) and greenhouse gases. GAINS, brings together data on economic development, the structure, control potential and costs of emission sources, the formation and dispersion of pollutants in the atmosphere and an assessment of environmental impacts of pollution (http://gains.iiasa.ac.at).

In this work, GAINS relies on the projections of economic activity and energy use from the International Energy Agency (IEA) World Energy Outlook 2018 (International Energy Agency [IEA] 2018), and for agriculture projections of the Food and Agriculture Organization of the United Nations (FAO). Emissions are estimated using the GAINS emission factor database that has been peer-reviewed and compiles both national and international data on source- and technology-specific measurements; more than 1000 measures to control emissions are represented. The analysis of mitigation options includes also potential for energy efficiency, nitrogen use efficiency, and dietary changes and all key air pollutants (SO_2, NO_x, PM [including BC and OC), NMVOC, NH_3) and greenhouse gases (CO_2, CH_4, N_2O, F-gases) are estimated.

The model computes the atmospheric dispersion and formation of secondary pollutants for each scenario, including specific response to each major solution analyzed in the report. This allows the quantification of $PM_{2.5}$ concentration changes from application of each measure/solution at the fine scale. As an indicator for population exposure to particulate matter (PM), the annual average population-weighted mean exposure to ambient $PM_{2.5}$ accumulated over the whole population.

1.2 Updated Methods and Data since the Solutions Report

In addition to the subregional and national focus, new data have been made available for historical statistics and status of implementation of environmental policies (see also section 3.2). Further, new results of measurements of emission factors as well as new projections of activities have been published. There have also been some methodological advances made in the GAINS model that allow for more accurate representation of emissions (in terms of source strength, spatial distribution, and mitigation potential) and calculation of particulate matter (PM) concentrations. A more detailed review of these updates can be found in Annex 1.

1.3 Setting the Baseline for 2015 and 2030

The core of the report's modelling result involves using the GAINS model to calculate the ambient concentrations of $PM_{2.5}$ for 2015 and 2030 as well as assess exposure to ambient $PM_{2.5}$ (excluding indoor household pollution). To build this core, it is important to establish a baseline for both 2015 and 2030. Such a baseline should be consistent with existing 2015 and expected 2030 emissions as well as policies that could curb those emissions. This section presents that baseline, highlighting some of the updates made since the *Solutions Report*.

The updated calculation of baseline concentrations for 2015 are similar to the *Solutions Report* (Figure 1). However, in some urbanized areas and megacities (e.g., Ho Chi Minh City, Kuala Lumpur) where methodological improvements allow for improved estimate of distribution of emissions and consequently concentrations, slightly higher concentrations are visible in 2015.

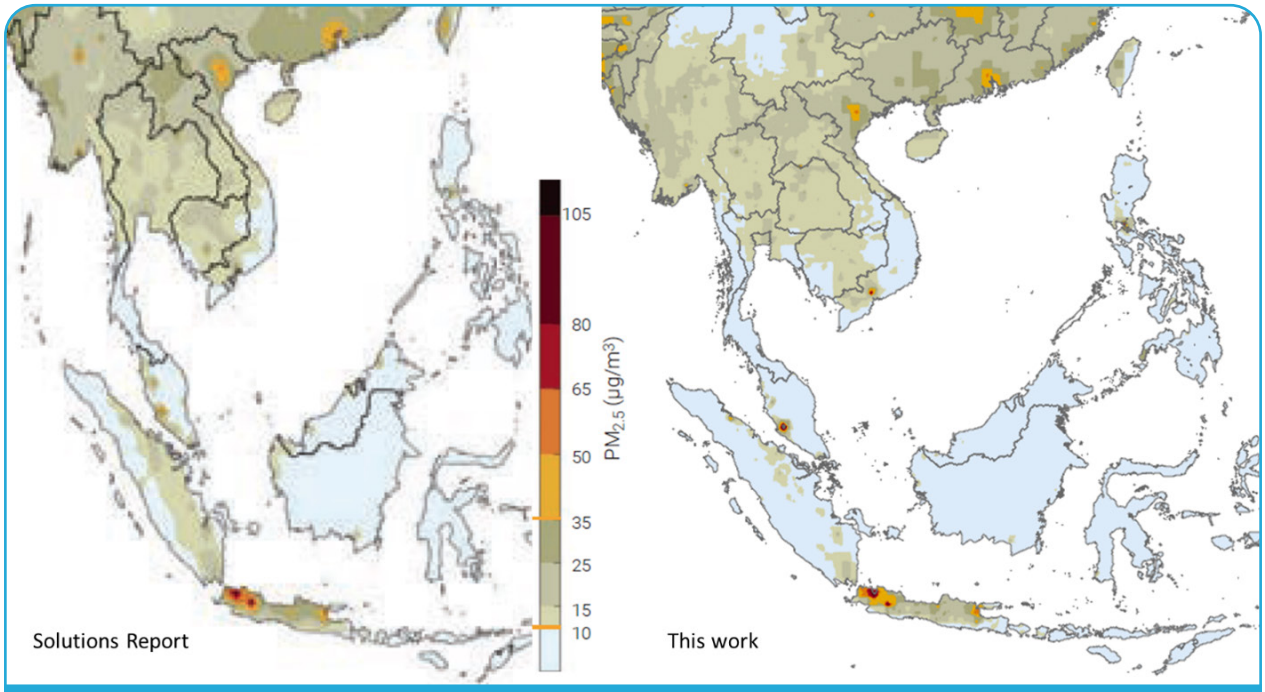


FIGURE 1. $PM_{2.5}$ concentrations across ASEAN region in 2015 as estimated in the *Solutions Report* and in the current assessment.

The baseline for the 2030 is influenced by a robust macroeconomic outlook for ASEAN; that outlook has not changed significantly from the assumptions used in the *Solution Report*. As a result of the continued strong growth projections, the modelling anticipates significant increase of CO_2 emissions for the 2030 baseline (which draws from the World Energy Outlooks New Policy Scenario [NPS] and includes Nationally Determined Contributions (NDCs) reported up to 2018) (International Energy Agency [IEA] 2018). The main contributions and growth of CO_2 emissions in the ASEAN region are from power, industry, and transport sectors (Figure 2).

The baseline also assumes that *existing and recently* introduced legislation in the power, industry and transport sectors are implemented effectively, and have slowed the growth of emissions of key PM precursors. In fact, these precursors are growing slower than CO_2, suggesting gradual decoupling of economic growth from air pollutant emissions. At the same time, however, the existing legislation is not sufficiently strong to offset the increase in fuel use and production activities, which explains the relatively faster growth in CO_2 (Figure 2).

Another notable trend in the baseline involves residential cooking. For primary $PM_{2.5}$ emissions, a trend towards clean fuels for cooking is clearly seen through declining emission in this subsector (Figure 2). This is likely the result of the long-standing policies to provide access to clean energy both for rural and urban residents in the region.

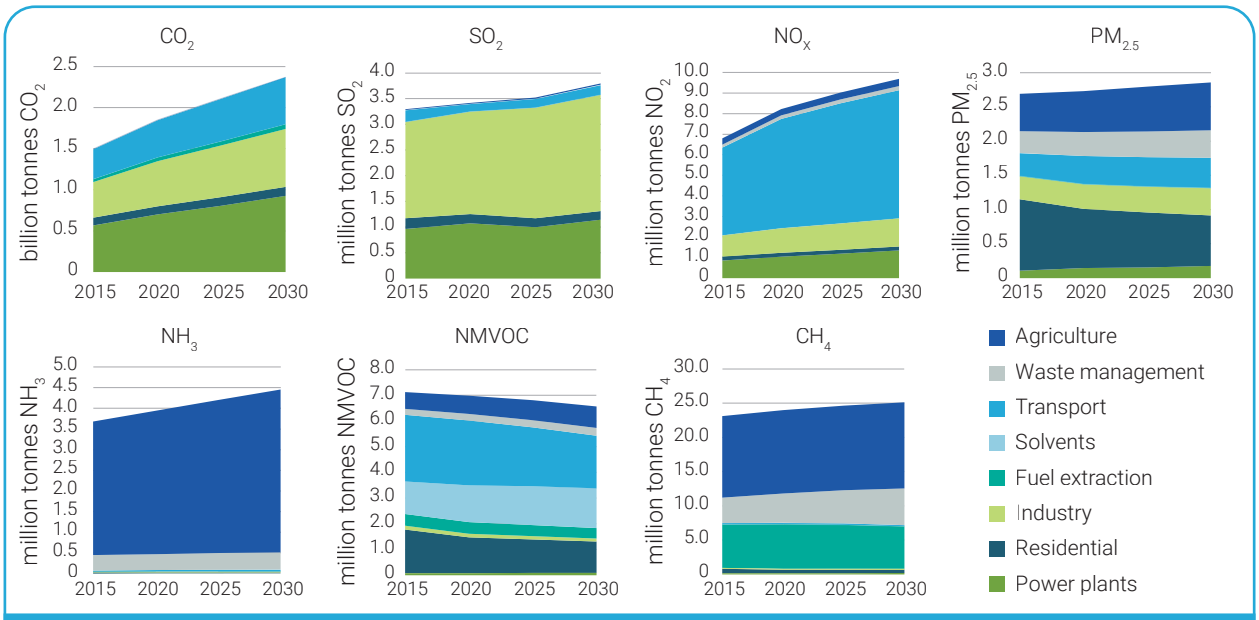


FIGURE 2. Emissions of CO_2, CH_4, primary $PM_{2.5}$, and key precursors of ambient $PM_{2.5}$ for the ASEAN region in the current legislation scenario; Source: GAINS model.

Even with some of the progress from existing air pollution, energy and other sectoral policies, the overall picture from the baseline is troubling. Currently observed and modelled baseline concentrations of $PM_{2.5}$ across the ASEAN region (Figure 1) are often well above the WHO Interim Target 1 (35 μg/m^3) (Figure 3). More concretely, an estimated 100 million people were exposed to pollution levels above the WHO Interim Target 1 levels in 2015. Less than 15 per cent of population lived in areas with $PM_{2.5}$ concentrations below the 2021 WHO air quality guideline of 5 μg/m^3 in 2015. The situation is not expected to improve markedly by 2030 without significant interventions. Even with assumed effective implementation of current legislation, by 2030 population exposed to levels above WHO Interim Target 1 could grow to nearly 170 million (Figure 3), owing to increasing concentrations (Figure 5) as well as population growth and continuing urbanization.

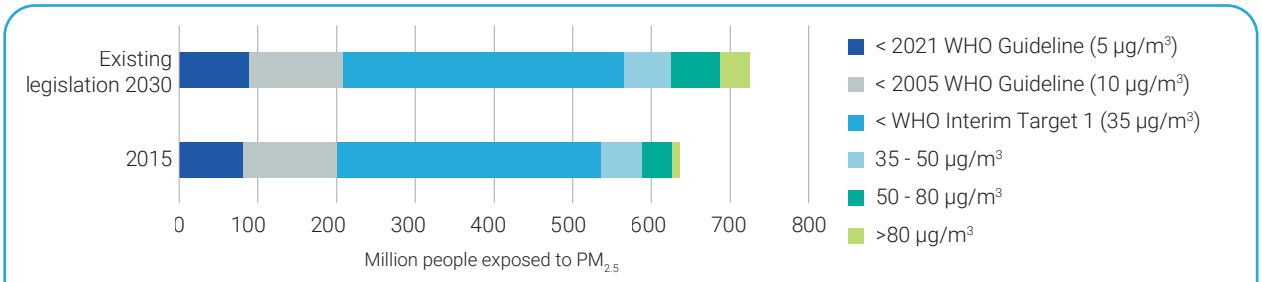


FIGURE 3. Population exposure to ambient $PM_{2.5}$ (household pollution excluded) in the ASEAN region in 2015 and 2030 assuming successful implementation of current policies

Though the overall picture is not encouraging, it merits highlighting that the situation varies across the ASEAN region. This variation is evident with respect to emission burdens, concentrations in 2015 (Figure 1) and change towards 2030 (Figure 5), and eventually the level of exceedance of the national standards for annual average concentration of $PM_{2.5}$; the national standards vary from 12 µg/m³ in Singapore, 15 µg/m³ in Indonesia, 25 µg/m³ in Philippines, Thailand, Viet Nam, to 35 µg/m³ in Malaysia.

Figure 4 illustrates this variation in the baseline across two countries: Cambodia and Indonesia. It shows that the levels of population exposure differ significantly between countries. Yet, though the exposure varies, for both Cambodia and Indonesia there is a significant increase in population exposed to elevated levels of pollution above the standards by 2030. Moreover, despite the implementation of existing legislation, there is only marginal improvement in number of people living in areas complying with the 2021 WHO air quality guidelines for $PM_{2.5}$.

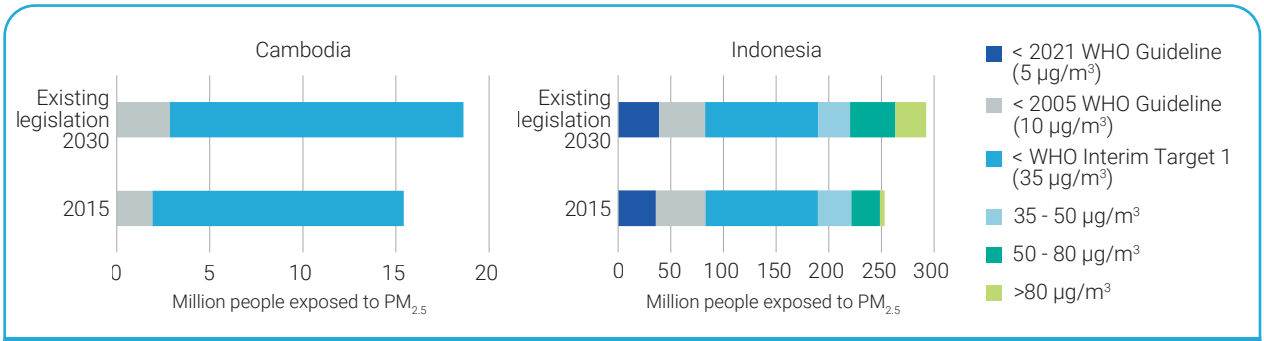


FIGURE 4. Population exposure to ambient $PM_{2.5}$ (household pollution excluded) in Cambodia and Indonesia as estimated in the GAINS model for 2015 and 2030, assuming successful implementation of current policies.

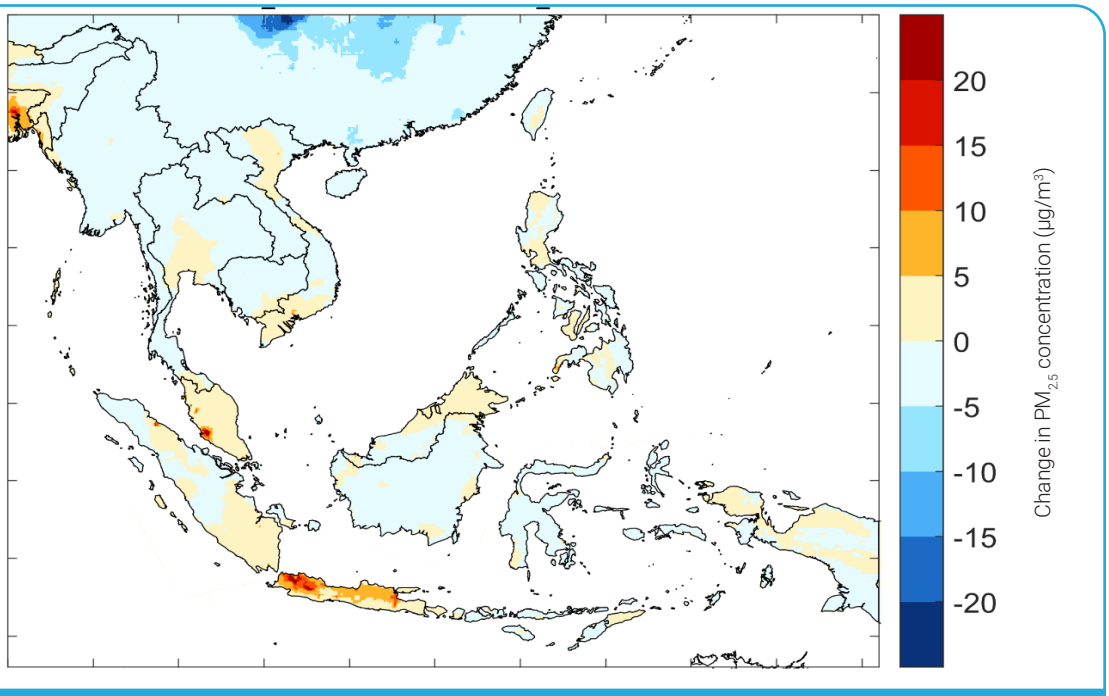


FIGURE 5. Change in $PM_{2.5}$ concentrations in the 2030 current legislation scenario compared to the concentrations calculated in 2015.

The finding that there is only a marginal impact of existing baseline policies actually holds across much of the region. As indicated in Figure 6, the exposure to $PM_{2.5}$ varies in ASEAN countries in 2015 and is expected to consistently increase for virtually all countries, except Brunei-Darussalam and Thailand (Figure 7). While the population exposed to levels beyond WHO Interim Target 1 levels increase, there is limited improvement, if any, in number of people living in areas where $PM_{2.5}$ levels are below 2021 WHO Air Quality Guideline or even the 2005 WHO Guideline; beyond increasing concentrations, also larger populations and continuing urbanization plays a role. The message that resonates most strongly from these findings is that there is scope for additional reductions and solutions that would deliver those benefits beyond the baseline.

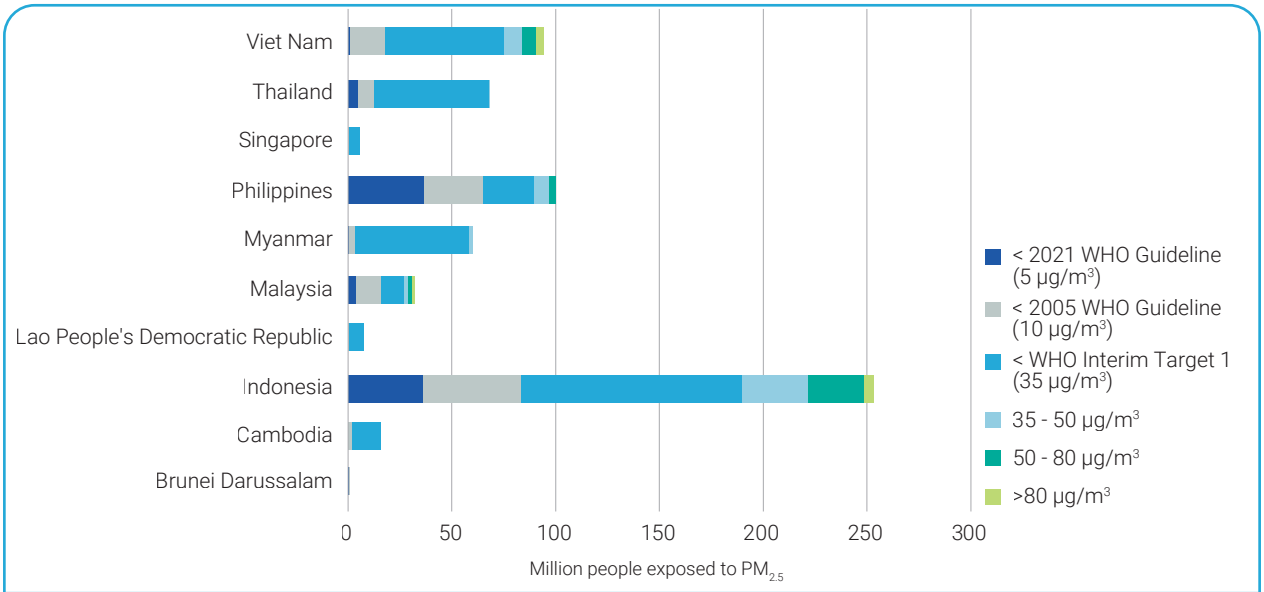


FIGURE 6. Population exposure to ambient $PM_{2.5}$ (excluding household pollution) in ASEAN region countries in 2015

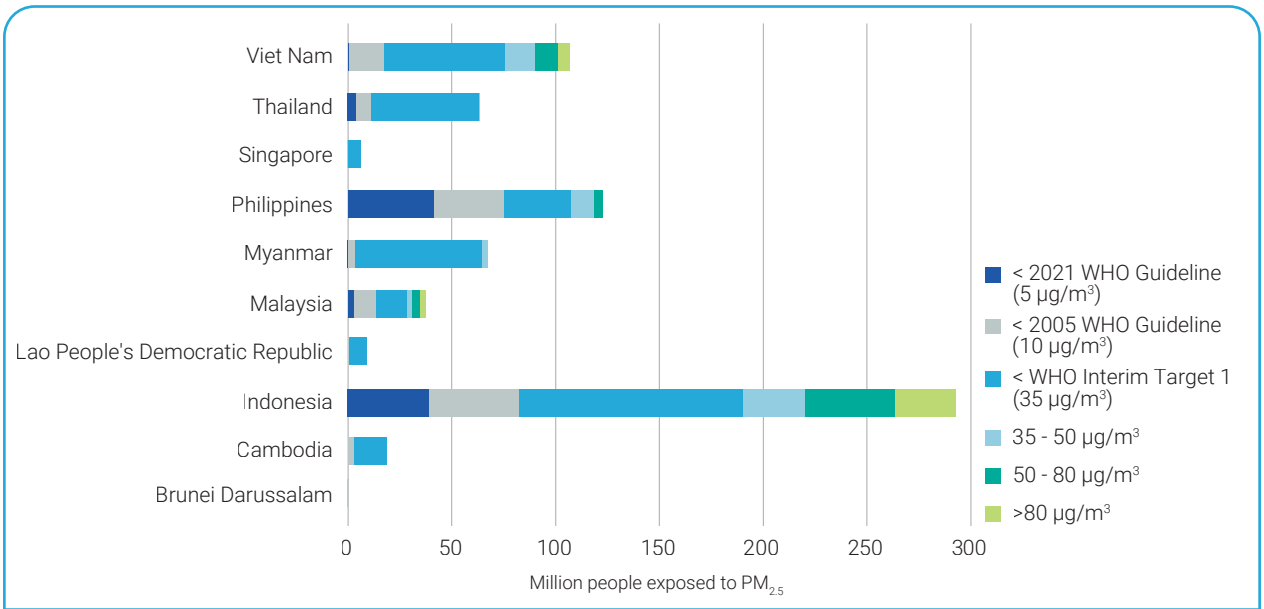


FIGURE 7. Population exposure to ambient $PM_{2.5}$ (excluding household pollution) in the ASEAN region countries in 2030, assuming successful implementation of current policies.

1.4 Identifying Clean Air Solutions for ASEAN

The next step is identifying clean air solutions for ASEAN. To take that next step, the report employs relatively intuitive selection criteria for possible solutions. The 15 measures are selected based on their potential to deliver the maximum reduction in population's exposure to $PM_{2.5}$ in the ASEAN subregion. Because the report is focusing on the subregional level, it was determined that it would be preferable to focus on a smaller, more tractable set of solutions than 25 measures featured in the larger *Asia Solutions Report*. Though smaller in number, the successful implementation of these solutions would still significantly improve air quality and health while having co-benefits for near- and long-term climate change from reductions in GHGs and SLCPs.

To determine which solutions met the selection criteria, several scenarios were constructed using past legislation and to identify future mitigation opportunities. Analyzing these scenarios allows for comparing changes in emissions and concentrations from past legislation (already committed and implemented), the most recent laws (published or announced after 2015), and finally to identify reduction potential from remaining measures. The following scenarios, beyond the Baseline or the CLE (current legislation) scenario (see section 2.1.2), were developed:

- **Implemented legislation** - no further control beyond the absolutely necessary pollution reductions to operate production processes. For example, electrostatic precipitators on large power plants (but of rather poor efficiency), cyclones or wet scrubbers on smaller industrial plants, and no control for transport sources or small combustion installations in the residential and industrial sectors. This scenario aims to replicate a hypothetical situation (from the current perspective) when regulatory processes of adapting and strengthening emission legislation would have stopped well before 2000. Comparing this emission trajectory to the Baseline allows to estimate the impact of the current legislation.
- **Recent legislation** - a scenario like the above but freezing air quality policy development in 2015 and assuming no further laws are introduced. Compared to the Baseline, this scenario allows to demonstrate the benefit of the most recent regulatory reforms.
- **Further potential** is estimated based on the following assumptions:

- Application of *lowest emission technologies*, assuming their full and effective application but considering the limits of technical feasibility. Compared to the *Solutions Report*, this report assumes that lessons learned in recent years in countries, where most ambitious air quality policy and emission standards were enforced, would result in increased market availability of high efficiency mitigation technologies across ASEAN. The greater market penetration, in turn, would allow to push the limits of low emission standards.
- *Consideration of non-technical measures*, i.e., measures that explore potential for further improvements in energy efficiency in different sectors, increasing the share of electric vehicles, accelerating access to clean energy for cooking, as well as achieving significant improvements in nitrogen use efficiency in agriculture, and dietary changes (e.g., lower meat protein consumption). The latter two options, nitrogen use efficiency and dietary changes, would have implications for livestock and crop production, resulting in changes to organic manure and mineral fertilizer application and thereby result in additional emission reductions. The potential for the first category of non-technical measures originates from the assessment and comparison of the IEA NPS scenario and the IEA Sustainable Development Scenario (SDS) that is designed to achieve CO_2 reduction consistent with the Paris Agreement targets (IEA 2018).

As mentioned previously, the scenario analysis for the ASEAN region suggests that existing legislation has been contributing to slower growth in air pollutants emissions and respective ambient concentrations, and that such trends would continue in the future. However, there are significant opportunities to mitigate emissions in the region. In fact, the modelling suggests that there are 15 key solutions that are particularly relevant for the ASEAN region and countries in the region (Table 1).

The 15 solutions offer mitigation potential across many sectors for which there is ample policy

TABLE 1. Description of key mitigation options associated with the identified 15 solutions

15 Solutions	Brief description
Clean cooking	Clean alternatives for traditional cooking including LPG stoves and higher efficiency solid fuel stoves incl. fan assisted stoves
Renewables, post-combustion controls	Consideration of potential for fuel switch and renewable energy and application of high efficiency flue gas cleaning technology in power plants and industrial boilers, including flue gas desulphurization, high efficiency dust removal.
Industrial Process standards, incl. energy efficiency	Improvements in process technology, more efficient capture and removal of process and fugitive emissions from industrial production.
Vehicle emission standards/electrification*	Introduction of more stringent emission limit values and energy efficiency standards for vehicles. Further potential is estimated assuming the immediate introduction of legislation requiring for new vehicles (road and non-road) the Euro VI/6 equivalent emission standards and/or accelerated electrification of fleet.
Vehicle inspection and maintenance	Introduction of stricter legislation requiring more frequent and enforced vehicle inspection and maintenance that will enable early recognition and elimination/repair of high emitting vehicles.
International shipping	Low sulfur fuel, i.e., 0.5 per cent S in heavy fuel oil with further reduction to 0.1%S, introduction of particulate filters and NOx Reduction Selective Catalyst Reduction (deNOX SCR) installations. Alternatively, flue gas desulfurization can be installed to achieve the same reduction of sulfur dioxide (SO_2) as when using low sulfur fuel.
Livestock and N fertilizer application	Control of ammonia emissions from livestock production and mineral nitrogen fertilizers application. Livestock measures include construction of new low emission housing, covered stores for manures, and efficient application of manures on land. For mineral fertilizers, emissions from urea application are addressed either by replacing urea with, for example, ammonium nitrate, improving urea application (proper timing and doses), and promotion of new formulations and urease inhibitors

TABLE 1. Description of key mitigation options associated with the identified 15 solutions

Dietary changes	Shift to less meat protein in diets resulting in lower numbers of livestock and lower mineral fertilizer use as well as improved use efficiency
Agriculture residue burning	Efficient enforcement or banning the open burning of agricultural residues
Waste management	Primarily addressing solid municipal waste management by reducing trash burning and introducing efficient waste collection and recycling schemes.
Prevention of forest, peatland fires	Improved forest, land and water management and fire prevention strategies. Enhance collaboration through ASEAN Agreement on Transboundary Haze Pollution.
Coal, oil and gas production and distribution	While most of the measures in fossil fuel extraction, processing, and distribution would reduce emissions of methane, there are some reductions of PM precursors (including BC) when routine flaring is reduced or banned as well as reducing tailing fugitive dust emissions from mining industry following reduced demand for coal in sustainable development scenarios.
Rice paddies	Encourage intermittent aeration of continuously flooded paddies. Established tradition of irrigation and drainage policy.
Wastewater treatment	Introduce well-managed two-stage treatment with biogas recovery. Promotion of decentralized wastewater treatment units.
HFC- refrigerant replacement	The Kigali Amendment to Montreal Protocol leads to reduced CO_2eq emissions of HFCs. Further measures are possible to reduce emissions beyond Kigali Amendment. Continuous efficiency improvements will also lead to reduced demand of electricity, consequently reducing CO_2 and air pollutants from the power sector.

* The future potential shown includes the potential scope for what accelerated electrification of vehicle fleet can achieve, i.e., most likely less than half of that could be achieved by electrification by 2030

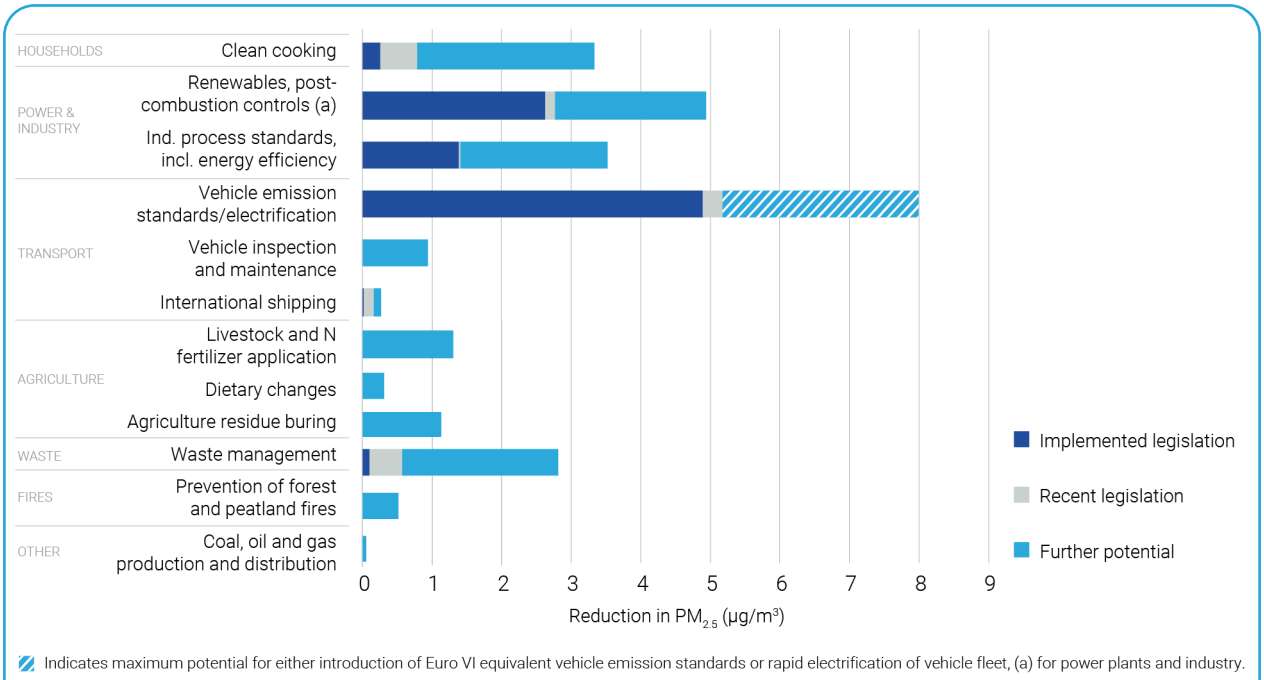


FIGURE 8. Impact of the priority solutions (measures with direct air quality benefits shown) on $PM_{2.5}$ concentrations in the ASEAN region by 2030

implementation experience to address emission sources (see also Chapter 3 of this report). In fact, modelling estimates show that nearly 40 per cent (20-60 per cent at the country level – see Annex 2 for country results) of identified potential is associated with existing legislation (Figure 8). This finding highlights the importance of effectively implementing air quality, energy efficiency, climate, and other relevant policies. Implementation includes building an enabling environment that supports enforcement and monitoring of progress.

Not surprisingly, many of the main solutions come from the "usual suspect" emission sources. These include transport and large-scale stationary combustion (power plants and industry). Transport, power, and industry account for more than half of the total potential associated with already implemented or recently announced legislation. At the same time, there is still significant mitigation potential that requires further action, including strengthening emission standards and steadily improving energy efficiency.

The transport sector (including road, non-road, and international shipping) is among the key sectors with further mitigation potential. That potential can be realized either through the introduction of tighter standards for new vehicles and/or promotion of electric vehicles. Additionally, the introduction of improved vehicle inspection and maintenance programs can capture emissions from malfunctioning vehicles (high-emitters); at least on paper, this is a rather affordable option compared to more expensive technologies needed on modern cars. International shipping offers modest opportunities in some countries. Though the overall impacts are modest, it is still it is an important measure, especially when considering air pollution levels in coastal communities (see Annex 2 for country results).

As with the Solutions Report (and other similarly focused analyses), clean cooking is among the most important interventions. The modelling analysis confirms its importance for the ASEAN region as a whole and especially for some countries (see Annex 2). However, partly due to recent policy progress, the potential is not as great as previous reports. Further, the impacts of this intervention would be greater if estimates included indoor as opposed to only ambient air pollution.

One of the areas that has seen the greatest growth in mitigation potential is not typically within the purview of air pollution policies: waste management. The potential air quality benefits from improved solid waste management are significant. Some of these benefits could be achieved by reducing the burning of residential waste—a practice that has become more common with changing consumption patterns. Additionally, efficient waste management including improved waste separation, collection, and recycling (including use of recovered gas for energy) would reduce methane emissions, an important SLCP.

Another sector that is not typically addressed by air pollution regulations but offers significant mitigation potential is agriculture. Agriculture sector emissions come from the open burning of crop residues and ammonia emissions from livestock production and mineral fertilizer that play an increasing role in formation of secondary PM. Most ASEAN countries have regulations forbidding the open burning of crop residues, unfortunately the observed reality (remote sensing) tells a different story, and the sizable potential for this source is reflected in the modelling.

While open burning of stubble is a well-known problem with well-known solutions (even though implementation can be challenging), there is far less experience in reducing emissions of ammonia from livestock and fertilizer use. Such experience is mostly limited to Europe. Given the lack of experience in ASEAN, the modelling extrapolates from this experience and available technology, and uses local data where possible to describe the structure of farming to determine the mitigation potential. To approximate the mitigation potential, the report estimates important mitigation potential via the introduction of not only control technologies, but also non-technical (behavioral) options. Specifically, we estimated the potential for reducing ammonia from improved nitrogen use efficiency, and promoting reduced meat protein in diets.

A final area that contributes to clean air is forest and peatlands management. This is a pressing concern on a seasonal basis and is clearly important for much of the region (see Annex 2)—though the modeling suggests its effects may be more limited when considering annual average

population weighted $PM_{2.5}$ concentrations at the country level.

For some of the solutions—notably the usual suspect sources (coal power plants, industrial combustion, transport, and solid fuel cooking)—there has been positive strides in controlling emissions in the region. Emissions reductions achieved through air quality legislation and efficiency improvements have, over time, brought significant air quality and health benefits. This is evident when looking at reduced exposure compared scenarios in which such policies were not introduced (Figure 9, left). This progress is especially pronounced in countries like Thailand, Viet Nam, and Indonesia where policies to reduce solid fuel use for cooking, strengthen emission limits standards for PM and SO_2 in the power sector, and gradually introduce EURO standards for new vehicles, avoided rapid increases in $PM_{2.5}$ concentrations in the past and will continue to do so in the future.

While this progress is commendable, it is not sufficient to protect the population from air pollution (see section 3 and Figure 10, 11, 12). The scope for greater reductions and related benefits is indicated in Figure 9 (right) introducing further measures (solutions) identified in this report would

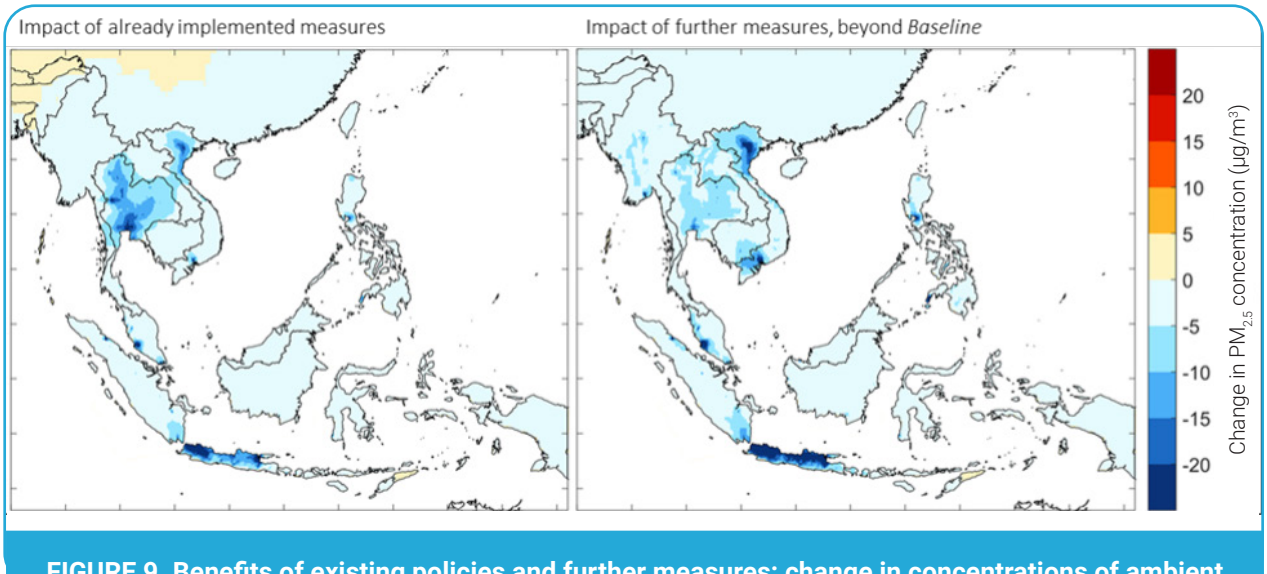


FIGURE 9. Benefits of existing policies and further measures: change in concentrations of ambient $PM_{2.5}$ in 2030 due to the introduction of air quality policies (assuming full enforcement of current legislation) compared to the pre 2000 policy situation (left) and due to the introduction of further mitigation measures, compared to the current legislation/Baseline (right).

bring further significant drops in exposure since estimates for several urbanized areas show a fall in $PM_{2.5}$ concentrations of up to 20 µg/m³.

In fact, the identified solutions have the potential to reduce population weighted $PM_{2.5}$ mean concentrations across the ASEAN region by nearly 75 per cent (Figure 10) and for most countries by 50 per cent to over 80 per cent by 2030 (Figure 11). Such ambitious reductions, considering the rather short time frame, would create the opportunity to achieve compliance with the 2021 WHO Air Quality Guidelines for about 35 per cent of the population living in the ASEAN region in 2030, i.e., over 250 million (Figure 12).

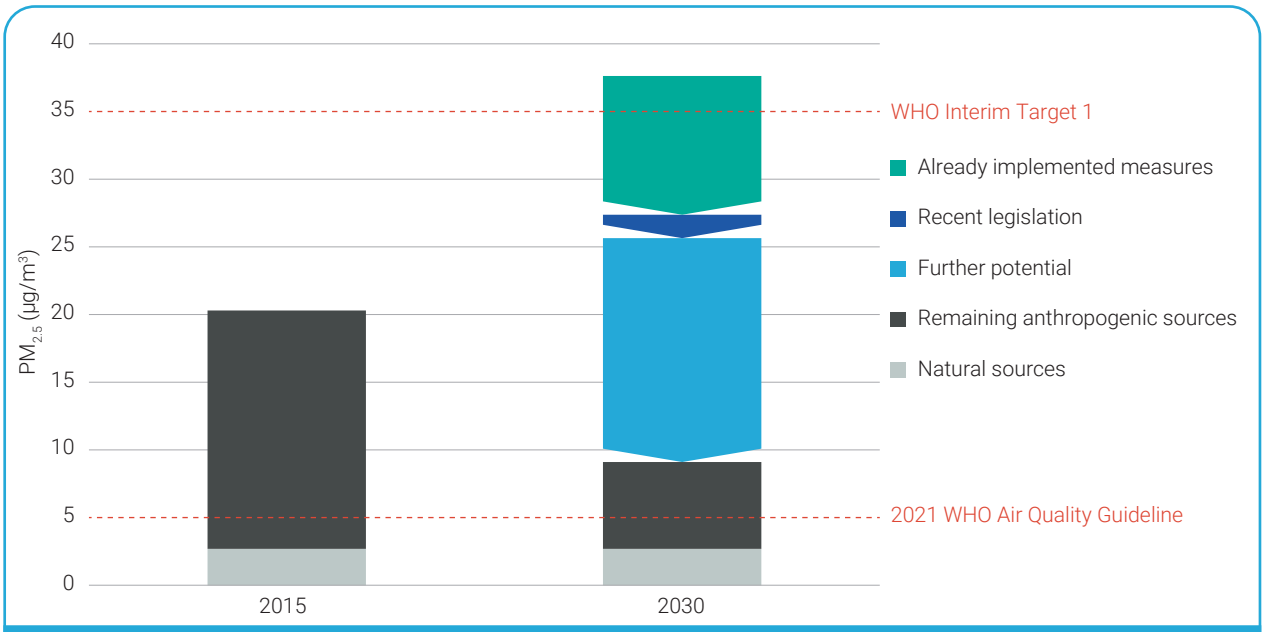


FIGURE 10. Contributions to reductions in population-weighted mean exposure to $PM_{2.5}$ in 2015 and 2030 in the ASEAN region

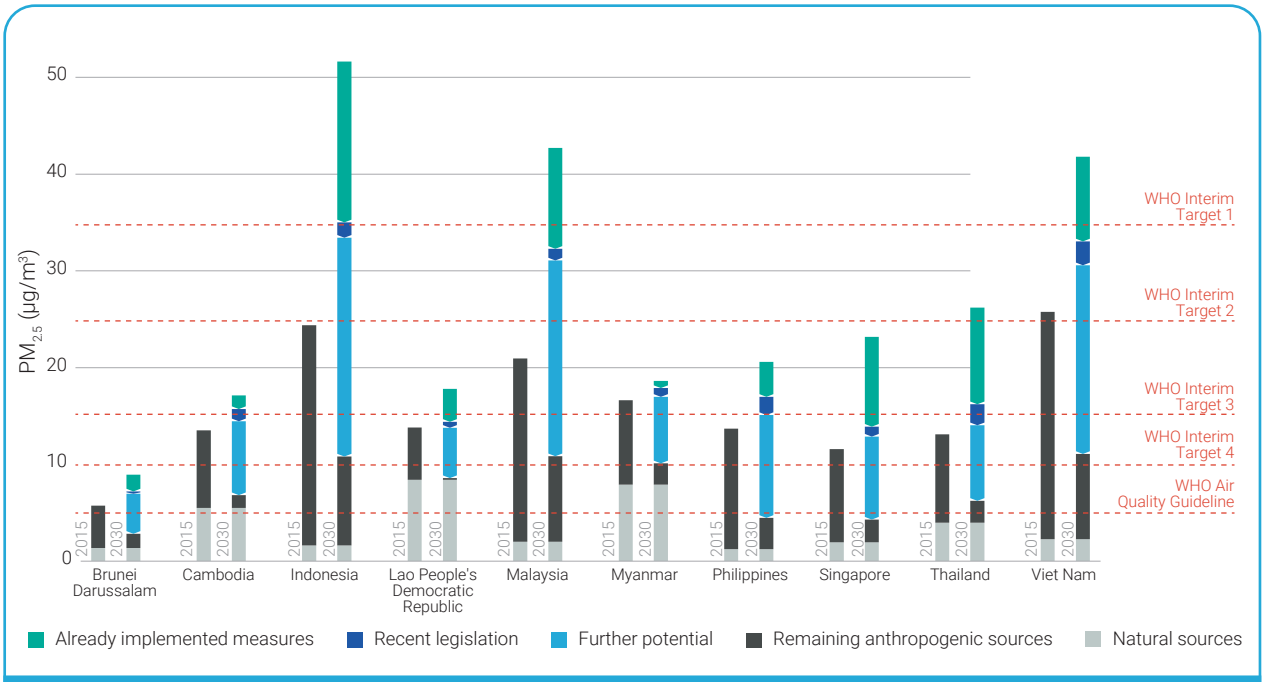


FIGURE 11. Contributions to reductions in population-weighted mean exposure to $PM_{2.5}$ in 2015 and 2030.

The overall impacts of the 15 clean air solutions cannot be overstated. Implementing the solutions could more than triple the population breathing 'clean air' ($PM_{2.5}$ less than 5 µg/m^3, consistent with current WHO guideline) in the ASEAN region, i.e., from about 80 million in 2015 or baseline scenario in 2030 to over 250 million in the scenarios where all solutions are effectively implemented (Figure 12). This would also mean that most of the population would live in areas complying with both national targets and WHO Interim Target 1 (see Figure 12 and Figure 13 for national results) and many countries would achieve more stringent WHO Interim Targets (Figure 11). Annex 4 provides also illustration of population shares exposed to different levels of $PM_{2.5}$.

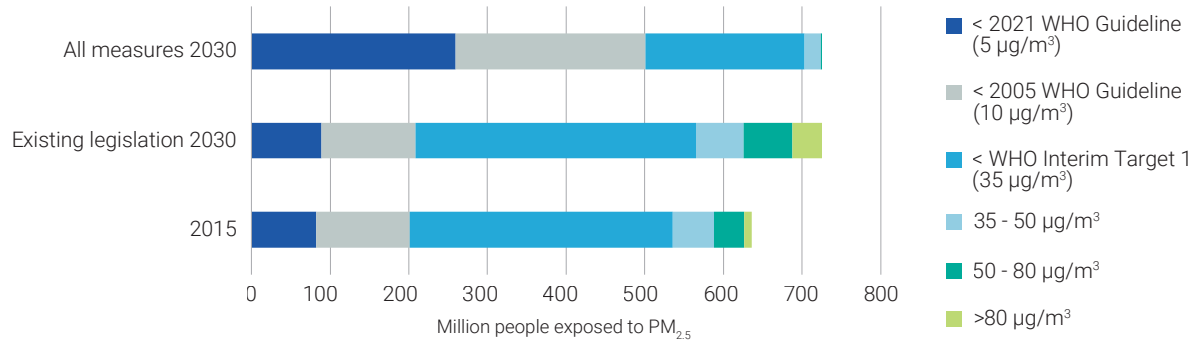


FIGURE 12. Population exposure to $PM_{2.5}$ in 2015 and 2030 different scenarios

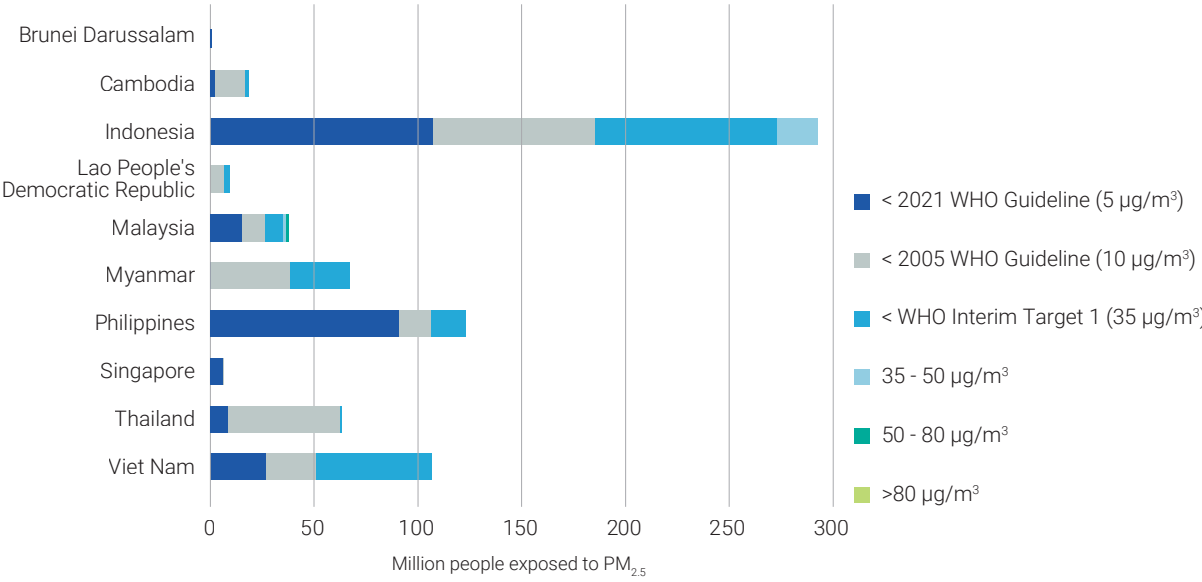


FIGURE 13. Population exposure to ambient $PM_{2.5}$ (excluding household pollution) in the ASEAN region countries in 2030, assuming successful implementation of all solutions identified in this report

There, in fact, many benefits from accelerating and strengthening implementation of the 15 solutions. Recent work on slightly smaller subset of 12 solutions for Cambodia, Indonesia and Thailand supported by UNEP has begun to estimate the size of benefits for economic development. In so doing, that project has underlined that there are actually significant costs to inaction. The same project is also planning concrete implementation activities in coordination with government partners based on this more complete analysis of costs and benefits (see Box 2 for a review of the project and related work on costs and benefits of specific interventions).

BOX 2: The costs of inaction of tackling air pollution and climate change in Southeast Asia

Assessing the costs of *not* acting on air pollution is one approach to understanding, prioritizing and communicating different mitigation options. As part of a UNEP project funded by the United Nations Development Account, the International Institute for Applied Systems Analysis (IIASA) developed national assessments in 2022 of the 'costs of inaction' of tackling air pollution in three Southeast Asian countries – Cambodia, Indonesia and Thailand. The assessments were developed through cooperation with The Ministry of Environment in Cambodia, The Ministry of Health in Indonesia, and The Ministry of Natural Resources and Environment in Thailand. Using 12 of the 15 solutions identified in this report, each assessment compared a baseline scenario–in which no new policies are introduced - with alternative future mitigation scenarios in which a bundle of new measures are implemented. The analysis employed the Greenhouse gas – Air pollution Interactions and Synergies (GAINS) model, which was extended to include additional health endpoints, impacts on workforce and their respective costs. The results give an approximate quantification of the economic costs related to morbidity and mortality that would be incurred if further mitigation actions are not taken.

Some of the key findings this work suggest that the costs of delays, considering health impacts from air pollution exposure, can be significant. For instance, in the case Cambodia an initial assessment suggests that delays can result in costs that are comparable to over 2% of GDP. Meanwhile, for Indonesia a similar calculation reveals postponing implementation of the 12 key solutions could result in losses equivalent to nearly 2% of GDP. Finally, results from Thailand tell a similar story: policymakers are confronted with health-related costs that are equivalent to nearly 1% of GDP in the face of delays. The main message that comes from this work is that there are not only sizable costs from waiting, but appreciable benefits from stronger and quicker implementation.

The above message is also consistent with studies focused on benefit and cost ratios for specific sectoral interventions. For instance, rigorous analyses of inspection and maintenance in programmes for vehicles in Bangkok, Thailand have shown that the benefits outweigh costs of effective implementation of this intervention (Li and Crawford-Brown 2011). Studies have also shown positive benefit-cost ratios for a range of clean cooking and residential energy interventions that would help clean the air, mitigate climate change, improve health, and improve gender equity (Jeuland and Tan Soo 2016).

1.4.1.1 Importance of Regional and International collaboration

Air pollution knowns no boundaries; fine particulate matter remains in the atmosphere for long enough to travel far from the emission source; secondary PM can travel even farther. In many contexts, regional and/or international collaboration has achieved significant and cost-effective reductions in air pollutant concentrations. This has been demonstrated in Europe and beyond, and recent studies show the necessity of coordinated action across larger regions. The ASEAN region is no exception, even though some countries are separated by ocean. In fact, there has already been notable progress in the region with the ASEAN Agreement on Transboundary Haze Pollution.

Modelling results indicate that there may be significant air quality benefits from sharing experiences and collaborating on some of the 15 solutions. The benefits of collaboration vary across countries (Figure 14), but are present everywhere across the region. Further, the benefits go well beyond air quality and may include: experience and technology exchange, creating new jobs and market opportunities, and contributions to climate goals and other SDGs. Perhaps most critically, the chief gains of increased collaboration could shift narratives about casting blame for emitting air pollution to capturing benefits from controlling it.

Figure 14 shows example results for two countries where the estimated impact of local and regional mitigation is important but differs for some sectors. Based on the calculations, Cambodia benefits primarily from actions reducing emissions in Cambodia while Laos benefits most from cooperation and action that achieves reductions in neighbouring countries, except in the case of forest fires where prevention and management of emissions from own domestic actions are decisive for both countries.

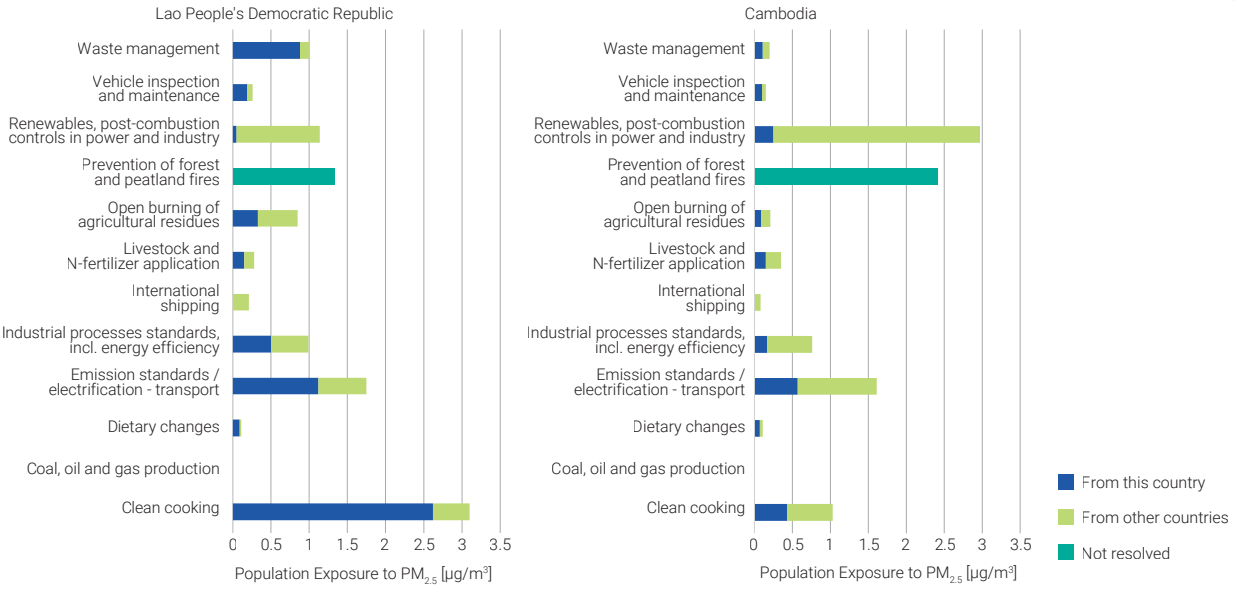


FIGURE 14. Impact on population weighted exposure to $PM_{2.5}$ in 2030 from implementation of 15 solutions in ASEAN discriminating between the contribution from local and remote/transboundary sources; example for two countries (see Annex 3 for all country results).

1.4.1.2 Climate Co-benefits from Clean Air Solutions

The 15 solutions focus on achieving improvements in air quality, primarily reducing concentrations of ambient $PM_{2.5}$. It nonetheless merits highlighting that air pollutant sources are often the same as of GHGs, and that some air pollutants are also SLCPs. Therefore, there are significant climate co-benefits from air quality policies. In the past, important black carbon (BC) and methane reductions were due to the gradual strengthening of PM emission standards for stationary power and industry combustion sources, transport (particulate filters), energy efficiency measures, and efforts to reduce reliance of solid fuels for cooking. This impact is shown in Figure 15 as 'already implemented' policies with BC reduced by a considerable fraction. The introduction of policies promoting the implementation of the 15 solutions would bring a greater reduction of black carbon (-70 per cent compared to the baseline) by 2030 and consequently additional climate benefits. Emissions of methane would decline by about 9 per cent, compared to the baseline through measures with clear ambient PM benefits; this would increase to about 39 per cent with measures primarily targeting methane, i.e., leaks in the fossil fuel industry, rice production, wastewater treatment, and livestock (Figure 15).

Implementation of these measures implies transformational changes towards sustainable development compatible with Paris Agreement goals and therefore include reduced fossil fuels use and efficiency improvements. These transformational measures would consequently lead to a reduction of CO_2 emissions by an estimated 25 per cent by 2030. Annex 5 shows impact of full implementation of 15 solutions on all analyzed pollutant and GHG species on total and sectoral emissions in the ASEAN region.

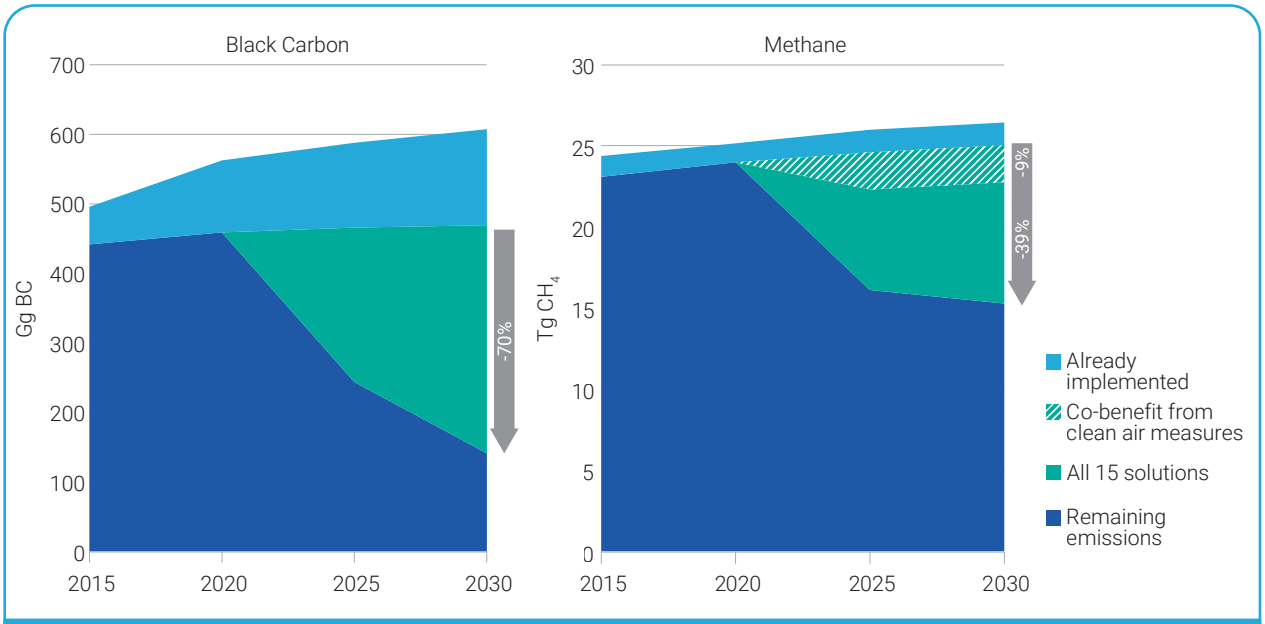


FIGURE 15. Co-benefits of introduction of air quality policy and 15 solutions on SLCP emissions: black carbon (BC) and methane (CH_4)

Finally, mitigation opportunities for F-gases were revisited and estimated for the ASEAN region (Figure 16). The implementation of low-GWP alternatives under the Kigali Amendment (KA) to the Montreal Protocol offers a mitigation potential of nearly 70 million tonnes (Mt) of CO_2eq by 2030. Further technical mitigation potential was identified that would allow to increase reduction to about 112 Mt CO_2eq. Importantly, a transition to low-GWP alternatives offers a significant potential to further reduce CO_2 emissions if energy efficiency improvements in stationary cooling technologies could be simultaneously achieved (Purohit et al. 2020). Fully realizing the technical potential for energy efficiency improvements could bring electricity savings of more than 25 per cent of ASEAN's entire future electricity consumption by 2050. Even by 2030, electricity savings could reach 10 per cent, and bring about estimated reductions of 225 million tonnes CO_2. If energy efficiency improvements were limited to economically profitable applications (economic potential in Figure 16), electricity savings in cooling could still make up over 6 per cent and 15 per cent of future electricity consumption in 2030 and 2050. This would, in turn, result in CO_2 reductions of about 133 and 555 million tonnes (Figure 16). Prioritizing the reduction of fossil fuel electric generation capacity would bring additional air quality benefits (Purohit et al. 2020).

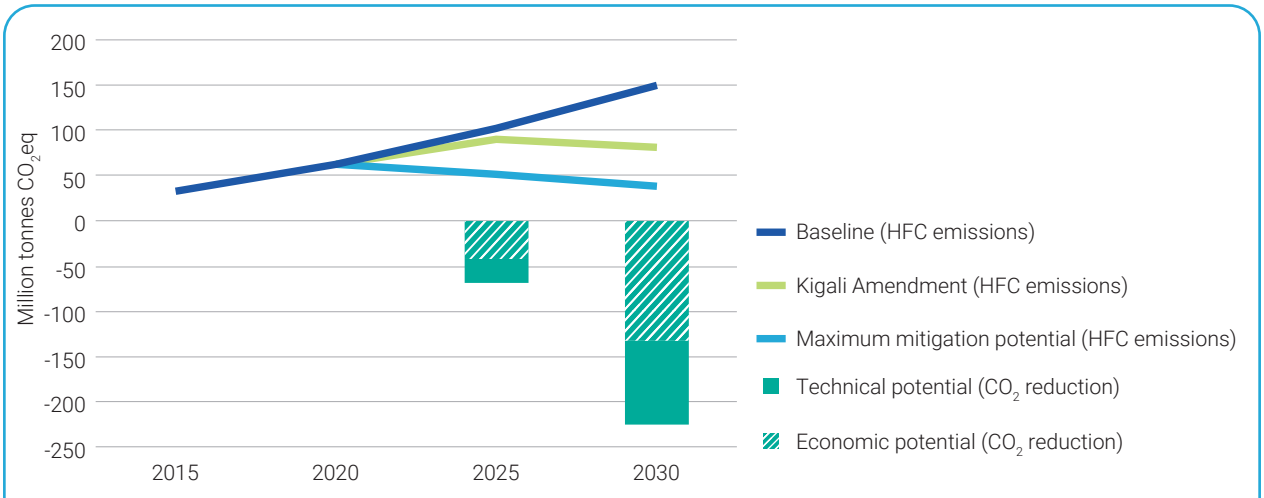


FIGURE 16. HFC emissions and CO_2 mitigation potential due to energy efficiency improvements in stationary cooling technologies. The estimates for ASEAN rely on the methods and data from Purohit et al. (2020). Economic mitigation potential (associated with energy efficiency improvements and resulting CO_2 reduction) refers to economically profitable applications.

1.5 SUMMARY OF FINDINGS

In this chapter, the GAINS model was used to indentify 15 clean air solutions for ASEAN. The 15 solutions were selected based on their potential to lead to maximum reduction in population exposure to $PM_{2.5}$ and emissions of SLCPs in ASEAN. Implementing the 15 solutions could more than triple the population breathing 'clean air' ($PM_{2.5}$ less than 5 µg/m^3) in the ASEAN region, i.e., from about 80 million in 2015 or baseline scenario in 2030 to over 250 million. This would also mean that most of the population would live in areas complying with both national and the WHO interim Target 1 standards.

The solutions can also reduce population weighted $PM_{2.5}$ mean concentrations across many countries by 50 per cent to over 70 per cent, allowing for over third of the ASEAN region population compliance with the 2021 WHO air quality guidelines by 2030.

Implementing the 15 solutions would also result in important climate co-benefits due to reduction of SLCPs, including black carbon (-70 per cent), methane (-39 per cent), HFCs (-75 per cent), ozone and CO_2 (-25 per cent); all reductions refer to 2030 and are compared to the baseline. Additional opportunities exist to reduce electricity consumption of stationary cooling technology when transitioning to low-GWP alternatives to comply with the Kigali Agreement – these could amount to 6-9 per cent of total electricity consumption in the region in 2030 translating into significant CO_2 reduction and additional air quality benefits if fossil fuel electric generation capacity reduction is prioritized.

Importantly, the 15 solutions come from many sectors for which there is ample experience with implementation in ASEAN and other regions. The estimates show that nearly 40 per cent (20-60 per cent at the country level) of identified potential is associated with existing legislation. This finding highlights the importance of continuing to strengthen implementation of existing air pollution, energy, climate, and other sectoral policies.

The full benefits of 15 solutions could be achieved if implementation is widespread across the ASEAN region. This highlights the need and benefits of country cooperation, including experience and technology exchange and the harmonization of regulations and other efforts.

The next section looks at experiences with implementation, reviews potential challenges to achieving the full range of benefits from the solutions, and outlines how these challenges can be overcome.

2 Implementing Solutions in Southeast Asia

2.1 Introduction

Chapter 1 drew upon the GAINS model to identify priority measures that could significantly reduce exposure to $PM_{2.5}$ in Southeast Asia. The modelling shows that effectively implementing the 15 measures could enable about 250 million people to breath clean air, boost food security, and advance progress on several Sustainable Development Goals (SDGs) (particularly SDG 3, 11, and 13; Table 2) (Elder and Zusman 2016). Less evident in the modelling but just as important on the ground is that implementing the measures could also narrow equity gaps and improve the livelihoods of women girls (see Box 3 for the gender impacts of air pollution).

TABLE 2. Contribution of the identified 15 solutions to the Sustainable Development Goals

	Goal 1: No Poverty	Goal 2: Zero Hunger	Goal 3: Good Health and Well-being	Goal 4: Quality Education	Goal 5: Gender Equality	Goal 6: Clean Water and Sanitation	Goal 7: Affordable and Clean Energy	Goal 8: Decent Work and Economic	Goal 9: Industry, Innovation and Infrastructure	Goal 10: Reduced Inequality	Goal 11: Sustainable Cities and Communities	Goal 12: Responsible Consumption and Production	Goal 13: Climate Action	Goal 14: Life Below Water	Goal 15: Life on Land	Goal 16: Peace and Justice Strong Institution	Goal 17: Partnerships to active the goal
Clean Cooking	✓		✓		✓		✓		✓				✓				
Post-combustion controls			✓				✓		✓						✓		
Industrial Process Standard			✓				✓		✓		✓	✓	✓		✓		
Emission Standard-transport			✓			✓	✓				✓		✓		✓		
Vehicle inspection and maintenance			✓				✓		✓		✓	✓	✓		✓		
Maritime Shipping			✓				✓						✓	✓			✓
Livestock and N fertilizer													✓	✓	✓		✓
Dietary Change											✓	✓	✓				
Agriculture residue burning			✓						✓		✓		✓		✓		✓
Waste Management			✓			✓		✓	✓		✓	✓	✓	✓	✓		✓
Prevention of forest, peatland fires													✓		✓		✓
Coal, oil and gas production							✓		✓			✓	✓				
Rice paddies			✓			✓						✓	✓		✓		
Wastewater treat ment			✓			✓	✓						✓				
Controlling F Gases							✓					✓	✓				

BOX 3: The gender impacts of air pollution and climate change

As with many parts of the world, the effects of air pollution and climate change are not gender neutral in Southeast Asia. Unfortunately, women often tend to bear an unequal share of these impacts. This is partially attributable to lifestyles and traditions that expose women and girls to higher levels of air pollution and climate risks. It is also due to norms and institutions that limit women's ability to own land or businesses that would help build resilience to air pollution and climate crises. At the same time, there is also a growing recognition that women and girls are not passive victims to air pollution and climate change. They can also be part of the solution to often related air pollution and climate challenges. A concrete of example of how they became part of the solution involved a project in Viet Nam that helped women build businesses that constructed biodigesters that were good for the air and the climate (Lee and Zusman 2019).

The above example underlines a more general point. Gender responsive solutions need to be put in place to reduce the impacts of climate and air pollution risks on women. Ensuring women are actively shaping, co-designing and influencing decision making processes involving air pollution and climate change can help ensure that their perspectives, needs and experiences are represented in relevant solutions. It can further ensure gender responsive interventions are included in policy discussions and decision-making processes, and that implemented solutions reduce gender inequality.

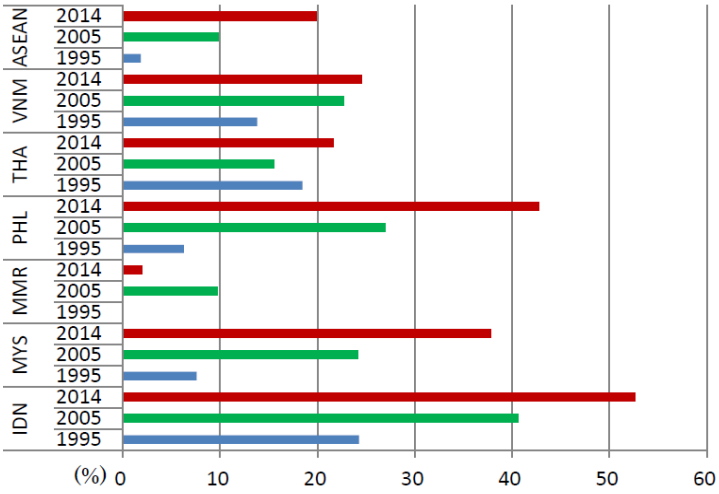
The 15 priority solutions will, however, not be implemented by themselves. They require the concerted efforts of policymakers and other stakeholders, at different levels of decision making, to support their uptake and spread. Though "implementation gaps" have frustrated progress on many of these measures, the main message from this chapter is that implementation is eminently doable. Not only have countries in ASEAN adopted a wide range of the measures outlined in the previous chapter, but there is growing knowledge of how to overcome some of the hurdles to implementation. Even more encouraging is that there is significant scope for countries, cities, and communities to share successes and capture the multiple benefits of collaboration on clean air.

Chapter 2 is divided into two related parts (beyond this introduction). The first part of the chapter reviews 10 key sectors or thematic areas covering the 15 priority solutions in ASEAN; for each of those areas, it highlights regional variation, implementation challenges, and ways forward. The second part highlights some of the governance, finance and other enabling reforms that could help strengthen implementation and spread success.

2.2 Implementing Solutions in ASEAN—Options, Challenges and Ways Forward

2.2.1 Energy

Reducing emissions from the energy sector, especially coal-fired power plants, is a fast-growing concern in Southeast Asia. The concern has become more salient as parts of the region appear primed to increase their reliance on coal (Figure 17) to boost electrification rates and enhance energy security even as pressures to divest from coal and adopt net zero targets pull in competing directions (Clark et al. 2020; Kurniawan et al. 2020). There is also variation in how countries in the region intend to manage these competing forces. Part of that variation is related to different natural resource endowments and development levels—for example, small developed countries in Southeast Asia such as Malaysia appear more inclined to transition from coal faster than other parts of the region (Morikawa et al. 2021)



IDN – Indonesia, MMR – Myanmar, MYS – Malaysia, PHL – Philippines, THA – Thailand, VNM – Viet Nam. Source: International Energy Agency (2016), World Energy Balances

FIGURE 17. Share of coal-fired power generation in selected ASEAN countries.

There are further differences in air quality and emissions standards (Table 3), enforcement capacities, capacity to plan and coordinate emission reductions, regulatory sanctions (fines, shut down orders, and imprisonment for violations), public disclosure requirements, and reporting and monitoring protocols that will have implications for how countries manage energy-related emissions (Motokura et al. 2017). To some extent, this variation is reflected in the solutions that countries choose to adopt. While many countries install end-of-pipe emission controls to existing and more conventional power plants, advanced coal technologies (efficient ultra-supercritical (USC) coal power plants and integrated coal gasification combined cycle (IGCC)) and shifting to natural gas and renewables are gaining traction in the region (Ali et al. 2021; Morikawa et al. 2021)

TABLE 3. Emission standards for new coal fired power plants in selected countries. Source: compilation by authors.

Country	SOx	NOx	PM
Australia	SO_3:200 mg/m^3	NO_2:800 mg/m^3	80 mg/m^3
Germany	SO_x:150 mg/m^3	NO_x:150 mg/m^3	10 mg/m^3
Japan	SO_x:50 mg/m^{3*} (SO_2:133 mg/m^3)	NO_x:200 mg/m^3 (NO_2:383 mg/m^3)	100 mg/m^3
Republic of Korea	SO_x:50 mg/m^3 (SO_2:133 mg/m^3)	NO_x:50 mg/m^3 (NO_2:96 mg/m^3)	10 mg/m^3
United States of America**	SO_2:130 ng/J	NO_2:88 ng/J	11 ng/J
Cambodia	SO_2:500 mg/m^3	NO_2:1000 mg/m^3	400 mg/m^3
Indonesia	SO_2:750 mg/m^3	NO_2:750 mg/m^3	100 mg/m^3
Lao People's Democratic Republic	SO_2:320 mg/m^3 (SO_2:853 mg/m^3)	NO_2:350 mg/m^3 (NO_2:670 mg/m^3)	120 mg/m^3
Malaysia	SO_x:500 mg/m^3	NO_x:500 mg/m^3	50 mg/m^3
Myanmar	SO_x:500 mg/m^3	NO_x:400 mg/m^3	50 mg/m^3

TABLE 3. Emission standards for new coal fired power plants in selected countries. Source: compilation by authors.

Philippines	SO_2:700 mg/m^3	NO_2:1000 mg/m^3	150 mg/m^3
Singapore	SO_2:1700 mg/m^{3***}	NO_2:700 mg/m^3 NOx: 400 mg/m^{3****}	50 mg/$m^{3******}$
Thailand	SO_2:180 ppm (SO_2:480 mg/m^3)	NO_2:200 ppm (NO_2:383 mg/m^3)	80 ppm
Viet Nam	SO_2:500 mg/m^3	NO_2:650 mg/m^{3*****}	200 mg/m^3

PM=particulate matter SO_x=sulfur oxides SO_2=sulfur dioxide NO_x=nitrogen oxides NO_2=nitrogen dioxide mg/m^3 =micrograms per cubic meter ppm=parts per million N/j=nanograms per joule

* Based on coal fired power plant location, sulfur content of the fuel, stack height etc. The standard varies based on the power plant. The value is an example of a specific plant based on an agreement between a plant and a local government.

**Gross output
***Applies to new power plants with sulfur content of coal applied upstream.
****This is for new plants; existing plants are to comply with 700 mg/m^3 until July 2023.
*****Coal volatile output >10%
******This is for new plants; existing plants are to comply with 100 mg/m^3 until July 2023.

Despite this variation and some traction, there are some common challenges to the uptake and spread of emissions controls (Motokura et al. 2017). In addition, as many countries rely on local governments to support enforcement of regulations and inspections, human resource and financial capacity shortfalls can be a challenge (Ha-Duong et al. 2016; Motokura et al. 2017). Finally, especially when it comes to the spread of renewables, some of the technical challenges such as the access to electricity can combine with previously mentioned subsidies to lock in fossil-fuel intensive development paths.

There are nonetheless some encouraging signs from the region that these challenges can be overcome. Part of the reason for this optimism is that countries are becoming more adept at responding to and harnessing public pressure. This is reflected in formal regulations such as requirements in Thailand that regulatory officials meet once every three months with communities residing near coal fired power plants to understand and address concerns that could curb emissions (Motokura et al. 2017) (Box 4), while civil society groups in countries such as Viet Nam advocate for clearer understanding of the socio-economic impacts of coal that could also generate calls for stronger emission controls (Ha-Duong et al. 2016). Other encouraging signs involve regulatory statutes that have seen local governments in countries such as Cambodia and Lao PDR agree upon stronger emission standards for power plants, with agreements on standards for individual power plants that are more stringent than existing national standards (Motokura et al. 2017). Additional positive signs include increased finance from international and regional development banks to scale up finance for renewables and plans to motivate countries in Southeast Asia to retire coal-fired power plants early, with use of an energy transition mechanism (Brown and Hauber 2021). Further, there may be growing support for decentralized renewables in countries such as the Philippines due to challenges with extending the electricity grid and concerns about investing in potentially stranded fossil fuel assets (Clark et al. 2020). In addition, countries such as Indonesia have reduced fossil fuel subsidies with targeted efforts to offset increased energy prices on the poor and improve public communication around these efforts (Burke and Kurniawati 2018). Many of these policies are reflected in the nationally determined contributions (NDCs) from countries in the region (Viet Nam 2020).

BOX 4: Regulating Air Pollution in Thailand: Progress and Opportunities.

Thailand has several plans and acts that control air quality and emissions. Some of the laws specific to air quality involve a variety of actions and actors like the 1992 National Environmental Quality Act. This act requires, inter alia, 23 specific project types such as dams, airports, mass transit infrastructure, power plants and industrial estates require an Environmental Impact Assessment (EIA) or an Environmental Health Impact Assessment (EHIA). Thailand has quite a few regulatory success stories involving collaboration of governmental and non-government actors. One such story is the two-stroke motorbike phase out that involved the cooperation of private sector motorbike makers and dealers and led to a 100% phase-out of high polluting two-stroke engines in motorbikes.

There has been some discussion of making air pollution regulations even more effective. Since the issue of air quality involves various sources of pollutants from different sectors, some discussion has centered on creating a national regulatory body with the overarching power to address all types of air pollutants and coordinate the action of different ministries. Positive steps have been taken towards creating a stronger overarching air quality policy, with groups such as the Thailand Clean Air Network and the Thai Chamber of Commerce submitting draft Clean Air Acts to Parliament for debate (Nikam et al. 2021).

2.2.2 Industry

For many countries in ASEAN, emissions from pollution- or energy-intensive industries have moved up environmental policy agendas. This is particularly true given the migration of some of these industries from other parts of Asia—especially China—to Southeast Asia (Pappas et al. 2018). Some of the largest air pollution emitters in Southeast Asia come from large-scale heavy industries, including steel, chemical and petrochemicals. Though large-scale sources are important in some parts of ASEAN, for most countries in the region, micro and small medium enterprises (MSMEs) constitute more than 90 per cent per cent of operations and are relatively more challenging to regulate due to their smaller size and diffusion.

Not only do MSMEs make up a significant share of the industrial sector, they also exemplify another point related to industrial emissions: namely, significant variation exists across the region in type of MSMEs. Countries such as Malaysia have a larger focus on the service sector while other countries concentrate on small-scale industries. There are also considerable differences in the pollution and energy intensity of similar industries in the region. Indonesia, for example, has higher energy intensity industries related to chemical, petrochemical, textile, and leather production than Thailand; on the other hand, Thailand has higher energy intensity industries focusing on in paper, pulp and the print industry than Indonesia (Pappas et al. 2018).

Solutions to reduce emissions from both large and MSMEs are well known in most of Southeast Asia. These include industrial process standards that boost end-of-pipe emissions capture efficiency end-of-pipe and make production processes more energy efficient. There are nonetheless equally well understood barriers to the uptake and spread of these solutions. This includes the size of some industries and the fact regulatory agencies may lack the staff and resources to consistently police enforcement and implementation. Similarly, many owners of these industries lack the initial capital to invest in end-of-pipe controls or more efficient technologies.

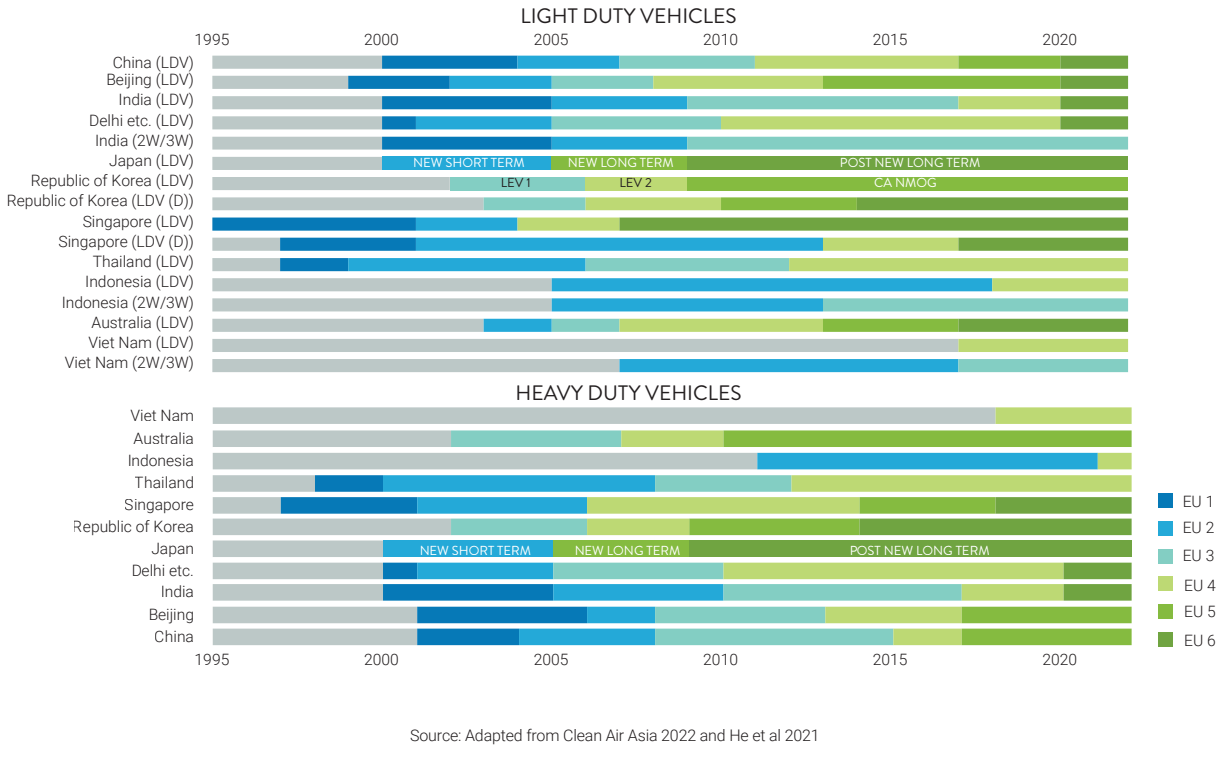
Countries in Southeast Asia have nonetheless exhibited creativity in surmounting these challenges. Indonesia, for instance, has implemented its PROPER programme for many years that publicly display color-coded scores based on industries' compliance with environmental regulations. The sharing of these scores with the public is intended to generate pressure on industries to comply with regulations while reducing some of the burden on regulatory agencies to consistently monitor emissions (Afsah et al 2013). Another visible trend in the region is to strengthen the integration with

pollution control and energy efficiency policies and programs. Thailand, for example, has used a wide range of energy policy reforms such as labelling and innovative finance schemes to provide incentives for industries to improve efficiency, save energy, and cut pollution (Chotichanathawewong and Thongplew 2012). Finally, there appears to be scope for enhanced awareness raising and technical support for MSMEs; studies from the Philippines of small businesses show that an "entrepreneurial strategic orientation [can lead to a] more proactive stance toward environmental sustainability practices… [and] superior firm performance" (Roxas et al. 2017).

2.2.3 Transport

The most straightforward approach to cutting emissions from motorized vehicles is strengthening emissions standards. As illustrated in Figure 18, several countries in Southeast Asia have steadily tightened standards for light and heavy-duty vehicles, placing several countries on a trajectory to achieve Euro 6 standards (He et al. 2021). Figure 18 also underlines that for some countries tightening standards for two- and three-wheel vehicles is a critical emissions reduction strategy. Two and three wheelers account for between 50 per cent to 90 per cent of the vehicle fleet in several of the most motorized countries in Southeast Asia (ASEAN-Japan Transport Partnership 2013).

Though strengthening standards seems straightforward, it can be more difficult than appearances suggest—and may explain why some countries in Southeast Asia have yet to adopt Euro



Source: Adapted from Clean Air Asia 2022 and He et al 2021

FIGURE 18. Vehicle emission standards in selected countries and cities.

standards. Part of the challenge is fuel quality. Complying with Euro 3 standards or above requires low or ultra-low sulfur fuels that are in limited supply in much of the region. Lowering sulfur from fuel supply requires sizable investment in refineries to remove sulfur from fuels to required levels (Owen and Tao 2016). This can be further frustrated by fossil fuel subsidies that reduce incentives for refineries to shift to higher quality fuels.

Some countries have nonetheless made strides to overcome these challenges. For example, Cambodia is now considering adopting Euro 3 standards. Meanwhile, countries like Indonesia have gradually made investments in improving fuel quality which will facilitate a transition to more stringent standards. Finally, several countries have seen an increase in investments in electric vehicles and supporting infrastructure as part of a broader effort to electrify their own transport sector while also positioning domestic vehicle manufacturers to capitalize on shifting market trends (Schröder et al. 2021).

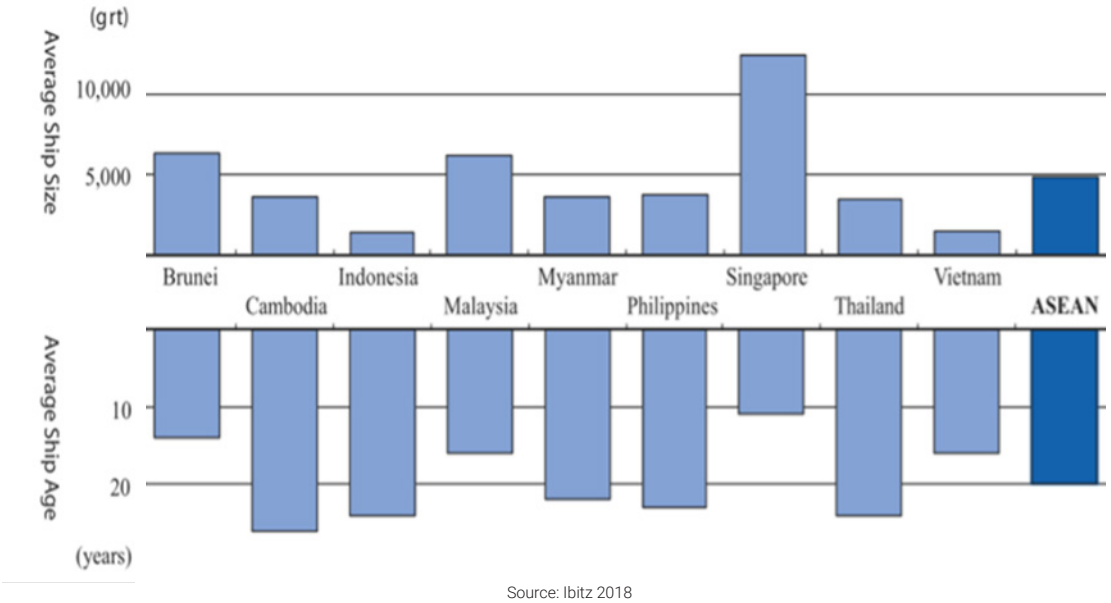
An effective inspection and maintenance program (I&M program) is essential to achieving significant reductions in emissions from the transport sector. It is critical because in many cases between 5 per cent to 10 per cent of the total vehicle fleet is responsible for between 50 per cent to 80 per cent of total vehicle emissions. This small proportion of vehicles are known as 'super-emitters' because of their outsized influence on emissions levels and air quality. In most cases, super-emitting vehicles tend to be older and have not been repaired for significant periods. Regular inspections and maintenance with appropriate repairs and removal from the vehicle fleet can rectify this problem. Studies have shown that such programmes can be cost effective in parts of ASEAN. To illustrate, studies have suggested that in the Bangkok Metropolitan Administration an annual investment of 147 million US dollars (year 2000 US dollars) would be much smaller than the total economic benefits (from reduced air pollution and improved health) of effective I&M programs for diesel vehicles and motorcycles (Li and Crawford-Brown 2011).

The effective implementation of I&M programs can be challenging. Some of the challenges are technical in nature. For instance, the type of testing equipment needs to be consistent with actual driving conditions and some inspection equipment (filter type smoke meters) lend themselves to tampering. Other issues involve driver behavior. Because the results of the I&M programs can lead to costly repairs, there is a natural inclination to evade the inspection and maintenance process. This can be particularly difficult because often the vehicle owners most in need of repairs have the least resources to invest in necessary modification. Arguably the greatest challenge for an effective I&M program involves the institutional design of the programme itself; many programs have a decentralized structure with testing administered by private test centres that may lack sufficient capacity and oversight.

Despite these challenges, there have been some positive signs in ASEAN that these hurdles can be overcome. For example, Jakarta's I&M program reduced diesel soot by 30 per cent and fuel consumption by 5 per cent (UNEP 2009). In addition, Thailand has effectively implemented I&M programs in some parts of the government-owned vehicle fleet—for example, the Bangkok Mass Transit Authority (BMTA) is charged with implementing preventive maintenance for the buses it manages. More generally, a review of the important design features of several programs in Asia found the following factors contributed to successful I&M: consistent enforcement and reliable detection technologies that build and maintain public trust, awareness, and participation (Clean Air Asia 2016).

2.2.4 Maritime Shipping

Since much of Southeast Asia is made up of many islands and peninsulas, countries in the region rely heavily on maritime trade for socioeconomic development. As a result, emissions from the shipping sector are a key pollution source. This is borne out in relevant data. Five of the world's top 35 ship owning countries are in ASEAN—Singapore (5), Indonesia (22), Malaysia (23), Viet Nam (32), and Thailand (34), while the region is also home to eight of the world's 44 largest ports (Ibitz 2018). The importance of maritime emissions are likely to grow. In fact, some have underlined that 98 per cent of the trade within Asia is maritime trade and trade volumes could increase sharply with regional economic integration (Cristea et al. 2013). While maritime trade is projected to expand regionally, it is useful to keep in mind the considerable variation across the region in ship size and age. As demonstrated in Figure 19, countries that tend



Source: Ibitz 2018

FIGURE 19. Shipping fleet characteristic (size and age) in the ASEAN region.

to have smaller ships also tend to have older ships, which has significant implications for the adoption and spread of solutions.

Possible solutions to maritime emissions are well known and they parallel remedies to emissions from heavy duty vehicles. Among the most frequently advocated options is a switch from pollution-intensive heavy fuel oil to distillate fuels, liquefied natural gas (LNG), or even biodiesel and methanol. In other instances, installing end-of-pipe controls like diesel particular filters (DPFs), electrostatic precipitators, and exhaust gas scrubbers (EGS) are viable options. A third group of options focuses on improving energy efficiency: these are outlined in the International Maritime Organization's (IMO) Energy Efficiency Design Index (EEDI) that offers progressively more stringent goal-based technical standards for newly built ships since it was adopted in 2011. This can be combined with the Ship Energy Efficiency Management Plan (SEEMP) (Wan et al. 2018) to encourage the adoption and monitoring of energy efficiency measures such as slow steaming or energy audits (International Maritime Organization [IMO] 2016).

There are, however, several challenges to implementing these solutions. The effectiveness of fuel switching, exhaust controls, and energy efficiency improvements are contingent on the condition of ships, the environment in which they operate, and other contextual variables (Lack 2017). As for financial hurdles, ship owners are unlikely to invest in several of end-of-pipe emission controls because they are expensive and can increase fuel use and costs (Eide et al. 2011). There are also notable gaps in policies and regulation. For example, the EEDI is only for large newly built ships (Marine Environment Protection Committee 2018), a point that is salient given the sizes and ages of ships in many countries in the region.

The encouraging news is there is a growing understanding of how to work around these obstacles. Some have argued for government-backed subsidies or preferential taxation treatment to make purchasing emission control technologies more affordable. Others include market-based instruments such as credit systems and emission quotas to motivate shipowners to make these investments (Zhu et al. 2017). A complementary set of options involves strengthening cooperation on these solutions at the regional level through initiatives to establish an ASEAN Single Shipping Market or regional frameworks on sustainable transport. Both national and regional solutions will be influenced by developments in the International Convention for the Prevention of Pollution from Ships (MARPOL) and the IMO.

2.2.5 *Controlling F Gases*

Controls on hydrofluorocarbons (HFCs) could lead to improvements in energy efficiency and possibly air pollution (depending on the power source). HFCs are a group of industrial chemicals that are a potent a GHG and SLCP; they are used primarily for cooling and refrigeration.

The Kigali Amendment, which calls for the phase-out of HFCs under the Montreal Protocol and entered into force in 2019, could help lower these emissions in ASEAN. Under the Kigali Amendment, countries committed to reduce HFC production and consumption by at least 80 per cent over the next 30 years. Solutions to reduce or replace HFC in line with this amendment are widely available. However, several barriers have frustrated their uptake. Some of the key challenges include a lack of awareness, and high technical and cost hurdles that discourage switching from HFCs.

There has nonetheless been some progress in select industries and cases. Indonesia's Alfamidi convenience stores, for example, introduced CO_2 refrigeration systems in more than 900 stores across Indonesia. These systems not only cut costs and saved energy but led to significant reductions in HFCs (UNEP/CCAC 2014). Meanwhile, in Japan, the government, industry, and academia are cooperating with domestic companies and industries to strengthen countermeasures against refrigerant leakage through periodic inspections as well efforts to recover HFCs and improve equipment (Japan Refrigerants and Environment Conservation Organization 2021).

Some of these efforts have also led to cooperation with ASEAN countries. At the UNFCCC's COP25, Japan, 13 countries, and international organizations launched the Initiative on Life Cycle Management of Fluorocarbons (IFL), which supports pilot projects on the management of fluorocarbons. Subsequently, Japan worked under its Joint Crediting Mechanism (JCM) to initiate a pilot project at an existing waste incineration facility that would destroy 12,512 tCO_2e/y of HFCs and other pollutants (Global Enivronment Centre Foundation 2020). Carbon credits will be issued for the amount of HFCs destroyed, providing a private sector incentive to recover collection, transportation, and destruction costs.

Some HFC control measures focus on phasing out production and consumption under the Kigali Amendment. While the focus of these measures is upstream, downstream "banking" also merits attention. Refrigerants are found in appliances and automobiles currently in use or will be produced and consumed before the beginning of the phase-out. Addressing HFCs that are currently locked in these product banks will be increasingly important in Southeast Asia and other regions (Ministry of Environment, Japan 2016).

2.2.6 *Residential Energy*

In energy-scarce and rural areas, traditional cook stoves use firewood, livestock dung, and other biomass for fuel. In addition to uneven combustion, the lack of ventilation from these traditional stoves worsens indoor air quality. This pollution can have particularly negative impacts on the health of women and children, who tend to spend more time indoors and have greater exposure to smoke from the cookstoves. A wide range of stakeholders in and beyond Southeast Asia are aware of these adverse impacts and have adopted various policies and initiated programmes to reduce them.

Many of these policies involve technical measures like electrification, switching to gas, and distribution of improved cookstoves that do not emit smoke. These can be coupled with awareness raising campaigns on the negative health effects of traditional cookstoves. There have nonetheless been challenges to the adoption of the cleaner stoves. Some of the barriers involve resistance from end users who prefer the taste of foods cooked on the traditional stoves. Another is the cost of improved and advanced stoves; these costs can be several times higher than traditional stoves; even modest increases in costs can be a sizable bottleneck as many families have limited incomes to invest in cleaner alternatives. Another broader institutional challenge is the separation of the energy development community from the health community, and the fact that neither is accustomed to addressing household-level issues so residential energy can "fall through the cracks."

There are some examples of efforts in different countries that have demonstrated the potential to overcome these challenges. The Indonesian government's "Zero-Kero" program provided more

than 50 million households with access to LPG for cooking in five years. This programme, enabled by a successful fuel subsidy policy, led to a fivefold increase in domestic LPG consumption, from 4.7 kg/person in 2007 to 24.4 kg/person in 2015, while the primary cost for firewood was halved (Thoday et al. 2018). In Cambodia, where cook stoves were fuelled by illegally cut firewood, NGOs, the public and private sectors, and national and international organizations collaborated to create an improved cooking stove, the New Lao Stove (NLS), that saves about 22 per cent of wood and charcoal compared to traditional stoves and created multiple benefits like reducing cooking time for women and created stove production jobs. Meanwhile in Laos PDR the Improved Cookstoves (ICS) programme initiated by the Netherlands Development Organization (SNV) developed a cookstove market by enhancing the performance of all the actors in the ICS value chain: producers, retailers, testing agencies and users (SNV Netherlands Development Organization 2016).

2.2.7 Agricultural Burning

Before sowing new crops, farmers in many parts of the world, including Southeast Asia, set fire to cultivated land to remove residue from earlier harvests. While this method quickly and cheaply prepares land for planting, it is unsustainable. Not only does it reduce soil fertility, but it also generates high levels of particulate pollution that contributes significantly to haze episodes in Southeast Asia.

Although policymakers and farmers are aware of the combination of factors that contribute to burning, altering the practices has proven easier said than done. This is partially attributable to the limitations of bans on burning. Many countries in the world have adopted permit systems to prohibit open burning or to limit burning to specific days, times, and atmospheric conditions. However, the effectiveness of legal measures varies, often depending on non-legal factors and unique national circumstances, including efforts to familiarize farmers with the law, a culture of rule compliance, the ability to detect and punish illegal burning, and whether economic and other incentives are consistent with the law. These experiences suggest that the most effective remedies are likely to work from the bottom up and consider a range of context-appropriate factors, including the hidden costs of changing the way agricultural residues are handled, farmers' perceptions of residues, different uses of residues, differences in behavior and intentions, and even socio-cultural constructs (i.e., mental models and habits).

With recent research and technological advances, several alternatives to burning agricultural residues have been proposed that consider some of the factors mentioned above. These include reusing residue as ground cover, soil amendments (mulch and compost), animal feed, or as raw materials for energy, building materials, paper products, bioplastics, and other artifacts. These can be done on-site or off the farm, with the latter requiring aggregation of residues from multiple farms to obtain economies of scale. Off-farm solutions involve a larger upfront investment and additional costs associated with moving the product and complications such as distribution (Cassou 2018). These bottom-up techniques can be combined with community-based enforcement systems and role models to discourage burning.

In Southeast Asia, there has been useful experience setting up programmes that can address burning. Thailand has set up an 11-point programme that involves multiple agencies, levels of governments and actors working together to combine targeted bans with awareness raising and incentives to use crop residues for revenues. In addition, there are growing attempts within and outside Southeast Asia (including India and China) to keep track of burning and its impacts–that can have implications for assessing progress. Last but not least, the ASEAN Haze Agreement and its Roadmap on ASEAN Cooperation towards Transboundary Haze Pollution Control offers a useful framework for regional cooperation on these issues (See Box 5) (ASEAN 2023).

BOX 5: Roadmap on ASEAN Cooperation towards Transboundary Haze Pollution Control.

The Second Haze-free Roadmap (2023-2030) serves as framework aimed at eliminating haze through the effective implementation of collective actions at the regional, subregional, national, and local levels. It does through nine strategies that are intended to help ASEAN prevent and control open burning from agriculture, land and/or forest fires, including peatland fires.

The Second Roadmap pursues these goals by focusing on the following targets:

- A significant and sustained reduction in the number of haze pollution episodes in ASEAN
- Achieving national $PM_{2.5}$ air quality targets with a view toward achieving the World Health Organization's annual and 24-hour Interim Targets 3 for $PM_{2.5}$

In recent years, the Haze agreement has made significant progress in achieving the above indicators.

Source: ASEAN 2023.

2.2.8 Waste Management and Waste Burning

Open burning of municipal waste is prevalent across many ASEAN countries, though the practice varies significantly depending on extent of waste collection coverage and quality, financing for service delivery, regulatory effectiveness, economic development and more broadly, levels of low awareness among residents about human health and the environment impacts (UNEP 2017). Although open burning can occur at all stages of waste management (Premakumara 2021), including waste generation to final disposal, there is also strong evidence to suggest that countries with more advanced waste treatment systems are less likely to rely on such activities (UNEP 2017).

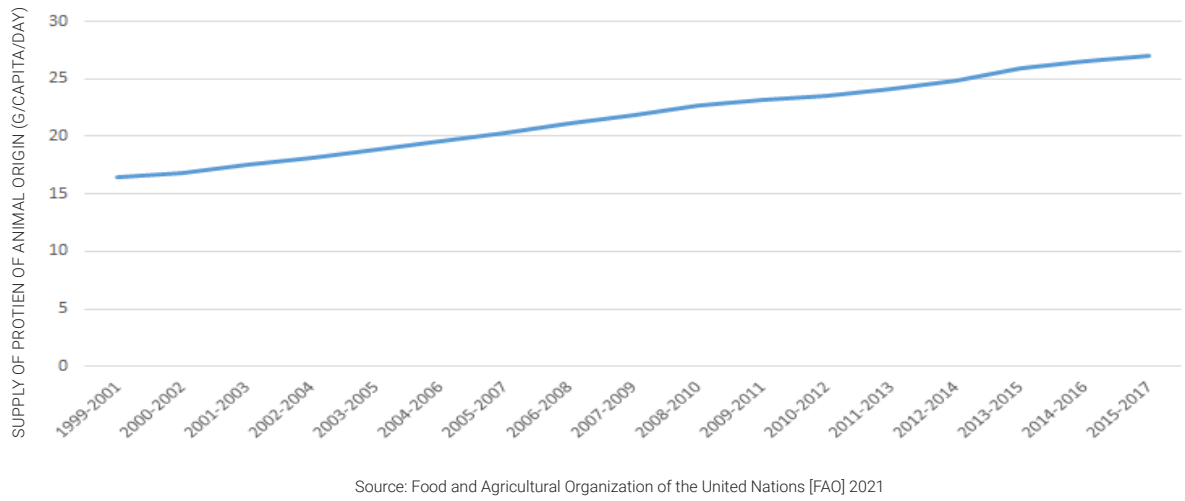
Despite these differences, a number of common challenges to addressing waste burning exist in Southeast Asia. Improving the affordability of high-quality waste management services remains a major obstacle, particularly in less industrialized countries across ASEAN. Similarly, in countries lacking a strong regulatory and institutional framework—one that sets out clear standards, robust monitoring procedures, and reliable enforcement mechanisms—controlling waste burning has proven difficult. In addition, the scarcity of mass and emission data make it difficult to reliably quantify the national and regional impact of open burning.

In recent years, several ASEAN governments have made efforts to move past these hurdles. Malaysia, for example, enacted sweeping reforms to transfer waste management responsibilities to its central government, which led to the passage of the country's Solid Waste Management and Public Cleansing Act (Act 672). Coming into force in 2011, Act 672 formally established Malaysia's National Solid Waste Management Department as a coordinating executive body on waste related issues. In contrast, other countries have followed a more decentralized approach to waste management planning and decision-making. According to the Philippines' Republic Act 9003 (RA 9003), all local government units are required to develop integrated solid waste management plans, with explicit prohibitions on open burning (Premakumara et al. 2018) with corresponding linkages to the climate change and Sustainable Development Goals (SDGs). More recently, Myanmar formulated its National Solid Waste Management Strategy and Action Plan (2018-2030), which in addition to providing a guiding framework for national and subnational coordination, outlines a number of goals and targets for eliminating waste burning over the short-, medium-, and long-term (Hla Maung et al. 2020).

Beyond institutional reforms, tackling open burning requires allocating sufficient financial resources for waste management operations. In this connection, there is strong evidence that community-based zero waste solutions can help in defraying the costs associated with upgrading collection, recycling and disposal systems (Premakumara et al. 2017). This is especially important, as findings suggest that residential burning is most effectively reduced through a combination of different waste options and interventions (Cook and Velis 2021). Also, open burning brings some benefits to citizens who have no access to official collection service or the informal sector who depend on their livelihood from collecting and burning waste. Thus, having evidence-based solutions with adequate awareness raising on the negative impacts are important to highlight (Premakumara et al. 2021).

2.2.9 Changing Diets

Driven by rapid socioeconomic development, urbanization and changing lifestyles, the past three decades has witnessed dramatic growth in meat consumption in Southeast Asia (Figure 20). Even with this significant growth, considerable variation exists in dietary preference with implications for the levels and types of meat consumed in the region. For example, Viet Nam consumes more beef than other countries in Southeast Asia. On the other hand, consumption of pork in Indonesia is lower than other countries in Southeast Asia. Further, the levels of meat consumption are also relatively low compared to global averages. Malley et al. (2021) estimate that the largest health burdens attributable to diets high in total red meat consumption are in Western and Eastern Europe, North America and East and Southeast Asia compared to the other dietary health risks, such as diets low in fruits and vegetable.



Source: Food and Agricultural Organization of the United Nations [FAO] 2021

FIGURE 20. Daily average supply of protein of animal origin (g/capita/day) in Southeast Asia; 3-year average.

Though the above background and regional variation should be considered, some common challenges to shifting dietary patterns are evident in much of the region. The most significant, and primary concern for many decision makers, is food security and ensuring that populations can reach globally recommended calorie intake standards of 2300 kcal per day (Khine et al. 2021). A different set of challenges involve what's been labelled the "meatification" of many economies in the region, referring to mutually reinforcing networks of consumers and suppliers of meat and the grains that are the main source of animal feed (Jakobsen and Hansen 2020). Finally, though there are some visible efforts to support large farms and agri-business in the region, Southeast Asia is still heavily populated by many small holders that would suffer from significant shifts in dietary patterns (Rigg et al. 2016).

There have been some encouraging signs that some of these challenges can be effectively managed. One of the encouraging signs is that many countries in the region—led by Malaysia—have adopted multi-sectoral national nutrition policies and action plans that employ a variety of tools to motivate consumers to reduce intake of meat for health reasons (Soon and Tee. 2014). There are also regional efforts to strengthen the link between food security and climate change under the ASEAN Socio-Cultural Community ASCC) and ASEAN Economic Community (AEC) (Caballero-Anthony et al. 2015). There is also considerable research on the impacts of healthy diet scenarios that recommends shifting to reducing animal numbers and animal products and increasing meat substitutes (i.e. tofu and tempeh) (Adhikari and Prapaspongsa 2020; Khine et al. 2021). Changing diets can have also significant implications for curbing other forms of environmental pollution and climate change as discussed below.

2.2.10 *Reducing Ammonia from Livestock and Fertilizer*

Reducing animal numbers and meat consumption (as in the previous subsection) and fertilizer inputs is the best way to directly reduce the amounts of nitrogen leaking into the environment. Such efforts are critical because nitrogen can have multiple environmental impacts once introduced into the food system. This includes the effects from ammonia and nitrogen oxide emissions, which can then contribute to $PM_{2.5}$ as well as climate change. The fate of the added nitrogen fertilizer depends on the type of nitrogen applied (e.g. synthetic or organic fertilizer), and nutrient management principles, such as the '4Rs Nutrient Stewardship' (i.e. the right form, right rate, right method and right time of application).

In Southeast Asia, experience focusing specifically on reducing ammonia emissions from livestock and fertilizer use is limited. However, Europe has promoted several technology and behaviour changes to mitigate the above effects. Some of the livestock measures include the requirement to construct low emission housings; covered stores for manure; and efficient application of manure on land. For mineral fertilizers, addressing emissions from urea application by replacing urea with ammonium nitrate, or improved application of urea (proper timing and doses) and potentially urease inhibitors. In addition, nitrogen fertilizer management increases its efficiency. Even with the best nutrient management, however, studies show environmental losses can be high: 43 per cent of the direct nitrogen inputs to agricultural soils reach harvests and biomass production for consumption by humans or animals (in Europe the crop NUE figure is estimated to be 58 per cent) (Sutton et al. 2013). This situation is often exacerbated by nitrogen fertilizer subsidies that are intended to promote food production but can lead to fertilizer overuse as farmers apply more fertilizer to avoid poor yields.

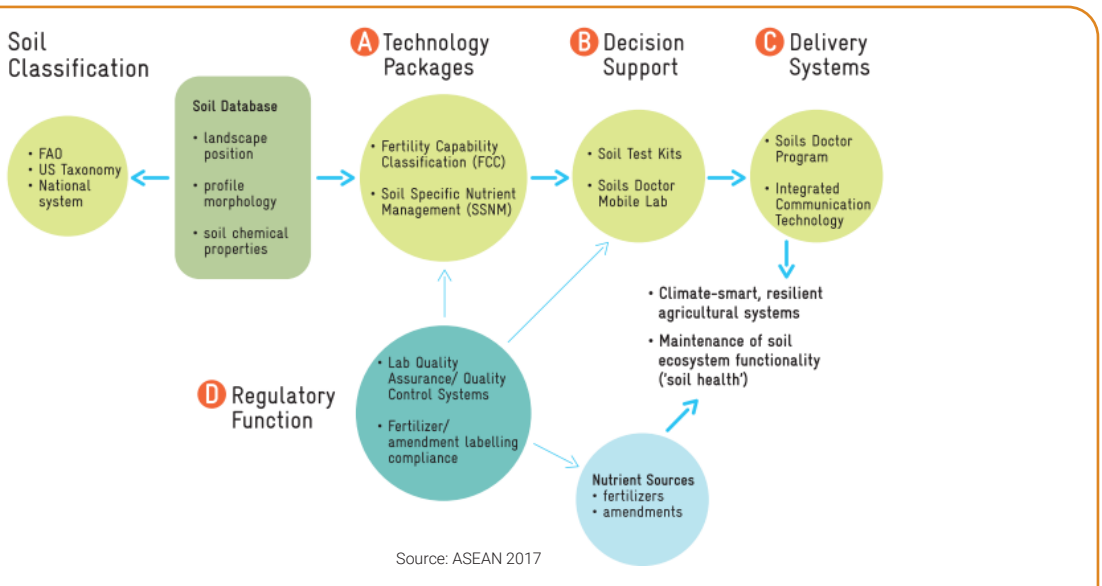


FIGURE 21. Implementation Framework for Soil and Nutrient Management In the ASEAN region

Another set of options involve manure management. In this case, it is crucial for farmers to have estimates of how much nitrogen will be available to their crop and improve manure management practices based on that assessment. Such improvements can involve using closed or covered storage tanks and rapid incorporation of manure into soil following application to reduce ammonia losses to the air. Such practices are becoming more common in Europe and North America, but more awareness and technical support is required to make them acceptable globally. This is evident in recent work in Viet Nam where interviews with farmers revealed that 90 per cent of farmers did not regard manure as a valuable fertilizer. On the other hand, about 50 per cent of the interviewed farmers had improved their manure management through the installation of biodigesters (Teenstra et al. 2014). Highlighting the additional benefits of biodigesters may also be useful in other countries outside Viet Nam in Southeast Asia given rising demand for pork, and the subsequent rapid increase in pig production and large volumes of animal manure to be managed (Roubík et al. 2018). Roubík et al. (2018) also show that the potential of biogas daily production per household in Viet Nam is more than two times higher than the actual production.

There may also be opportunities to demonstrate a range of benefits in related policy areas in Southeast Asia. For example, more integrated systems to manage soils, nutrients, water and crops to optimise crop production and improve soil health has been recognized by the 'ASEAN Guidelines on soil and nutrient management' (ASEAN 2017). These guidelines follow the goals in the Vision and Strategic Plan for ASEAN Cooperation in Food, Agriculture and Forestry (2016-2025) (Figure 21). There are opportunities in ASEAN for a more holistic approach to nutrient management to reduce the impacts to water and air quality, GHG emissions, biodiversity, and soil health. Such approaches, though not yet mainstream, have been adopted in Germany, which is one of the first countries to produce an Integrated National Targets for Nitrogen that considers all these impacts together (Geupel et al. 2021). Last but not least, there is scope to make the link between strategies to reduce nitrogen and alternate wetting and drying (AWD) of rice paddies that is used to save water, reduce methane, and mitigate climate change in many parts of Southeast Asia (Chidthaisong et al. 2018; Setyanto et al. 2018; Sibayan et al. 2018; Tirol-Padre et al. 2018; Tran et al. 2018). This approach has cut nitrous oxide emissions emission in India (Kritee et al. 2018).

2.3 Implementing Solutions at Scale: Financing and Governance

Implementing many of the priority solutions at scales that can achieve the air quality, public health, food security, and climate benefits estimated in Chapter 1 requires financing and supportive governance arrangements. The levels of resources and the types of governance reforms will vary for different solutions. Solutions involving emission controls for power plants necessitate significant increases in investment capital while cookstoves require more modest levels of targeted funding. There is also some variation in the types of governance that can support these reforms. Solutions such as strengthening vehicle emissions standards require government-led standards from the top-down while controlling open burning involves creating opportunities and peer learning from the bottom-up.

Further, the levels of financing and appropriate governance arrangements will differ from one country to the next. This reflects some of the unique features of existing institutional arrangements and differences in human resource levels in relevant agencies. This section will nonetheless outline options that countries can and have used to mobilize finance and strengthen governance arrangements more generally across the region. As many of the solutions also help mitigate climate change, many of the options in the section aim to strengthen integration with climate policies and access growing pools of climate-related green finance.

2.3.1 Financing

One of the keys to implementing the solutions at scale is accessing necessary finance gaps. Especially for the energy sector, there are growing pools of green finance that can help in this regard. As noted previously, some of this finance is available through energy efficiency and energy savings programs in countries such as Thailand. In addition, there has been a sharp uptick over the past decade in the offering of green bonds globally—increasing from US$5 billion to more than US$270 billion—that are typically assessed and monitored in terms of

their effects on greenhouse gas (GHG) emissions. Likewise, green bonds are also gaining traction in Southeast Asia, supported by governments' favourable policies. The Sustainable Bond Grant Scheme in Singapore, for example, seeks to support the issuance of green, social, sustainability, sustainability-linked, and transition bonds by funding eligible expenses attributable to obtaining pre-issuance external review or rating, as well as post-issuance external review or report for such bonds. Meanwhile, in countries such as Malaysia with large Muslim populations, the growth of green Green Sukuk as Shari'ah compliant investments in renewable energy and other environmental programmes offer a chance to tap an alternative source of socially responsible fund.

Another source of funding for some of the MSMEs and smaller emissions sources involves central banks and financial inclusion programmes. These programmes have traditionally been designed to provide finance to small businesses and individuals who would otherwise struggle to access capital. In recent years, however, central banks and financial regulators have explicitly sought to green these programmes using a variety of tools to encourage banks to not only lend to disadvantaged groups and unbanked segments of the population. In the Philippines, the Bangko Sentral ng Pilipinas (BSP) has sought to raise the awareness of banks that green investments can serve a broader social good. Meanwhile, Indonesia has taken a more direct approach, providing a list of green activities for banks to inform their lending.

Outside of bonds and lending, there are also chances for governments to reform policies or budgeting practices. In terms of reforming policies, the reduction and reallocation of fossil-fuel subsidies to clean energy arguably has the greatest potential in the region. In terms of budgeting practices, efforts to "tag" or explicitly recognize how public spending contributes to a wider range of socioeconomic environmental goals. This tagging had been adopted in Indonesia for climate change and, more recently, a broader set of SDGs. Such an approach may also help policymakers better understand the impacts of environmentally related programmes on health and other development outcomes.

2.3.2 Governance

To this point, much of the discussion has focused on implementing specific solutions in particular sectors. However, the widespread implementation of these solutions often depends on horizontal integration across air pollution, energy, transport, agricultural, health, finance, and other sectoral policies and agencies. It will also frequently rest on vertical integration between national and local levels of government. In many cases, the engagement and empowerment of stakeholders outside of government–ranging from civil society groups to actual resource users–will prove crucial. In short, there will be a growing need for multi-level, multi-stakeholder forms of governance to achieve the co-benefits presented in Chapter 1. This subsection will illustrate some promising examples of governance that facilitates this kind of multi-agency, multi-actor cooperation.

Many of the solutions would be enhanced with cooperation across administrative remits and portfolios. In Southeast Asia, there have been some encouraging examples of cross-agency exchanges and collaboration that could provide a basis for further integration. For instance, in Thailand, efforts to manage emissions from shipping have led to collaboration between the Ministry of Transportation and the Ministry of Natural Resources and the Environment. In Viet Nam, interagency cooperation has been reflected in the set of climate actions that it pledged to the United Nations Framework Convention on Climate Change (UNFCCC) known as the Nationally Determined Contribution (NDC). The technical work that contributed to Viet Nam's NDC places a great deal of emphasis on the linkages between climate change, health, and a range of sustainable development benefits (Viet Nam 2020).

While this integration is often due to institutional reforms that enable agencies to work closer together, it can also be purposively facilitated by targeted support for integrated planning. The last decade has seen substantial increases in capacity building toward these ends. Support to enhance capacity and to develop more integrated air quality and climate change planning has been undertaken in ASEAN countries (discussed in greater depth in the next section of the report). For instance, Cambodia has developed its first air quality plan and as part of that has developed an integrated air pollution

and climate change mitigation assessment to underpin that plan. The Philippines has championed the issue of SLCPs in ASEAN and is developing its planning as part of its national strategy on climate and air pollution. In Thailand the Pollution Control Department is currently in the process of developing its national SLCP planning. Efforts like these have resulted in a large wealth of experience, lessons, best practices and guidance on effective approaches to increase action on air pollution and climate change (Malley et al. 2021) (see also Chapter 3 for a discussion of champion countries).

Another important dimension of governance involves vertical integration between levels of decision making. Ensuring many of the small-scale solutions reach scale will often depend on integration between the national and local governments. There are also some instances where this cooperation is also gaining traction. In the Philippines, some local government units are crafting local climate change plans that recognize linkages with air pollution, waste management, health and other development needs that are aligned with national policies. A similar phenomenon is evident in Malaysia where local governments such as Kuala Lumpur are adopting energy savings measures that are consistent with national climate policies. Importantly, in several cases local policies are more innovative and ambitious than national policies. National policies instead provide a framework that can justify the transfer of fiscal resources needed to implement and spread local actions.

To fully capitalize on this bottom-up dynamic, the participation of stakeholders outside of government can often enhance the quality and durability of decisions (Fischer 2000; Reed 2008) and tailor solutions to local conditions (Martin and Sherington 1997) concentrating on implementation. Arguments in favour of farmer participatory research (FPR. Here too there have been encouraging trends. In Thailand, building on a tradition of community engagement, there is regular consultation on the operation of power plants. In Laos PDR, women have been actively engaged in the manufacturing, sale, and marketing of improved cookstoves, amplifying the impacts across the value chain.

The example of Laos PDR suggests a more general point. Many of the 15 solutions have underappreciated effects on gender. Further, though many of the solutions are not directly intended to promote gender equality, highlighting the effects on gender or socioeconomic equity from these solutions can help harness the energy of diverse stakeholders and accelerate their implementation. This may be especially true for solutions that require social and behavioural changes. In a similar vein, it may also be helpful to expand the participation of women and other frequently overlooked stakeholders in relevant processes. This could be achieved by ensuring women's unions and social affairs agencies can meaningfully participate in environmental policy decision making bodies. Efforts to enable greater female participation could also contribute to a broader push for just transitions in climate policies.

Yet another increasingly important governance dynamic involves planning and coordination across urban and rural areas. A growing body of research suggests that much of the air pollution that impairs health in cities is actually emitted outside urban areas. For example, the reason why it is so difficult to prevent air pollution in Bangkok, Thailand is that urban and rural sources mix to form a toxic brew that is challenging to manage because it originates from multiple sources. This problem can be addressed by improving coordination across urban and rural areas. Though this is a relatively new area for Southeast Asia, there are some positive lessons to draw from China's efforts to coordinate air pollution responses across cities and provinces at the airshed level. There may also be scope for conceiving of innovative financing schemes that transfer resources from cities to rural areas to help shift to alternative crops and curb open burning.

Finally, and to foreshadow the next chapter, there is ample opportunity to strengthen cooperation across countries in Southeast Asia on these solutions. This is already happening to a significant extent under the ASEAN Haze Agreement. However, there may be even more scope to build cross-national cooperation by focusing on the multiple benefits. Input of expertise from domestic and international research institutions, support from donor agencies and donor countries, and proactive involvement of local governments, local residents, civil society groups, and businesses in developing policies and projects can be drivers for effective implementation of many of the solutions.

3 Regional Cooperation on Integrated Solutions to Air Pollution and Climate Change

3.1 Introduction

Chapter 1 underlined that countries in Southeast Asia could achieve significant air quality, climate protection, public health, and other sustainable development benefits by implementing 15 priority solutions. Chapter 2 suggests that the region has significant experience with overcoming barriers to implement many of these solutions. In addition, further efforts to strengthen relevant financing and governance arrangements could enhance implementation. This chapter focuses on strengthening subregional cooperation on integrated air pollution and climate planning.

3.2 Cooperation on Integrated Air Pollution and Climate Change Planning Needed

The chapter draws upon 17 semi-structured key informant interviews with policymakers, representatives of international organizations, and other experts in Southeast Asia. It also synthesizes inputs from exchange sessions with the ASEAN Secretariat and other relevant stakeholders. The results underlined three salient points that could support coordination on integrated air pollution and climate planning in Southeast Asia.

- The first key point is that considerable interest exists in integrated planning in Southeast Asia. At the same time, interviewees noted more effort is needed to achieve the multiple benefits from integrated planning.
- A second relevant point is that understanding of an integrated climate change and air quality approach remains limited. An officer from one country in the region made this clear when he suggested that his government only focuses on GHGs when designing the countries' nationally determined contribution (NDC). A related observation suggested why this is the case: namely, SLCPs often fall "through the cracks" between climate (international donor resources) and air pollution (local and national resources) when it comes to financially supporting more integrated planning.
- A final key point involves the nature of capacity building needs. Some interviewees pointed to the importance of understanding core concepts--i.e. what are SLCPs? Others noted the need for support for the technical aspects of integrated planning, including on the tools to identify key mitigation measures. Yet another set of respondents suggested that demonstration projects and mobilizing finance would be needed to offer a concrete image and practical application of how multiple benefits can be achieved. The next subsection describes these needs in greater detail.

3.3 Summarizing Three Key Needs

Based on the interviews, three key needs were identified that, if met, could support integrated solutions to air pollution and climate change in ASEAN.

1. The first need involves **integrated planning.** This need was broken into several smaller steps. The first step would be relevant government staff and academics understand background information. The next step is to identify solutions and implement policies that address air pollution and climate change. This needs to be led and implemented by teams embedded within the academic community and government agencies. This includes developing an emission inventory for the most recent year. In the work supported by the CCAC, the tool used at national scales has been the Low Emissions Analysis Platform (LEAP). LEAP can is a flexible template that users can customize to create and understand the benefits of integrated air pollution and climate plans. Other

tools were used by the CCAC at regional scales with national resolution such as the GAINS from IIASA.

2. A related need is **demonstration projects**. A shared sentiment among interviewees is that planning on paper will not resonate without evidence on the ground. Whether it is reducing emissions from energy efficient abatement technologies or encouraging reductions in open burning with mulching equipment, it is important that policymakers can point to specific cases that demonstrate successful experiences with solutions. There are, in fact, many cases in the ASEAN region that are successful; however, new projects that demonstrate reduced emissions and improvements in air quality and health were seen as particularly important. To quote one of the interviewees "[we need to] actually implement a project, so that they can test what they learned, improve their practical skills with trial and error, and produce results."
3. A final need involves **mobilizing funding**. In terms of attracting funding, one of the possible channels is leveraging resources from climate change funds like the Green Climate Fund. Another possibility is working with development banks, like the ADB, to tap funds that can support the implementation of air pollution and health benefits of investment projects. In addition to finance for hardware, interview also revealed key stakeholders in the region need the softer technical expertise to develop funding proposals. This may involve policymakers getting technical support to work on a project concept that is developed into a full-fledged proposal.

3.4 Several Existing Initiatives Could Help Address these Needs

The interviews also underscored that there is no need to start from scratch in addressing these needs. Several initiatives in Asia that are promoting integration between air quality and climate, and health that could help address the three above needs.

Among the most recent regional initiatives is Regional Action Programme on Air Pollution that is under resolution 75/4 of the Economic and Social Commission for Asia and the Pacific (ESCAP) on strengthening regional cooperation to tackle air pollution challenges in Asia and the Pacific. The Regional Action Programme is intended to "promote science-based and policy-oriented cooperation for improved air quality management." It is also aiming "to establish an open regional platform for the exchange of information and best practices on air pollution challenges and solutions.

A related set of activities are helping boost individual country efforts to control air pollution and mitigate climate change. For example, several UN agencies launched an Issue-based Coalition (IBC) on Environment and Climate Change in 2020 to provide a platform for coordinated support to member states in their implementation of the 2030 Agenda. Under the Coalition, there is a work stream on climate change mitigation and air pollution co-chaired by the United Nations Environment Programme (UNEP) and the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP). This work stream concentrates on the following objectives: to raise ambitions on climate action through NDCs; to accelerate action on air pollution in Asia Pacific to move towards achieving WHO air quality guidelines by 2030; and to accelerate the phase out of coal in Asia Pacific (UNESCAP 2020).

Another regional initiative that helps address the three needs above is the Asia Pacific Clean Air Partnership, APCAP, managed by the UNEP Regional Office for Asia Pacific (UNEP-ROAP). APCAP is organized around three sets of activities meant to strengthen air quality management at chiefly the national and regional levels:

1. The Joint Forum: provides a major opportunity for the Asia-Pacific region to share the latest policy-relevant scientific knowledge and information on the state of national and international efforts.
2. The Scientific Advisory Panel: brings together scientific expertise from existing regional initiatives to provide clear policy options based on the best available science on air pollution in the Asia Pacific.
3. Country Support: provides demand driven support for capacity building.

In addition to overseeing APCAP, UNEP-ROAP is also coordinating the aforementioned project that could provide insights into the costs of failing to adopt 12 of the 15 recommended solutions in this report.

The report's recommendations are also likely to fit well within ongoing efforts to promote clean air from the Asian Development Bank. The ADB recently launched the Asia Clean Blue Skies Program (ACBSP) in an effort to help policymakers strengthen air pollution and climate change planning. The ACBSP is also aiming to bring more investment to potentially scalable projects that have co-benefits potential in Asia and the Pacific.

Another possible channel for support and synergy is the Acid Deposition Monitoring Network in East Asia (EANET). EANET is an intergovernmental initiative created to promote a common understanding of the status of acid rain problems in East Asia, to share information, and to facilitate cooperation among thirteen member countries. Since 2001, EANET has conducted acid rain monitoring, data collection, evaluation, storage, and information dissemination. Recently member countries are discussing possible expansion of its activities to include a work on $PM_{2.5}$ and a project-based finance mechanism.

An additional mechanism that help raise awareness of the report is the Asian Co-benefits Partnership (ACP). The ACP is an initiative focusing on the concept of "co-benefits." The ACP has been supporting the mainstreaming of co-benefits into sector development plans, policies, and projects in Asia for the last ten years. Its role is to serve as an informal and interactive platform to improve information sharing and stakeholder coordination on co-benefits.

Last but not least, another initiative that could help to mainstream the report's recommendations is Clean Air Asia. Clean Air Asia has a long and well documented track record of working with policymakers to adopt science-based solutions to air quality and climate challenges. With an extensive network of cities and partnerships with industries in Southeast Asia, Clean Air Asia could incorporate the report recommendations in training activities and advocacy efforts.

3.5 A Role for ASEAN Countries and the ASEAN Secretariat

As noted in the previous subsection, there are several regional initiatives working on air quality and climate change. However, the nature of these initiatives are voluntary partnerships that are led by international organizations (with participation from select countries). None of these initiatives have the same convening power and institutional standing to support policy coordination and harmonization on integrated climate change and air pollution planning at the subregional level like ASEAN and its Secretariat. This point was emphasized in several interviews conducted for this project.

Those interviews further underlined that ASEAN and its Secretariat is well-placed to support an engagement and learning process that could support the integration between climate change and air pollution. Further, this engagement and learning process would need the strong support of a coalition of at least three champion or leading countries (the rationale for selection and roles of possible champions is detailed later in this subsection).

To give the engagement and learning process shape and substance, the ASEAN secretariat could initially work with the three champions to help other countries in ASEAN meet the three needs described in Section 3.3: namely, 1) integrated planning; 2) demonstration projects; and 3) mobilizing resources. More concretely, the ASEAN secretariat and the champion countries could do the following:

- Create learning events and training opportunities that help raise awareness of the benefits and potential for **integrated planning;** training with technical staff LEAP or integrated/co-benefits assessments could follow from those initial outreach efforts.
- Work with the champion countries to raise awareness of **demonstration projects** that overlap with the 15 solutions in the report—for instance, information could be shared on efforts to strengthen vehicle and maintenance or sustainable rice production.
- Engage with international organizations, development partners, industry and civil society to **mobilize resources** for implementing actions

identified through the integrated planning (need 2) and spread successful demonstration projects (need 3). Some of the resource mobilization efforts could concentrate on strengthening partnerships with organizational efforts and initiatives previewed in Section 3.2.

For the proposed set of activities to move forward, it makes sense to use existing institutional mechanisms and modalities in ASEAN; there is no need to reinvent the wheel. As such, the proposed set of activities could be placed under auspices of the ASEAN Environment Division (under the Sustainable Development Directorate) as well as the ASEAN Working Group on Climate Change (AWGCC) under the ASEAN Senior Officials on the Environment (ASOEN). Much of the initial efforts would fit under the AWGCC given that its focus on "enhancing regional and international cooperation to address climate change and its impacts on socio-economic development, health and the environment." The fact that it pursues this objective through efforts to build capacity to establish common understanding on climate change among policymakers and other stakeholders suggests it is well positioned to support relevant activities.

In addition, the AWGCC could also work with other divisions that cover air pollution, climate change or related sectoral concerns (i.e. energy, transport, agriculture, haze). This might involve, for instance, bringing in sectoral expertise from ASEAN Working Group on Environmentally Sustainable Cities (AWGESC) to demonstrate how cities can support e-mobility solutions to improve air quality and stabilize the climate. It might also involve sharing information of this report 15 solutions and main findings at Conference of the Party (COP) meetings for the ASEAN Haze Agreement.

Table 4 summarizes the responsibilities of different divisions in the ASEAN Secretariat that could contribute to—and benefit from—working with the AWGCC and countries in ASEAN in raising the profile of the report's findings. These efforts would also serve the broader and deeper needs of ASEAN such as achieve many of the key result areas and strategic measures under the sustainability element in the ASEAN Sociocultural Community Blueprint 2025.

Another critical part of the engagement process will be enlisting the support of the aforementioned three champion ASEAN countries. The champion countries

TABLE 4. ASEAN Socio-Cultural Community Department – Sustainable Development Directorate-Environment Division

Division/Organizational Unit	Relevant Responsibilities
ASEAN Working Group on Climate Change (AWGCC)	Enhance regional and international cooperation to address climate change and its impacts on socio-economic development, health and the environment, in ASEAN Member States through implementation of mitigation and adaptation measures, based on the principles of equity, flexibility, effectiveness, common but differentiated responsibilities, respective capabilities, as well as reflecting on different social and economic conditions.
ASEAN Working Group on Chemicals and Waste (AWGCW)	Further strengthen regional coordination and cooperation in addressing chemicals-related issues under relevant multilateral environmental agreements such as Basel Convention, Rotterdam Convention, Stockholm Convention, and Minamata Convention, as well as internationally agreed-upon systems such as the Globally Harmonized System of Classification and Labeling of Chemicals (GHS) in order to manage chemical wastes.
ASEAN Working Group on Coastal and Marine Environment (AWGCME)	Foster the conservation and sustainable management of coastal and marine ecosystems while highlighting their importance as resources of livelihood for the ASEAN.
ASEAN Working Group on Environmental Education (AWGEE)	Promote coordination and collaboration among relevant ASEAN sectoral bodies and dialogue partners to ensure a well-coordinated approach towards promoting environmental education.

ASEAN Working Group on Environmentally Sustainable Cities (AWGESC)	Ensure that cities/urban areas in ASEAN are environmentally sustainable, while meeting the social and economic needs of the people. Also functions as a consultative forum to enhance coordination and collaboration among various ASEAN sectoral bodies and dialogue partners in addressing environmental sustainability challenges including clean air.
ASEAN Working Group on Natural Resources and Biodiversity (AWGNCB)	Further strengthen regional coordination and cooperation in addressing problems associated with natural biodiversity and to undertake concrete actions in ensuring that the region's rich biological diversity is protected, conserved and sustainably managed.
ASEAN Working Group on Water Resources Management (AWGWRM)	Promote sustainability of water resources to ensure equitable accessibility and sufficient water quantity of acceptable quality to meet the needs of the people of ASEAN.
ASEAN Economic Community Department – Transport Division	Hosts the ASEAN Transport Ministers (ATM) Meeting which works to set policy directions in the transport sector and discuss issues of common interest. The ASEAN Senior Transport Officials Meeting supervise, coordinate, and review programmes as well as directions set by ASEAN Transport Ministers.
Sub-Committee on Meteorology and Geophysics (SCMG)	Enhance the capability of ASEAN National Meteorological Services to monitor and model transboundary air pollution in particular haze episodes and to enhance ASEAN's capabilities in satellite meteorology and atmospheric acidification measurement.
ASEAN Specialised Meteorological Centre (ASMC)	Undertake research and development to improve scientific understanding and prediction of weather and climate systems of significance to ASEAN, including provision of early warning for transboundary haze.
ASEAN Agreement on Transboundary Haze Pollution (AATHP)	Agreement on Transboundary Haze Pollution that AMS signed in 2002 to prevent, monitor, and mitigate land and forest fires to control transboundary haze pollution through concerted national efforts, regional and international cooperation. Currently aiming to achieve a vision of Transboundary Haze-free ASEAN by 2030.
ASEAN Health Cooperation Governance and Implementation	Composed of two main governing bodies of ASEAN health development: 1. ASEAN Health Ministers' Meeting (AHMM) which determines the policies of ASEAN Health and endorses decisions and reports of SOMHD. 2. Senior Officials' Meeting on Health Development (SOMHD) which is responsible for strategic management and provides guidance on the overall implementation of the APHDA ensuring that all goals and targets are achieved.
ASEAN Consultative Committee on Standards and Quality	Aims to harmonize national standards with international standards and implement mutual recognition arrangements on conformity assessment to achieve its end-goal of "One Standard, One Test, Accepted Everywhere".

would not only work with the ASEAN secretariat to put issues covered in the report on meeting agendas and address the three aforementioned needs; they would serve as exemplary role models and living laboratories on how those needs can met elsewhere in the region. The good news in this connection is that there are several countries in the ASEAN region that have exhibited a keen interest and gained the experience needed to serve as champions. Three countries stand out in this regard.

- The first country that is well-positioned to serve as a champion is Thailand. Thailand is currently in the process of developing a report that draws upon the LEAP modelling to identify solutions that cut across climate, air pollution and health concerns. In addition, during an information sharing session for this project, the Pollution Control Department in Thailand raised the possibility of creating a Mekong sub-regional 'branch of the CCAC' to promote SLCP issues in the Mekong region. Increased efforts to address haze from the opening burning of agricultural residue suggest it may also be able to share experiences on this problem with other countries in Northern ASEAN that are similarly suffering from this issue.
- The Philippines is a logical choice for a second champion country. The Philippines has already developed a national waste management plan on SLCPs and is about to engage in a broader cross-sectoral SLCP plan. In addition, cities such as Quezon in the Philippines have developed forward-looking climate plans that also underline air quality and health co-benefits. This local level example could be shared and spread to other countries in ASEAN.
- A third champion country could be Cambodia. Cambodia has used the LEAP tool to integrated climate concerns into its Clean Air Act. In so doing, it has also gone through the process of coordinating across different ministries and engaging multiple stakeholders in a process that explicitly makes the link between air pollution and climate change.

While the previously three countries appear well-positioned to serve as leaders and models for other countries in ASEAN, there are also other countries in the region that may also join and expand the coalition within the AWGCCC. For instance, Indonesia is home to large group of researchers conducting studies on more integrated approaches to air pollution and climate change. Meanwhile, Viet Nam where there has been successful collaboration on CCAC sectoral projects and has exhibited an interest in co-benefits. While the next two to three years would focus on building and expanding the coalition of champion countries, the ultimate goal over the next decade would be the harmonization of policies that can promote the 15 solutions.

For the champion countries and ASEAN secretariat to spearhead work on the three identified needs, more human and financial resources will likely be needed. To help fill capacity gaps, the ASEAN secretariat may consider requesting resources from international partners for a focal point to coordinate the proposed learning and training process and meeting the three identified needs from Section 3.2. Another way to address capacity limitations is strengthening collaboration the organizations and initiatives described in Section 3.4.

The CCAC can work with relevant stakeholders to promote this report's 15 solutions and use the momentum generated by it to advance many of the above recommendations. These include helping to assemble the previously mentioned coalition of champion countries to support more coordinated work under the ASEAN Secretariat and the AWGCC. In addition, the CCAC could focus more effort attracting more countries in the region to join the CCAC and considering country views on how such sub-regional coordination could be effectively organized. The same initial set of champion countries—Thailand, the Philippines, Cambodia—could encourage other countries to join the CCAC to enhance their capacity and request support for their strategy planning efforts.

3.6 Conclusions

The ASEAN region can achieve significant benefits through integrated air pollution and climate projects and planning. The report has identified 15 solutions that can improve air quality, better health and stabilize the climate in ASEAN. It has further suggested that many countries in ASEAN have valuable experience implementing the solutions. Efforts to strengthen governance and tap finance could help to spread that success within countries. Broader efforts to strengthen regional cooperation on the 15 solutions supported by an engagement process that promotes integrated planning, demonstration projects, and resource mobilization strategies could help to make the report's recommendations mainstream at the subregional level. That process could be coordinated by the ASEAM Secretariat, led by at least three champion countries, and fall under the AWGCC. Enhanced cooperation within ASEAN and with international and regional initiatives could help address capacity limitations. At the same time, a externally funded focal point for air pollution (or integrated approaches to air pollution and climate change) will likely be needed to coordinate activities.

In addition to the main recommendations, a few additional points on subregional policy coordination and harmonization merit attention moving forward. While there is hope that the report would lead to a subregional effort to strengthen air quality standards, it is not recommending a one-size-fits-all approach. Rather there are likely to be variation across countries in priorities and entry points for action in ASEAN—with some countries working through air pollution policies and then making connections to climate change. In other instance, countries may want to focus on bringing air pollution and health into climate policies such as their nationally-determined contributions (NDCs) or long-term development strategies (with supporting net zero goals).

It should also be highlighted that, relative to regions such as Latin America and Africa, the ASEAN region still offers potential for achieving the multiple benefits of a more coordinated approach to air pollution and climate change. In Latin America, countries have developed their capacity to integrate air pollution and climate change issues and add SLCP actions to their climate plans. Chile, Colombia, and Mexico have all included targets to reduce black carbon in their NDCs and are promoting integrated policy development. Countries in Africa meanwhile are making links between air quality and development priorities covered under the sustainable development goals (SDGs). These experiences can be communicated through the awareness raising and information sharing activities across regions. At the same time, ASEAN has significant potential to become an example of how to do integrated air pollution and climate change planning at the subregional level. That experience could, in turn, be shared with other subregions.

The benefits of subregional cooperation leads to a final concluding point. Some of the most significant benefits of implementing this report's recommendations extend beyond air quality, health, and climate change. Cooperation on environmental issues can help build the trust and mutual understanding that can deepen subregional integration and lead to a more prosperous and sustainable future for ASEAN.

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Annex 1

Differences in Data and Modelling Specifications between the 2019 Solutions Report and this Report

As noted in Chapter 2, there have been 10 updates and methodological changes in the GAINS model, data used in the models, and modelling scenarios that were made since the *Solution Report*. This annex provides a review of those 10 changes.

First, the current calculations are based on the development of a new sub-model for the **waste management** sector as well as elements of transport model (high emitting vehicles). For waste management, since 2017 the information that is necessary to estimate emissions of methane and HFCs has been updated based on the recently published papers (Purohit et al. 2018; Höglund-Isaksson et al. 2020; Gómez-Sanabria et al. 2021) breaking reductions down to regional and sector levels using the most recent version of IIASA's Greenhouse gas and Air pollution Interactions and Synergies (GAINS). The update relies on the datasets reported in those papers. For example, instead of estimating total municipal waste generation and then assuming share of waste that is burned, the new model distinguishes different types of waste (e.g., food, textile, plastic, metal, glass, paper, wood) and various management options including uncontrolled burning of trash, more or less well managed landfills where some trash can burn too while at the same time also gas can be recovered and reused. The macroeconomic data, mostly population, urbanization, and GDP were used to develop regionally specific projection of waste generation while local information was used about waste management and emission factors, provided they were available (otherwise IPCC defaults were used). For details see (Gómez-Sanabria et al. 2018; Höglund-Isaksson et al. 2020; Gómez-Sanabria et al. 2021). The use of this data allows for a more accurate accounting of emissions from the waste sector, including the burning of residential waste.

Second, the data for **high-emitting vehicles** have been improved. Important update follows the principles described by Klimont et al. (2017) but is directly included in GAINS and the parameterization considers data on vehicle numbers by category and implemented policies for respective scenarios. We have also included a dedicated technology to reflect the impact of repair of such vehicles.

Third, there have been adjustments of estimates of **NO_x emissions from agriculture**. These estimates have been revisited introducing emissions from soil, i.e., application of mineral and organic manures will result in emissions of NO from soil.

Fourth, there have been updates to the 2015 **socioeconomic and energy data** as well as updated to projections of future economic activities (e.g., energy use, industrial production, agricultural activities) up to 2030, *inter alia*, based on the regional trends of the World Energy Outlook 2018 of the International Energy Agency (IEA 2018). The choice to use the WEO 2018 dataset has been motivated by the fact that it has been also used in development of global scenarios in GAINS (ECLIPSE_V6b) that served as input for large scale modelling studies, for example, for Asia (Kanaya et al. 2020), Arctic (Im et al. 2021), Europe (Gauss et al. 2021), and at a global level (Amann et al. 2020; Evangeliou et al. 2020; Lund et al. 2020). The papers listed above include principal documentation of the data sources and scenarios developed for use in these studies as well as for the forthcoming Arctic Monitoring and Assessment Program 2021 assessment report. The WEO 2018 scenarios also include interpretation of the NDCs (as of 2018) and the sustainable development scenario consistent with the Paris Agreement goals of staying under 2°C warming, compared to the pre-industrial period.

Fifth, beyond importing updated statistical data from IEA as well as FAO for agriculture, IIASA has been evaluating some particular aspects of **sectoral distribution of activities** where the GAINS model has higher resolution compared to the available international and national data. In particular, sector

and technology distributions have been revised and updated for the solid fuel cooking as well as for the aforementioned transport and waste management sectors.

Sixth, there have been updates on **solid fuel cooking data**. Solid fuel cooking is a key pollution source in Asia but data about type and amounts of fuels used is often poor. IEA has been working to improve the statistical information that is collected but often must rely on the national sources or proxies. IIASA has been independently evaluating the reported fuel use comparing it with the available surveys in several countries (e.g. Hoang 2011) and using a simple model calculating energy demand for cooking, considering information about access to electricity, gas, coal, wood or agriculture residues. In case the IIASA calculation resulted in ±20% difference with IEA, IIASA retained original IEA numbers but where the difference was much larger data was re-estimated and updated with newly developed GAINS numbers. The most prominent example is data for Indonesia where according to IIASA estimates, IEA statistics significantly overestimate use of solid fuels for cooking. Therefore, IIASA has adjusted this figure to achieve consistency with reported gas and electricity availability and use for this purpose. This change is one of the factors contributing to the difference in estimating future mitigation potential compared to the *Solutions Report* which used the original IEA data.

Seventh, the **transport sector data** has been updated to include a revision of fuel, vehicle numbers, and vehicle kilometres driven distribution for several categories. This includes passenger cars, light duty trucks, motorcycles, heavy duty trucks, and busses. This is relevant since the emission factors and status of legislation varies for these categories impacting not only quality of estimating current emissions but also potential for further mitigation. Further updates have involved the systematic consideration of high emitting vehicles, which are introduced in the model calculation assuming region and vehicle type specific shares of vehicles that emit several-fold of the valid emission standards due to e.g., malfunction or purposeful manipulation of engine or emission control system – the assessment is based on the measurements in Asia and elsewhere in the world as some of the malfunctioning is related to age and technology, therefore being captured also in other regions.

Eighth, in this analysis we use several sets of **emission factors** which represent recent developments in several countries in Asia where more experience, and more ambitious emission limits requirements, exist. Introduction of ambitious air quality policy in parts of Asia resulted in application (and often own production) of very efficient cleaning technologies which represent often state of the art also from the global perspective. Consequently, in the assessment of the mitigation potential we have applied higher reduction efficiencies that were shown to be achievable in Asia, especially to reduce emissions of primary $PM_{2.5}$ (e.g., highly efficient multistage electrostatic precipitators or fabric filters) and SO_2 (high efficiency flue gas desulphurization). For residential sector, specifically cooking on solid fuels, GAINS model includes now an explicit representation of LPG stoves and for agriculture impact of significant improvements in nitrogen use efficiency has been also modelled introduced new emission factors representing such development.

Ninth, the **spatial distribution of emissions** has been revisited and improvements in distribution of activities between provinces or states within a given country have been made. This is especially relevant for countries for which GAINS includes sub-national regionalization, i.e., for Malaysia, Philippines, Thailand, Viet Nam, and Indonesia. Another aspect of these improvements involves spatial distribution proxies that include information about location of key sources like power plants, refineries, cement plants, steel mills, smelters, etc. IIASA has been acquiring new data, e.g., Power Watch for the power sector, or USGs data for smelters, road networks, etc. and used it in updated spatial proxies. The reassessment of the historical data and structure of sources has also implications for projections and mitigation potential as well as for spatial distribution of impacts (population-weighted PM exposure).

Tenth, the **baseline and policy scenarios** have been updated for the year 2020. Therefore, databases on air pollution, energy, climate and other sectoral policies and their foreseen implementation schedules reflects now the status of mid-2020 (see also section 3.2). This includes also the NDCs communicated in 2018 which are included in the IEA baseline (new policy scenario-NPS) that is used in this work (IEA 2018). The implications of the current legislation are also estimated for 2030, assuming typical lifetime of technologies – this assumption

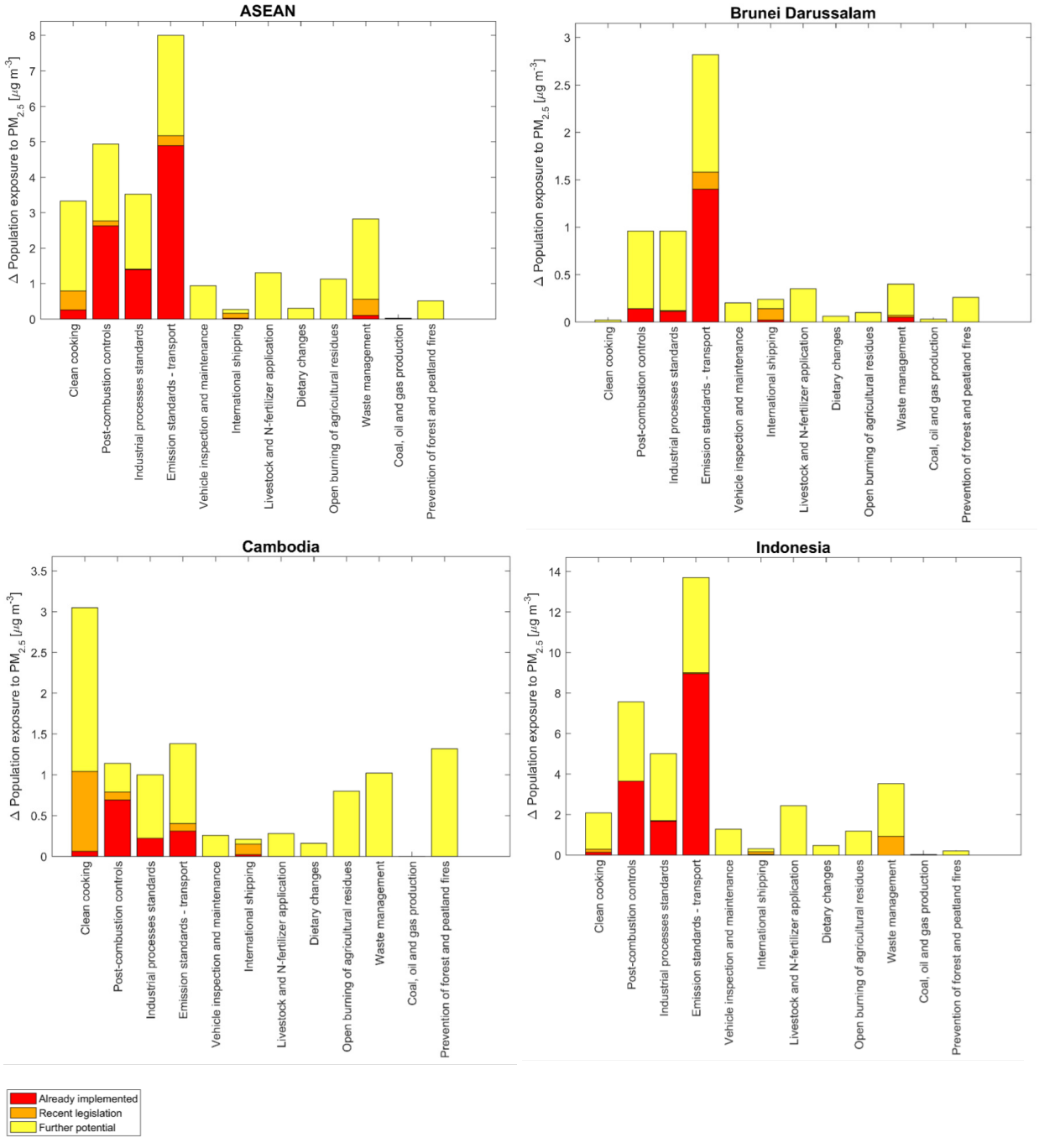
is reflected in the scenario referred in further text as *CLE* or *Baseline*. The updated policies have implications extending well beyond the baseline as they also determine what has been achieved in the past and what is the remaining mitigation potential - the scenarios to analyse the future potential and impact of particular solutions is provided in further sections of this report.

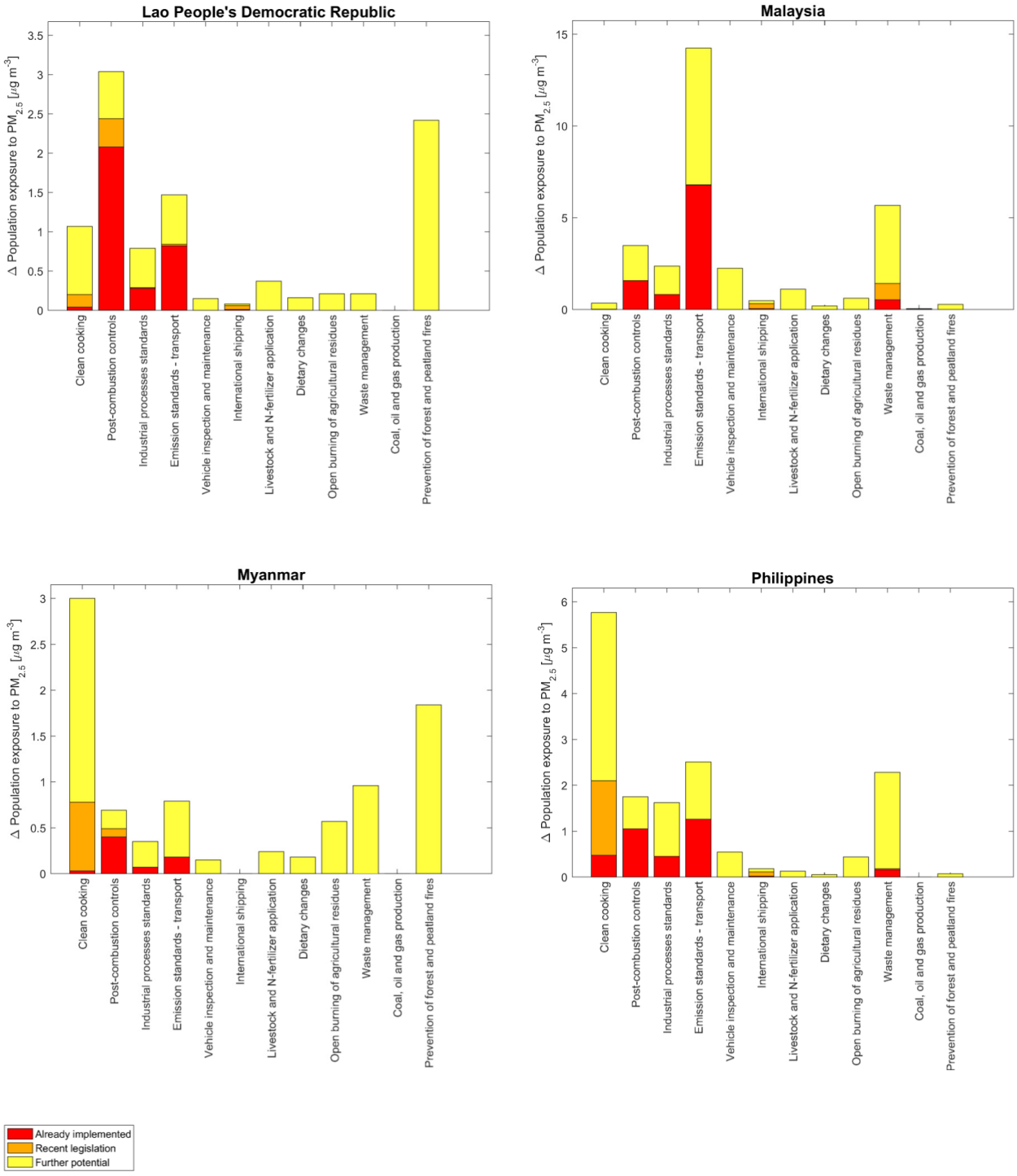
In the revision and updating process (both for base year activities and information about recent policies), IIASA has benefited greatly from joint activities with its member organizations or collaborating projects; examples include work with the Vietnamese Academy of Science and Technology (VAST) in Hanoi; Bandung Institute of Technology in Bandung (Indonesia); and King Mongkut's University of Technology Thonburi (KMUTT) in Bangkok, Thailand.

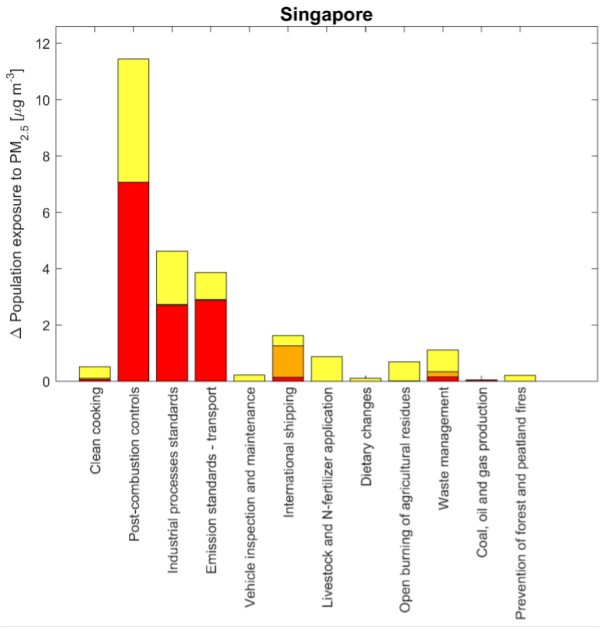
Annex 2

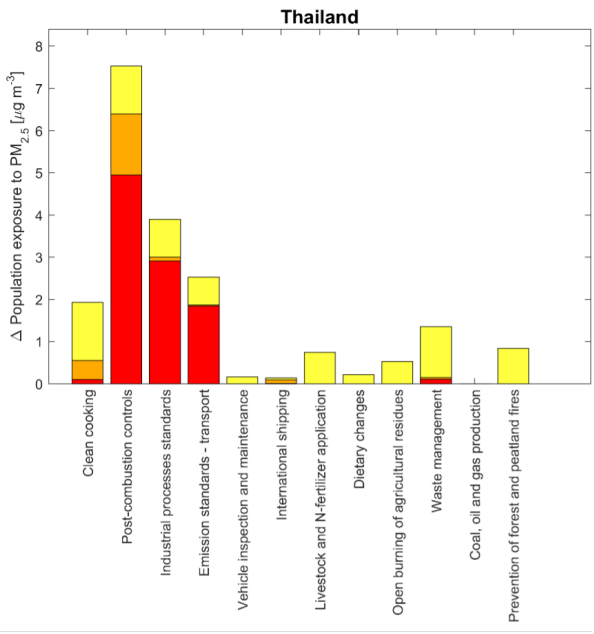
Contribution of the key measures to reduction of population weighted $PM_{2.5}$ concentrations by 2030 - country results

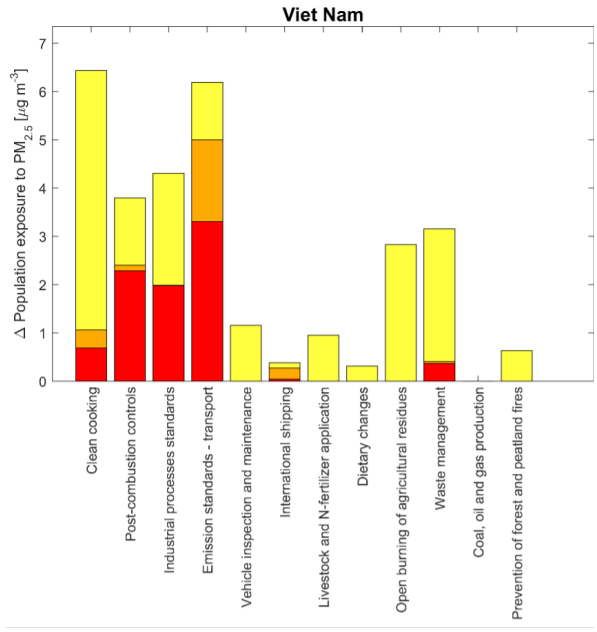
The charts show impact of the implemented legislation, recent legislation, and further measures on reduction of population weighted $PM_{2.5}$ concentrations in all ASEAN countries by 2030.

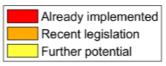



Lao People's Democratic Republic
Malaysia
Myanmar
Philippines
Δ Population exposure to PM2.5 [μg m-3]
Clean cooking
Post-combustion controls
Industrial processes standards
Emission standards - transport
Vehicle inspection and maintenance
International shipping
Livestock and N-fertilizer application
Dietary changes
Open burning of agricultural residues
Waste management
Coal, oil and gas production
Prevention of forest and peatland fires
Already implemented
Recent legislation
Further potential


Singapore
Δ Population exposure to PM2.5 [μg m-3]
0
2
4
6
8
10
12
Clean cooking
Post-combustion controls
Industrial processes standards
Emission standards - transport
Vehicle inspection and maintenance
International shipping
Livestock and N-fertilizer application
Dietary changes
Open burning of agricultural residues
Waste management
Coal, oil and gas production
Prevention of forest and peatland fires


Thailand
Δ Population exposure to PM2.5 [μg m-3]
0
1
2
3
4
5
6
7
8
Clean cooking
Post-combustion controls
Industrial processes standards
Emission standards - transport
Vehicle inspection and maintenance
International shipping
Livestock and N-fertilizer application
Dietary changes
Open burning of agricultural residues
Waste management
Coal, oil and gas production
Prevention of forest and peatland fires

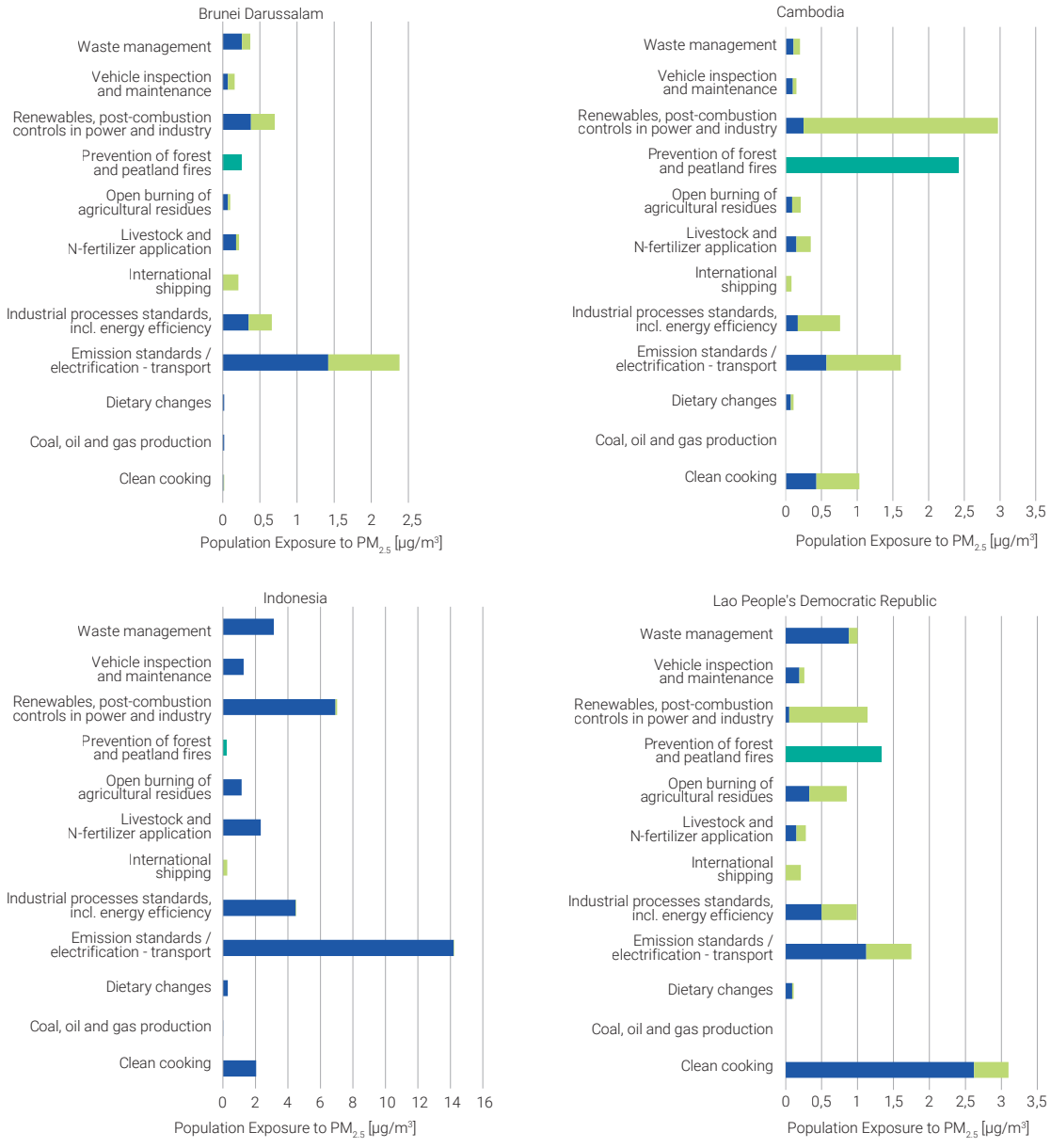

Viet Nam
Δ Population exposure to PM2.5 [μg m-3]
0
1
2
3
4
5
6
7
Clean cooking
Post-combustion controls
Industrial processes standards
Emission standards - transport
Vehicle inspection and maintenance
International shipping
Livestock and N-fertilizer application
Dietary changes
Open burning of agricultural residues
Waste management
Coal, oil and gas production
Prevention of forest and peatland fires


Already implemented
Recent legislation
Further potential

Annex 3

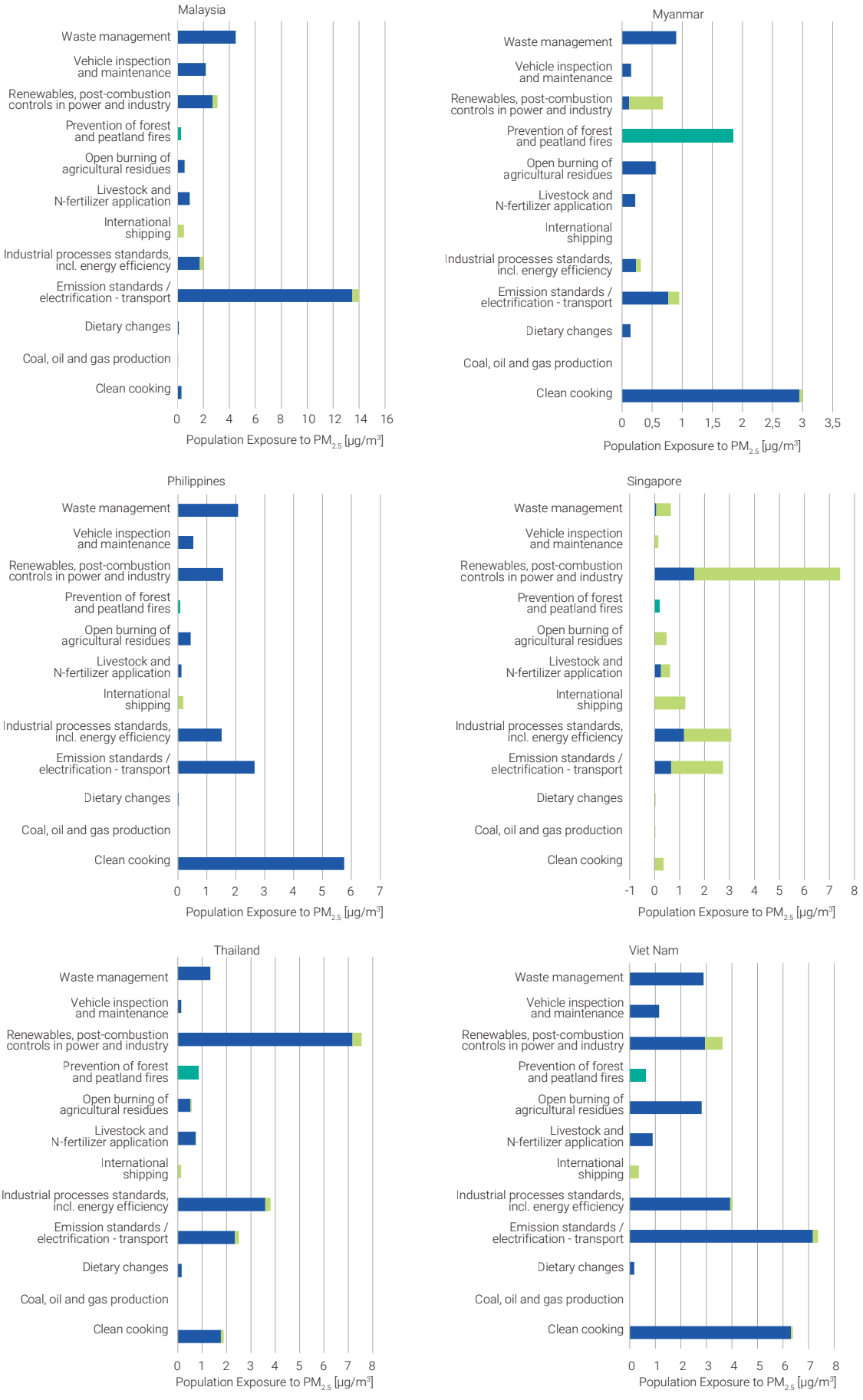
Contribution of local and transboundary mitigation; potential by key measures – country results

The charts show impact of the implemented legislation, recent legislation, and further measures on reduction of population weighted $PM_{2.5}$ concentrations in all ASEAN countries by 2030.



** Forest/peat fires and open burning of agricultural residue are included in the modelling work. Emissions include temporal (monthly) distribution but the calculated concentrations of $PM_{2.5}$ represent annual averages since the impact analysis focuses on the health impacts from long-term rather than short-term peak exposure.*

Episodic high pollution events due to forest fires can result in acute short-term exposure while are often perceived as a major source affecting long-term exposure. However, in most cases, the annual average concentrations and exposure will not be affected strongly and therefore strategies to control long term pollution impacts often prioritize other sources than fires. The quantification of emissions from fires is associated with significant uncertainties since they rely on remote sensing retrievals where several assumptions have to be made about land cover, biomass density, type, moisture, etc., to derive first biomass burned and then emissions.


Malaysia
Waste management
Vehicle inspection and maintenance
Renewables, post-combustion controls in power and industry
Prevention of forest and peatland fires
Open burning of agricultural residues
Livestock and N-fertilizer application
International shipping
Industrial processes standards, incl. energy efficiency
Emission standards / electrification - transport
Dietary changes
Coal, oil and gas production
Clean cooking
0 2 4 6 8 10 12 14 16
Population Exposure to PM2.5 [µg/m3]
Myanmar
Waste management
Vehicle inspection and maintenance
Renewables, post-combustion controls in power and industry
Prevention of forest and peatland fires
Open burning of agricultural residues
Livestock and N-fertilizer application
International shipping
Industrial processes standards, incl. energy efficiency
Emission standards / electrification - transport
Dietary changes
Coal, oil and gas production
Clean cooking
0 0,5 1 1,5 2 2,5 3 3,5
Population Exposure to PM2.5 [µg/m3]
Philippines
Waste management
Vehicle inspection and maintenance
Renewables, post-combustion controls in power and industry
Prevention of forest and peatland fires
Open burning of agricultural residues
Livestock and N-fertilizer application
International shipping
Industrial processes standards, incl. energy efficiency
Emission standards / electrification - transport
Dietary changes
Coal, oil and gas production
Clean cooking
0 1 2 3 4 5 6 7
Population Exposure to PM2.5 [µg/m3]
Singapore
Waste management
Vehicle inspection and maintenance
Renewables, post-combustion controls in power and industry
Prevention of forest and peatland fires
Open burning of agricultural residues
Livestock and N-fertilizer application
International shipping
Industrial processes standards, incl. energy efficiency
Emission standards / electrification - transport
Dietary changes
Coal, oil and gas production
Clean cooking
-1 0 1 2 3 4 5 6 7 8
Population Exposure to PM2.5 [µg/m3]
Thailand
Waste management
Vehicle inspection and maintenance
Renewables, post-combustion controls in power and industry
Prevention of forest and peatland fires
Open burning of agricultural residues
Livestock and N-fertilizer application
International shipping
Industrial processes standards, incl. energy efficiency
Emission standards / electrification - transport
Dietary changes
Coal, oil and gas production
Clean cooking
0 1 2 3 4 5 6 7 8
Population Exposure to PM2.5 [µg/m3]
Viet Nam
Waste management
Vehicle inspection and maintenance
Renewables, post-combustion controls in power and industry
Prevention of forest and peatland fires
Open burning of agricultural residues
Livestock and N-fertilizer application
International shipping
Industrial processes standards, incl. energy efficiency
Emission standards / electrification - transport
Dietary changes
Coal, oil and gas production
Clean cooking
0 1 2 3 4 5 6 7 8
Population Exposure to PM2.5 [µg/m3]
From this country
From other countries
Not resolved

Annex 4

Share of population exposure to different $PM_{2.5}$ levels

Here we show the share of population exposed to different levels of ambient $PM_{2.5}$ concentrations for 2015, 2030 baseline and 2030 with full implementation of 15 solutions.

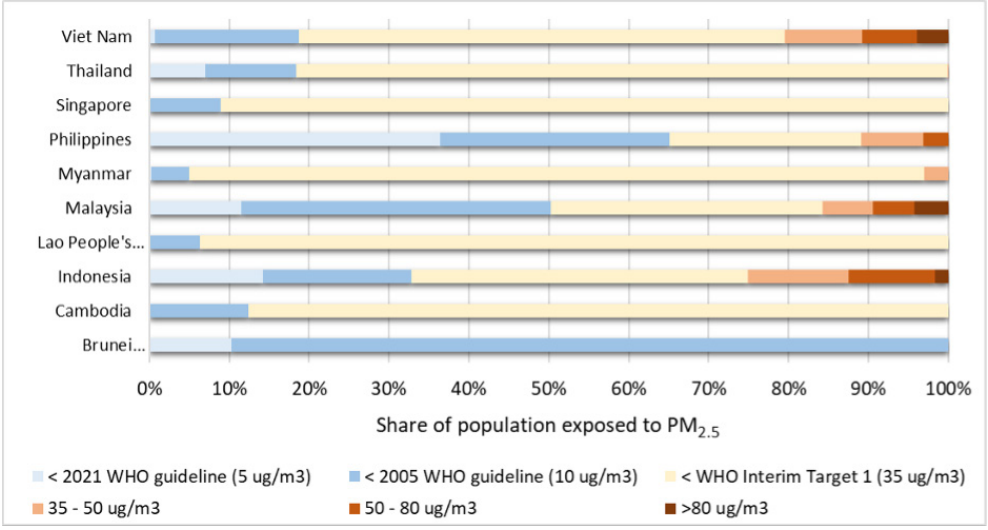


FIGURE A4.1: $PM_{2.5}$ population exposure across ASEAN region in 2015;

Source: GAINS model

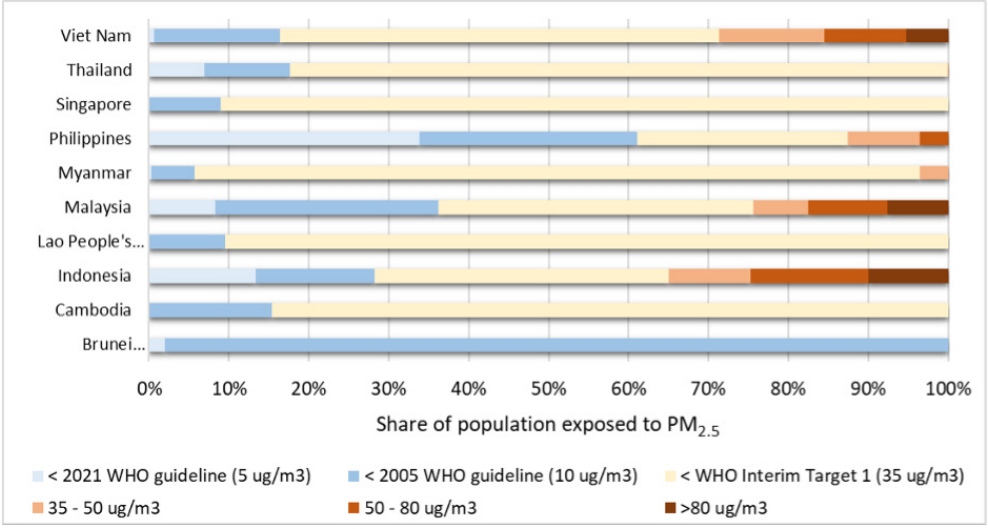


FIGURE A4.2: $PM_{2.5}$ population exposure across ASEAN region in 2030 (Baseline);

Source: GAINS model

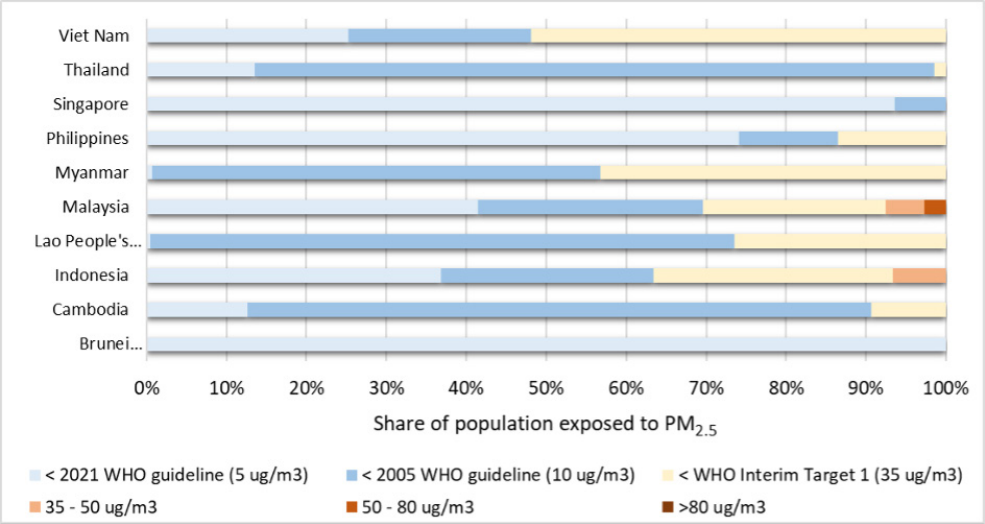


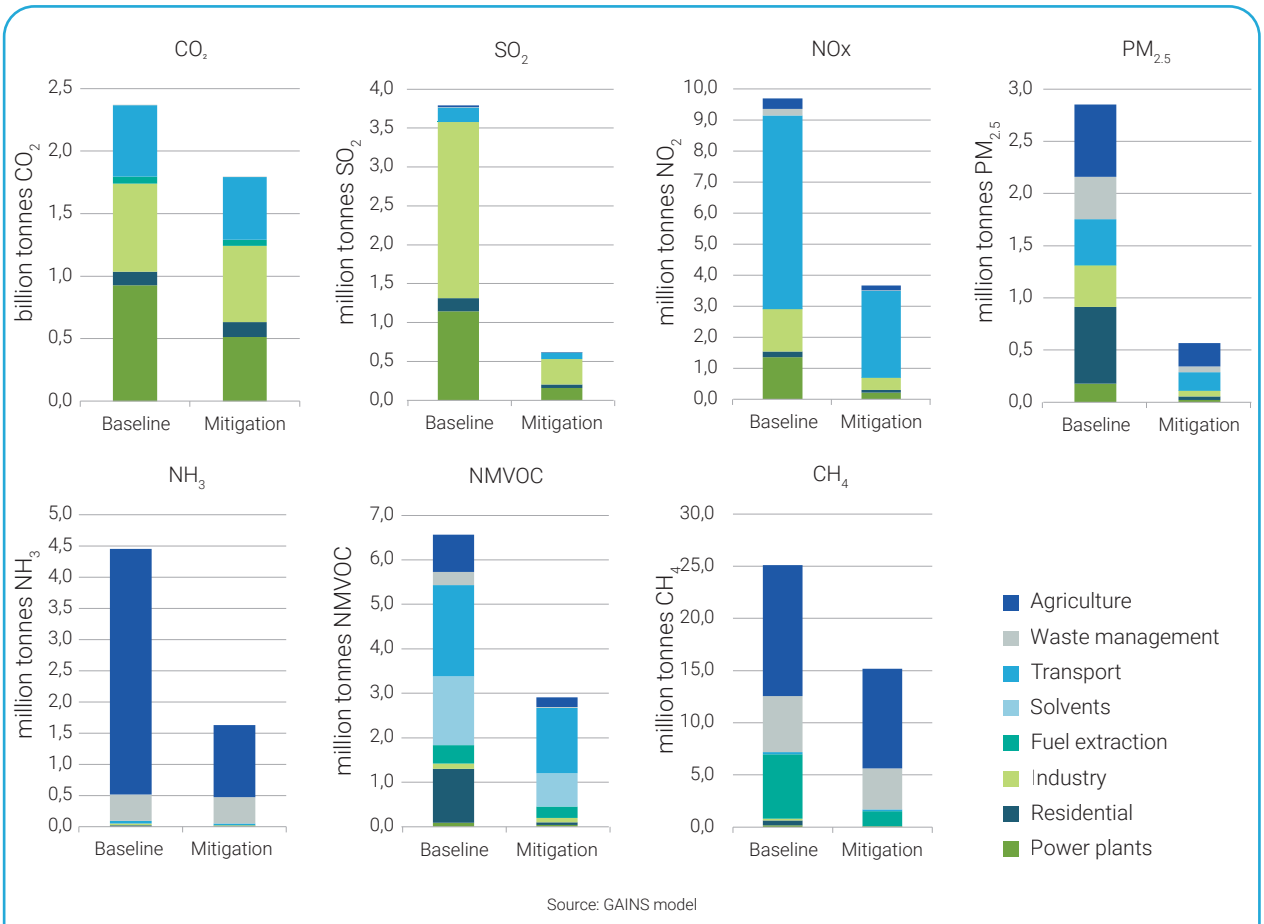
FIGURE A4.3: $PM_{2.5}$ population exposure across ASEAN region in 2030 (full implementation of 15 solutions);

Source: GAINS model

Annex 5

Impact of mitigation policy on emissions on key species

Full implementation of 15 solutions discussed in this report would result in reduction of emissions of greenhouse gases and several air pollutants. The figure below illustrates the reduction for total ASEAN region and the change in sectoral emission structure for each of the emitted species.



Source: GAINS model

FIGURE A5.1: Emissions of CO_2, CH_2, $PM_{2.5}$ and its precursors in 2030 for the Baseline and the scenario where full implementation of 15 solutions is considered.Results for total ASEAN region by key sectors; Source: GAINS model

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