Simultaneously Achieving Climate Change and Air Quality Goals in Thailand

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กรมควบคุมมลพิษ
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Disclaimer

Foreword

Pollution Control Department has joined the Climate and Clean Air Coalition (CCAC) in 2019. We have developed a project to identify solutions to reduce 'short-lived climate pollutants' (also known as SLCPs). This project is part of the Climate and Clean Air Coalition (CCAC)'s Supporting National Planning and Action to reduce SLCPs (SNAP) Initiative.

This report provides sets of data including i) policies and measures with the potential to achieve both air pollution and climate change benefits, ii) the air pollutant, SLCP and greenhouse gas emission reduction potential of these policies and measures, iii) the evaluation of the public health benefits from their implementation and iv) different barriers to their implementation and evaluate the impact of these barriers in reducing the speed and effectiveness of the emission reductions and other benefits from their implementation. The results from this project will help achieve Thailand's climate change goals, while at the same time improving air quality across Thailand and protecting the health of Thais.

I wish to express my sincere appreciation to the Climate and Clean Air Coalition (CCAC), Institute for Global Environmental Strategies (IGES), Stockholm Environment Institute (SEI) and relevant persons with this project for their kind cooperation in providing and evaluating data and information to make the report accurate and complete.

(Dr. Pinsak Suraswadi)
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Executive Summary

Thailand has introduced a wide range of policies intended to reduce the adverse impacts of air pollution on human health, crop yields, and other development priorities. Thailand has also adopted increasingly ambitious climate policies as part of global efforts to keep warming within safe levels. Since emissions contributing to air pollution and climate change often share sources, Thailand could save lives, money, and time from integrated responses to these two interrelated concerns. In short, Thailand has a significant--but often untapped--opportunity for integrated air pollution and climate change policies.

After joining the Climate and Clean Air Coalition (CCAC) in 2019, Thailand initiated a CCAC Supporting National Action & Planning initiative (SNAP) project in 2021 to take advantage of that opportunity. This assessment report is the first main output of that engagement. The report has several objectives meant to support the design and implementation of integrated air pollution and climate policies in Thailand:

1. Identify policies and measures with the potential to achieve both air pollution and climate change benefits;
2. Quantify the air pollutant, short-lived climate pollutant (SLCP) and greenhouse gas emission (GHG) reduction potential of these policies and measures;
3. Evaluate the public health benefits (avoided premature deaths) from the potential implementation of these measures; and
4. Identify different barriers to their implementation and evaluate the impact of these barriers in reducing the speed and effectiveness of the emission reductions and other benefits from their implementation.

Method

A project team composed of policymakers from Thailand's Pollution Control Department (PCD) as well as researchers inside and outside of Thailand to go through the following steps to achieve the above objectives:

- First, the project team used a consistent methodology to develop an historic emission inventory of air pollutants, SLCPs, and GHGs, i.e. the same activity data were used to estimate emissions of all pollutants. The inventory helped identify common pollution sources , and where mitigation should focus to achieve multiple (and possibly maximum) air pollution and climate change benefits.
- Second, the team developed baseline projections of emissions from 2020 to 2030 and 2050, linking emission trends to anticipated changes in Thailand's socioeconomic development. These business-as-usual emissions projections did not reflect possible reductions in emissions from the implementation of policies and measures.
- Third, the team quantified the effects of 19 policies and measures identified from existing policies and some additional measures in Thailand. The impacts of these policies and measures were evaluated at the national scale as well as across six regions.
- Fourth, the team conducted a health impact assessment to evaluate how these emission reductions are expected

to reduce exposure to fine particulate matter and improve public health.

- Finally, the team analysed the technical, economic, social and institutional barriers to the effective implementation of several of the key mitigation measures. The impacts on the delayed implementation of the several measures were also assessed. In addition, it recommended reforms to the enabling environment such as strengthening interagency coordination and multi-level integration that could accelerate and boost the effectiveness of key measures.

Key Results

This assessment shows that there is currently substantial overlap in the major sources of air pollutants, SLCPs and GHGs (Figure 1). For particulate matter, agricultural residue burning is the largest source, followed by charcoal production (for residential energy and cooking), industry, transport and open burning of waste. The transport sector is the single largest source of nitrogen dioxide emissions, while the agriculture, waste, and fossil fuel production sectors account for most of Thailand's methane. This overlap in the sources of key pollutants underlines the substantial opportunity to target specific sources for mitigation, and is a key starting point to identifying the measures with the greater mitigation and co-benefits potential.

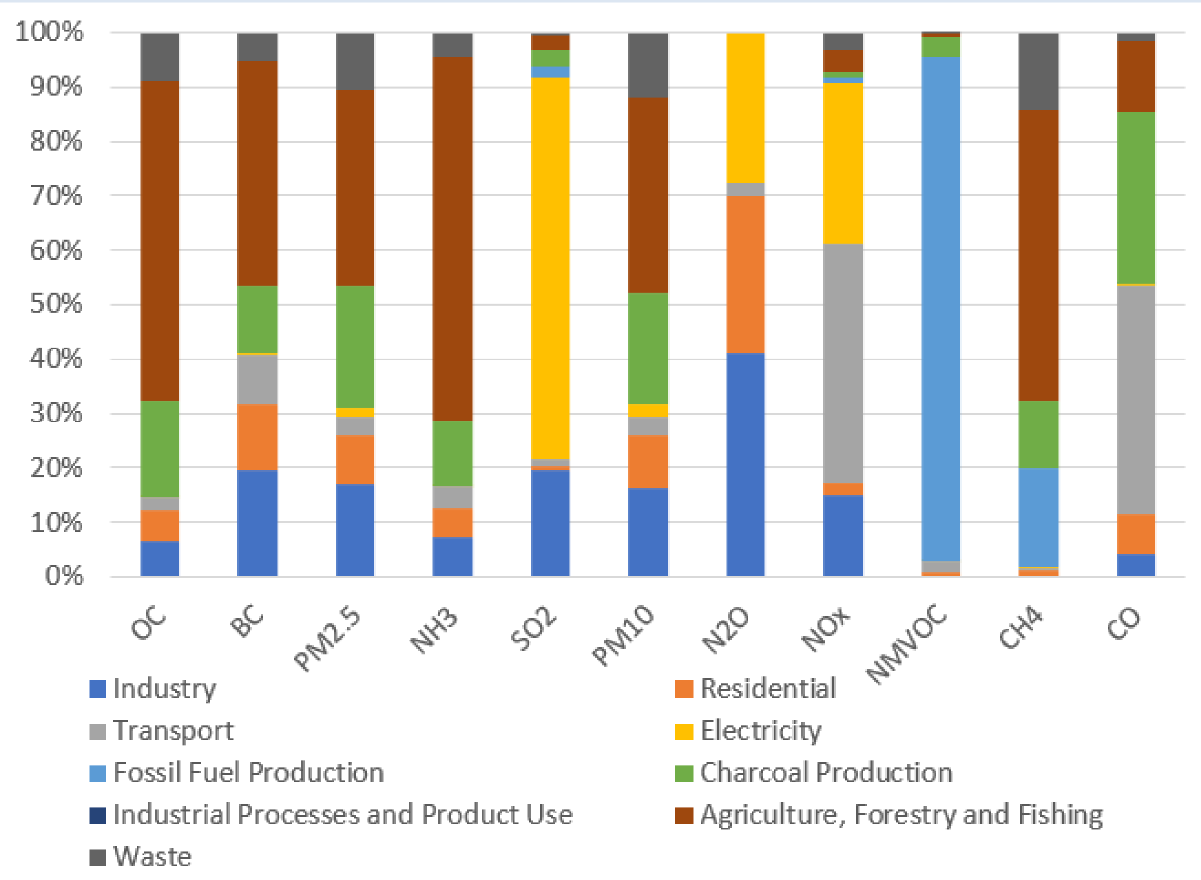


Figure 1: Contribution of key source sectors to national total emissions in 2020 in Thailand. Agriculture, Forestry and Fishing includes open burning of agricultural residues

Within these major air pollutants, SLCP and GHG emitting sources, there are already policies and measures within Thailand's air pollution (e.g., $PM_{2.5}$ action plan), climate change (Nationally Determined Contribution and Long-term Strategy), and sectoral planning that could yield emission reductions. These measures were extracted, and combined with other measures from international assessments to produce a list of 19 priority mitigation measures that could achieve air pollution and climate change benefits. The analysed measures are presented in Table 1, and explained in greater detail in the body of the report (Section 4).

Table 1: Priority mitigation measures identified and evaluated within the integrated air pollution and climate change mitigation assessment

No.	Subsector	Mitigation Measure
1	Transport	Implementation of Euro 5 Emission standards and fuel quality in 2024.
2	Transport	Switching diesel buses to be electric buses (BMTA) about 500 buses in December 2021 and replace all 6,500 diesel buses by CNG and Electric buses in 2024.
3	Transport	The Government has promoted EVs in Thailand with the target in 2030 as following: motorcycle 650,000, light passenger car 440,000, bus 33,000, truck 34,000 including 1450 charging stations with 12,000 charging ports.
4	Transport	Retrofit Program (The government planned to install a DPF to the used diesel bus and truck which are being 10-15 years average)
5	Residential	More efficient charcoal stoves
6	Residential	Energy Efficiency
7	Services	Energy Efficiency
8	Industry	Energy Efficiency
9	Crop	Zero agricultural residue burning
10	Solid Waste	Zero waste burning
11	Electricity	Renewable Electricity Expansion: 74% renewable electricity generation by 2050
12	Transport	Electric Vehicle expansion: 60% of passenger vehicles are electric by 2050
13	Residential	Switching from LPG to electricity for cooking
14	Fossil Fuel Production	Minimise fugitive methane emissions
15	Solid Waste	Methane capture from landfill sites
16	Liquid waste	Methane capture from wastewater management sites
17	Rice Production	Alternate wetting and drying implemented for rice production
18	Livestock	Reduce enteric fermentation emissions from livestock
19	Forest	Forest fire control

The full implementation of the 19 mitigation measures were estimated to result in substantial reductions in the majority of pollutants (Figure 2). Particulate matter would witness the greatest reductions--with up to a 70% drop by 2030. However, other air pollutants, such as NO_x and SO_2, would also fall significantly. In total, the 19 mitigation measures also achieve substantial climate change benefits, reducing national total carbon dioxide emissions by almost 25%, and methane emissions by 65%. The substantial potential to reduce methane emissions demonstrates that Thailand can make a substantial contribution to global efforts to mitigate climate change and keep global temperature increases within 1.5 °C.

Perhaps most importantly were that the estimated reductions would also bring sizable health benefits. The reduction in air pollutant emissions were estimated to result in a 22% reduction in population-weighted particulate matter concentrations across Thailand. This reduction in air pollutant exposure estimated to avoid over 3,000 premature deaths per year by 2030 in Thailand.

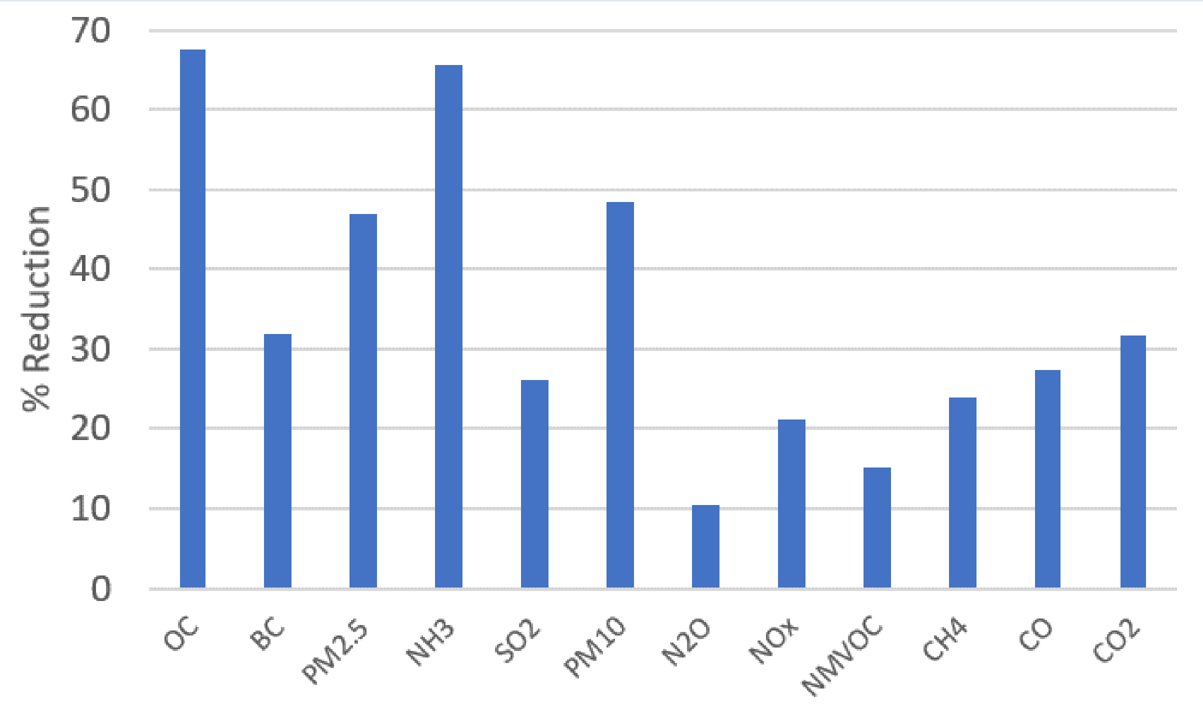


Figure 2: Percentage reduction in national total air pollutant, short-lived climate pollutant and greenhouse gas emissions from the effective implementation of all 19 policies and measures in 2030 compared to the baseline scenario.

Though the potential benefits are significant, their achievement is not guaranteed. In fact, there are significant barriers to implementation of many of the mitigation measures that are not typically considered in modelling scenarios. If not overcome, these barriers could substantially delay or limit the scope of implementation, slowing and lowering the emission reductions as well as the delivery of related benefits. Stakeholder surveys and literature reviews on institutional, economic, technical and social barriers for each measure suggest that only half of the achievable emission reductions from full implementation of the mitigation measures would be achieved. This underlines that the measures require supportive enabling reforms such as interagency coordination mechanisms (especially between the PCD, MONRE/ONEP, and relevant sectoral agencies); fiscal reforms that allocate resources for local actions; targeted capacity building programmes; and follow-up and review to assess effectiveness.

Recommendations

The results from this assessment demonstrate that Thailand has a significant opportunity to simultaneously improve air quality and health while mitigating climate change. To capitalize on this opportunity, the project team recommends that policymakers and other stakeholders work on the following seven areas:

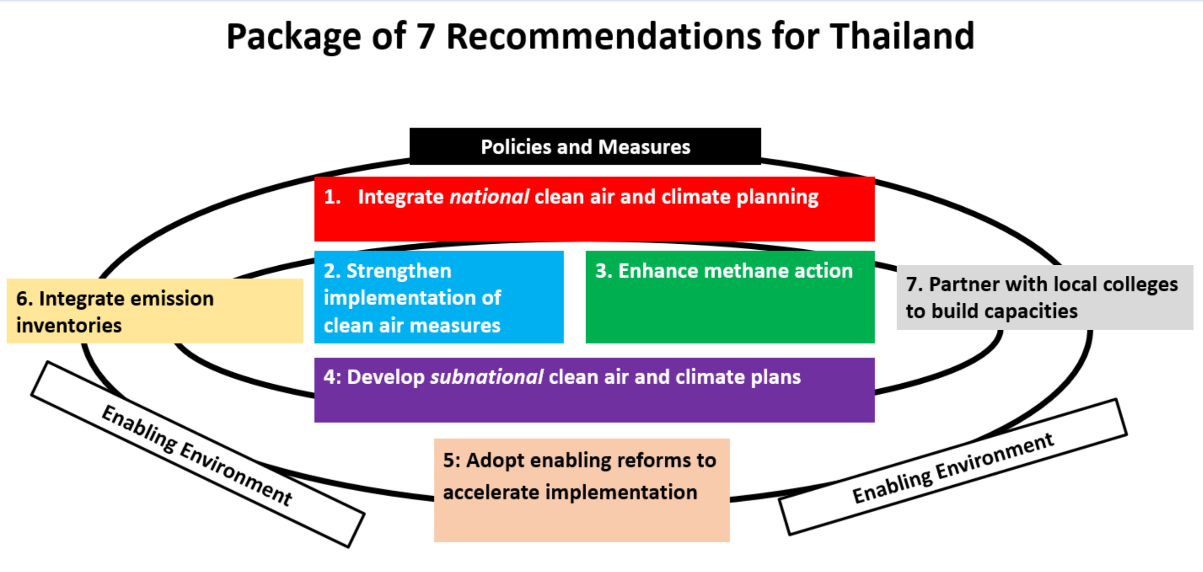


Figure 3: Summary of recommendations to increase actions on integrated air pollution and climate change mitigation in Thailand

Recommendation 1: Enhance Thailand's national air quality planning by strengthening implementation of priority air pollution measures.

Specifically, the priority measures were concerted action is needed include:

- Reducing open burning of agricultural residues
- Reducing open burning of solid waste
- Switching households to cooking using clean fuels and more efficient biomass stoves
- Euro V and VI vehicle emission standards for all vehicles
- Industrial emission controls, especially particle filters

Recommendation 2: Develop subnational clean air and climate plans featuring regionally important solutions

Different regions in Thailand could also improve air quality and public health with targeted efforts to bring down emissions from key sources at the subnational level. The assessment shows that there are specific measures that could dramatically reduce emissions at the local level that can be the basis subnational clean air plans. The key national measures were broadly also identified as the priority mitigation measures, and therefore subnational clean air actions plans covering these regionally important measures could underpin these plans.

Recommendation 3: Strengthen the integration between national clean air and climate planning

The integrated assessment is relevant not only for air pollution but climate planning. To leverage synergies between climate and air planning, it would be useful to report air quality and health benefits in key climate policies such as the NDC. This would potentially build more support for more the implementation of the NDC and other climate policies. It would similarly be useful to consider including measures that are not covered in the NDC but feature in air pollution policies such as the vehicle retrofit programme. The inclusion of these measures would potentially raise mitigation ambition while also bring climate finance to improve health and deliver other development benefits.

Recommendation 4: Enhance methane action to achieve multiple benefits

This integrated air pollution and climate change mitigation assessment provides the basis for the development of a methane action plan for Thailand. The 3 mitigation measures implemented in key sectors show that Thailand could reduce 65% of methane emission by 2030, contributing to the Global Methane Pledge. Key mitigation measures that achieve this reduction and would feed into methane action plan are as follows:

- Methane emission reductions from livestock enteric fermentation
- Intermittent aeration of rice paddy fields
- Fugitive oil and gas emission reductions
- Landfill gas capture

Recommendation 5: Adopt institutional and other enabling reforms to accelerate recommended actions

Many of the recommended reforms and mitigation measures could be delayed due to economic, technical, capacity and social barriers. In fact, the report suggests that expected emission reductions are less than half those achieved without significant barriers and the on-third of maximum achievable health benefit from implementation of all policies and measures. The adoption of institutional and other enabling reforms could help overcome these barriers. Key reforms include strengthening interagency coordination mechanisms; supporting fiscal transfers for action at the national and local levels; and creating follow-up and review mechanisms to assess effectiveness. The proposed reforms could accelerate and increase the effectiveness of implementation.

Recommendation 6: Integrate air pollution and climate change emission inventories to track progress

There is substantial overlap in the methods and data necessary to quantify and track progress on air pollutant, SLCPs and GHG emissions. Therefore, it can be more efficient to set up a common, integrated system for the quantification and reporting of air pollutant and GHG emissions. Such systems have been developed in multiple countries, including those in Europe for reporting under the Convention on Long-Range Transboundary Air Pollution (CLRTAP), and other countries within the Climate and Clean Air Coalition Support National Action & Planning initiative (SNAP).

Recommendation 7: Partner with local colleges and universities to build local capacities

Partnering with local colleges and universities can help accelerate the transfer and spread of knowledge of the techniques used in this research to the local level. Carefully designed programmes are increasingly important because there is a risk that knowledge on solutions and benefits from integrated air pollution and climate planning does is concentrated a few policymakers and decision makers. Efforts to build local capacity can also create communities of scientists, policymakers and practitioners needed for subnational planning and implementation of priority air and methane measures. These efforts could be supported, for instance, by creating mentoring relationships between universities and opening opportunities for secondment of government staff and researchers to local universities.

Contents

1. Introduction

1.1 Air Pollution, Climate Change and Short-Lived Climate Pollutants

Air pollution and climate change are two of the biggest environmental problems globally that also share many common solutions to mitigate their impacts. Exposure to air pollution from indoor and outdoor sources was associated with approximately 6.6 million premature deaths in 2019 due predominantly to respiratory and cardiovascular diseases (Murray et al., 2020). It is also linked to other non-fatal health effects, such as difficulties during pregnancy, asthma and emergency room visits (Anenberg et al., 2018; Christopher S. Malley et al., 2017). The two air pollutants with the greatest impact on human health are fine particulate matter ($PM_{2.5}$) and ground-level ozone (O_3). Fine particulate matter is made up of different components. Some, such as black carbon, and organic carbon, are 'primary $PM_{2.5}$', and directly emitted into the atmosphere from different emission sources. However, a substantial fraction of $PM_{2.5}$ is 'secondary $PM_{2.5}$' that is formed through chemical reactions in the atmosphere from the emission of gaseous pollutants. This includes 'secondary inorganic $PM_{2.5}$', which is formed from emissions of nitrogen oxides (NO_x), sulphur dioxide (SO_2) and ammonia (NH_3), and 'secondary organic aerosol', which is formed from emissions of volatile organic compounds (Fuzzi et al., 2015; Heal et al., 2012). Ozone is not directly emitted, but is formed in the atmosphere through the photochemical reactions of nitrogen oxides, volatile organic compounds, methane and carbon monoxide (Jenkin and Clemitshaw, 2000).

To underline the impact that air pollutant exposure has on human health, in 2021 the World Health Organisation updated guidelines on air pollutant exposure levels for the protection of human health for the first time in 15 years (Table 2). For $PM_{2.5}$ and ozone, as well as the majority of other classical air pollutants, the guideline exposure levels were revised downwards. This means that based on updated evidence on the impact of air pollutants on human health, the WHO set more stringent air quality guidelines. The practical implication of this revision is that more ambitious policies and measures that reduce air pollutant emissions are necessary to ensure that human health is protected (WHO, 2021).

At the same time as air pollutants impact public health, atmospheric emissions are warming the atmosphere. Since pre-industrial times, global average temperatures have risen by 1.1°C (IPCC, 2021), while the Paris Agreement sets the goal of limiting the increase in global average temperatures to "well below 2°C", and ideally to 1.5°C (United Nations, 2015). Current climate change commitments are estimated to lead to a warming of more than 3°C by 2100, so more action is needed to meet the Paris Agreement targets (Rogelj et al., 2016). The consequences of climate change include increased frequency of extreme weather events, such as storms, floods, droughts and heat waves, impacts on agriculture and food security, impacts on human health and biodiversity. Scientific studies have concluded that the level of GHG emission mitigation achieved through current NDCs needs to be increased if the Paris Agreement long-term temperature goals are to be achieved. Estimates of future warming based on emission pledges in current NDCs, assuming they are fully implemented, vary between 2.3 and 3.7°C of warming by 2100 (Gütschow et al., 2018; Jeffery et al., 2018; Robiou Du Pont et al., 2017). The necessity for substantially enhanced and fast emission reductions is emphasised by the Intergovernmental Panel on Climate Change (IPCC) Report on 1.5°C of Global Warming (Myles et al., 2018). The report concluded that to limit warming to 1.5°C, there is a requirement for global net anthropogenic CO_2 emissions to be reduced by 45% from 2010 levels by 2030, and reach 'net zero' emissions by 2050. This is in addition to substantial (35%) reductions in methane, black carbon, and hydrofluorocarbons (HFCs) emissions (UNEP/WMO, 2011).

The issues of climate change and air pollution are closely linked because (i) in many cases, greenhouse gases and air pollutants are emitted from the same sources, such as Residential cooking, industry, electricity generation, transport, agriculture and waste and (ii) some of the substances contribute to climate change and the adverse effects of air pollution, such as methane, black carbon and ground-level ozone, i.e. short-lived climate pollutants (SLCPs) (IEA, 2016). These two linkages offer considerable opportunities to design strategies and identify mitigation measures that can simultaneously reduce air pollution and mitigate climate change. Global and regional studies have shown that there is a range of strategies and actions that can be taken to target major sources of SLCPs and simultaneously improve local air pollution while reducing countries' contribution to global climate change. The common solutions to climate change and air pollution include actions to switch to renewable energy for electricity generation, electrification of vehicles, energy efficiency improvements, improved waste collection and separation (CCAC SNAP, 2019; UNEP/WMO, 2011; UNEP, 2019). Some measures may also have trade-offs for air quality and/or climate change. For example, diesel vehicles incentivised in Europe in the 2000s for their lower CO_2 emissions compared to gasoline vehicles led to substantially higher black carbon particulate matter emissions, leading to poorer air quality.

Table 2: World Health Organisation updated air quality guidelines for different air pollutants for the protection of human health

Pollutant	Averaging time	Interim target 1	Interim target 2	Interim target 3	Interim target 4	AQG level
$PM_{2.5}$, µg/m³	Annual	35	25	15	10	5
	24-hour[a]	75	50	37.5	25	15
PM_{10}, µg/m³	Annual	70	50	30	20	15
	24-hour[a]	150	100	75	50	45
O_3, µg/m³	Peak season[b]	100	70	–	–	60
	8-hour[a]	160	120	–	–	100
NO_2, µg/m³	Annual	40	30	20	–	10
	24-hour[a]	120	50	–	–	25
SO_2, µg/m³	24-hour[a]	125	50	–	–	40
CO, mg/m³	24-hour[a]	7	–	–	–	4

[a] 99th percentile (i.e. 3–4 exceedance days per year).
[b] Average of daily maximum 8-hour mean O_3 concentration in the six consecutive months with the highest six-month running-average O_3 concentration.

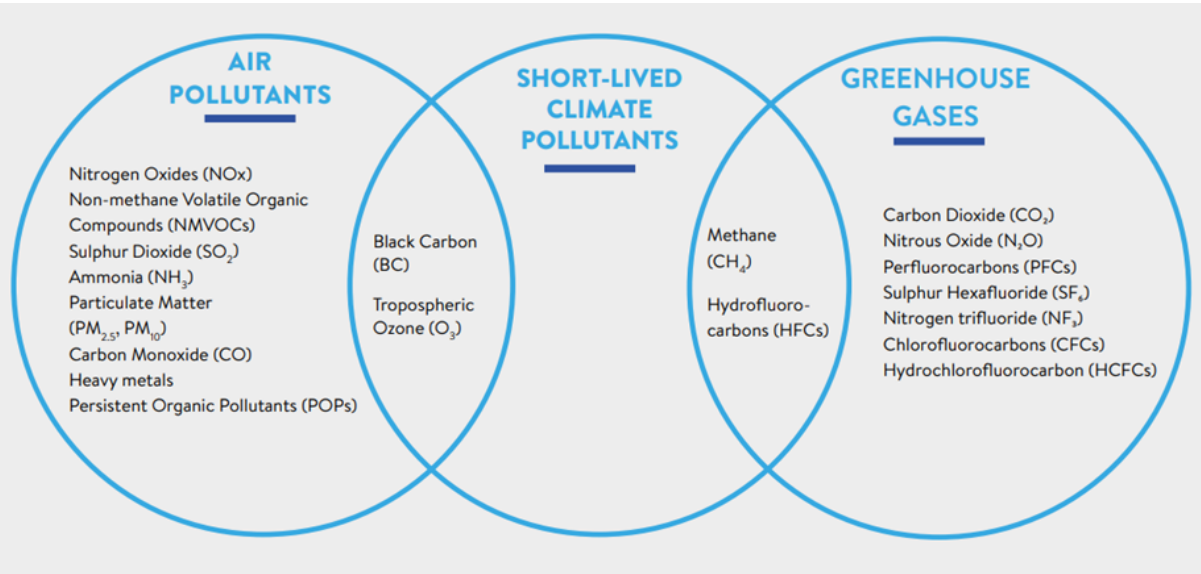


Figure 4: Summary of pollutants that are classified as air pollutants, short-lived climate pollutants and greenhouse gases (Source: (CCAC SNAP, 2019))

Targeting short-lived climate pollutants (SLCPs) is an opportunity to address climate change and air quality simultaneously, especially reducing the rate of near-term warming. The SLCPs include methane, tropospheric ozone and hydrofluorocarbons (HFCs), which are all also greenhouse gases, and black carbon, a component of $PM_{2.5}$ which warms the atmosphere but which is not a greenhouse gas. They have been grouped together due to their i) relatively short atmospheric lifetime (days to a couple of decades), ii) warming effect on the atmosphere and iii) effects on human health and agricultural crop yields as air pollutants (except HFCs). The UNEP/WMO (UNEP/WMO, 2011) Integrated Assessment of Black Carbon and Tropospheric Ozone identified 16 measures targeting the main sources of black carbon and methane in key sectors such as residential, agriculture, transport, industry, waste and oil and gas. The air quality benefits from full implementation of these measures globally by 2030 was calculated to be 2.4 million premature deaths avoided in 2030 compared to the reference scenario, as well as avoiding the loss of 52 million tonnes of 4 staple crops (rice, wheat, maize and soy), due to less crop damage from ozone exposure. These air quality benefits are mainly achieved locally, in those countries and regions where the emission reductions occur. Simultaneously, implementing these measures was estimated to avoid 0.5°C of global temperature increase making an important contribution to limiting global temperature rises in the near-term. When combined with fast and ambitious CO_2 mitigation, SLCP strategies can help to limit the rate of temperature rise to achieve the Paris targets (Figure 5) (Myles et al., 2018). The mitigation measures identified to reduce SLCPs have also been shown to contribute to achieving multiple sustainable development goals (Haines et al., 2017).

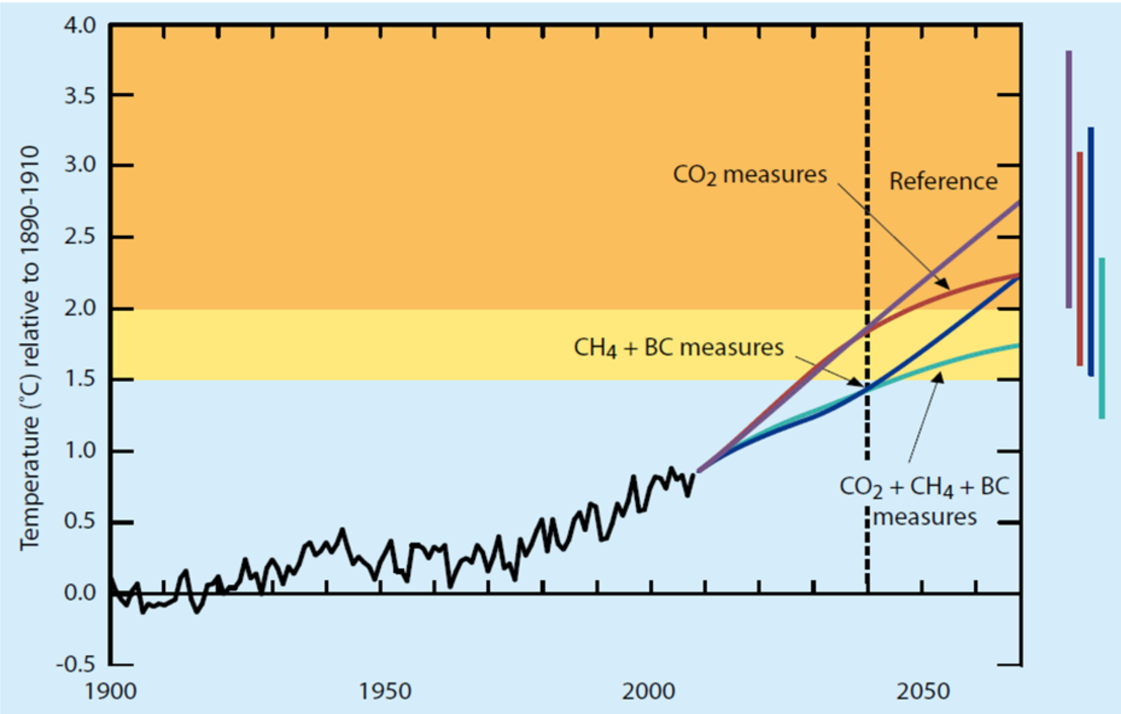


Figure 5: Progression of global average temperature change from 2010 to 2070 for a reference scenarios (purple), implementation of CO_2 mitigation measures (red), implementation of 16 black carbon and methane measures (blue), and implementation of CO_2, black carbon and methane measures together (green).

More broadly, action on climate change mitigation can achieve air quality benefits. Vandyck et al. (2018) calculated that implementation of the mitigation measures included in the first NDCs in all countries could avoid 77,000-91,000 premature deaths attributable to air pollution exposure globally in 2030. Additional GHG mitigation to limit global temperature increases to below 2°C could yield even larger benefits of 178,000-346,000 avoided premature deaths in 2030, and over 1 million premature deaths in 2050.

These are strong arguments to look at greenhouse gases, SLCPs and other air pollutants in an integrated way to ensure that the most efficient measures for both climate change and air pollution mitigation are selected and possible trade-offs are considered and compensated for, where possible. As countries undertake planning on air quality and/or climate change, consideration of integrated air pollution and climate change mitigation provides a substantial opportunity to enhance their climate change mitigation ambition to achieve the Paris temperature targets. Global, regional and national assessments have identified key, specific, concrete mitigation options that can be implemented to simultaneously improve air quality, mitigate climate change and reduce SLCP emissions. CCAC SNAP (CCAC SNAP, 2019) described these mitigation measures, and they are summarised in Figure 6.

This report describes an integrated air pollution and climate change mitigation assessment for Thailand. This assessment evaluates the current contribution of major source sectors to air pollutant, Short-Lived Climate Pollutant and greenhouse gas emissions in Thailand, and identifies and evaluates key mitigation measures that could be implemented to improve human health and reduce Thailand’s contribution to climate change.

Opportunity 1: Include specific methane and hydrofluorocarbon (HFC) mitigation measures

- Minimise venting, flaring and fugitive emissions from oil and gas sector
- Minimise methane emissions from coal mining through pre-mine degasification and recovery and oxidation of methane from ventilation air
- Minimise methane emissions from solid waste at landfills sites
- Upgrade wastewater treatment plants with methane gas recovery
- Control of agricultural methane emissions from livestock enteric fermentation and manure management
- Reduce methane emissions from rice production through intermittent aeration of continuously flooded paddy fields
- Eliminate HFC emissions from contained and emissive applications

Opportunity 2: Include specific black carbon measures which have a net reduction in warming

- Introduce vehicle emission standards for diesel vehicles requiring best available control technology and eliminate high emitting diesel vehicles
- Adopti more efficient fuels and technologies for cooking and heating
- Replace traditional brick kilns with more efficient brick production techniques
- Eliminate open burning of agricultural waste
- Replace traditional coke ovens with modern recovery ovens
- Eliminate gas flaring in oil and gas sector

Opportunity 3: Include additional CO2 mitigation measures that achieve air quality and human health goals

- Replace fossil fuel-based electricity generation with renewable alternatives
- Implement energy efficiency standards for industry, households, commercial sector
- Increase percentage of electric vehicles in vehicle fleet
- Improve public transport, and increases in walking and cycling, to reduce number of journeys taken by passenger cars
- Control forest and peatland fires

Opportunity 4: Include additional mitigation measures that fully align NDC with other strategies

- Air Quality Strategy/Air Quality Management Plan
- National Development Plan/Sustainable Development Goals Voluntary National Reviews
- HFC reduction strategy to meet Montreal Protocol Kigali Amendment HFC phase-down schedule
- Sectoral Strategies (e.g. road transport plan, agricultural plan, sustainable energy for all strategy etc.)

Figure 6: Specific mitigation measures that can reduce SLCPs, and achieve integrated air pollution and climate change mitigation.

1.2 Air Pollution and Climate Change National Context

The integrated air pollution and climate change mitigation assessment described in this report reflects that Thailand has undertaken substantial efforts on air pollution and climate change planning over the past 3 decades. This section describes the key context on air pollution and climate change planning in Thailand to inform the integrated air pollution and climate change mitigation assessment described in Sections 2.6.

1.2.1 Air Pollution

1.2.1.1 Air pollution concentrations

In 2022, there are 100 automatic air quality monitoring stations in 56 provinces and totally 1,680 $PM_{2.5}$ Low Cost Sensors in Thailand. As a result of the integration of driving operations of relevant agencies according to the National Agenda Action Plan on “Solving the Pollution Problems of Particulate Matter” together with Work From Home due to the pandemic situation of the coronavirus disease 2019 (COVID-19), the amount of annual average of PM2.5 nationwide was 22 µg m^{-3} (4% decrease from those in 2020). While the amount of annual average of PM_{10} nationwide was 40 µg m^{-3} (7% decrease from those in 2020). The highest 8-hour average level for ozone gas nationwide was 86 µg m^{-3} (5% decrease from those in 2020). The major pollutions which were still a problem in the same areas were $PM_{2.5}$ (Bangkok and its vicinity and northern areas) and PM_{10} Na Phra Lan Subdistrict, Saraburi Province) and ozone gas (Bangkok and its vicinity and the central region).

The overall image of the area tended to be improved in Bangkok and its vicinity. The days that $PM_{2.5}$ level exceeded the standard were 64 days which decreased from the previous year (9% in 2020 which exceeded the standard of 70 days). This was partly due to the implementation driving of the National Agenda Action Plan on “Solving the Pollution Problems of Particulate Matter” and stricter measures such as proactive in inspections, increasing of the frequency of notifications, communication to increase awareness among people, integration and promotion of participation from all sectors, the use of academic information to prevent and solve air pollution problems, and the success in integrating problem solving between agencies. The $PM_{2.5}$ 24-hr average in Bangkok from 2016 - 2022 is shown in Figure 7.

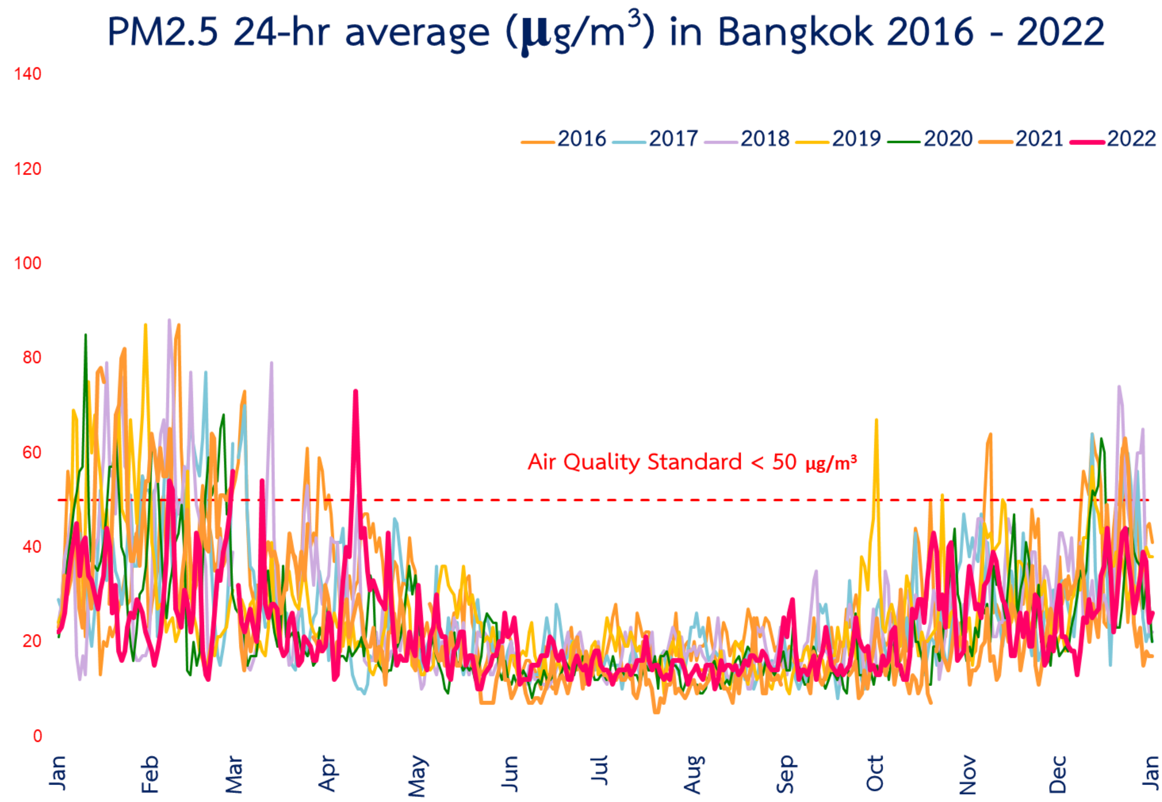


Figure 7: The $PM_{2.5}$ 24-hr average in Bangkok from 2016 -2022

There are 2 sensitive areas in industrial air pollution currently. The number of days that the level of PM_{10} exceeded the standard were 101 days (10% increase from those in 2020) in the Na Phra Lan Subdistrict, Chaloem Phrakiat District, Saraburi Province. The average annual level of PM10 was 98.6 µg m^{-3} (8% decrease from those in 2020.) These were caused by the dispersion of dust from the stone crushing plants, cement plants, lime plants, quarry plants in the area and nearby areas as well as the traffic, local transportation, and damaged public roads. Management of PM10 problems was taken such as a meeting to discuss and drive policies and measures on preventing and solving dust problems in Na Phra Lan sub-district into strict implementation and enforcement, monitoring pollution and other air pollutants in the general atmosphere from the automatic air quality monitoring station located in the area of Na Phra Lan Provincial Police Station; coordinating with local agencies; inspecting and monitoring pollution problems by Spot Check; and detecting dust exhaustion in the form of black soot from vehicles in Na Phra Lan areas.

The area of Map Ta Phut, Rayong Province is another sensitive area in Thailand found that Volatile Organic Compounds such as benzene and 1,3 - butadiene tended to increase from the previous year, while 1,2 - dichloroethane tended to decrease from the previous year. This was due to the main pollution sources in the area were chemical industrial factories that released VOCs into the atmosphere. The VOCs incidence in Rayong province has been monitored and communicated for continuous measurements to the provinces and related agencies to perform surveillance, control and supervise business establishments in the area to be practical. The Department of Industrial Works has prepared a draft law and manual on practice for the refinery industry, natural gas separation plant and petrochemical plants and review of troubleshooting operations and launched an action plan to solve VOCs in Map Ta Phut and nearby Rayong provinces.

In addition, during July-September in every year, it is the dry season of the lower ASEAN region as the Southern haze and transboundary haze. There is a chance of forest fires in the peat swamp forest area both domestically and around the island of Sumatra. The situation of such forest fires triggers haze problems affecting the southern region of Thailand and the lower ASEAN region. In general, haze situation in the south has developed from last year. A small number of hotspots were found in the peat swamp forest area. There was no exceeding standard of $PM_{2.5}$ during the period of 1 July - 31 October 2021. The results of the measurement of $PM_{2.5}$ found that the 24-hour average level had the highest value at 33 µg m^{-3}.

1.2.1.2. Air pollution health impacts

The health impact of air pollution (specific to ambient particulate, ozone, and household exposure) has been calculated by the Global Burden of Disease (GDB) project. Based on the GBD project as a function of epidemiological studies, estimates of population exposure to O_3, $PM_{2.5}$, and household air pollution, country-specific data on disease and death, and comprehensive population data are provided for each country.

According to the State of Global Air(Health Effects Institute, 2020), 38,700 (32,300–45,600) deaths were attributable to air pollution in Thailand in 2010. The number slightly decreased to 36,500 (29,800–44,500) in 2014 and continued to increase to 40,900 (29,600–54,600) in 2019. Household air pollution contributed 26.6% in 2010 and reduced to 18.2% in 2019. In contrast, ambient particulate matter contributed 71.8% in 2010 and increased to 78.7% in 2019. Ozone contributed less significantly to deaths due to air pollution, equating to 2.2% in 2010 and increasing to 3.8% in 2019. Country air pollution and health factsheets indicate that 5% of total air pollution-attributable deaths in Thailand concern children under five and 9% of adults over 70. Air pollution reduces life expectancy in Thailand by 1 year. In Thailand in 2019, 20% of stroke deaths, 21% of diabetes deaths, 19% of ischemic heart disease deaths, 28% of COPD deaths, 21% of lung cancer deaths, 17% of lower respiratory infection deaths, and 9% of neonatal deaths were due to air pollution.

Thailand now faces many environmental problems, particularly air pollution, resulting in adverse health consequences. The three major sources of air pollution are vehicular emissions in cities, biomass burning and transboundary haze in rural and border areas, and industrial discharges in concentrated industrialized zones. Health impact assessment (HIA) is a methodology used to estimate the change in health impacts on a population level based on a given change in an exposure. In addition to predicting impacts from different policy options, HIA can also be used to quantify the overall burden of disease from a given exposure. Exposure to ambient $PM_{2.5}$ is estimated to lead to over 4 million deaths globally each year (Cohen et al., 2017). In Thailand specifically, annual all-cause mortality has been estimated to be almost 40 000, with the percentage of deaths attributed to $PM_{2.5}$ at nearly 17% for lung cancer (Pinichka et al 2017). To update and expand earlier work on the burden of disease from particulate air pollution, we undertook an HIA to quantify the health and economic impacts across Thailand from long-term exposure to ambient $PM_{2.5}$. We included health endpoints where evidence of exposure to ambient particulate air pollution is more established (i.e. respiratory and cardiovascular disease) and also investigated in supplementary analyses those still emerging (i.e. neurological and metabolic diseases). The results of this assessment could be used to provide justification for stricter air pollution regulations, both in Thailand and in other jurisdictions. This study is part of a research project to study the effects of air pollution in Thailand: Thailand Air Pollution Health Impact Assessment (TAPHIA).

The latest air pollution health impacts study as a title A health impact assessment of long-term exposure to particulate air pollution in Thailand by (Mueller et al., 2021) quantified health and economic impacts from long-term exposure to ambient $PM_{2.5}$ in the population of Thailand for 2016 using ambient $PM_{2.5}$ concentrations from automatic monitoring stations across Thailand over 1996–2016 to estimate the mortality in each province from lower respiratory infections (LRIs), stroke, chronic obstructive pulmonary disease, lung cancer, and ischemic heart disease, and also assessed diabetes mortality, as well as incident cases of dementia and Parkinson's disease, in supplementary analyses. The risk estimates from the Global Exposure Mortality Model was applying to calculate attributable mortality and quantify disability-adjusted life years (DALYs) which based economic costs on the value of a statistical life (VSL). It was calculated 50 019 premature deaths (95% confidence interval [CI] : 42 189–57 849) and 508 918 DALYs (95% CI: 438 345–579 492) in 2016 attributed to long-term $PM_{2.5}$ exposure in Thailand. Population attributable fractions ranged from 20% (95% CI: 10% to 29%) for stroke to 48% (95% CI: 27% to 63%) for LRIs. Based on the VSL. In addition, a cost of US$ 60.9 billion (95% CI: US$ 51.3–70.4 billion) was calculated, which represents nearly 15% of Thailand's gross domestic product in 2016. While progress has been made to reduce exposure to ambient $PM_{2.5}$ in Thailand, continued reductions based on stricter regulatory limits for $PM_{2.5}$ and other air pollutants would help prolong life, and delay, or prevent, onset of cardiorespiratory and other diseases.

The main objective of such air pollution health impacts estimation is to illustrate the potential health damage that may be prevented and substantial costs that may be saved. This can be done by designing and implementing appropriate policy interventions. These include: controlling PM emissions from various sources in urban city particularly diesel vehicles, industries and open burning activities and providing appropriate fiscal and economic incentives to reduce traffic volume in cities, especially at peak hours including controlling emission of industries and decreasing open burning activities.

1.2.1.3.Air pollution plans and regulations

Air quality in Bangkok has gradually improved and for the most part, the number of air pollutants meet the Thailand ambient air quality standard. This success can be attributed to the combined effort of all sectors and stakeholders. Various government, private, academic and public sectors cooperated to continually mitigate air pollution. In particular, they worked to solve problems at the source by raising the standard of pollution emissions from automobiles and the quality of fuel. However, at present, some areas in Bangkok are confronted with $PM_{2.5}$ air pollution, with 60% of pollutants coming from diesel-engine automobiles, 35% from open burning, and 5% due to other causes (PCD,2019). These sources of emissions present the main challenge that needs to be addressed. Additionally, the meteorological condition of still air and calm wind has trapped dust particles in the air. The situation may get more severe if there is a lack of efficient solution planning for the future. It is also necessary for stakeholders to cooperate in solving the problems. Therefore, the government has announced that the challenge of the $PM_{2.5}$ air pollution phenomenon is on the national agenda and all stakeholders must proceed with effective action to improve air quality for Thai citizens and visitors.

The Governor of Bangkok, as a Single Commander with the full authority of the issue for Bangkok, has invited other government stakeholders to define actions to pursue during periods when the amount of $PM_{2.5}$ exceeds the standard. This is to ensure the relevant agencies or authorities can promptly take action. Some stakeholders include the Pollution Control Department, Department of Health, Department of Disease Control, Thai Meteorological Department, Department of Land Transport, Metropolitan Police Bureau, Traffic Police, the 1st Army Area, etc. These agencies have provided management guidelines for the governor to take action under the level-three situation of $PM_{2.5}$ with the emphasis on solving the pollution at the original sources and lessening the impact on people's health through the following measures :

- Controlling automobiles
- Controlling industrial factories
- Controlling construction
- Controlling open burning
- Monitoring air quality near schools
- Distributing surgical masks

This action plan is initiated under the National Agenda Action Plan to eradicate $PM_{2.5}$ between December-April, attempting to ensure the number of days of $PM_{2.5}$ does not exceed the Thailand air quality standards during the critical period increasing by 5% per year. Each measure will be implemented based on the level of $PM_{2.5}$ and the potential impact on people's health.

1.2.2 Climate Change

Climate change can affect our health, ability to grow food, housing, safety and work. Some of us are already more vulnerable to climate impacts, such as people living in small island nations and other developing countries. Conditions like sea-level rise and saltwater intrusion have advanced to the point where whole communities have had to relocate, and protracted droughts are putting people at risk of famine. In the future, the number of "climate refugees" is expected to rise.

In the meantime, many climate change solutions can deliver economic benefits while improving our lives and protecting the environment. We also have global frameworks and agreements to guide progress, such as the Sustainable Development Goals, the UN Framework Convention on Climate Change and the Paris Agreement. Three broad categories of action are: cutting emissions, adapting to climate impacts and financing required adjustments.

In Thailand, a study by the World Bank Group show temperature increases across Thailand since the mid-20th century and an increase in annual precipitation. Most of this increase occurs during the wet season. By the 2090s, the average temperature is projected to increase by 0.95°C–3.23°C above the 1986–2005 baseline, with the rate of warming dependent on the emissions pathway. Projected temperature increases are strongest in the south, and in daily maximum and minimum temperatures. In addition, floods are by far the greatest natural hazard facing Thailand in terms of economic and human impacts. Thailand is cited as one of the ten most flood-affected countries in the world. Drought and cyclone impact also represent major hazards. All may intensify in future climate scenarios. The number of people affected by an extreme river flood could grow by over 2 million by 2035–2044, and coastal flooding could affect a further 2.4 million people by 2070–2100. Projections suggest that Thailand's agriculture sector could be significantly affected by a changing climate, due to its location in the tropics where agricultural productivity is particularly vulnerable to temperature rises. The combination of rising seas and sinking land, as well as potential cyclone-induced storm surge resulted from the climate change impact, place the country's capital Bangkok in a precarious position when the net, or relative, rate of sea-level rise. Large amounts of critical public and private infrastructure are in areas which are likely to be exposed under future climate change situation. The aftermath of devastating floods in 2011 provides an example of how climate change can adversely affect poorer people in Thailand, with studies showing that post-flood, higher income groups received more government compensation than lower income groups and the human impacts of climate change in Thailand remain dependent on the approach to adaptation adopted, but there is a significant risk that the poorest and marginalized groups will experience disproportionately greater loss and damage.

Climate change is a global environmental problem that endangers sustainable development. The international community has taken a significant collective step toward addressing the global challenge of climate change. The Paris Agreement was adopted 12 December 2015 at the 21st session of the Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC). Thailand is one of the Parties that ratified the Paris Agreement on 21 September 2016 and put forward its best efforts through the Nationally Determined Contribution (NDC).

As a responsible member of the international community, the Kingdom of Thailand is committed to sustainable development and as such is working to achieve low carbon emission and a climate resilient society consistent with the strategies of the 12th National Economic and Social Development Plan (NESDP) 2017-2021. In addition, Thailand's Climate Change Master Plan 2015–2050 corresponds with these national strategies and policies. In alignment with its greenhouse gas (GHG) emission reduction policy, Thailand has employed a global approach by submitting Nationally Appropriate Mitigation Actions (NAMAs) to lower greenhouse gas emissions below business as usual (BAU) levels by 2020. Moreover, as stated in NDC, Thailand will work to reduce emissions a further 20–25 % in 2030 compared to the BAU level. With this aim, Thailand has been engaging national and subnational networks to explore a comprehensive range of mitigation measures to achieve the defined emissions targets. These measures include further developing and improving institutional and technical capacity for effective cooperation and management.

The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 Parties at COP 21 in Paris, on 12 December 2015 and entered into force on 4 November 2016.Its goal is to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels. To achieve this long-term temperature goal, countries aim to reach global peaking of greenhouse gas emissions as soon as possible to achieve a climate neutral world by mid-century. The Paris Agreement is a landmark in the multilateral climate change process because, for the first time, a binding agreement brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects. Thailand is one of the Parties that ratified the Paris Agreement on 21 September 2016 and put forward its best efforts through the Nationally Determined Contribution (NDC).

Thailand has continued to track GHG emissions, the six main types of which (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride) are required to be reported according to the UNFCCC. In December 2020, the national greenhouse gas (GHG) emissions reported in the third Biennial Update Report (BUR) of Thailand have been made in accordance with 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The total GHG emissions in 2016 (excluding those from LULUCF) were 354,357.61 GgCO2eq and net GHG emissions were 263,223.46 GgCO2eq (including those from LULUCF). In 2016, the Energy sector was the largest contributor to Thailand's GHG emission, accounting for 71.65% of total GHG emissions, while emissions from the Agriculture, Industrial Processes and Product Use (IPPU) and Waste sectors accounted for 14.72%, 8.90% and 4.73%, respectively.

Thailand submitted its Intended Nationally Determined Contribution (INDC) to UNFCCC in 2015, which was later to become Thailand's first NDC. The NDC was formulated in accordance with the Philosophy of Sufficiency Economy and the principle of Sustainable Development, and based on relevant national plans already approved or in the pipeline for approval by the Cabinet. It also builds upon measures, and takes into account lessons learnt and good practices during NAMAs implementation. Thailand's first NDC indicates an emission reduction of 20% from the projected BAU level by 2030. The level of contribution could increase up to 25%, subject to adequate and enhanced access to technology development and transfer, financial resources and capacity building support through a balanced and ambitious global agreement under UNFCCC. Besides, adaptation priorities and support need are clearly outlined.

In 2020, Thailand communicated its updated NDC to the UNFCCC, confirming its mitigation contribution by 2030. It also provided the most up-to-date information on its progress in the implementation of its pre-2020 action, concrete implementation plans, and key information of adaptation component and support needs.

In November 2021, at COP26 in Glasgow, United Kingdom, the Prime Minister announced his intention that "Thailand achieves carbon neutrality by 2050 and net zero emissions by 2065 with full and equitable support of finance and technology, as well as strengthening capacity through international cooperation and mechanisms under the Convention. Thailand will be able to raise the NDC to 40% by 2030, bringing Thailand's net greenhouse gas emissions to zero by 2050." Thailand's latest climate change reporting to the UNFCCC, the 4th National Communication and 4th Biennial Update

Report (BUR4) dated December 27, 2022 and December 28, 2022, respectively. Reflect this latest climate change mitigation commitment.

In addition, Thailand is taking practical steps in the implementation of its climate change commitment to take actions that will also reduce SLCPs. For example, the Thailand Environment Institute (TEI) is working on the introduction of green labelling for automotive products. This labelling, which will highlight more efficient vehicles, will lead not only to reduction in carbon dioxide but also SLCPs and air pollutants.

Methane, a potent greenhouse gas, is believed to be responsible for about half of the 1.1 degrees Celsius net rise in the global average temperature since the 1850s. It is the second biggest contributor to human-induced climate change, after carbon dioxide. Major sectoral sources of methane emissions include oil and gas, coal, agriculture, and landfills.

To combat methane emissions, the Global Methane Pledge (GMP) was announced by the United States and the European Union in September 2021. Countries that join the pledge commit to a collective goal to reduce methane emissions by at least 30% from 2020 levels by 2030. For Thailand, greenhouse gas emissions are needed to bring down to 388 million tons by 2025 and then to 120 million tons by 2037, in order to meet its COP26 goals. There are six-point plan covers the following : 1. Integrating carbon neutrality and net zero targets into national policies across all sectors, including industry, transportation, business, and agriculture.

2. Employing the CCUS (carbon capture, utilization and storage) technology across several industries. The ministry is in the process of negotiating a reduction in adoption and technology transfer costs for entrepreneurs.

3. Issuing trade and investment policies that promote environmentally friendly or green businesses. The Board of Investment (BOI) has been tasked with providing tax breaks and other privileges to attract green investments, while related authorities will accelerate the registration of environmentally friendly products to boost their consumption and export.

4. Developing a mechanism for carbon credits to be used locally and overseas with the Natural Resources and Environmental Policy and Planning Office acting as a central agency. The office will also work with the Federation of Thai Industries (FTI) to promote carbon-credit trading in the private sector and to connect clean energy trading platforms with the carbon-credit market.

5. Expanding forested areas to maximize the absorption of greenhouse gases. Totally 600,000 rai of new forest area has been set as a target this year, especially mangrove forests in coastal provinces as they have up to 10 per cent more carbon absorption power than terrestrial forests.

6. Enforcing the Climate Change Act to combat climate change and be achieve goals.

1.3 Objectives of Integrated Air Pollution and Climate Change Mitigation Assessment

This report describes an integrated assessment of air pollution and climate change mitigation in Thailand. Its overarching aim is to identify, evaluate and highlight a set of concrete, specific mitigation measures that could be integrated into Thailand's air pollution and climate change planning and whose implementation would result in simultaneous benefits locally in Thailand through improved air quality, and globally through reductions in Thailand's contribution to climate change. This report includes practical actions and recommendations as to policies and measures that would allow Thailand to simultaneously achieve multiple national and international commitments, through the development of national and regional Clean Air Plans, enhancing climate change mitigation targets in Nationally Determined Contributions (NDCs), and in Thailand's participation in the Global Methane Pledge. To achieve these aims, the report's objectives are :

- To estimate historic Short-Lived Climate Pollutant, air pollutant and greenhouse gas emissions for Thailand between 2010 and 2020.
- To estimate the historic Short-Lived Climate Pollutant, air pollutant and greenhouse gas emissions for individual regions between 2010 and 2020
- To estimate the contribution of major source sectors to SLCP, air pollutant and GHG emissions in Thailand and regions between 2010 and 2020
- To project emissions into the future (2030, 2050) for a baseline scenario reflecting socioeconomic development in Thailand and individual regions without implementation of new policies or measures designed to reduce emissions
- To quantify the reduction in air pollutant, SLCP and GHG emissions from implementation of specific policies and measures in major emitting source sectors. The policies and measures evaluated in the integrated air pollution and climate change mitigation assessment include policies and measures included in existing plans and strategies in Thailand, as well as additional policies and measures from international assessments whose implementation could further reduce emissions, improve air quality and mitigate climate change in Thailand.

2. Overview of integrated air pollution and climate change mitigation assessment

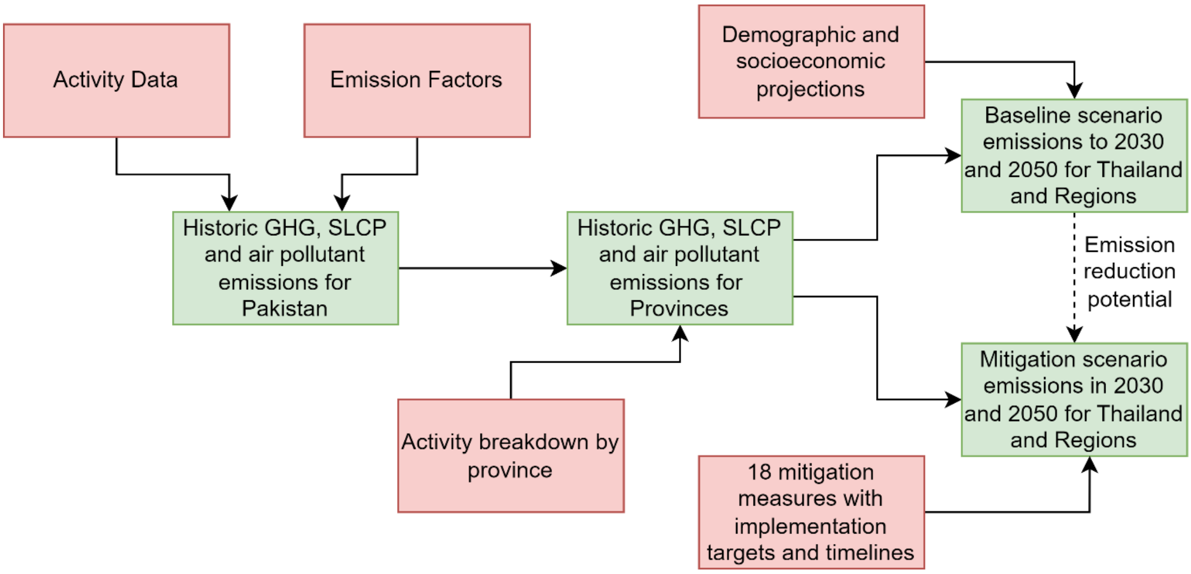


Figure 8: Generalised overarching modelling framework used to develop the integrated air pollution and climate change mitigation assessment

The integrated air pollution and climate change mitigation assessment was undertaken in 4 stages to estimate the effectiveness of different policies and measures in reducing air pollutant, SLCP and GHG emissions in Thailand. The overall modelling framework is shown in Figure 8. The output in each stage of the assessment was the estimate of air pollutant, SLCP and GHG emissions for a particular time period for a particular scenario. Therefore, the pollutant characterized in this inventory are those that are greenhouse gases, like carbon dioxide and methane, and those pollutants that contribute to the formation of particulate matter (PM), and tropospheric ozone (O_3). These are the two pollutants that have the largest effect on human health, and therefore the pollutants whose emissions are quantified in this emission inventory make the largest contribution to air pollution in Thailand, as well as Thailand's contribution to global climate change. The emission inventory of short-lived climate pollutants, greenhouse gases and air pollutants cover 11 pollutants in total, including:

- **Black carbon (BC):** A component of direct particulate matter (PM) emissions that contributes to the negative effects of air pollution on human health. Emissions of black carbon also warm the atmosphere through direct absorption of incoming solar radiation, and through indirect effects such as deposition on snow and ice and cloud interactions. With an atmospheric lifetime of a few days, it is a short-lived climate pollutant. It is mainly emitted through incomplete combustion.

- **Methane (CH_4):** A greenhouse gas and short-lived climate pollutant with an atmospheric lifetime of approximately 15 years, methane emissions make the second largest contribution to global temperature increases after carbon dioxide. It also contributes to the formation of tropospheric ozone (O_3), which has negative effects on respiratory health.

· **Particulate Matter ($PM_{2.5}$ and PM_{10}):** Particulate matter (with aerodynamic diameter less than 2.5 µm ($PM_{2.5}$) and 10 µm (PM_{10})) are small solid particles in the atmosphere. They make the largest contribution to air pollution effects on human health through effects on the cardiovascular and respiratory systems. The emissions of $PM_{2.5}$ and PM_{10} calculated here represent the direct emissions to the atmosphere of particulate matter. However, other gaseous pollutants, like Nitrogen oxides, Sulphur dioxide, ammonia and volatile organic compounds, also contribute to the $PM_{2.5}$ and PM_{10} concentrations that people are exposed to, through chemical reactions in the atmosphere that convert gaseous pollutants into solid particles.

· **Nitrogen Oxides (NO_x):** An air pollutant which is a precursor to the formation of particulate matter and tropospheric ozone, NO_x is made up of two pollutants, nitrogen oxide (NO) and nitrogen dioxide (NO_2).

· **Sulphur dioxide (SO_2):** An air pollutant which is a precursor to the formation of particulate matter.

· **Ammonia (NH_3):** An air pollutant which is a precursor to the formation of particulate matter.

· **Organic Carbon (OC):** A component of direct particulate matter (PM) emissions that contributes to the negative effects of air pollution on human health.

· **Non-methane volatile organic compounds (NMVOCs):** A collection of a range of different organic molecules emitted from a range of emission sources. NMVOCs are precursors to the formation of tropospheric ozone and particulate matter

· **Carbon monoxide (CO):** A gaseous air pollutant which contributes to the formation of tropospheric ozone

· **Carbon dioxide (CO_2):** A greenhouse gas with an atmospheric lifetime of hundreds of years, that makes the largest contribution to global climate change.

To estimate the emissions of each of these GHGs, SLCPs and air pollutants in an integrated air pollution and climate change mitigation assessment, the four steps followed were:

Step 1: Estimate historic emissions of GHGs, SLCPs and air pollutants for Thailand.

To understand the extent to which mitigation measures could improve air quality and mitigate climate change, it is first necessary to understand the magnitude of emissions of the pollutants contributing to both issues (listed above), and to understand the contribution of major source sectors to emissions of different pollutants. Doing so allows the sectors with the largest emissions of key pollutants, and therefore the primary targets for mitigation, to be identified. It also allows the emission source sectors which emit a range of different air pollutants, SLCP and GHGs to be identified so that those sectors where mitigation measures could simultaneously contribute to reductions in multiple pollutants can be targeted.

In this work, the key source sectors for which historical (and future, see Steps 3 and 4) emissions were estimated are listed in Table 3. The emission sources covered include all the major sources of SLCPs and air pollutants, and greenhouse gases, with the exception of land-use and land-use change emissions. Emission sources were grouped according to the IPCC source categories. Table 3 lists the source sector alongside the IPCC code for each emission source.

Historical air pollutant, SLCP and GHG emissions were estimated for the time period 2010 to 2021 due to the availability of data to quantify emissions during this time period.

Table 3: Breakdown of source sectors used to estimate GHG, SLCP and air pollutant emissions in Thailand

Source Sector	**Sub-categories**
1 Energy	1A1a Public Electricity and Heat Production
	1A2 Manufacturing Industries and Construction
	1A3b Road transportation
	1A4a Commercial/Institutional
	1A4b Residential
2 Industrial Processes and Product Use (IPPU)	2A Mineral Industry
	2B Chemical Industry
	2C Metal Industry
	2F Product Uses as Substitutes for Ozone Depleting Substances
3 Agriculture, Forestry and Other Land Use (AFOLU)	3A Livestock
	3B Land
	3C Aggregate sources and non-CO2 emission sources on land
	3D Other
4 Waste	4A Solid Waste Disposal
	4D Wastewater Treatment and Discharge (CH_4 only)

To estimate emissions of GHGs, SLCPs and air pollutants from the key sources listed above for historic years, the key equation used to estimate emissions from all major sources of the pollutants listed above is the multiplication of an *activity* variable multiplied by an *emission factor* (Equation 1). The activity variable quantifies how big a particular sector or process is in a country (e.g. the number of Terajoules of fuel consumed in a particular sector, the number of tonnes of production of a particular mineral, chemical or other product). Emission factors quantify the mass of pollutant emitted per unit of activity (e.g. the kilogrammes of black carbon emitted per Terajoule of fuel consumed).

Emissions = Activity x Emission Factor Equation 1

The specific activity data, emission factors and methodologies used to quantify emissions in each source sectors are defined according to international guidelines on the quantification of GHG and air pollutant emissions. Specifically, the methodologies follow the Intergovernmental Panel on Climate Change (IPCC) 2006 emission inventory guidelines. The IPCC 2006 guidelines provide methodologies for the quantification of GHG emissions (IPCC, 2006). However, in comparison to national emission inventories, which focus on historical years, methods were adapted to allow assessment of GHG, SLCP and air pollutant emissions in the future and to evaluate implementation of specific policies and measures. Therefore, the methodologies for quantifying GHG emissions (and activity data and emission factors) may differ compared to those used for official GHG emission reporting by Thailand to the United Nations Framework Convention on Climate Change. They also recommend that for other pollutants, the EMEP/EEA air pollution emission inventory guidebook is used (EMEP/EEA, 2019). These were followed to develop this inventory. The methods and data used for each source sector are described in in Section 2.2. The major sources of emission factors for each pollutant were predominantly from IPCC 2006, and the EMEP/EEA emission inventory guidebook. In addition, for some sources emission factors were taken from the scientific literature, and are included in Section 2.3 for each pollutant for each source.

In the future, the Intergovernmental Panel on Climate Change is preparing a guidebook for the quantification of national Short-Lived Climate Pollutant (SLCP) emissions. This guidebook starts from the EMEP/EEA air pollutant emission guidebook and will make the methods and default data globally applicable. When published, this could provide the basis for the updating of this assessment, and/or integration of SLCPs within Greenhouse Gas mitigation assessments.

Step 2: Break down national emission estimates to quantify regional emission

The first step in the integrated assessment models emissions at the national scale, to understand the major sources of SLCPs, air pollutants and GHGs across the whole of Thailand. However, there are multiple reasons why it is useful to understand not just the national total emissions (historically and in the future), but to also understand the emissions in individual regions. Firstly, the demographic, economic, industrial and social characteristics of Thailand’s seven regions are not the same. This means that some emission sources may occur more frequently in some regions compared to others. For example, vehicle ownership, the number of households cooking using wood and charcoal, the number and type of major industries all vary between regions, and therefore the contribution to provincial emissions from these sources will also differ from a national average picture. A detailed understanding of the contribution of air pollutant, SLCP and GHG emissions at the provincial level allows the impact of different mitigation measures to be evaluated in each Province, to understand the effectiveness of implementing policies and measures at reducing GHG, SLCP and air pollutant emissions in different Provinces. In terms of air quality management in Thailand, The Thailand Clean Air Programme outlines a national framework to improve air quality across the country. However, Provinces have responsibility for the development of provincial clean air plans. Undertaking this mitigation assessment at the provincial scale allows bespoke quantitative assessment of mitigation measures and their effectiveness of reducing emissions in each region to inform development of provincial clean air plans.

In this step, the national statistics used to estimate emissions for the whole of Thailand (i.e. the activity variables used in Equation 1) were broken down to understand the contribution of activity in each sector from each province. For example, in the residential sector the largest emission source is residential cooking, and the number of households cooking using different fuels/technologies is the activity variable used to estimate emissions. The fraction of the national total number of households cooking using each fuel/technology in each province, available from was used to break down national total residential cooking emissions into the emission in this sector from each region. This process was repeated for each source sector to build an historic inventory of Thailand's GHG, SLCP and air pollutant emissions disaggregated by regions.

The breakdown of emissions to regions aimed to characterise the totality of emissions occurring within the geographic boundary of each region. In practise, the data available to disaggregate activity data between regions means that there are limitations to this approach. For example, to disaggregate vehicle emissions between regions, the only available data are the number of vehicles registered in each province. A vehicle registered in one province may travel (and emit air pollutants) in another province. This was not able to be accounted for in the analysis due to data limitations.

Step 3: Estimate future emissions for a baseline scenario

Over the past decades, emissions of air pollutants, SLCPs and GHGs in Thailand have not remained constant, due to socioeconomic development resulting in greater fuel consumption, electricity generation, industrial output, livestock and crop production, waste generation etc. It is therefore unrealistic to expect that emissions will remain constant in the future even if policies and measures designed to reduce emissions are not implemented. A baseline scenario, often also referred to as a business-as-usual or reference scenario, is designed to estimate how future emissions could change into the future as a result of socioeconomic trends, and without air quality or climate change mitigation policies implemented. Its purpose is to act as a reference against which the reduction in emissions from implementing specific policies and measures can be compared. The baseline scenario therefore provides the basis for assessing the effectiveness of different policies and measures, by projecting what emission levels could reach without their implementation.

To develop the baseline scenario, each activity variable used in the development of the historic emission estimates for Thailand and each region, was projected into the future, and the calculation of emissions, using Equation 1, was repeated based on the projected activity variables in future years. In this work, the timespan of future scenarios was 2022-2050, with 2030 (the end year for implementation of Thailand's NDC), and 2050 chosen as focus years. The assumptions used to project activity variables were based on projections of key socioeconomic variables, such as population and Gross Domestic Product (GDP). A full description of the data used to project emissions is provided in Section 2.3

Step 4: Estimate emission reduction potential from implementation of policies and measures

In addition to the baseline scenario described above, the other future scenarios modelled reflect the implementation of different, specific policies and measures that are designed to reduce emissions contributing to climate change and air pollution. This fourth step first involved the identification of specific policies and measures to reflect the implementation of within mitigation scenarios. First, policies and measures were identified from a review of current plans, strategies and policies, to understand the air pollutant, SLCP and GHG emission reductions achieved from implementation of existing plans and strategies. Secondly, additional policies and measures that are not currently included in Thailand's plans and strategies were identified from international assessments to understand the extent to which their implementation in Thailand could effectively reduce air pollutant, SLCP and GHG emissions.

To be modelled, each mitigation measure needed to be described in sufficient detail that it has a target (i.e. level of implementation) and a timeline by which this target would be met, so that its GHG emission reduction potential, compared to the baseline, could be modelled in the mitigation assessment. Each mitigation measure was first modelled individually to understand how each measure could reduce emissions when implemented in isolation.

The individual mitigation scenarios were grouped into two categories of measures, so that the effect of implementing a group of mitigation measures could be assessed, accounting for interactions between different mitigation actions (e.g. the overall effect of implementing renewable electricity generation alongside demand side energy efficiency measures). The measures were grouped into two scenarios reflecting measures included in existing plans and strategies in Thailand (current measures) and new measures from international assessments (additional measures). Section 2.4 describes the key mitigation measures included in this assessment.

3. Major sources of air pollution, short-lived climate pollutant, and greenhouse gas emissions

The mitigation assessment first quantifies the emissions of air pollutants, short-lived climate pollutants and greenhouse gases for historic years (Section 3.1) and projects them into the future for a baseline scenario. The aim of the baseline scenario is to show how emissions could change without implementation of any policies or measures designed to reduce emissions. This provides a reference against which the implementation of policies and measures can be evaluated. The baseline scenario is presented in Section 3.2.

The purpose of this report is to outline how effective policies and measures could be at reducing air pollution and short-lived climate pollutants. Section 4 describes the policies and measures evaluated, and their overall emission reduction at the national scale. Further sections elaborate on specific aspects of implementing these mitigation measures, specifically, i) the impact of delaying implementation of the measures, ii) the emission reduction potential at the regional scale, and iii) the health benefits of reducing emissions.

3.1 National Emission Inventory

Air pollutant, SLCP and GHG emissions emitted between 2010 and 2020 (historic estimates) and to 2050 (projections) are shown in Table 4, with the contribution of different sources shown in Figure 9. There are a range of sources which contribute to the emissions of different pollutants in Thailand. For particulate matter ($PM_{2.5}$, PM_{10}, OC and BC), the agriculture sector makes the largest contribution to national total emissions, due to the large emissions emitted by crop residue burning. Industry, waste, residential biomass use, charcoal production and transport make smaller, but significant contributions to these particulate matter emissions. Agriculture is also the largest source of ammonia and methane emissions in Thailand, but the agricultural subsectors contributing to these emissions differs. For ammonia, manure management and application, and synthetic fertiliser application are the largest sources. While for methane livestock enteric fermentation, and rice production, are the large agricultural sources.

Transport make the largest contribution to nitrogen oxide emissions, and to carbon monoxide emissions, as well as making a significant contribution to black carbon emissions, particularly from diesel engines. For methane, in addition to agricultural sources, fossil fuel production (i.e. oil, gas and coal extraction and processing), and waste account for the remainder of the emissions. Hence assessment of historical emissions from Thailand demonstrate that multiple air pollutant sources require the identification and implementation of mitigation measures to effectively reduce air pollution across Thailand.

Table 4: National total emissions of air pollutants, GHGs and Short-Lived Climate Pollutants in Thailand in 2010, and 2020, and projected to 2025 and 2030 for the baseline scenario (units: thousand metric tonnes)

	2010	2020	2030	2040	2050	2050 (% increase vs 2020)
OC	328.5	317.1	325.9	342.3	371.4	17.1
BC	67.7	66.1	67.2	79.1	97.4	47.3
$PM_{2.5}$	511.5	497.3	542.9	622.2	740.3	48.9
NH_3	130.0	133.7	134.7	142.2	155.7	16.4
SO_2	609.8	830.5	758.2	1059.7	1368.6	64.8
PM_{10}	561.0	547.5	595.6	679.9	805.1	47.0
N_2O	4.0	4.2	4.9	6.8	9.3	123.2
NO_x	907.2	834.1	815.5	1036.2	1357.2	62.7
NMVOC	33691.1	38210.6	44960.6	63701.1	94841.9	148.2
CH_4	4558.9	4700.3	5410.6	5923.9	6533.2	39.0
CO	14890.9	13375.5	13153.8	14192.3	16663.8	24.6
CO_2	156944.5	178016.6	220139.5	361538.6	550443.9	209.2

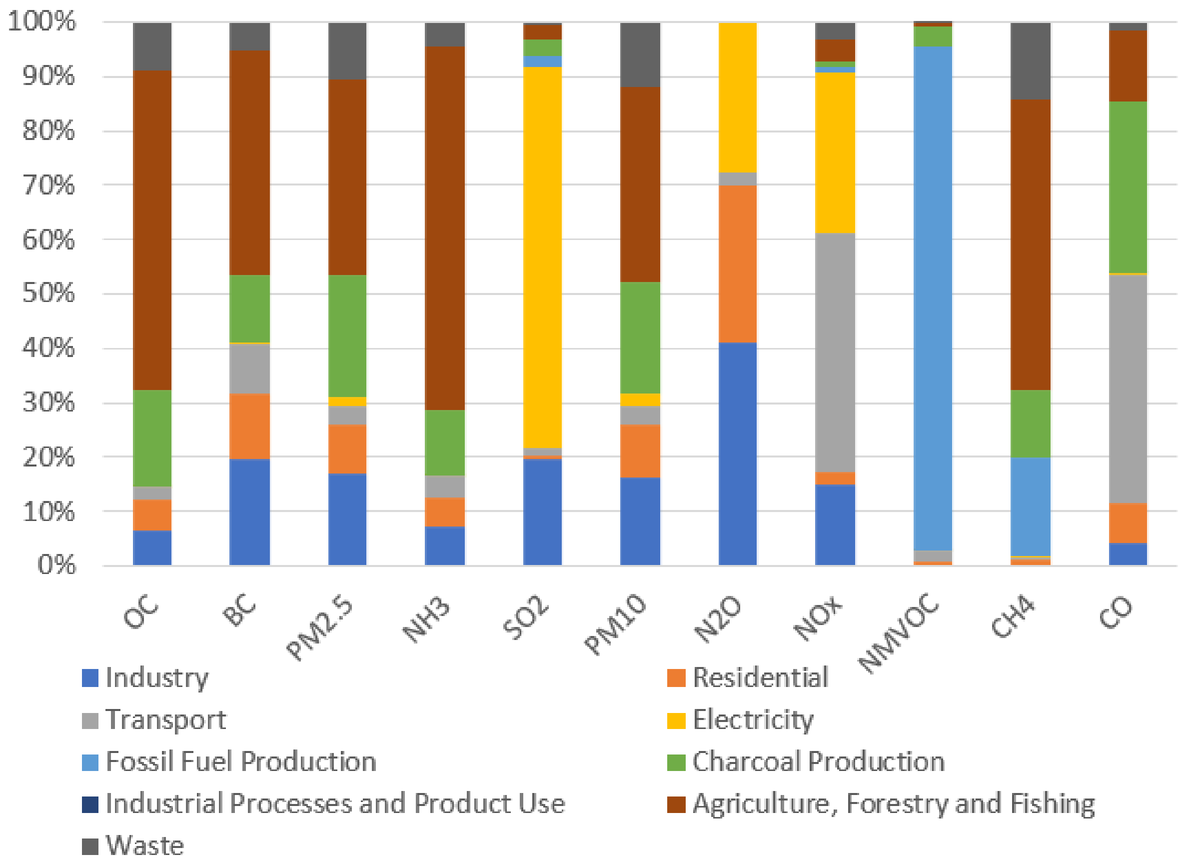


Figure 9: Contribution of key source sectors to national total emissions in 2020 in Thailand

3.2 Baseline projections to 2030 and 2050

In the baseline scenario, without implementation of policies and measures designed the reduce emissions, emissions of all major air pollutants, as well as Greenhouse gases, are projected to increase in the future (Figures 10-14, Table 4). $PM_{2.5}$ emissions are projected to increase nearly 50% by 2050 compared to 2020 levels, with similar increases as for other air pollutants. Air pollutant emissions are projected to increase primarily due to assumptions about economic growth in Thailand between 2020 and 2050. Gross Domestic Product in Thailand is projected to increase at ~3.9% per year to 2050. This increase in economic activity is expected to occur alongside increase in fuel consumption, agricultural and industrial production, which results in increasing air pollutant emissions. The baseline scenario assumes that this economic growth does not occur alongside implementation of measures which reduce emissions, and hence air pollutant emissions are not abated as the economy grows.

However, air pollutants are not expected to increase at the same rate as greenhouse gases. Carbon dioxide emissions (CO_2) are estimated to increase three times in the baseline scenario by 2050 compared to 2020 levels. The reason for the larger increase in CO_2 emissions compared to air pollutants is the contribution that electricity generation makes to CO_2 emissions. This sector, and industry and transport, constitute the largest contribution to CO_2 emissions from any sector in Thailand (Figure 13). Therefore, as these sectors experience substantial growth, CO_2 emissions increase even more than air pollutants.

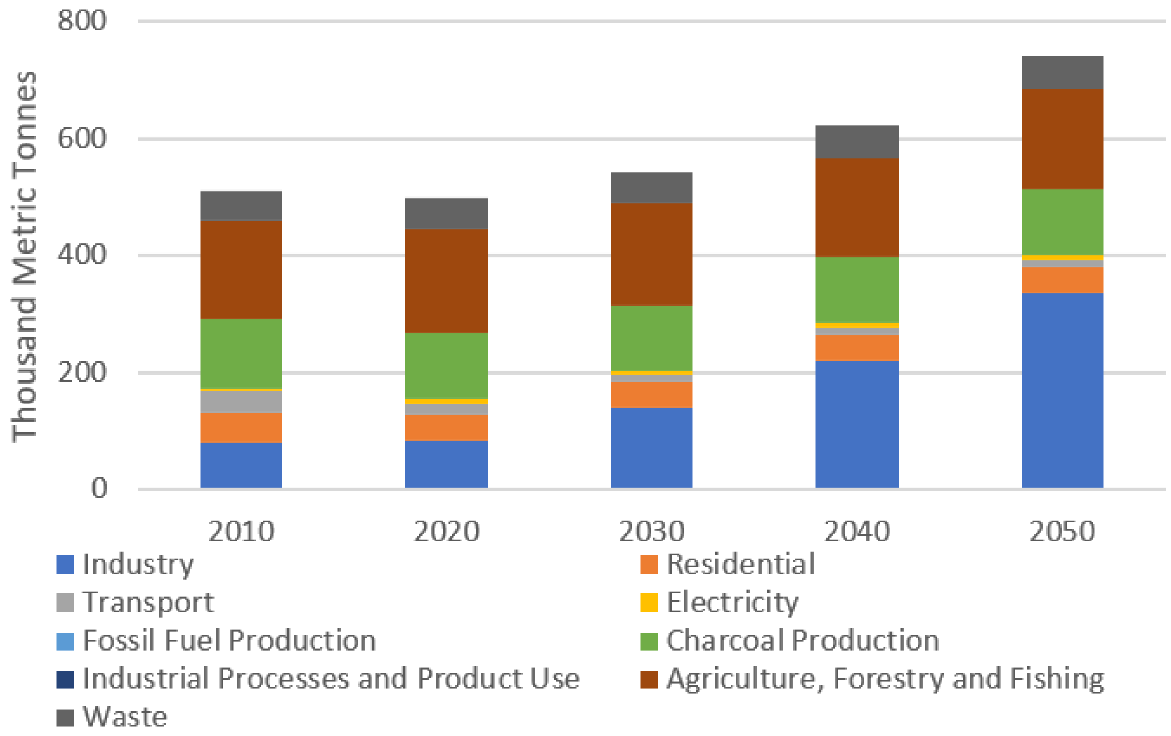


Figure 10: Baseline Projections in national total $PM_{2.5}$ emissions between 2010 and 2050 across Thailand

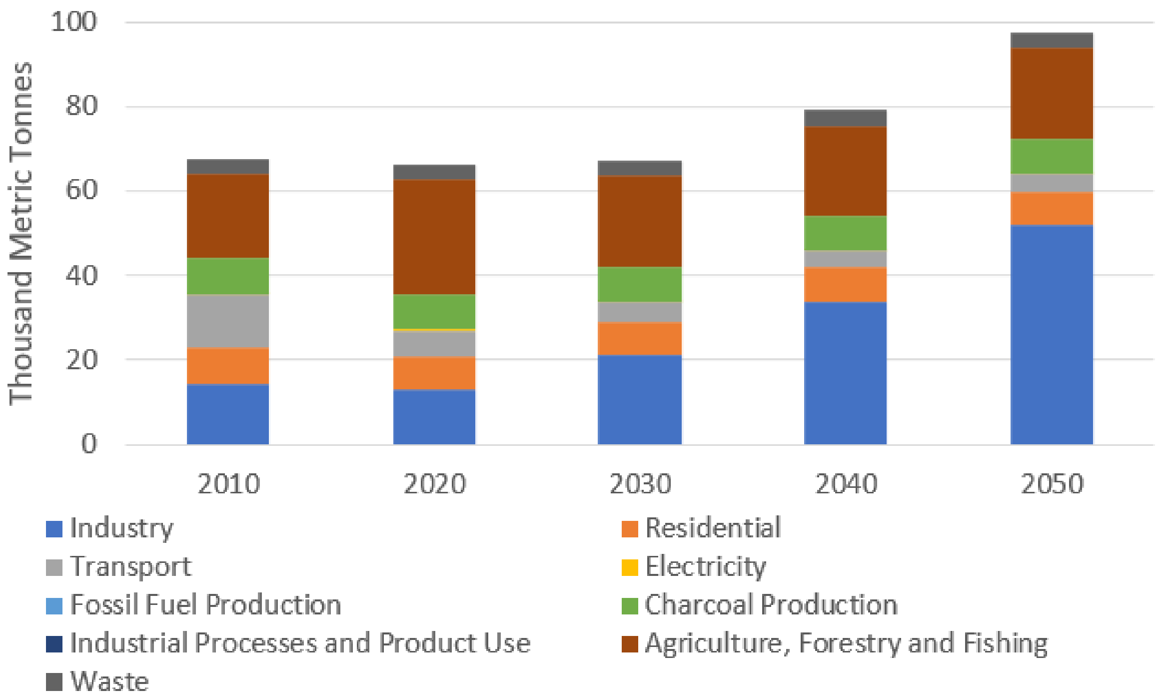


Figure 11: Baseline Projections in national total black carbon emissions between 2010 and 2050 across Thailand

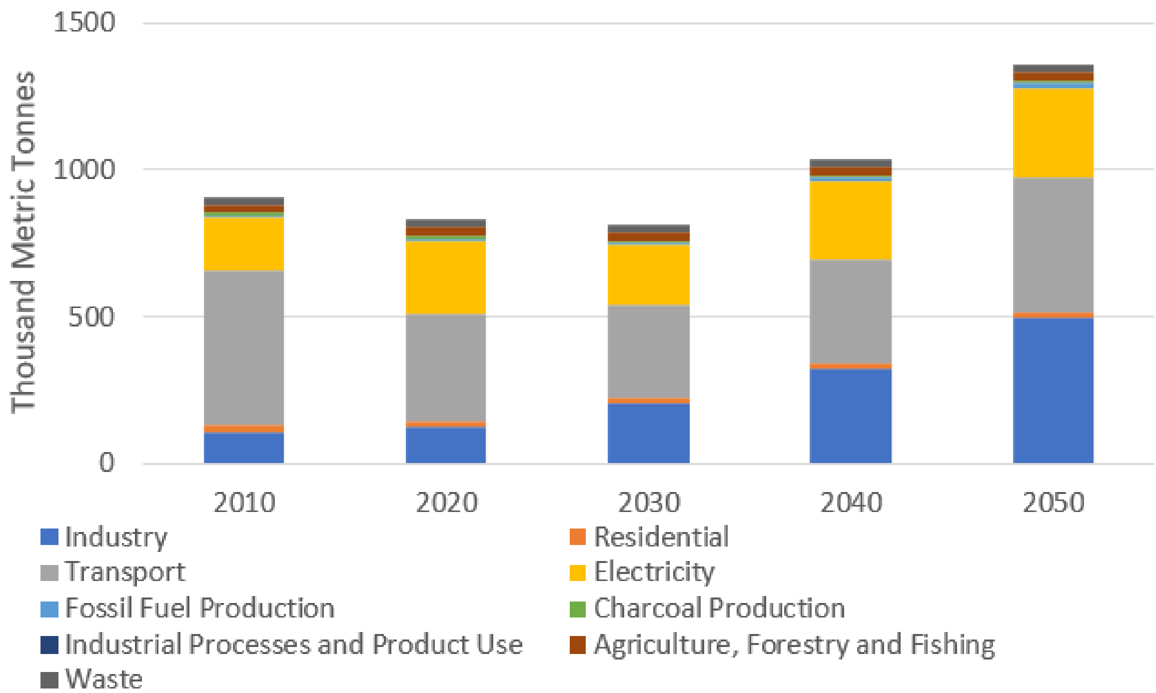


Figure 12: Baseline Projections in national total Nitrogen Oxide emissions between 2010 and 2050 across Thailand

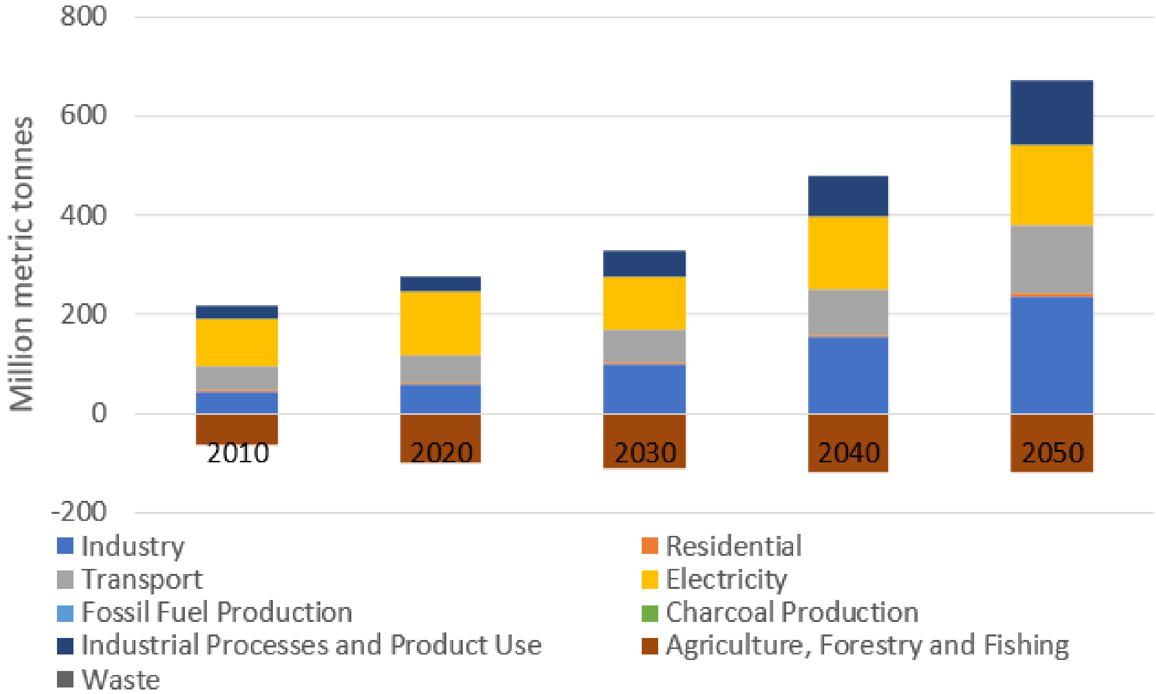


Figure 13: Baseline Projections in national total CO_2 emissions between 2010 and 2050 across Thailand

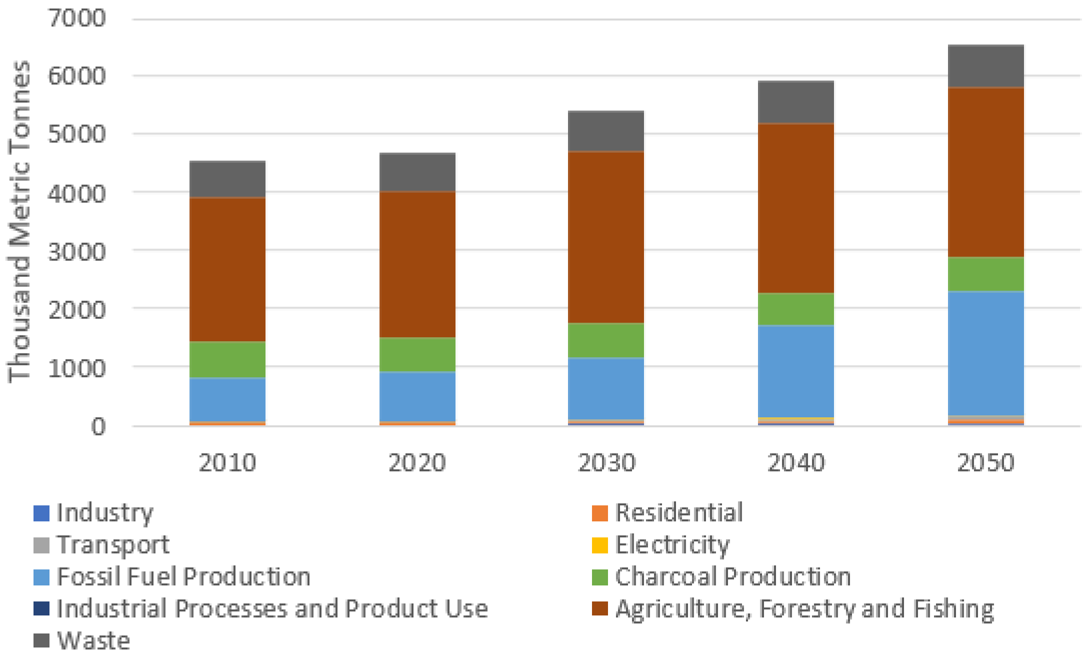


Figure 14: Baseline Projections in national total methane emissions between 2010 and 2050 across Thailand

4. Priority Mitigation Measures for integrated air pollution and climate change mitigation

Table 5 lists all policies and measures that were evaluated within this assessment. The policies and measure evaluated are listed alongside specific targets and timelines for their implementation. In total, 19 mitigation measures were identified and evaluated across all major source sectors. The measures were taken from three main sources. First, actions included to mitigate air pollution were identified. These measures were primarily taken from the National Action Plan on $PM_{2.5}$ and include actions such as zero agricultural burning, zero waste burning, Euro 5 and 6 emission standards for transport. These measures are primarily technical measures designed to reduce specific pollutants from the largest sources. The second set of mitigation measures were identified from Thailand's climate change planning, which include some actions that could also reduce air pollutants, including renewable electricity generation and electric mobility. Finally, for methane, additional measures were identified by the authors to evaluate how methane specifically could be reduce from its three major anthropogenic source sectors.

Table 5: Priority mitigation measures identified and evaluated within the integrated air pollution and climate change mitigation assessment

Number	Subsector	Mitigation Measure	Target	Timeline	Region	Reference
1	Transport	Implementation of Euro 5 emission standards and fuel quality in 2024.	Euro 5 Fuel Quality and emission Standard Euro 6 Fuel Quality and emission Standard	2024	Whole Country	National Action Plan $PM_{2.5}$
2	Transport	Switching diesel buses to be electric buses (BMTA) about 500 buses in December 2021 and replace all 6,500 diesel buses by CNG and Electric buses in 2024.	500 diesel buses switched to electric 6500 diesel buses switched to electric	2021 2024		National Action Plan $PM_{2.5}$
3	Transport	The Government has been promote EVs in Thailand with the target in 2030 as following: motorcycle 650,000 , light passenger car 440,000 , bus 33,000 , truck 34,000 including 1450 charging stations with 12,000 charging ports.			Focus on Bangkok Only Bangkok and Met Area	National Action Plan $PM_{2.5}$
4	Transport	Retrofit Program (The government planned to install a DPF to the used diesel bus and truck which are being 10-15 years average)	Assume retrofit of buses and trucks begins in 2025 and achieves 95% reduction in PM emissions (applies to all pre-Euro 4 vehicles)	2025		National Action Plan $PM_{2.5}$
5	Residential	More efficient charcoal stoves	25% reduction in charcoal	2030		

			consumption through more efficient charcoal stoves			
6	Residential	Energy Efficiency	54% reduction in energy consumption per household due to energy efficiency improvements	2030		Thailand 20-year Energy Efficiency Development Plan 2011-2030
7	Services	Energy Efficiency	55% reduction in energy consumption per household due to energy efficiency improvements	2030		Thailand 20-year Energy Efficiency Development Plan 2011-2030
8	Industry	Energy Efficiency	22% reduction in energy consumption per household due to energy efficiency improvements	2030		Thailand 20-year Energy Efficiency Development Plan 2011-2030
9	Crop	Zero agricultural residue burning	Zero agricultural residue burning	2030	Whole Country	National Action Plan $PM_{2.5}$
10	Solid Waste	Zero waste burning	100% waste collected 100% of waste sent to landfill sent to managed landfill site	2030	Whole Country	
11	Electricity	Renewable Electricity Expansion	74% renewable electricity generation	2050	Whole country	Low Emission Development Strategy
12	Transport	Electric Vehicle expansion	60% of passenger vehicles are electric	2050	Whole Country	Low Emission Development Strategy (assumption of target made by report authors)
13	Residential	Switching from LPG to electricity for cooking	40% of households cook using electricity	2050	Whole Country	Low Emission Development Strategy (assumption of target made by report authors)
14	Oil, Gas and Coal Production	Minimise fugitive methane emissions	96% reduction in fugitive methane emissions	2030	Whole Country	Additional measure proposed by authors
15	Solid Waste	Methane capture from landfill sites	100% reduction in methane emissions from landfill sites	2030	Whole Country	Additional measure proposed by authors
16	Domestic liquid waste	Methane capture from wastewater management sites	93% reduction in methane emissions from wastewater sites	2030	Whole Country	Additional measure proposed by authors
17	Rice Production	Alternate wetting and drying implemented for rice production	AWD implemented for all irrigated rice production in Thailand (assuming AWD produces 45% less methane than continuously irrigated)	2030	Whole Country	Additional measure proposed by authors
18	Livestock	Reduce enteric fermentation emissions from livestock	30% reduction in livestock enteric fermentation emissions	2030	Whole Country	Additional measure proposed by authors
19	Forest	Forest fire control	Annually 20% reduction of forest fire in terms of hotspot number or	2030	Whole Country	

area burned (compared to the previous year)

The full implementation of the 19 mitigation measures identified in this assessment are extremely effective at reducing emissions of the most health-damaging air pollutants. In 2030, particulate matter air pollutant emissions ($PM_{2.5}$, PM_{10}, BC, OC) are reduced by between 45% and 75% compared to the baseline scenario emissions in 2030, and large emission reductions persist into 2050 (Figure 15). These pollutants are the most toxic and contribute the largest fraction of the health burden from air pollution in Thailand and globally. These measures provide an effective method by which they can be reduced. The most effective single measure to reduce these emissions is the reduction in the open burning of agricultural residues. Crop residue burning is the largest source of PM emissions, and therefore removing this source is the largest contributor to the >45% emission reductions achieved by 2030. Other measures which contribution substantially to the reduction are banning open burning of waste, implementation of Euro 5 and Euro 6 standards, and more efficient biomass stoves. After implementation of all mitigation measures by 2030, the remaining unabated air pollutant emission source is the industry sector. In industry, there is a reduction in emissions as a result of an ~20% energy efficiency target, but increases in industrial output, resulting in an increasing contribution from industry to PM emissions means that it remains the largest source of PM emissions after implementation of all mitigation measures.

In addition to large reductions in black carbon from reductions in particulate matter air pollutants, other SLCPs are also reduced (Figure 16). Methane is reduced by ~65% in 2030 compared to the baseline scenario (Figure 17). This reduction is achieved through the implementation of a suite of measures. In the oil and gas sector, a >90% reduction in fugitive methane emission is achieved through implementation of, e.g. advanced leak detection and repair methods for oil and gas infrastructure. In solid and liquid waste, capturing of methane at landfill sites reduces methane emissions by >80% across solid and liquid waste. These technical measures are effective at reducing the majority of emissions from these sources. In the agriculture sector, the implementation of alternate wetting and drying across all irrigated rice in Thailand, as well as measures to reduce enteric fermentation, reduce methane emissions from the largest source in Thailand. However, these measures are not 100% effective at reducing methane emissions from agriculture, and therefore while 65% is a large reduction in methane emissions, the main unabated emissions after implementation of all measures occur in agriculture.

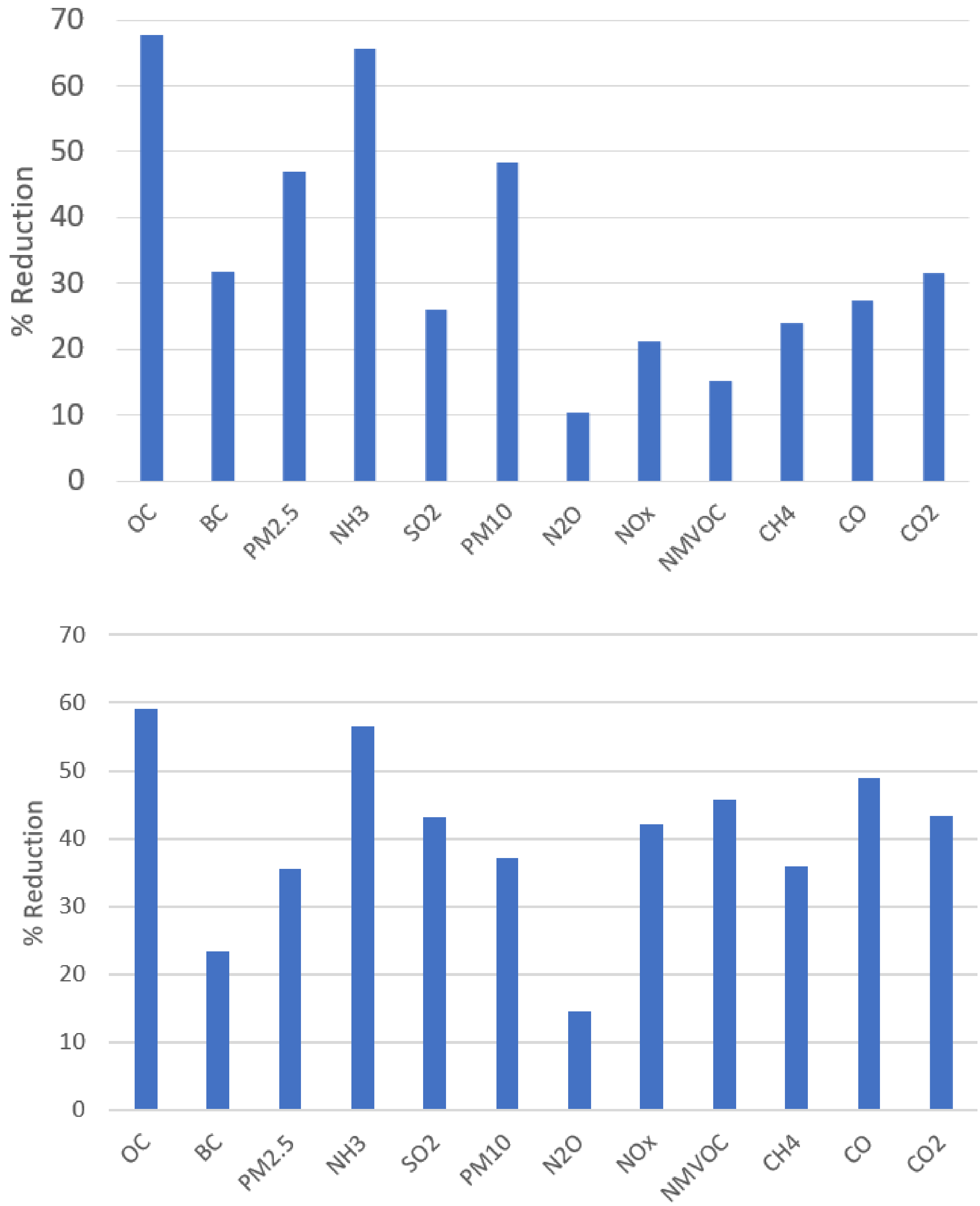


Figure 15: Percentage reduction in emissions of GHGs, SLCPs and air pollutant from implementation of policies and measures included in this assessment in a) 2030 and b) 2050

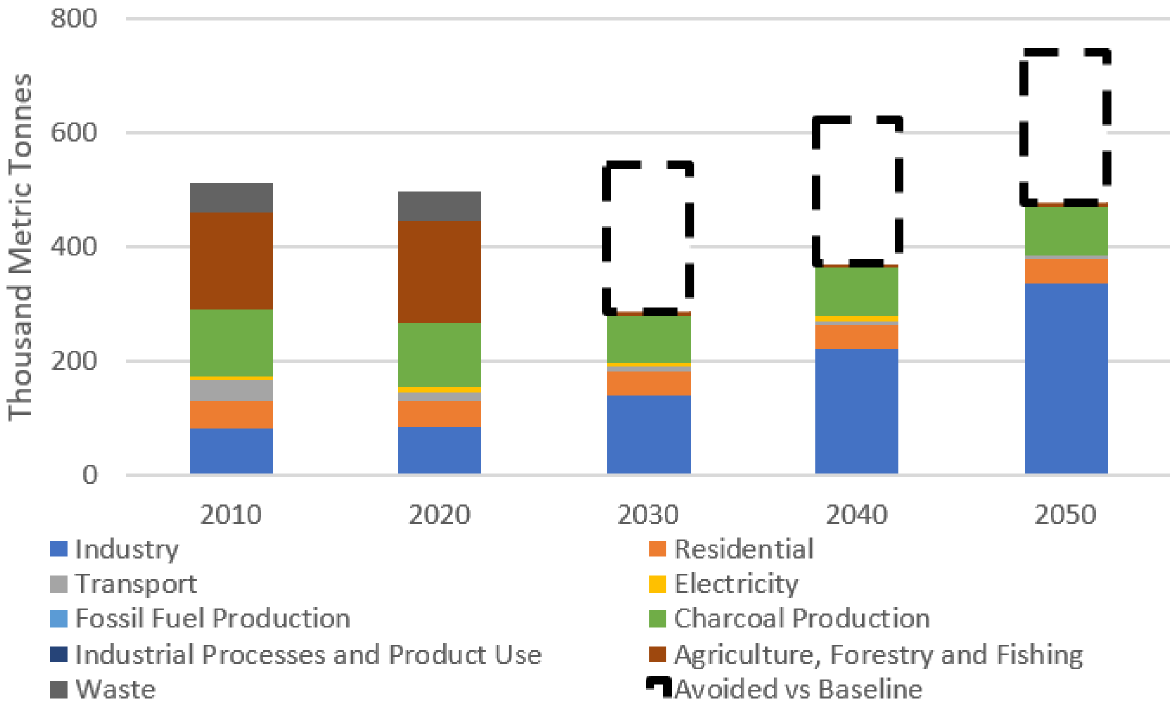


Figure 16: Reduction in $PM_{2.5}$ emissions across Thailand from full implementation of mitigation measures

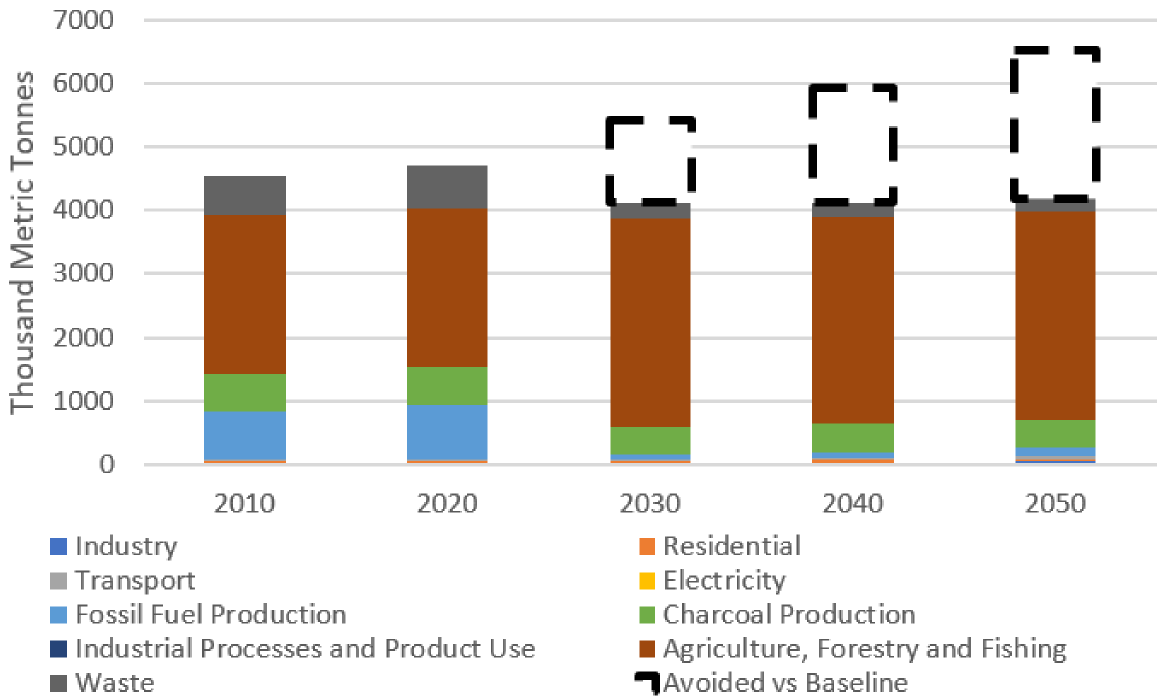


Figure 17: Reduction in methane emissions across Thailand from full implementation of mitigation measures

Table 6: GHG, SLCP and air pollutant emissions in the baseline and mitigation scenarios after implementation of each measure in 2030 (Unit: thousand metric tonnes)

Measure	Sector	Description	OC	BC	PM2.5	SO2	NOx	NMVOC	CH4	CO	CO2
	Baseline		325.9	67.2	542.9	758.7	815.7	44962	5420	13154	225417
1	Transport	Implementation of Euro 5 emission standards and fuel quality in 2024.	325.9	67.1	542.7	758.8	792.6	45109	5420	12802	225555
2	Transport	Switching diesel buses to be electric buses (BMTA)	325.9	67.2	542.8	758.6	814.1	44962	5420	13154	225159
3	Transport	The Government has been promote EVs in Thailand	325.8	67.0	542.5	770.9	811.4	44493	5433	13149	226682
4	Transport	Retrofit Program (The government planned to install a DPF to the used diesel bus and truck which are being 10-15 years average)	325.7	66.9	542.0	758.7	815.7	44962	5420	13154	225417
5	Residential	More efficient charcoal stoves	311.4	64.4	513.2	752.0	812.3	44603	5272	11982	225417
6	Residential	Energy Efficiency	325.8	67.2	541.9	698.9	785.8	44953	5351	13146	209327
7	Services	Energy Efficiency	325.8	67.2	541.9	697.6	785.1	44952	5350	13146	208972
8	Industry	Energy Efficiency	325.8	67.2	542.3	724.1	798.4	44957	5380	13150	216099
9	Agricultur	Zero agricultural residue burning	150.3	53.5	376.1	747.9	794.0	44825	5228	11379	225417
10	Waste	Zero waste burning	296.3	63.6	487.9	755.9	788.2	44835	5790	12941	225417
11	Electricity Generation	Renewable Electricity Expansion	325.8	67.2	542.1	601.6	747.8	44945	5290	13140	191056
12	Transport	Electric Vehicle expansion	325.7	66.6	543.1	878.6	854.2	38668	5550	13104	248939
13	Residential	Switching from LPG to electricity for cooking	325.8	67.2	542.8	758.5	815.4	44956	5419	13149	224535
14	Oil and Gas	Minimise fugitive methane emissions	325.9	67.2	542.9	758.7	815.7	44962	4391	13154	225417
15	Waste	Methane capture from landfill sites	325.9	67.2	542.9	758.7	815.7	44962	4965	13154	225417
16	Waste	Methane capture from wastewater management sites	325.9	67.2	542.9	758.7	815.7	44962	5401	13154	225417
17	Rice	Alternate wetting and drying implemented for rice production	325.9	67.2	542.9	758.7	815.7	44962	6136	13154	225417
18	Livestock	Reduce enteric fermentation emissions from livestock	325.9	67.2	542.9	758.7	815.7	44962	5245	13154	225417

Table 7: Percentage reduction in GHG, SLCP and air pollutant emissions from implementation of individual mitigation measures included in this assessment

Measure	Sector	Description	OC	BC	PM2.5	SO2	NOx	NMVOC	CH4	CO	CO2
1	Transport	Implementation of Euro 5 emission standards and fuel quality in 2024.	0.0	0.1	0.0	0.0	2.8	-0.3	0.0	2.7	-0.1
2	Transport	Switching diesel buses to be electric buses (BMTA)	0.0	0.1	0.0	0.0	0.2	0.0	0.0	0.0	0.1
3	Transport	The Government has been promote EVs in Thailand	0.0	0.4	0.1	-1.6	0.5	1.0	-0.2	0.0	-0.6
4	Transport	Retrofit Program (The government planned to install a DPF to the used diesel bus and truck which are being 10-15 years average)	0.0	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0
5	Residential	More efficient charcoal stoves	4.5	4.2	5.5	0.9	0.4	0.8	2.7	8.9	0.0
6	Residential	Energy Efficiency	0.0	0.0	0.2	7.9	3.7	0.0	1.3	0.1	7.1
7	Services	Energy Efficiency	0.0	0.0	0.2	8.1	3.8	0.0	1.3	0.1	7.3
8	Industry	Energy Efficiency	0.0	0.0	0.1	4.6	2.1	0.0	0.7	0.0	4.1
9	Agricultur	Zero agricultural residue burning	53.9	20.5	30.7	1.4	2.7	0.3	3.5	13.5	0.0
10	Waste	Zero waste burning	9.1	5.4	10.1	0.4	3.4	0.3	-6.8	1.6	0.0
11	Electricity Generation	Renewable Electricity Expansion	0.0	0.0	0.1	20.7	8.3	0.0	2.4	0.1	15.2
12	Transport	Electric Vehicle expansion	0.1	0.9	-0.1	-15.8	-4.7	14.0	-2.4	0.4	-10.4
13	Residential	Switching from LPG to electricity for cooking	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
14	Oil and Gas	Minimise fugitive methane emissions	0.0	0.0	0.0	0.0	0.0	0.0	19.0	0.0	0.0
15	Waste	Methane capture from landfill sites	0.0	0.0	0.0	0.0	0.0	0.0	8.4	0.0	0.0
16	Waste	Methane capture from wastewater management sites	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
17	Rice	Alternate wetting and drying implemented for rice production	0.0	0.0	0.0	0.0	0.0	0.0	-13.2	0.0	0.0
18	Livestock	Reduce enteric fermentation emissions from livestock	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0

Table 8: National total emission reductions in key sectors from implementation of the 10 mitigation measures included in this integrated air pollution and climate change mitigation assessment. (Unit: thousand metric tonnes)

2030

Baseline emissions	OC	BC	PM2.5	NH3	SO2	PM10	N2O	NOx	NMVOC	CH4	CO	CO2
Industry	33.9	21.4	138.8	15.8	268.4	146.7	2.8	204.2	202.2	20.4	943.9	97893.4
Residential	18.7	7.9	44.3	7.5	6.6	53.7	1.2	19.4	198.7	41.6	958.9	4395.0
Transport	3.8	4.4	11.5	4.3	11.0	12.1	0.0	316.3	483.5	30.8	5016.2	65579.4
Electricity	0.7	0.1	6.3	0.1	406.1	8.9	0.8	203.2	3.7	2.5	50.5	109203.7
Fossil Fuel Production	0.0	0.0	0.0	0.0	19.8	0.0	0.0	7.7	42383.3	1092.4	2.9	456.0
Charcoal Production	55.8	8.2	112.4	16.0	24.9	112.4	0.0	7.8	1418.1	579.3	4185.1	0.0
Industrial Processes and Product Use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	52612.0
Agriculture, Forestry and Fishing	183.3	21.6	174.6	84.8	18.6	194.9	0.0	29.5	144.3	2939.9	1783.1	-110000.0
Waste	29.6	3.6	55.0	6.3	2.8	66.8	0.0	27.5	126.8	703.8	213.2	0.0
Total	325.9	67.2	542.9	134.7	758.2	595.6	4.9	815.5	44960.6	5410.6	13153.8	220139.5

All Measures - Baseline	OC	BC	PM2.5	NH3	SO2	PM10	N2O	NOx	NMVOC	CH4	CO	CO2
Industry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Residential	-0.6	-0.8	-1.7	-0.6	-0.5	-1.7	-0.2	-1.7	-10.4	-3.5	-129.7	-879.0
Transport	-0.5	-1.1	-2.5	-0.4	-2.8	-2.6	0.0	-43.0	1.5	-3.1	-420.2	-9065.7
Electricity	-0.1	0.0	-1.1	0.0	-171.9	-2.0	-0.3	-76.0	-1.2	-0.6	-15.9	-38821.4
Fossil Fuel Production	0.0	0.0	0.0	0.0	-2.2	0.0	0.0	-0.9	-6219.3	-1033.2	-0.3	-61.9
Charcoal Production	-13.9	-2.1	-28.1	-4.0	-6.2	-28.1	0.0	-1.9	-354.5	-144.8	-1046.3	0.0
Industrial Processes and Product Use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-20712.0
Agriculture, Forestry and Fishing	-175.6	-13.8	-166.8	-77.0	-10.8	-187.1	0.0	-21.7	-136.5	348.8	-1775.3	0.0
Waste	-29.6	-3.6	-55.0	-6.3	-2.8	-66.8	0.0	-27.5	-126.8	-456.3	-213.2	0.0
Total	-220.3	-21.4	-255.1	-88.4	-197.3	-288.3	-0.5	-172.6	-6847.2	-1292.6	-3600.9	-69539.9

All Measures (% reduction vs Baseline)	OC	BC	PM2.5	NH3	SO2	PM10	N2O	NOx	NMVOC	CH4	CO	CO2
Industry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Residential	-3.1	-10.1	-3.8	-8.6	-8.0	-3.1	-16.8	-8.7	-5.2	-8.5	-13.5	-20.0
Transport	-13.6	-24.8	-22.0	-9.0	-25.4	-21.6	-10.8	-13.6	0.3	-10.0	-8.4	-13.8
Electricity	-12.6	-8.7	-17.4	-31.6	-42.3	-22.2	-36.7	-37.4	-32.3	-24.3	-31.5	-35.5

Fossil Fuel Production					-11.2			-11.2	-14.7	-94.6	-11.2	-13.6
Charcoal Production	-25.0	-25.0	-25.0	-25.0	-25.0	-25.0		-25.0	-25.0	-25.0	-25.0	
Industrial Processes and Product Use												-39.4
Agriculture, Forestry and Fishing	-95.8	-63.9	-95.5	-90.8	-58.2	-96.0		-73.6	-94.6	11.9	-99.6	0.0
Waste	-100	-100.0	-100.0	-100.0	-100.0	-100.0		-100.0	-100.0	-64.8	-100.0	
Total	-67.6	-31.8	-47.0	-65.6	-26.0	-48.4	-10.4	-21.2	-15.2	-23.9	-27.4	-31.6

5. Implementing Air Pollution and Climate Policies in Thailand: Governance and Enabling Reforms

5.1 Introduction

The previous section highlighted 19 measures from the $PM_{2.5}$ plan, climate policies and other interventions in Thailand that could achieve reductions in short-lived climate pollutants (SLCPs). The effective implementation of those measures could deliver sizable air quality, health, and climate benefits. However, effective implementation may be difficult. Different technological, economic, social and institutional barriers may slow progress and contribute to "persistent" implementation gaps.

The purpose of this section is to provide an overview of the barriers and consider enabling reforms that could overcome key constraints. This would, in turn, strengthen implementation and accelerate changes to realize the co-benefits estimated in previous chapters.

To discuss barriers and enabling reforms, the section begins with a review of what is needed for the successful implementation in key sectors featured in the scenario analysis. This includes discussions focused on Thailand's industry, residential energy, transport, and waste sectors. The section then looks more broadly at governance and institutional reforms--beyond some of sector-specific enablers—that could enhance the enabling environment. That discussion draws upon surveys and focus groups discussions that centred on four themes: 1) institutional coordination and policy coherence; 2) policy instruments; 3) policy enforcement and compliance; and 4) science-policy interface. A final section discusses how governance and institutional reforms can be integrated into the modelling to accelerate and strengthen implementation.

5.2 Enabling the Implementation of Measures

5.2.1 Industry

One of the key measures involves improving energy in Thailand's industries. Though achieving the benefits from improved energy efficiency from industry appear simple on paper, it may prove challenging in practice. Part of the challenge is that even as key industries adopt energy efficiency reforms, they may boost energy consumption and emissions. Other hurdles are that many industries in Thailand are micro, small and medium enterprises (MSMEs) that lack resources to purchase more efficient or clean technologies. In part due to the lack of resources, MSMEs may also be motivated to limit regulatory compliance checks.

There are enabling reforms that could overcome these challenges. On possibility is strengthening Thailand existing support for low-cost financing for climate-friendly technologies (Chotichanathawewong and Thongplew, 2012). In a similar way, Thailand could draw on experiences from information disclosure programme has been used to publicly share scores of industrial compliance with environmental regulations. The widespread dissemination of those scores create pressures for industrial regulatory compliance (Afsah et al., 2013).

5.2.2 Transport

There are many interventions that could reduce emissions of SLCPs in the transport sector, ranging from strengthening emissions standards to the promoting e-vehicles. This subsection focuses on three sets of solutions.

Emissions Standards

One of the key solutions involves strengthening emissions standards from Euro 4 to Euro 6. Initially, many of the challenges related to this solution were technical in nature. There was a lack of low-sulfur fuels that would be needed to operate more efficient vehicles. There was hence a need to invest in refineries and infrastructure for low-sulphur fuels (Owen and Tao 2016).

However, in recent years the tightening of standards is less a technical than institutional issue as auto manufacturers have delay shifts to stronger controls. Overcoming this hurdle requires building an effective working relationship between the vehicle industry and government regulators. Strengthening that relationship could include, *inter alia*, regularly scheduled meetings and greater engagement with civil society groups to motivate industry to move faster. The uptake and spread of e-vehicles can also help in this regard.

Retiring Vehicles

Another key solution is retiring or repairing older vehicles. Repairing or retiring these vehicles is critical because older vehicles can account for 50% to 80% of fine particulate emissions in the Bangkok Metropolitan Administration (Li and Crawford-Brown, 2011). A critical part of the shift to newer or well-maintained vehicles are inspection and maintenance (I and M) programmes. One type of I and M program regularly checks whether a vehicle is registered and meeting specified performance standards. I and M programmes also may operate on the road to identify operating vehicles that are exceeding standards.

While I and M programmes are essential, they also have proven challenging to implement effectively. Some of the difficulties involve limitations on staffing in inspection centres and oversight agencies. They also include corruption: both vehicle owners and testing centres may work together to undermine a testing result in return for payments.

To some extent, the solutions to these issues are straightforward. Investments in capacity building and training may boost human resources. At the same time, the widespread installation of on-board diagnostic (OBD) systems can reduce the regulatory burden by clarifying when vehicles require repairs. In addition, a consultation process with vehicle owner groups can help determine how to make the programmes more effective without overburdening poorer segments of the population has promise. Another promising alternative is to rely more on crowd-sourcing and micro reporting of non-compliant vehicles and making reporting violations a performance indicator for regulatory agencies.

E-vehicles

Another set of solutions in the transport sector involves promoting transitions to electric vehicles (e-vehicles). In contrast to tighter standards on conventional vehicles or retiring vehicles, this approach might confront fewer challenges. This is partially due to a growing push globally and in Thailand to capture shares of the evehicle market (Tungsuwan et al., 2021). Because of this shift, there may be less opposition from industries and consumers.

At the same time, this transition is still likely to take time. Part of the reason this transition will not happen quicky are the still high costs of electric vehicles. The availability and access to charging stations also poses an additional constraint. Lingering concerns about vehicle distances are another reason the transition might move slower than hoped. Finally, it is absolutely critical that transitions to e-vehicles occur in parallel the transitions to renewable energy—otherwise emissions will not be reduced but simply displaced.

At the same time, the response to these challenges are also clear. Targeted price supports and public investment in transport vehicles to lower costs. Additional enabling reforms consist of investments in charging stations and ensuring standards for the stations are uniform.

5.2.3 Residential Energy

Thailand has made significant progress on reducing emissions from cookstoves in many parts of the country. At the same time, cookstoves remain a major source of pollution in Northern Thailand. There are many well-chronicled challenges to transitioning to improved or more efficient stove designs or stoves powered by cleaner fuels or electricity. Some of the key challenges are the relatively higher costs of the cleaner stoves. There can also be low levels of public acceptance and awareness of the benefits of cleaner alternatives. Limited access to infrastructure for liquified petroleum gas (LPG) or other cleaner fuels can also be problematic.

Some of the potentially most promising reforms involve strengthening government support for cookstove programmes. The cookstove issue can tend to fall through the cracks of different agency remits, limiting needed attention. With this increased support and attention could be price supports be improved stoves and fuels as well as training and awareness raising programmes. The price supports can be particularly important to bring down the initial costs of improve or electric stoves. Finally, greater attention to building sustainable business models for the manufacturers, marketing, and sales of alternatives to less-efficient stoves.

5.2.4 Agricultural Burning

Perhaps more so than the other solutions, halting the burning of agricultural residue (i.e. rice straw and sugarcane) has proven very challenging (Oanh et al., 2018). Many of the challenges begin with the pressures that farmers face to grow more food quickly. Farmers in many parts of ASEAN are now harvesting two-three rice crop cycles per year with limited time for land clearing (Oanh et al., 2018). In addition, there are several challenges in the distribution of land; there can be significant distances between small scale land plots that can make it difficult to monitor and enforce restrictions. Beyond these difficulties are the limited supplies of labour for manual harvesting. Further, there is limited resources and high levels of farmer debt. The lack of resources and high debt make it challenging to afford technologies that could help limit burning of residues such as rice straw. Cost constraints may also be compounded by a lack of awareness of the impacts of burning on health and development priorities. Last but not least, are changing climatic conditions that have made the conditions and impacts of burning more intense.

There are several possible enabling reforms that can help address these challenges. These begin with enhanced monitoring and better dissemination of information on the impacts of burning. These efforts could be coupled with community-based programmes that raise awareness of both impacts and alternatives to burning (such as planting and sales of mushrooms that generate less residue). There are also growing opportunities to work with the private sector to build more sustainable value chains for the residue—for example, using the residue to manufacture furniture or generate energy (Noipa and Pakdeelun, 2021). Many of the above enabling reforms could be packaged together as suite of mutually reinforcing reforms (TEI, 2021). They could also be linked to ongoing efforts to develop a Clean Air Law that would strengthen the legal basis for implementing some of the proposed changes.

5.2.5 Waste Burning

Controlling the burning of residential waste is an emerging concern as shifts in lifestyles and consumption generate more waste. To some extent, the challenges of addressing this problem mirror those associated with agricultural waste. There can be limited knowledge of the impacts of the practice and few resources to monitor and enforce restrictions on burning. At the same time, a limited number of sanitary landfills and waste collection services can leave residents with limited alternatives. These challenges can be most intractable in poorer and remote communities. (Premakumara et al., 2017).

The kinds of enabling reforms that can address these challenges are likely to involve a mix of remedial countermeasures. Some of the countermeasures will need to focus on enhanced reporting and monitoring of the practice; community hotlines and online reporting channels may hold promise to reduce the burden on local officials. These efforts will need to be combined with broader strategies to improve the collection and management of waste. This might entail not only landfills but greater attention to composting for organic waste and recycling of non-organic waste. Many of the proposed countermeasures will be oriented to sustainable waste management in general rather than limiting burning in particular.

5.3 Governance and Institutional Reforms

The previous subsection discussed enabling reforms for sectoral interventions related to the 19 priority measures featured in the scenario modelling. This subsection expands the focus to assess broader governance and institutional issues that could strengthen the integration between air pollution and climate planning. The underlining assumption is that addressing these issues and strengthening integrated planning can reinforce some of the sector-specific enabling reforms—for instance, by generating more climate finance. This can then further enhance implementation and accelerate action.

To offer this broader analysis, this subsection will draw upon work on governance. Governance is defined as “the totality of interactions in which government, other public bodies, private sector and civil society participate [to solve] public challenges or creating public opportunities” (Meuleman, 2018). There are numerous governance issues that could support—or undermine—more integrated air pollution and climate planning. To make the analysis easier to follow, the section focuses on four key governance dimensions: 1) institutional coordination and policy coherence; 2) policy instruments; 3) policy enforcement and compliance; and 4) science-policy interface. A quick review of how these different issues could affect integrated planning and some relevant good practices in other countries follow.

- Institutional coordination and policy coherence can improve cooperation between and within government agencies as well as with other stakeholders. Several countries have improved coordination with implications for air quality and climate change. Ghana, for example, set up a multi-disciplinary inter-ministerial team to identify data sources and reached consensus on the results of assessment modelling that drew upon an integrated perspective. Chile, to highlight another illustration, created a super-intendency of the environment (SMA) with a legal mandate to improve institutional coordination and enforce environmental quality standards and regulations.
- The next category, policy instruments, refers to the kinds of tools within policies that governments can use to a steer implementation. In some cases, those instruments rely heavily on government-backed regulations. Mexico, for instance, has a Climate Change Law, and an Integrated SLCP Strategy to Improve Air Quality and Reduce the Impact of Climate Change that draw heavily on the equipping agencies with the tools and authority to implement provisions. Norway's climate policy took a more varied approach based on a policy mix consisting of polluter pays principle, environmental taxes (CO_2 tax), emissions trading, direct regulation, subsidies, and information that can help enhance implementation (Norwegian Ministry of Climate and Environment, 2019).
- A third and related category involves policy enforcement and compliance. In this case, countries such as Finland has authorized national and municipal governments the mandate to issue regulations, permits, and other enforcement activities. In the UK, compliance is helped by better data sharing between environmental regulators in different sectors. Underlining that many of these issues overlap with other governance themes, the UK has also established a cross-agency joint enforcement programme.
- The fourth set of governance issues pertains to the interface between science and policy. Several countries have established mechanisms that can ensure the latest science underpins policy. In Norway, policymakers draw upon a 'multiple-benefit methodology' that analyses GHGs and SLCPs in short and long terms. To return to a previous good practice, Chile has relied on modelling that emphasizes the net economic benefits of any proposed plans based on evidence-base techniques.

5.3.1 Translating Governance and Institutional Reforms to Thailand's Context

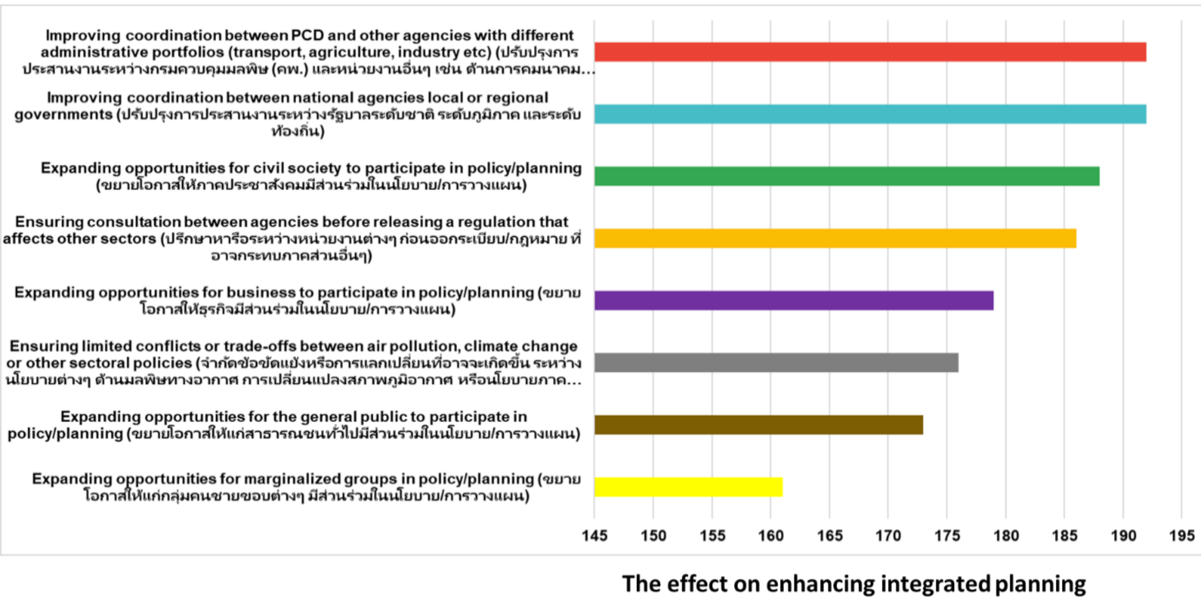
The relative importance for each of these themes for integrated planning is likely to vary from one to context to another. To determine how much the four areas (and pertinent issues under them) matter for Thailand, the research team followed a two-step process.

The first step was a survey that was disseminated in preparation for the project's kick-off workshop. In total, there were 79 respondents to the survey. Respondents came from different backgrounds and experiences. Respondents included policymakers, academics, international development specialists, and representatives of the civil society organizations. The survey questions were presented in English and Thai language.

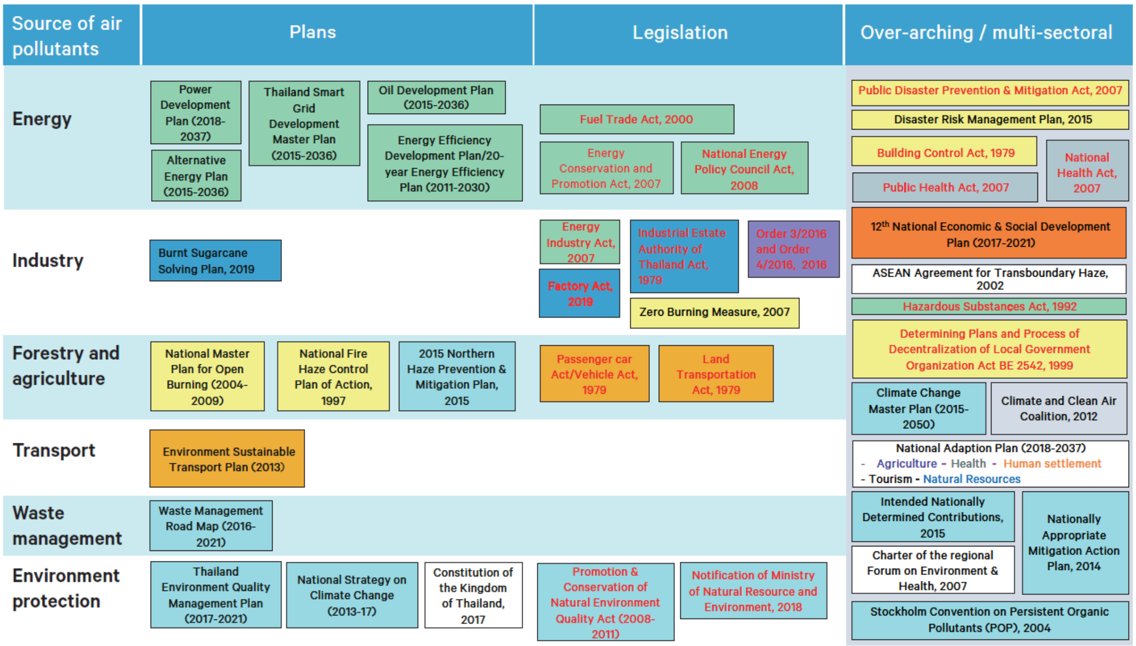
The survey asked respondents the following question: “How much would the below governance areas enhance Thailand’s performance on integrated air pollution and climate change planning?” Respondents were then able to indicate whether sets of issues falling under each of the four governance categories outlined at the beginning of section 5.3 had a significant, moderate, small, or no influence on integrated planning. To summarize the overall impacts of issues under the four categories, the results were then coded such that significant influence was scored as 3, moderate influence was scored as 2, small influence was scored as 1, and no influence was scored as 0.

The results from the survey were helpful in illustrating some of the key challenges to more integrated planning. Figure 18 presents some of the main results for the category of institutional coordination and policy coherence. It shows, based on the scoring system described above, that the issues that could have the greatest influence on strengthening integrated planning are improving “horizontal’ coordination between Thailand’s Pollution Control Department as well improving coordination between national and local or regional governments. Both issues received a score of 192 out of a possible maximum score of 237 (3 x 79 respondents). Box 1 further illustrates some of the challenges to horizontal and vertical coordination for integrated air pollution and climate planning.

Figure 18: Results of Survey on Institutional Challenges (see above text for how the “effect on enhancing integrated planning” was calculated”)



Box 1: Policy Incoherence and Institutional Coordination in Thailand



Source: Nikam et al., 2021

As illustrated in the figure above, there are a wide variety of policies that directly or indirectly address air pollution. Many of these policies also have implications for climate change. However, the figure above also suggests that there is limited coherence across these policies. The lack of coherence is arguably attributable to a tendency for relevant agencies to work in silos. This siloed approach cannot only limit integration across air pollution, climate change and other policies, it can also reduce the amount of resources that can be allocated to overcome some of the barriers to the sectoral-specific solutions discussed at the beginning of section 5.3. The end result is likely to be slower and less effective policy implementation.

One of the main conclusions that can be drawn from the survey is that there is room for improving institutional coordination and coherence within and across levels of decision making in Thailand.

A second step that followed from the survey was a series of focus group discussions with approximately 30 policymakers, researchers and representatives of civil society that aimed to identify ways to address the governance challenges identified in the survey. The focus groups pointed to some potentially useful suggestions.

One of the key reforms involve strengthening the integration of the kinds of analysis featured in this report in climate policies, especially NDCs. For more science-based calculations to consistently feature in both climate and air pollution policies, it will be critical for greater coordination and communication across divisions focusing on climate change in ONEP and divisions focusing on air pollution in PCD. While there might be understandable resistance to merging divisions, there are some more modest steps that can be taken that can improve upon the current situation. These include the seconding of staffing across divisions, the sharing of climate and air pollution data, the issuing of requirements for cross-division reviews of emissions analysis and proposed regulatory, and the sharing of budgets for projects where there are clear overlaps between air pollution and climate change (Peters, 1998).

A related set of possible interventions to improve institutional coordination and coherence that the focus groups identified was that the Thai government establish an interagency task force with members from the PCD, the ONEP, Thailand Greenhouse Gas Management Organization (TGO), Office of Transport and Traffic Policy and Planning (OTP), Department of Industrial Works (DIW), Ministry of Agriculture and Cooperatives (MAoC), Ministry of Higher Education, Science, Research and Innovation (MHESI), local governments, and civil society organizations. The taskforce could consist of a technical working group and a policy working group. The technical working group would work on harmonizing data and reporting; it could use the LEAP model and other integrated assessment models to identify solutions that address climate and air-pollution to be included in Thailand's NDC. The policy working group would then work on linking solutions to relevant policies (including shipping and aviation), and also communicate benefits of policy proposals to the public to garner wider support for achieving co- benefits.

The interagency task force could also develop and hold trainings on integrated assessments to build capacity among stakeholders. It was also pointed out that the task force should use clear, simple and consistent language to deliver information on health, employment, income and climate co-benefits to the public. It could also expand distribution channels by involving "influencers" to help spread information about benefits to the "new generation" through Facebook, Tik Tok, Twitter, Instagram etc.

In addition to the above reforms, there will also need to be reforms that focus on strengthening vertical integration between national and local/regional governments. Some of the possible reforms that could help in this regard are similar to those aiming to strengthen horizontal coordination. For instance, there could be greater efforts to second staff between levels or requirements to share data on climate and air pollution between levels of decision making. Arguably the most important of the possible reforms will be greater use of fiscal transfers to help address some of the barriers for sectoral specific measures such as curbing open burning or promoting clean cooking. These fiscal reforms can also target strengthening human resources and enforcement capacities at the local level.

Yet another set of reforms can focus on building the capacities of the next generation of policymakers and regulators. In this connection, the government may want to invest in capacity building programmes that enable university students to learn and applied the kind of the modelling that underpins this report. In a similar vein, there may also be greater investment in providing students with more foundational knowledge about the impacts of air pollution and climate change and integrated solutions. Both efforts are likely to have the greatest impact if they aim to build capacities at the local level and with universities outside of large cities such as Bangkok and Chiang Mai. It may also be possible build a network for knowledge sharing across universities in different regions and with different student profiles.

5.4 Impact of delayed implementation of measures on improving air quality and mitigating climate change

The targets and timelines outlined in Section 4 for the implementation of the 19 mitigation measures assume are taken from national plans and strategies or based on the authors judgement. They are chosen to motivate policymakers to raise their ambitions and support reforms enabling their these measures effective implementation. The intention results presented is to demonstrate the possible emission reductions from the effective implementation of the policies and measures identified. Section 5.4 demonstrate that by 2030 it is possible to more than halve emissions of key air pollutants, and SLCPs, such as methane.

However, the achievement of these large emission reductions is not guaranteed; as noted early in Section 5, there are multiple barriers, economic, technical, social hurdles that stand between an estimated reduction and real-world achievement.

Based on relevant literature and stakeholder surveys and interviews—some of which is presented in the barriers analysis (see subsection 5.2)—delays have been estimated for a subset of the most effective measures at reducing air pollutant emissions. The barriers were assessed and classified into technical, economic, institutional and social categories, and rated as to whether they were small, moderate or significant. In making this assessment, an estimate was made as to how much these barriers implementation of the mitigation measures.

Table 9 summarises the revised timelines and/or targets for implementation of the mitigation measures for the delayed implementation scenario. The revised targets and timelines translated the categorisation of barriers into the inputs necessary to model the impact of these barriers on the magnitude of air pollutant and SLCP emissions in Thailand.

The delayed implementation scenario substantially affects the achievable emission reductions by 2030 (Figures 19-22). In comparison to the scenario in which all mitigation measures are implemented, the delayed implementation scenario reduces the 2030 emission reduction of PM emissions by ~50%. In 2030 when all 19 measures are fully implemented, $PM_{2.5}$ emissions are reduced by 47% compared to the baseline. However, with delayed implementation, $PM_{2.5}$ emissions are only reduced by 22% compared to the baseline scenario. Hence, the scale of the air pollutant and SLCP emission reductions achievable by 2030 is dependent on the removal and overcoming the key barriers identified for the key mitigation measures. Other pollutants, SLCPs and GHGs also have lower emission reductions for the delayed implementation scenario, highlighting that the ability to achieve simultaneous air quality and climate change goals is impacted if the barriers identified result in substantial delays to implementation of the mitigation measures.

Table 9: Details of impact on implementation of the measures from barriers identified in barriers assessment, that fed into delayed implementation scenario.

Number	Subsector	Mitigation Measure(s)	Target	Timeline	Barriers Scenario	Barriers Assessment (Significant / Moderate / Small / No Barrier)				Enabling Reforms
						Tech	Eco	Inst	Soc	
1	Transport	Implementation of Euro 5 and 6 emission standards and fuel quality in 2024 and 2025 respectively.	Euro 5 Fuel Quality Standard Euro 6 Fuel Quality Standard	2024 2025	Delay Target by 3 years to 2028 and 2030	Small	Significant	Significant	Small	• Financial support for refineries to switch to low sulphur fuels (reallocation of fossil fuel subsidies) • Mechanism to coordinate with transport and energy agencies on fuel quality improvements • Awareness raising on the benefits of tighter standards • Programme to assess policy effectiveness
2	Transport	Switching diesel buses to be electric buses (BMTA) about 500 buses in December 2021 and replace all 6,500 diesel buses by CNG and Electric buses in 2024.	500 diesel buses switched to electric 6500 diesel buses switched to electric	2021 2024	No Delay	No Barriers	No Barrier	No Barrier	No Barrier	--
3	Transport	The government has been promote EVs in Thailand with the target in 2030 as			Reduce Target by 40% as follows:	Significant	Moderate	Small	Small	• Financial support for purchasing e-vehicles • Financial support for charging stations

		following: motorcycle 650,000 , light passenger car 440,000 , bus 33,000 , truck 34,000 including 1450 charging stations with 12,000 charging ports.			390000 motorcycles, 264000 passenger cars, 19800 buses, 20400 trucks					• Awareness raising on the benefits of evehicles
4	Trans port	Retrofit Program (The government planned to install a DPF to the used diesel bus and truck which are being 10-15 years average)	Assume retrofit of buses and trucks begins in 2025 and achieves 95% reduction in PM emissions (applies to all pre-Euro 4 vehicles)	2025	Delay target by 5 years					• Financial support for vehicles users to finance repairs • On-board diagnostics (OBD) to monitor vehicles performance • Greater capacity and programme oversight to reduce corruption • Awareness raising on the benefits of newer vehicles
5	Resid ential	More efficient charcoal stoves	25% reduction in charcoal consumption through more efficient charcoal stoves	2030	Reduce target by 70% 7. 5% reduction through more efficient stoves					• Financial support for more efficient stove producers • Financial support for fuel shifting—to liquid petroleum gas and biogas • Awareness raising on the benefits of cleaner stoves
6	Resid ential	Energy Efficiency	54% reduction in energy consumption per household due to energy efficiency improvements	2030	Reduce target by 10%: 50% reduction in energy consumption per household due to energy efficiency improvements					• Financial support for manufactures of energy efficiency appliances • Labelling programmes for energy efficiency appliances
7	Servi ces	Energy Efficiency	55% reduction in energy consumption per	2030	Reduce target by 10%:					• Financial support for manufactures of energy efficiency appliances

			household due to energy efficiency improvements		50% reduction in energy consumption per household due to energy efficiency improvements					• Awareness raising for energy efficient service companies
8	Indus try	Energy Efficiency	22% reduction in energy consumption per household due to energy efficiency improvements	2030	Reduce target by 10%: 20% reduction in energy consumption per household due to energy efficiency improvements					• Financial support (low-interest loans) for enterprises to invest in energy efficient technologies—especially micro, small, and medium sized enterprises (MSMEs) • Strategic use of informational instruments to detect non-compliance with • Awareness raising for energy service companies
9	Crop	Zero agricultural residue burning	90% reduction in agricultural residue burning	2030	Reduce target by 60%: 36% reduction in agricultural residue burning					• Increased enforcement capacity for regulatory agencies • Strategic use of monitoring technologies (including satellites and low-cost sensors) • Incentives to purchase baling machines, mulching equipment and other management technologies • Creation of sustainable value chains to manage and convert residue into products • Awareness raising on the benefits of improved air quality
10	Solid Wast e	Zero waste burning	100% waste collected 100% of waste sent to landfill sent to managed landfill site	2030	Reduce target by 50%: 40% waste collected sent to the landfill					• Increased enforcement capacity for regulatory agencies • Strategic use of monitoring technologies (including satellites and low-cost sensors) • Awareness raising on prohibitions on burning of residential waste

										• Investments in sanitary landfills, composting and 3Rs
19	Fores t	Forest fire control	Annually 20% reduction of forest fire in terms of hotspot number or area burned (compared to the previous year)	2030	Reduce target by 60%: 10% reduction in hotspots number or area burned (compared to the previous year)					• Increased enforcement capacity for regulatory agencies • Strategic use of monitoring technologies (including satellites and low-cost sensors)

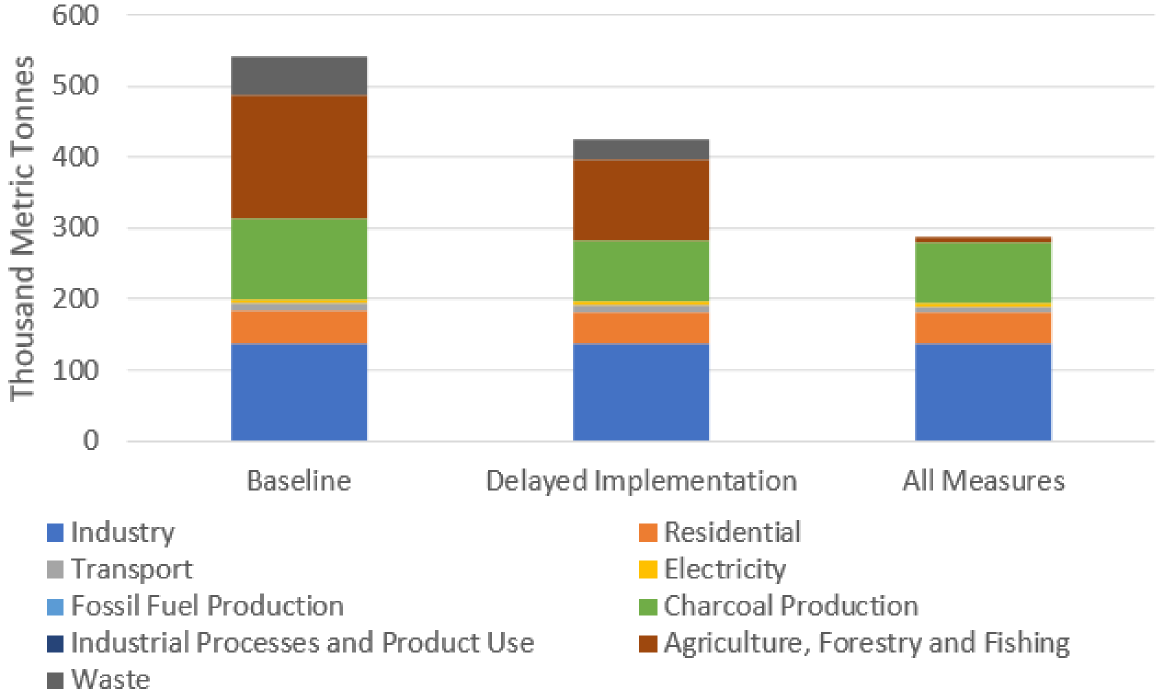


Figure 19: $PM_{2.5}$ emission in 2030 for the baseline, delayed implementation and all measures scenarios (unit: Thousand metric tonnes)

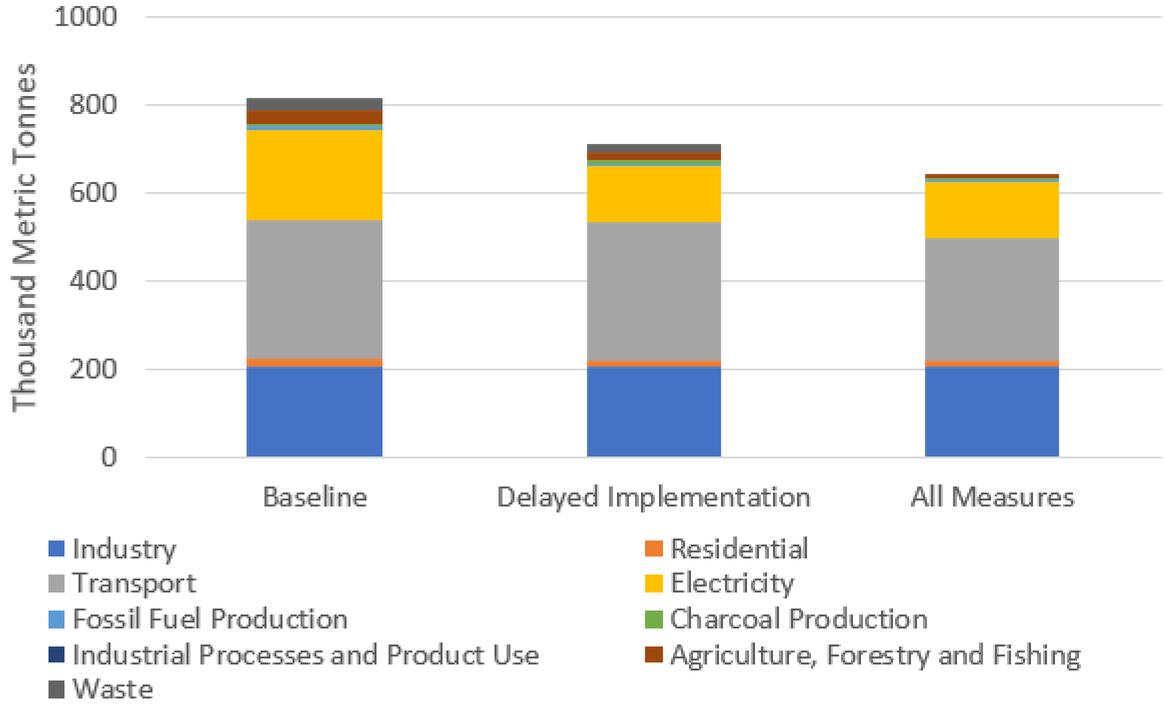


Figure 20: NO_x emission in 2030 for the baseline, delayed implementation and all measures scenarios

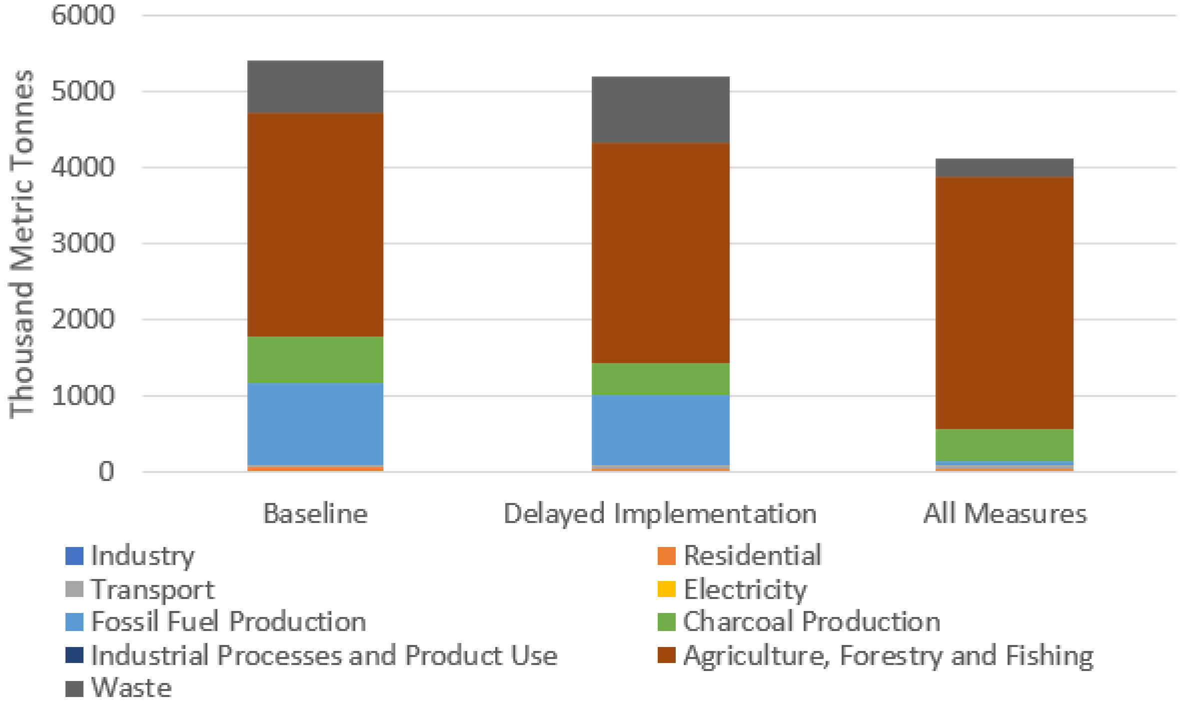


Figure 21: CH_4 emission in 2030 for the baseline, delayed implementation and all measures scenarios

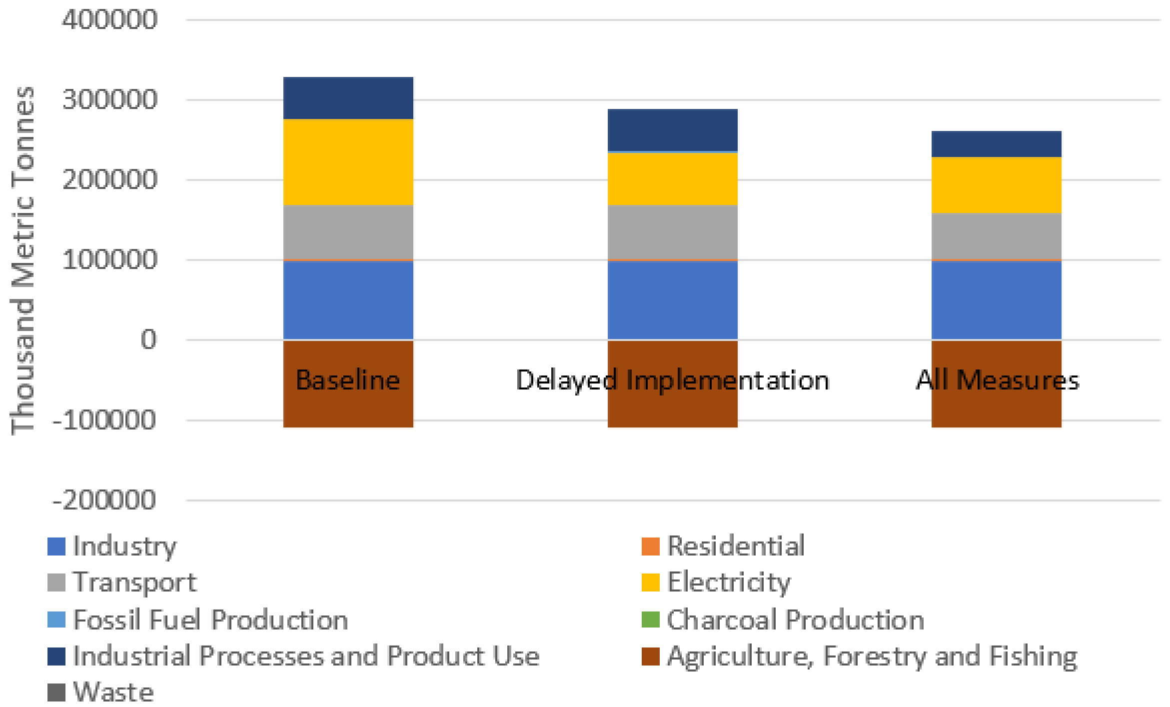


Figure 22: CO_2 emission in 2030 for the baseline, delayed implementation and all measures scenarios

6. Regional mitigation results

The national-scale results presented in Section 3,4, and 5 of this assessment show that, at the national scale, implementation of 19 mitigation measures could be effective at reduce emissions of air pollutants, SLCPs and GHGs. However, the national overview does not highlight that across different regions there are substantial differences in the magnitude of emissions and the contribution of major sources, which means that the emission reduction potential of different measures varies substantially. Therefore, the assessment also evaluated the emissions across six Thai regions, Northern, Northeast, Central, Greater Bangkok, Eastern and Southern. The historic, baseline and mitigation scenarios were developed for each region to identify which of the measures that achieve substantial reductions in emissions nationally are most effective at reducing emissions in each region.

Figure 23 shows the $PM_{2.5}$ emissions in 2020 disaggregated by region. Northeastern Thailand has the largest absolute $PM_{2.5}$ emissions, while southern Thailand has the lowest. The $PM_{2.5}$ emissions in Northeast, North and Central are dominated by the emissions from agricultural residue burning, and in Northeast and Northern Thailand, there is also a large contribution from the residential sector. In Greater Bangkok, industry, waste, and transport are the largest sources. The contribution of different emissions remains relatively constant across regions between 2020 and 2030 (Figure 24). The difference in the contribution of sources means that a different combination of the 19 measures are effective at reducing $PM_{2.5}$ emissions in different locations.

For $PM_{2.5}$, the implementation of the 19 mitigation measures are effective at reducing $PM_{2.5}$ emissions across all regions However, the measures which are effective differ. In Northern, Northeast and Central Thailand, it is the reduction in crop residue burning that contributes the majority of the emission reductions Despite there being a measure to increase the efficiency of charcoal stoves, in northern and northeast Thailand, there is still a substantial contribution from residential sector emissions in 2030 after implementation of the mitigation measures (Figure 25). In Greater Bangkok, the transport measures, and reducing waste burning are the measures contributing he majority of the emission reductions in this region. There is a similar pattern for NO_x emissions as for $PM_{2.5}$, except that, because NO_x emissions are mainly emitted from transport, the overall emission reductions in all regions is smaller than for $PM_{2.5}$.

For methane, the agriculture sector is the largest source of methane emissions in all regions except Greater Bangkok, where the waste sector emissions were largest (note that the waste sector emissions are assigned to regions based on where the waste was generated, and not the location of the landfill or other waste disposal site where the waste is disposed to and where emissions occur). Hence methane emissions are mitigated to a greater extent in Bangkok compared to other regions because of the greater methane reduction potential of the waste sector measures compared to actions in the rice and livestock sector.

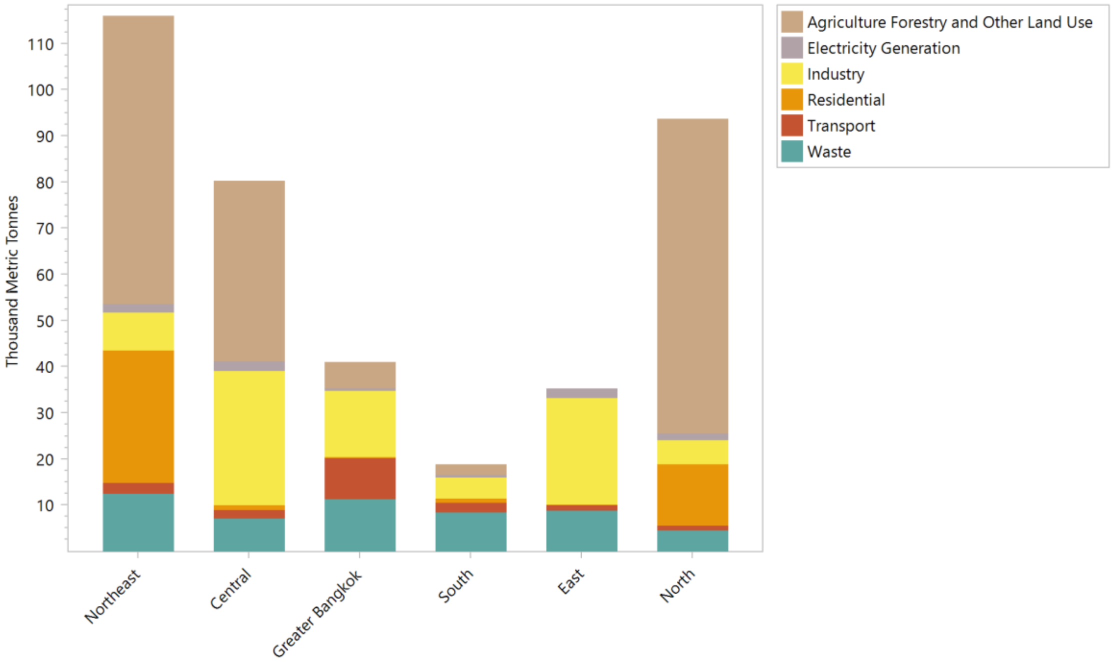


Figure 23: $PM_{2.5}$ emissions by region, disaggregated by major source sector in 2020

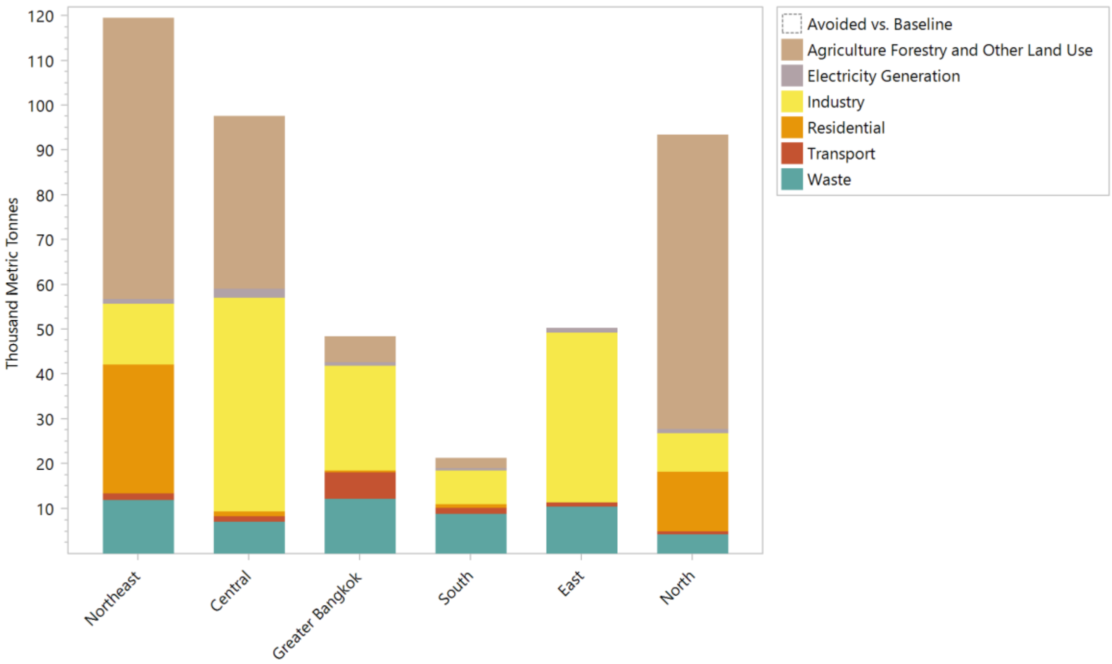


Figure 24: $PM_{2.5}$ emissions by region, disaggregated by major source sector in 2030 in the baseline scenario

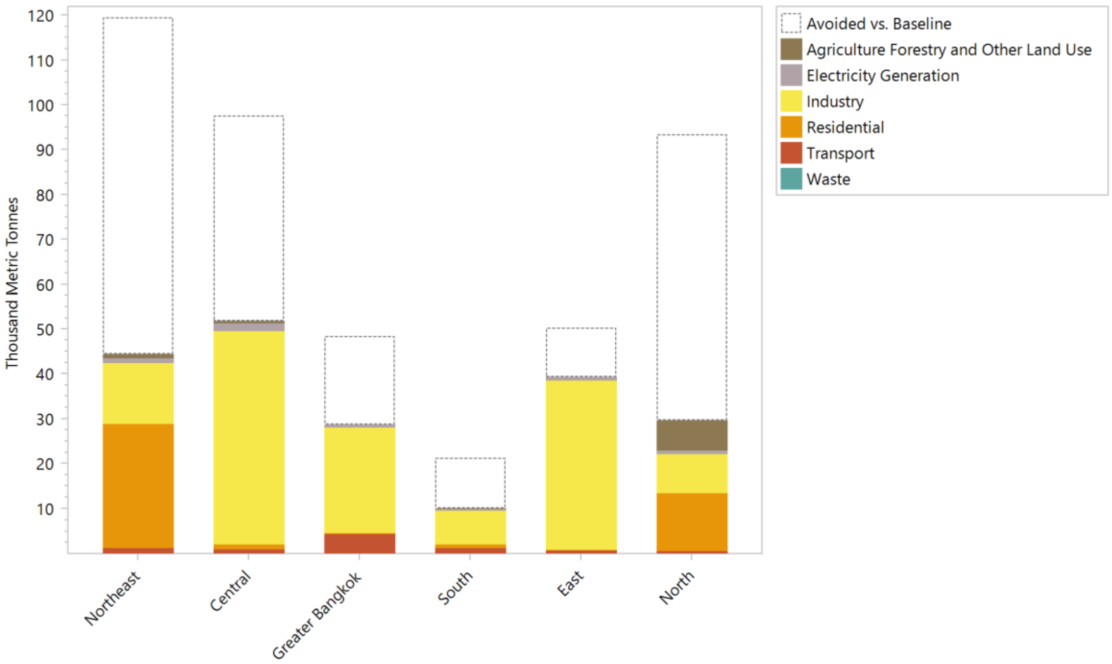


Figure 25: $PM_{2.5}$ emissions by region, disaggregated by major source sector in 2030 in the mitigation scenario after implementation of all mitigation measures

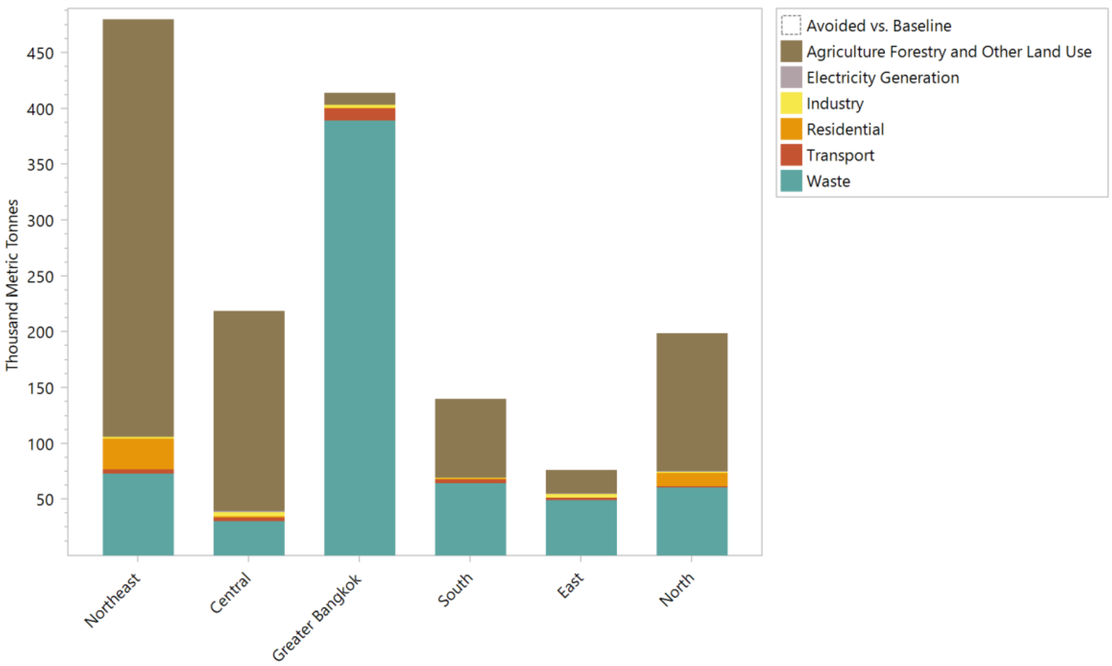


Figure 26: Methane emissions by region, disaggregated by major source sector in 2020

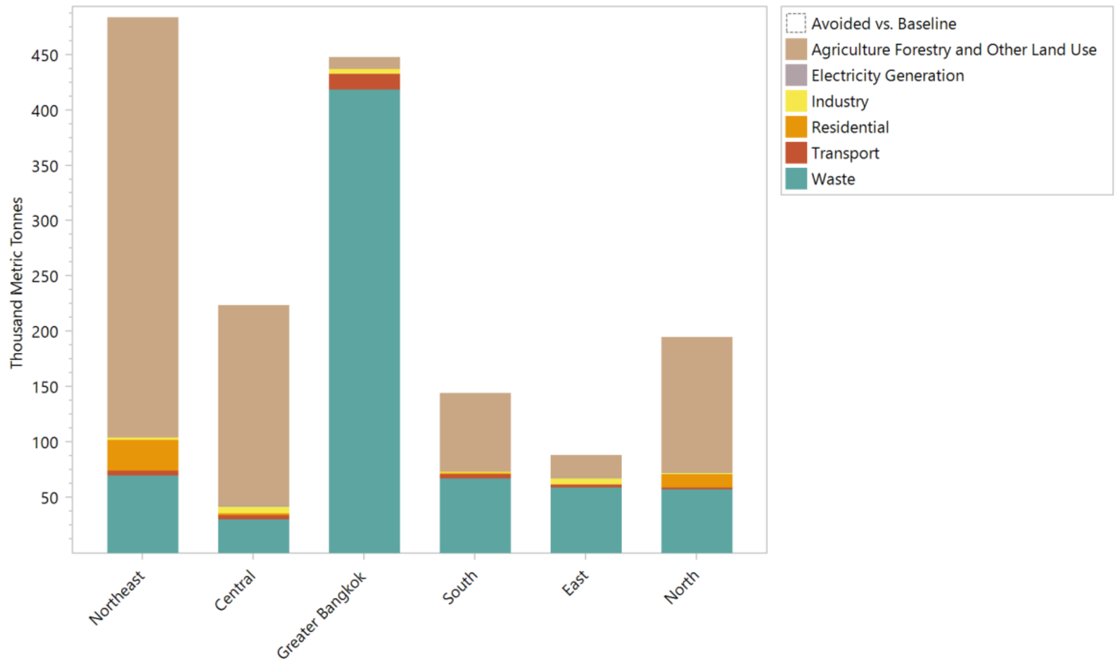


Figure 27: Methane emissions by region, disaggregated by major source sector in 2030 in the baseline scenario

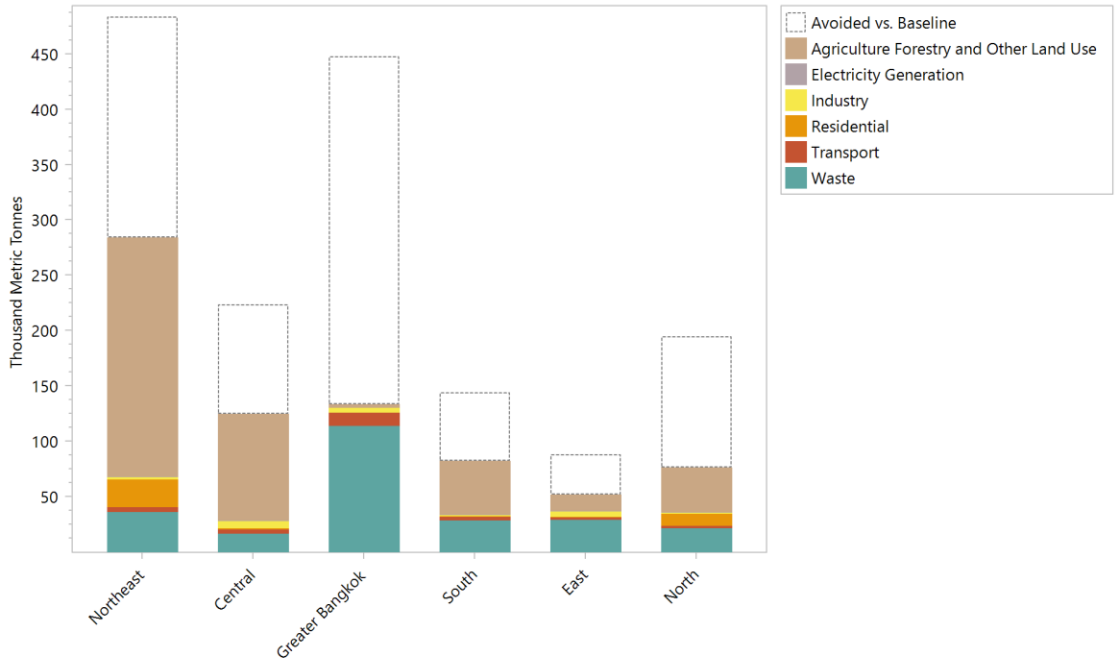


Figure 28: Methane emissions by region, disaggregated by major source sector in 2030 in the mitigation scenario after implementation of all mitigation measures

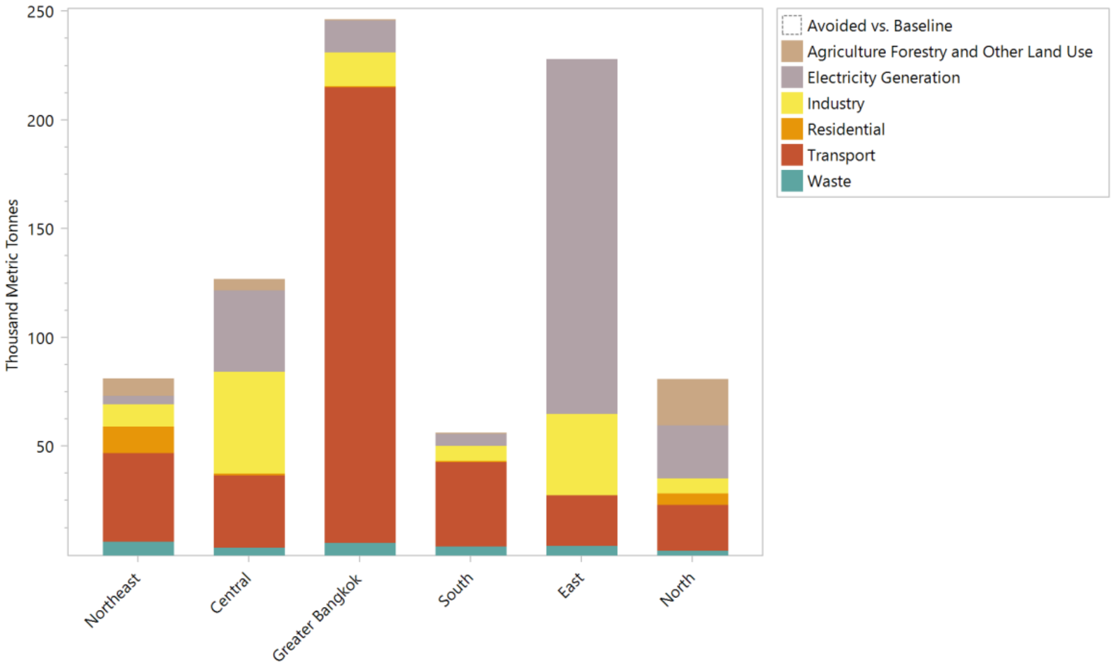


Figure 29: NO_x emissions by region, disaggregated by major source sector in 2020

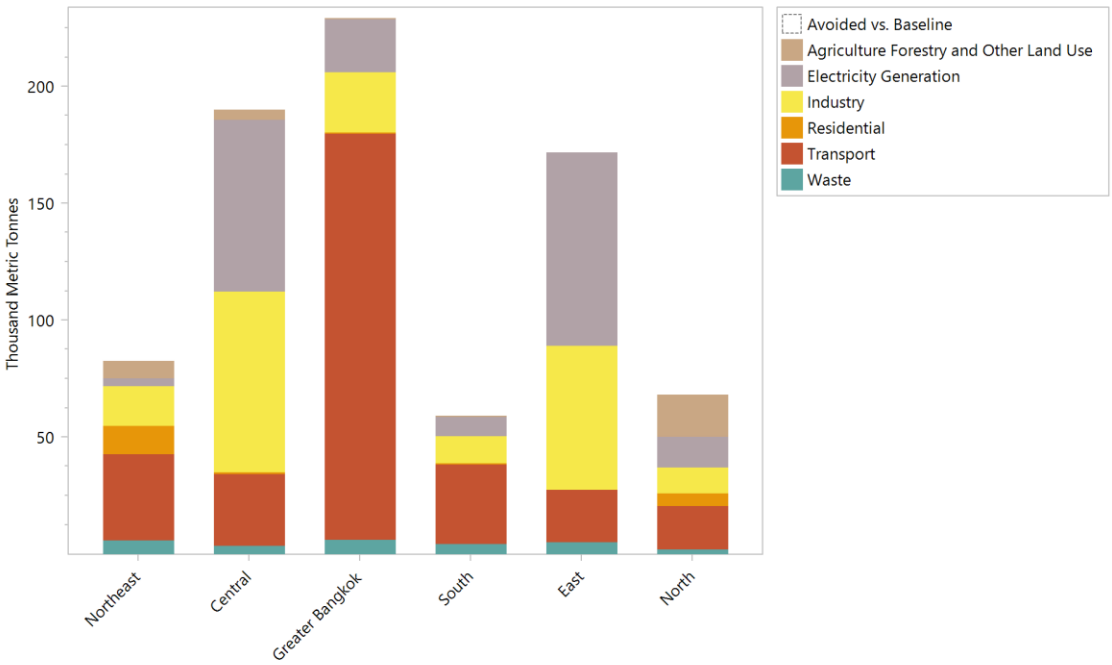


Figure 30: NO_x emissions by region, disaggregated by major source sector in 2030 in the baseline scenario

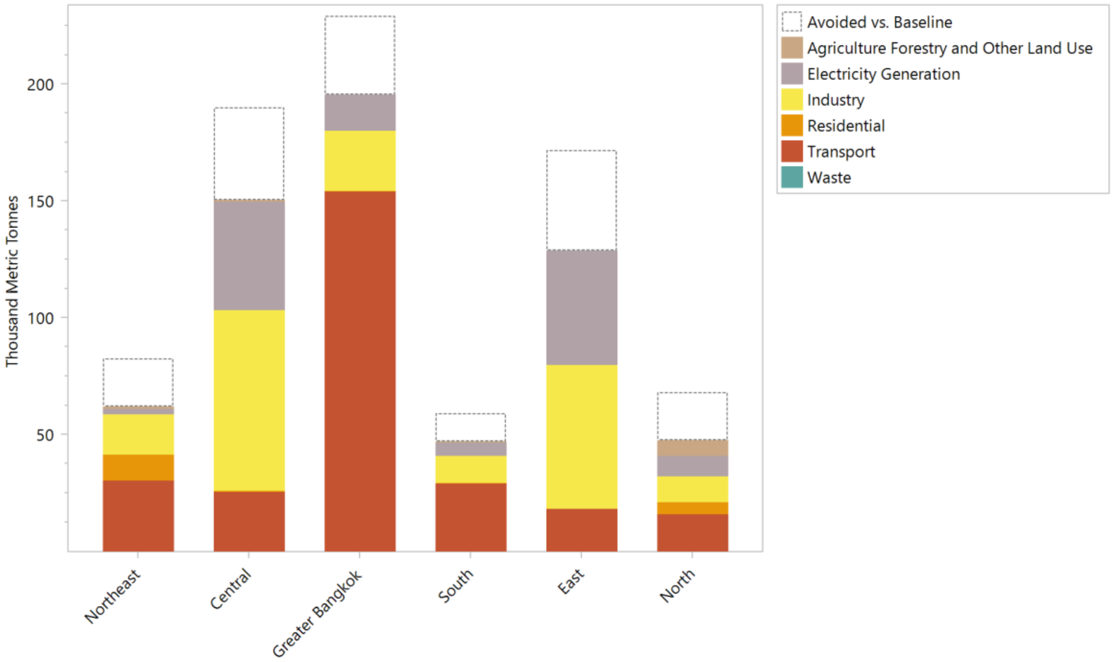


Figure 31: NO_x emissions by region, disaggregated by major source sector in 2030 in the mitigation scenario after implementation of all mitigation measures

7. Health Impact Assessment

Air pollution is the world's largest environmental health risk, and therefore the motivation for implementing actions that can reduce air pollutant emissions is the opportunity to avoid millions of premature deaths globally every year. In Thailand, thousands of premature deaths per year are attributable to air pollution exposure. The substantial emission reductions estimated in this assessment from the implementation of the 19 priority mitigation measures shown in Table 5 includes reductions in those pollutants most damaging to human health. Fine particulate matter ($PM_{2.5}$) is the pollutant with the largest contribution to air pollution's human health impacts. In this assessment the emission reduction of primary $PM_{2.5}$, and the precursors or secondary $PM_{2.5}$ (e.g. NO_x, SO_2, NH_3). The measures implemented in this assessment are estimated to reduce emissions of these pollutants by between 25% and over 70% by 2030 compared to a baseline scenario, indicating that a substantial reduction in $PM_{2.5}$ concentrations, $PM_{2.5}$ exposure and associated health impacts may be achievable from the implementation of these measures.

The aim of this section is to describe the health impact assessment conducted to quantify the health benefits that could result from the implementation of the policies and measures included in this work. It aims to demonstrate the likely level of health benefit achievable across Thailand from the implementation of Thailand's air quality plans, as well as from implementation of Thailand's climate change mitigation strategies.

7.1 Overview of methodology

To quantify the health benefits that could result from the implementation of the mitigation measures included in this assessment, an air pollution health impact assessment was undertaken using the methods described in Kuylenstierna et al. (2020). The health endpoint used is premature mortality attributable to $PM_{2.5}$ exposure for children (less than 5 years) and adults (>30 years) in 5-year age groups (30–34, 35-39…75-79, >80 years) from 5 disease categories (children: acute lower respiratory infection; adults: chronic obstructive pulmonary disease, ischemic heart disease, cerebrovascular disease and lung cancer). The metric used to quantify long-term exposure to ambient air pollution is the national population-weighted annual average ambient $PM_{2.5}$ concentration, i.e. the average exposure across all Thailandns, averaged across the year (REVIHAAP, 2013).

To quantify premature mortality attributable to ambient $PM_{2.5}$ exposure for each population group and each disease category, national population-weighted annual average $PM_{2.5}$ concentrations were combined with 'integrated exposure response' (IER) functions that have previously been extensively used for quantifying air pollution health burdens (Burnett et al., 2014; Cohen et al., 2017). The IER functions (Equation 1) quantify the relative risk (RR) for mortality from specific diseases for $PM_{2.5}$ exposures up to very high levels (up to 10,000 µg m^{-3}), by integrating RRs derived from epidemiological studies between cause-specific mortality and $PM_{2.5}$ exposure from ambient air pollution, household air pollution, second hand smoke, and active smoking.

$$RR_{IER} = 1 + \alpha(1 - e^{-\gamma(z - z_{cf})^{\delta}})$$

Eq. 1

Where z_{cf} is the $PM_{2.5}$ low concentration cut-off, z is the $PM_{2.5}$ concentration that a population is exposed to, and α, δ, and γ are IER-specific parameters (Burnett et al., 2014; Cohen et al., 2017). The RR derived from the IER function for a particular disease and age group, is then used in combination with the baseline mortality rate for that disease for the population in the target country, and the exposed population in the age category in the target country to estimate the number of premature deaths attributable to ambient $PM_{2.5}$ exposure from the particular disease in that age group (Equation 2).

$$\Delta\text{Mort} = y_0 \left(\frac{RR_{IER} - 1}{RR_{IER}}\right) Pop$$

Eq. 2

Here y_0 is the baseline mortality rate for each disease category, and Pop is the exposed population for each child or adult age category. Baseline mortality rates for each disease category were taken from Abbafati (2020).

Following methods outlined in Kuylenstierna et al. (Kuylenstierna et al., 2020), population-weighted annual average $PM_{2.5}$ concentrations were estimated by combining the emissions estimated for each $PM_{2.5}$ and $PM_{2.5}$-precursor pollutants described in previous sections with outputs from source-receptor calculations performed with the adjoint of the atmospheric chemistry transport model GEOS-Chem (Bey et al., 2001; Henze et al., 2007; Kuylenstierna et al., 2020). National total emissions of primary $PM_{2.5}$ (black carbon, organic carbon and other primary PM emissions), and secondary inorganic $PM_{2.5}$ precursors (NO_x, SO_2 and NH_3) for Thailand were spatially distributed into 2° x 2.5° grids covering the country to match the scale of the GEOS-Chem adjoint model results (see below). The proportion of national total emissions of each pollutant assigned to the 2° x 2.5° grids covering the country was based on the spatial distribution of emissions across Thailand in an existing gridded emission dataset, the IIASA GAINS ECLIPSE emissions dataset (Stohl et al., 2015). ECLIPSE estimates emissions of SLCPs and air pollutants for historical and future projections in 0.5° grids globally. For those grids that cover the target country, the ECLIPSE emissions were apportioned between Thailand and neighbouring countries based on population distribution (using the Gridded Population of the World v3 dataset (CIESIN, 2005)). This ensured that the LEAP-derived emissions only replace the emissions associated with the target country. Air pollutant emitted outside of Thailand can also be transported and impact $PM_{2.5}$ concentrations in Thailand. Therefore, air pollutant emissions for the rest of the world were represented by the gridded ECLIPSE emissions outside of the target country (Stohl et al., 2015). The ECLIPSE 'current legislation' scenario was used to represent future air pollutant emissions outside of Thailand for both baseline and mitigation scenarios.

To translate gridded emissions to population-weighted annual average $PM_{2.5}$ concentrations, accounting for transport and chemical processing in the atmosphere, the gridded emissions are then combined with output from the adjoint of the GEOS-Chem global atmospheric chemistry transport model (Henze et al., 2007). The GEOS-Chem adjoint model quantifies the relationship between emissions of a particular pollutant that contributes directly to $PM_{2.5}$ (BC, OC or other PM), or is a precursor to $PM_{2.5}$ (NO_x, SO_2 and NH_3) in any location, and the associated change in population-weighted $PM_{2.5}$ in the target country. GEOS-Chem simulates the formation and fate of pollutants globally at a grid resolution of 2° × 2.5°, with 47 vertical levels. Emissions of aerosols and aerosol precursors include both natural (i.e., ocean, volcanic, lightning, soil, biomass burning, biogenic and dust) and anthropogenic (transportation, energy, residential, agricultural, etc.) sources. The adjoint of the GEOS-Chem model calculates the sensitivity of a particular model response metric (in this case population-weighted annual average surface $PM_{2.5}$ concentration across the target country) with respect to an emission perturbation in any of the global model 2° × 2.5° grid cells (Henze et al., 2007), accounting for all of the mechanisms related to aerosol formation and fate. These sensitivities are output from the GEOS-Chem adjoint as gridded 'coefficients', which are then multiplied by emission estimates in IBC to estimate the change in population-weighted annual average $PM_{2.5}$ concentrations in Thailand for each year and emission scenario.

Adjoint coefficients were produced for each pollutant that contributes to population-weighted annual average $PM_{2.5}$ concentrations, namely, BC, OC, NO_x, SO_2, NH_3 and other PM (in this case, predominantly mineral dust), reflecting their different reactivity and formation pathways in the atmosphere. The coefficients applied were derived using meteorological parameters for 2010 for all years, to assess the impact only of changes in air pollutant emissions on ambient $PM_{2.5}$ concentrations, as opposed to changes in climate. Emission changes have been shown to be the dominant factor in long-term changes in air pollutant concentrations, and are the focus of this work (Pye et al., 2009). The adjoint coefficients were applied by multiplying, in each grid and for each pollutant, the coefficient by emissions, and summing across all grids to estimate the population-weighted $PM_{2.5}$ concentration across Thailand for a particular year for a particular scenario. These population-weighted annual average $PM_{2.5}$ concentrations were then used in Equations 1 and 2 to estimate the number of premature deaths attributable to ambient air pollution for each year and emission scenario. Premature mortality attributable to ambient $PM_{2.5}$ exposure was estimated for 2015, and for 2030 for the baseline scenarios and for the scenario that reflect the implementation of all mitigation measures. See Kuylenstierna et al. (2020) for further details.

7.2 Historic health burden from air pollution in Thailand

In 2020, population-weighted annual average $PM_{2.5}$ concentrations across Thailand were estimated to be approximately 27 µg m^{-3} (Figure 32). This is more than five times higher than the World Health Organisation standard for $PM_{2.5}$ for the protection of human health. Emissions occurring within Thailand were estimated to be only on factor in determining the level of $PM_{2.5}$ concentrations that people in Thailand were exposed to on average. An estimated 42% of the $PM_{2.5}$ concentration across Thailand was estimated to be the result of $PM_{2.5}$ and $PM_{2.5}$-precursor emissions emitted in Thailand. The majority (51%) of population-weighted $PM_{2.5}$ concentrations across Thailand were estimated to result from emissions occurring outside the country, e.g. transboundary transport of biomass burning emissions, with the remainder from natural background emissions. These levels of $PM_{2.5}$ exposure in Thailand were estimated to result in ~17,000 premature deaths in 2020. This health burden falls most heavily on the elderly, with over 60% of premature deaths occurring for people over 70 years of age.

In the baseline scenario, population-weighted $PM_{2.5}$ concentrations are estimated to remain approximately constant between 2020 and 2030, reflecting the trends in emissions of $PM_{2.5}$ and $PM_{2.5}$-precursor emissions across Thailand (Figure 32). However, despite a constant level of exposure to $PM_{2.5}$, the health burden associated with this exposure is expected to increase substantially, with more than 25,000 premature deaths per year estimated to result from $PM_{2.5}$ exposure in 2030 in the baseline, 8,000 more premature deaths than in 2020. Thailand's population is estimated to remain relatively constant over the next decade, and therefore the number of people being exposed to this level of $PM_{2.5}$ is not expected to change substantially. However, Thailand's population is estimated to age over the next decade, so that there is a substantially larger elderly population more susceptible to air pollution exposure and negative health outcomes. As a result, even with flat $PM_{2.5}$ concentrations, changes in demographics is expected to substantially worsen the health burden from air pollution exposure (Figure 33).

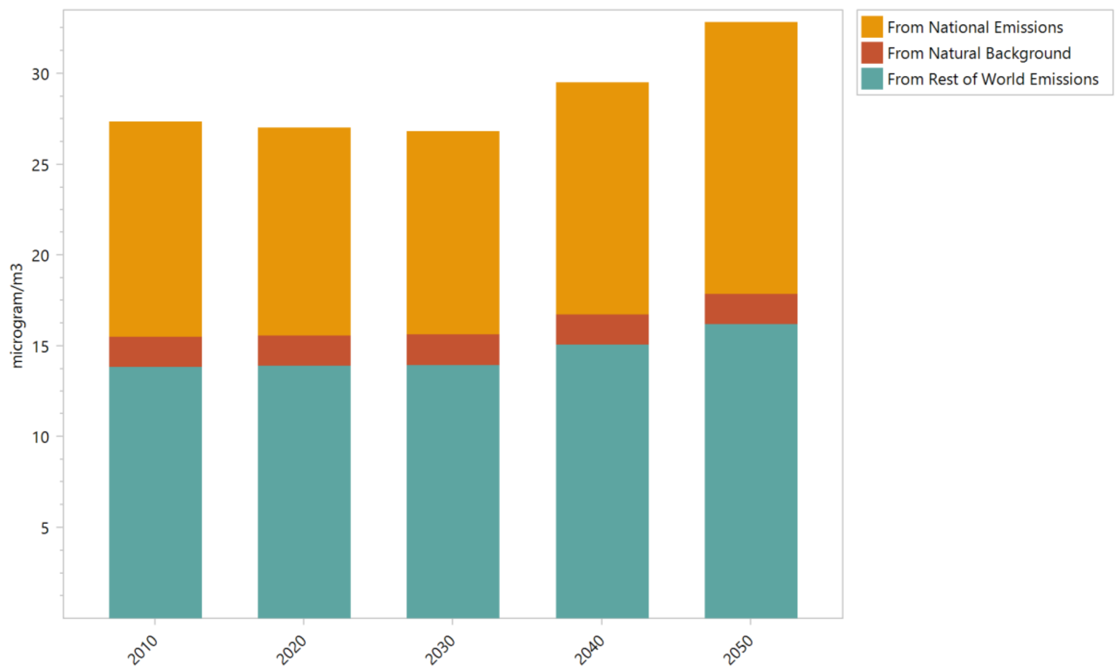


Figure 32: Population-weighted annual average $PM_{2.5}$ concentration across Thailand in 2010 and 2020 (historic years) and projected to 2030 and 2050 for the baseline scenario.

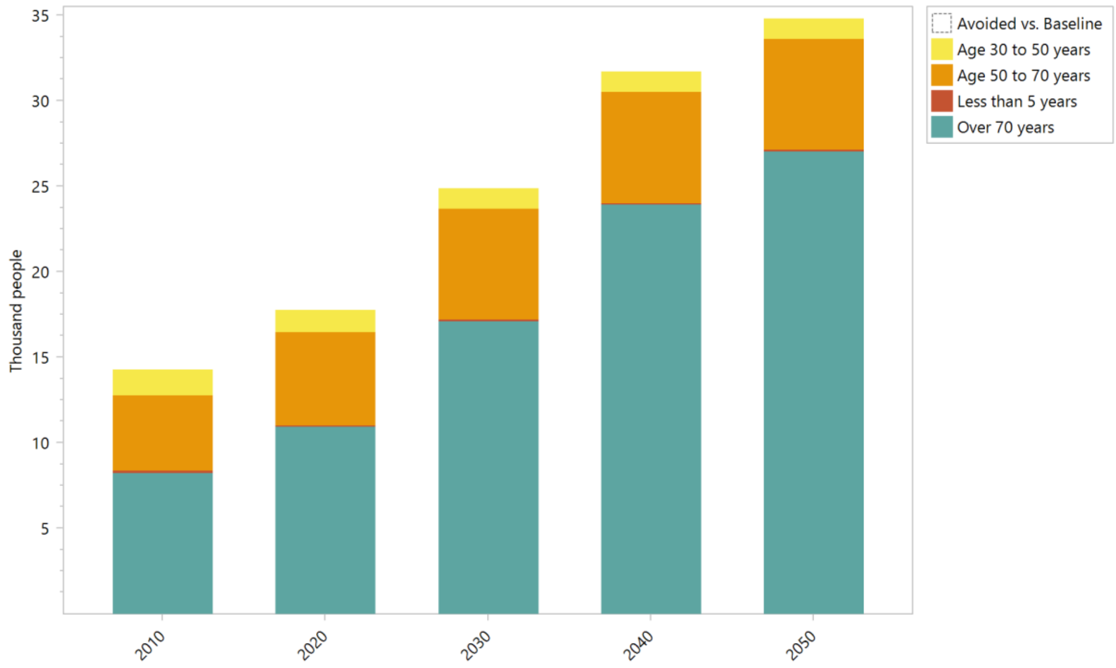


Figure 33: Premature deaths attributable to annual ambient $PM_{2.5}$ exposure in Thailand between 2010 and 2050 in the baseline scenario.

7.3 Health benefits from implementation of mitigation measures

The implementation of the 19 policies and measures included in this assessment reduce $PM_{2.5}$ and $PM_{2.5}$-precursor emissions by between 25% and over 70%. As a result, population-weighted $PM_{2.5}$ concentrations across Thailand are also expected to decrease substantially (Figure 34). In 2030, population-weighted annual $PM_{2.5}$ concentrations are 21 µg m^{-3} after implementation of all measures, 22% lower than the 2030 baseline population-weighted $PM_{2.5}$ concentration. However, this level of reduction is less than the emission reductions that occur in Thailand from the implementation of the policies and measures because there is a substantial fraction of $PM_{2.5}$ across Thailand that is determined by emissions emitted outside of Thailand, which are not reduced in this assessment. Of the component of $PM_{2.5}$ in Thailand that is determined by Thai emissions (11.2 µg m^{-3} in 2030 in the baseline scenario), the implementation of the policies and measures more than halves the population-weighted $PM_{2.5}$ concentrations from Thailand's emissions (5.2 µg m^{-3} in 2030 in the mitigation scenario).

This reduction in Thailand's emissions, and population-weighted $PM_{2.5}$ concentrations also results in substantial health benefits (Figure 35). There is a 12% reduction in premature deaths attributable to outdoor $PM_{2.5}$ exposure in Thailand from the full implementation of all 19 mitigation measures. This is equivalent to 3,100 avoided premature deaths every year by 2030 from the implementation of these mitigation measures. The reduction in health burden is less than the percentage reduction in $PM_{2.5}$ concentrations because of the shape of the concentration-response function, i.e. how the risk from dying prematurely from air pollution exposure changes as exposure to $PM_{2.5}$ changes. As outlined above, a substantial portion of the $PM_{2.5}$ concentrations in Thailand results from emissions emitted outside of

Thailand. The human health burden from Thailand's emissions is reduced by a substantially greater fraction, by 48% in 2030 compared to the baseline scenario.

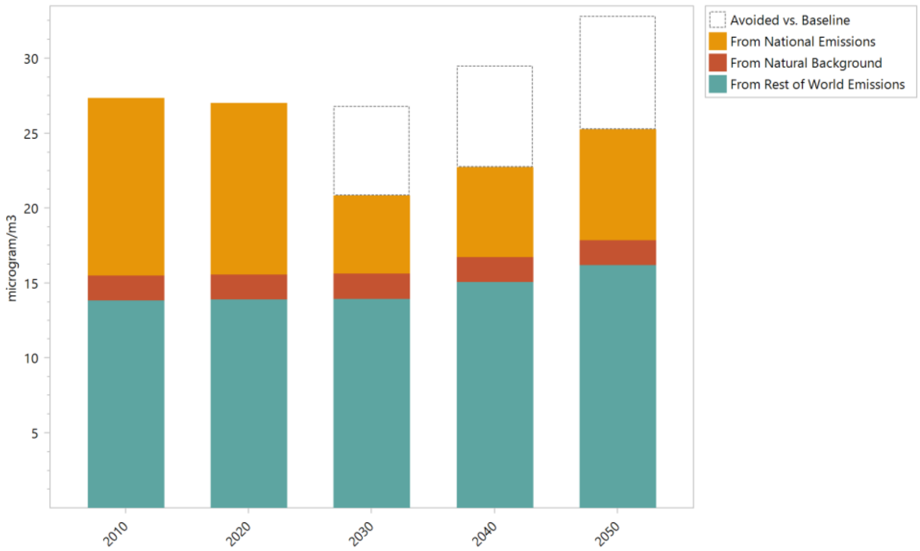


Figure 34: Population-weighted annual average $PM_{2.5}$ concentration across Thailand in 2010 and 2020 (historic years) and projected to 2030 and 2050 for the mitigation scenario after implementation of all policies and measures.

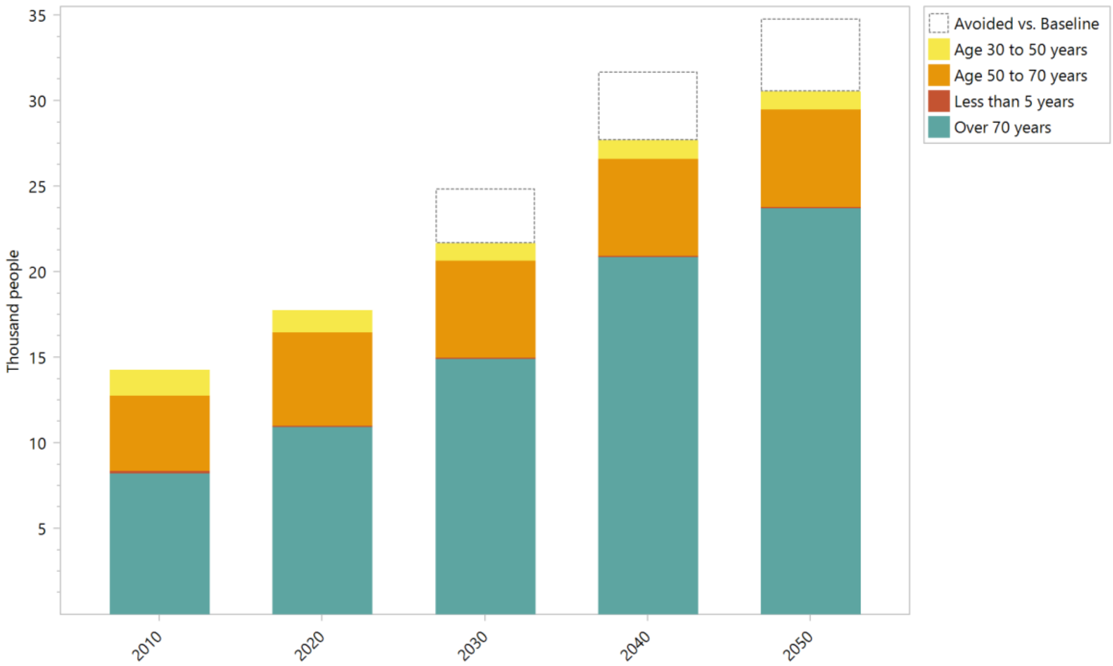


Figure 35: Premature deaths attributable to annual ambient $PM_{2.5}$ exposure in Thailand between 2010 and 2050 in the mitigation scenario.

Chapter 5 outlines how there are substantial barriers, financial, regulatory, institutional, that stand between the estimated benefits achievable from implementation of the 19 mitigation measures in this report, and their real-world achievement on the ground. Section 5 outlines that if these barriers are not efficiently overcome, then by 2030 only ~50% of the emission reductions achieved from the full implementation of the measures without significant barriers and hurdles. This slower and lower emission reduction in Thailand also translates to a smaller reduction in population-weighted $PM_{2.5}$ concentrations, and fewer avoided premature deaths if implementation of the 19 mitigation measures is delayed. When the barriers outlined in Section 5 result in significant delays to implementation (assumptions shown in Table 9), by 2030 the measures have been implemented to the extent that population-weighted $PM_{2.5}$ concentrations have been reduced by 11%, less than half the reductions from their full implementation without significant barriers (Figure 36). This means that, instead of ~3,100 avoided premature deaths annually by 2030 from full implementation of the mitigation measures, delayed implementation results in only 1,300 avoided premature deaths per year, only ~1/3 of the total with full, undelayed implementation.

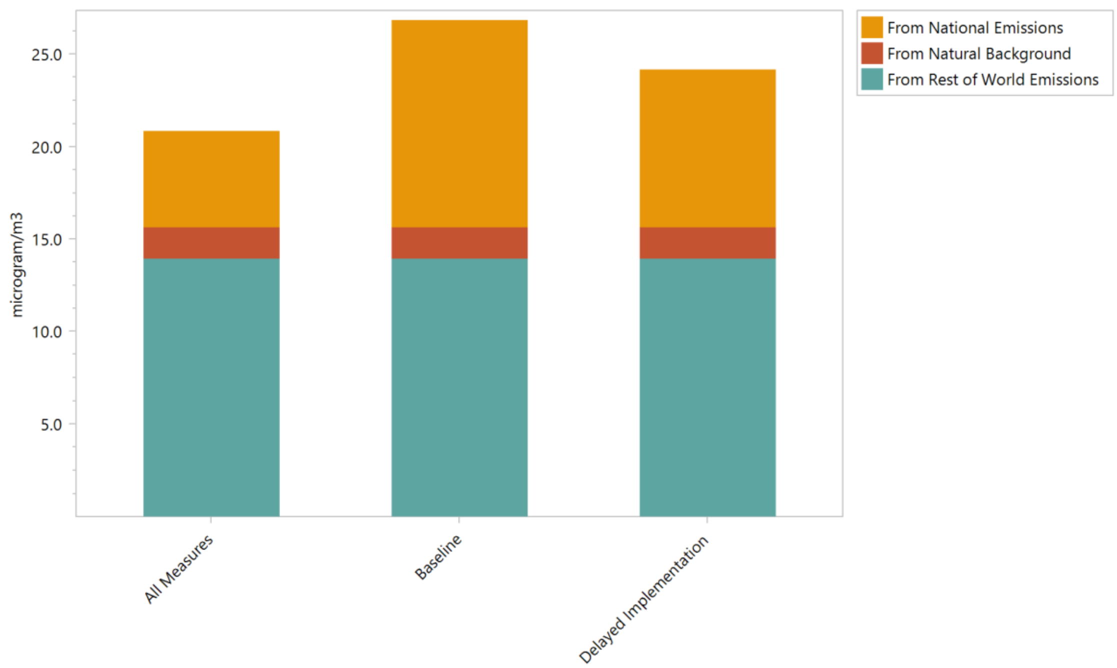


Figure 36: Population-weighted annual average $PM_{2.5}$ concentration across Thailand in 2030 for the baseline, delayed implementation and mitigation scenarios

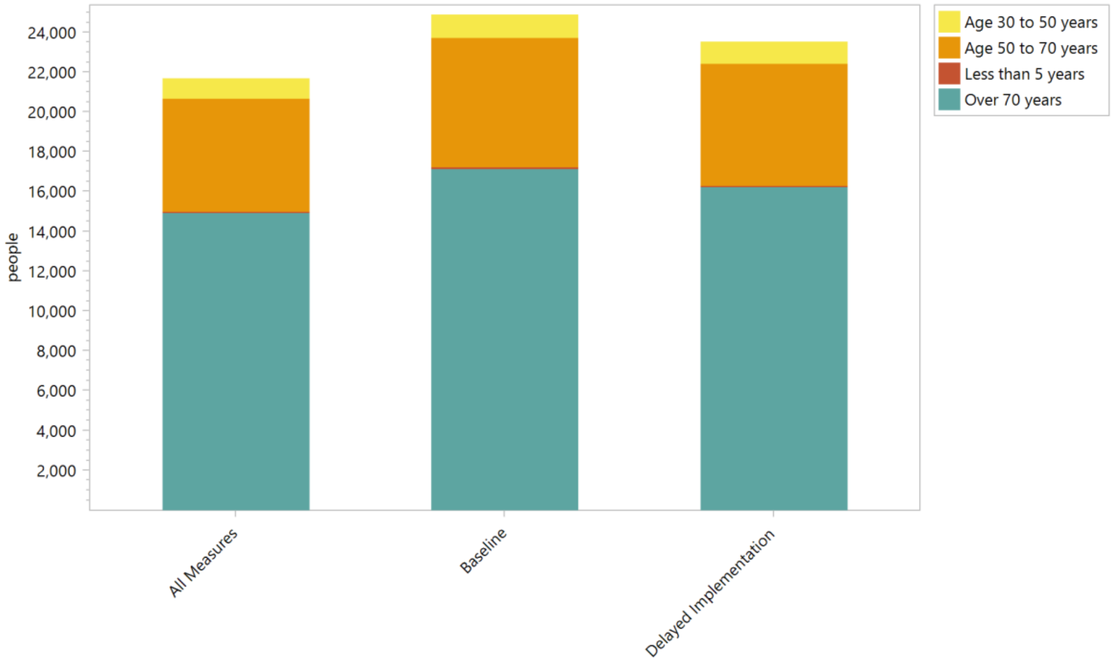


Figure 37: Premature deaths attributable to annual ambient $PM_{2.5}$ exposure in Thailand in 2030 for the baseline, delayed implementation and mitigation scenarios

The assessment of the consequences of changes in air pollutant emissions in Thailand from implementation of measures in this assessment on annual average population-weighted $PM_{2.5}$ concentrations and attributable health impacts was based on the application of linearised coefficients from the GEOS-Chem model developed at the global scale (Kuylenstierna et al., 2020). These coefficients quantify the sensitivity of national $PM_{2.5}$ concentrations to changes in emissions across 2° × 2.5° grids globally. Limitations associated with their application are that atmospheric chemistry and transport is only represented at a coarse global grid resolution, and therefore finer scale transport and chemical reactivity is not captured within these coefficients. Applying these linearised coefficients assume that a change in $PM_{2.5}$-precursor emissions in a grid results in a linear change in annual average population-weighted $PM_{2.5}$ concentrations in Thailand. Therefore, non-linear interactions between, e.g. SO_2, NH_3 and NO_x to form secondary inorganic aerosol, are not represented in the application of these coefficients, as previously discussed in Kuylenstierna et al. (2020).

The approximately 3100 avoided premature deaths per year estimated by 2030 through implementation of Thailand's Clean Air Plan is likely an underestimate of the scale of the health benefits that could result from implementing the Plan. In this study, only the health benefits from exposure to ambient air pollution were estimated, but did not include formation of secondary organic aerosol, which contributes ~15% of ambient $PM_{2.5}$ mass (Nault et al., 2020). The implementation of the Plan would also reduce exposure to household air pollution for those transitioning from cooking using traditional biomass stoves, increasing the avoided health impacts from household air pollution exposure. Additionally, exposure to $PM_{2.5}$ is also associated with a range of non-fatal health outcomes, such as adverse pregnancy outcomes (Malley et al., 2017), and asthma exacerbations (Anenberg et al., 2018). Finally, the implementation of the measures in this assessment would also impact exposure to other health-damaging air pollutants, such as ground-level ozone, and nitrogen oxides, due to the reduction in the emissions, and emissions of ozone precursors. These other pollutants are also associated with negative health outcomes (Lefohn et al., 2018; Malley et al., 2017), and the health benefits from reduction in exposure to these pollutants was not considered in this work.

8. Strengthening Institutions to Increase Action on SLCPs, air pollution and climate change

8.1 Introduction

The previous section highlighted 19 measures from Thailand's $PM_{2.5}$ plan and other policies that could achieve significant reductions in short-lived climate pollutants (SLCPs). If implemented effectively, those measures could also deliver sizable air quality, health, and climate benefits. In fact, the benefits of effective implementation likely outweigh associated costs by several orders of magnitude. This cost-benefits ratio underlines the need for implementing the planned measures quickly. By the same token, delays are likely to result in lost benefits and sharply increasing implementation costs.

Capturing these benefits quickly may nonetheless be easier said than done. Many technological, economic, social and institutional barriers affect implementation and thus may undermine the achievement of a given measure's intended targets. These barriers are, in fact, frequently behind "persistent implementation gaps" that separate what is written on paper from what is achieved on the ground. The purpose of this section is to not only detail those barriers but consider what kinds of governance and enabling reforms could help overcome them and thereby close implementation gaps. This would, in turn, accelerate technical and behavioural changes that are central to maximizing the co-benefits presented in the modelling section.

To discuss those reforms, the section begins with a focused look at what is needed for the successful implementation within the particular sectors featured in the emissions inventory and scenario analysis. This includes, for instance, discussions of implementation barriers and enabling reforms for priority actions in Thailand's agriculture (open burning), industry, residential energy, transport, and waste sectors. The section then zooms out to look more at what kinds of governance reforms could more generally enhance the enabling environment. That higher-level discussion draws upon surveys and focus groups that centred on four areas: 1) institutional coordination and policy coherence; 2) policy instruments; 3) policy enforcement and compliance; and 3) science-policy interface. A final section discusses how governance and enabling reforms can be integrated into the scenario analysis to demonstrate the gains not only adopting the measures but adopting supportive institutional and enabling reforms in Thailand.

8.2 Enabling the Implementation of Key Measures

8.2.1 Industry

One of the key measures involves improving energy efficiency in Thailand's industrial sector. Though achieving the benefits of these shifts this seems straightforward, looks can be deceiving. Part of the challenge is that there is the well-known possibility that even as key industries adopt energy efficiency reforms, they may be tempted to increase production in ways that lead to higher levels of energy consumption and emissions. Another set of issues is that many industries in Thailand are micro, small and medium enterprises (MSMEs). Almost by definition, MSMEs may lack the capital to invest in more efficient technologies. They might also find it easier to avoid regulations because government officials lack the resources to monitor their performance.

There are, however, enabling reforms that could help overcome these challenges. These include, for instance, continuing and further strengthening programmes that extend low-cost financing to industries for energy-efficient technologies. Thailand has several programmes in place related to low-carbon development that could be strengthened further (Chotichanathawewong and Thongplew, 2012). They could also seek to target MSMEs with heightened awareness raising efforts of the nature of finance and the benefits from energy savings for a company's bottom line (Roxas et al., 2017). Another set of enabling reforms could involve relying on information instruments to supplement government-baked regulatory efforts. In Indonesia, the PROPER programme has been used to publicly share intuitive collar coded score of industrial compliance with environmental regulations (Afsah et al., 2013). By circulating those scores widely, industries feel a compulsion and peer pressure to adhere to regulation. This, in turn, reduces the time, energy, and resources regulators need to expend monitoring industries.

8.2.2 Transport

Emissions Standards

In the transport sector, one of the key measures is strengthening emissions standards—for instance, from Euro 5 and 6. In this case, there are also enabling reforms that need to be put in place to make this shift feasible. Chief among them is the provision of low-sulphur fuels required for more aggressive standards. Related to the upgrading of fuels, there is also a need to ensure refineries are investing in technologies that can produce those fuels at sufficient scale (Owen and Tao, 2016). In addition, there may be a need to build a more effective working relationship between the vehicle industry, fuel companies, and government regulators that move ahead with investments in clean fuels.

On many of the above points, there are enabling reforms that could ease transitions to tougher standards. These include, of course, ensuring that shifts in standards are supported by mandates on lower sulphur levels. They mays also entail providing targeted financial assistance to refineries to produce those fuels. Last but not least, regulatory agencies may need to set up an effective mechanism to work with industry on these issues. That mechanism could include regularly scheduled meetings that demonstrate clearly the health benefits from cleaner fuels. There could also be more engaging with supportive legislators and environmental civil society groups to build a stronger political case for action and compel industry to make necessary investments.

Retiring Vehicles

Perhaps even more than any of the measures reviewed thus far, retiring or repairing older vehicles has both some of the greatest potential as well as challenges to realizing it. Overcoming those hurdles is particularly important because studies have shown that older vehicles account for 50% to 80% of fine particulate emissions in Bangkok Metropolitan Administration (Li and Crawford-Brown, 2011). Some of the key barriers include the difficulties of running and overseeing an effective inspection and maintenance programme. These well-chronicled difficulties begin with limitations on staffing within inspection centres as well as central oversight agencies. They also include incentives to avoid inspection and maintenance or otherwise engage in corrupt practices such as paying for a positive result even if the test fails. The fact that many of the oldest and most polluting vehicles belong to poorer segments of the population suggests that there are important equity dimensions involved in implementing inspection and maintenance.

Working around the above challenges will likely require working on many parts of the enabling environment. One step with merits is working to improve the institutional design of the programme with greater staffing and budgeting. This could be complemented by advanced technologies that help bolster oversight as well as greater penalties for non-compliance or false reporting. Another approach to curbing corruption would be offering subsidized repairs or funding for the early retirement of vehicles beyond agreed threshold ages. These efforts could also be supported with the installation of on-board diagnostic (OBD) systems that help owners (and potentially regulators) know when vehicles require repairs. Last but not least, will be a well-structured consultation process with vehicle owner groups—especially freight operators—so that both sides can determine which courses of action can improve the environment but not impose too heavy a cost burden on operators.

Evehicles

Amid rising oil prices and the need to slow down global warming from fossil fuels, the Thailand government's vow to give electric vehicles a big policy push is more than welcome. In 2021, the National Electric Vehicle Policy Committee announced that 30% of vehicles made in Thailand will be zero-emission vehicles (ZEV) by 2030. Dubbed the "30@30" policy, it aims to move Thailand into a low-carbon society and to make the country the manufacturing hub of electric vehicles and auto parts in this region. There are 3 phases under the "30@30" policy which are phase 1 (2021-2022), the government will promote electric motorcycles and support infrastructure nationwide, phase 2 (2023-2025), the EV industry will be developed to produce 225,000 cars and pick-up trucks, 360,000 motorcycles and 18,000 buses/trucks by 2025, including the production of batteries. This first milestone is designed to deliver cost advantages via economies of scale and phase 3 (2026-2030) is driven by the "30/30 policy" to produce 725,000 EV cars and pick-ups plus 675,000 EV motorcycles. This will account for 30 per cent of all auto production in 2030 and includes domestic manufacture of batteries.

To make the country ready for the production of zero-emission vehicles, the government should first focus on creating consumer demand for electric and biofuel vehicles through tax incentives and other measures. Local auto manufacturers should also receive investment support so they can improve their production capacity and competitiveness. Equally important are the rules and regulations on EV charging stations. Since the number of these stations will soon rise, the government should quickly develop rules and regulations to set EV charging industry protocols and standards. For environmental protection and a smooth transition towards clean energy, the government should also have concrete and environmentally-friendly measures to manage obsolete cars and dead batteries.

Furthermore, the government must have comprehensive plans to get all sectors of society ready for the era of clean energy. The plans and policies to reduce production costs should be based on extensive research so that they can still support future technologies. The disruptions will affect vulnerable groups in society the most. The government should, therefore, have some financial mechanisms to assist oil palm farmers and workers in the automobile manufacturing industry. The world needs to shift to clean energy. It is a matter of global survival. Thailand must chip in to cut down the use of fossil fuels. The 30@30 policy is part of the country's journey towards zero emissions. For the policy to be fully effective, the electricity generating system must provide clean energy for electric vehicles. State intervention is also necessary to help the auto industry go electric. Those who are affected by the energy transition must receive state assistance. With a comprehensive plan to address the repercussions, the country will enjoy a smooth energy transition and the public will fully benefit from the 30@30 policy (Thongphat and Sukruay, 2022).

8.2.3 Agricultural Burning and Forest Fires

Similar to many of the reviewed interventions, putting an end to the burning of crop residues is complicated. Many of the key constraints involve the impracticality of policing bans: it is often difficult for regulatory agencies with limited staff and resources to monitor the practice in real-time. On a similar note, the agribusiness and farmers that are engaging in the burning may feel that they have little choice but to engage the practice. Growing pressures to boost crop yields quickly requires clearing fields quickly. In addition, there may be a lack of affordable equipment to help with clearing the land as well as few channels to secure finance to purchase this equipment. Last but not least, there may be limited knowledge of alternatives to burning. Such alternatives could include planting crops that do not generate residue or having channels to sell the residue so that it could be used for other productive purposes as part of the circular economy.

To some extent, the enabling reforms that can help surmount these barriers are readily apparent. For monitoring the practice, there have been important advances in using satellite data as well as low cost sensors that may alert regulators to violations of prohibitions. Another set of potentially useful reforms could be price supports for keeping land fallow for certain periods of the year. Financial support to invest in mulching or baling machines crop residues may also be useful. Yet another piece of the enabling environment could involve creating greater awareness of the benefits of alternative crops. This could be complemented by a programme and value chains that aims to use the biomass to manufacture items such furniture. Many of the above enabling reforms could be linked to efforts to strengthen the ASEAN

Transboundary Haze Agreement and its Roadmaps; this may boost the political salience of those efforts and bring more resources to some of the proposed enabling reforms.

8.2.4 Waste Burning

The burning of residential waste is emerging as another concern with sizable impacts and equally sizable barriers. Part of the challenge in this case is that people may have limited knowledge of the impacts of burning or regulations prohibiting the practice (Premakumara et al., 2021). A related difficulty is that there is often a shortage of sustainable waste management alternatives—including sanitary landfills or composting facilities (Premakumara et al., 2017). Not surprisingly, the limitations of waste management tend to be greatest in poorer or remote areas where there are fewer resources and more challenges to monitoring burning.

The reforms that would help address many of these challenges follow logically from the nature of the challenges themselves. These begin with greater efforts to raise awareness of relevant laws, regulations and penalties. There similarly may be scope to reform laws and policies in ways that focus on communities with high-burning rates. Such policies could aim to improve collection and disposal services and encourage low-cost community treatment methods such as composting. While nationally governments may set the broad framework for action, local government are likely to be tasked with developing the kinds of integrated solid waste management plans that could gradually lead to limitations on burning.

8.3 Governing Integrated Air Pollution and Climate Change Planning

In this section, the term governance is defined as “the totality of interactions in which government, other public bodies, private sector and civil society participate [to solve] public challenges or creating public opportunities” (Meuleman, 2018). There are numerous issues that could affect how successfully those interaction support more integrated air pollution and climate planning. To make the analysis more tractable, the section focuses on four key dimensions of governance that could foreseeably enhance integrated planning: 1) institutional coordination and policy coherence; 2) policy instruments; 3) policy enforcement and compliance; and 4) science-policy interface.

Institutional coordination and coherence can improve cooperation between and within government agencies as well as with other stakeholders. Several countries have improved coordination in context appropriate manner. Chile, for instance, created a superintendency of the environment (SMA) with a legal mandate to improve institutional coordination and enforce environmental quality standards and regulations. Ghana set up a multi-disciplinary inter-ministerial team to identify data sources and reached consensus on which employed the same modelling tools used for Thailand.

The next category, policy instruments, tools that governments can use to a steer implementation. In some cases, those instruments rely heavily on government-backed regulations. Mexico, for instance, has a Climate Change Law, and an Integrated SLCP Strategy to Improve Air Quality and Reduce the Impact of Climate Change that draw heavily on the agencies efforts to implement provisions. Norway’s climate policy is based on a policy mix consisting of polluter pays principle, environmental taxes (CO2 tax), emissions trading, direct regulation, subsidies, and information (Norwegian Ministry of Climate and Environment, 2019).

A third and related category involves policy enforcement and compliance. Here examples include external incentives, as for example Chile which strengthened its environmental enforcement as the country joined the Organisation for Economic Co-operation and Development (OECD). In Finland, the Environmental Protection Act gives national and municipal governments the mandate to issue regulations, permits, and other enforcement activities. In the United Kingdom (UK), compliance is helped by better data sharing between environmental regulators in different sectors, and there is also a cross-agency joint enforcement programme. In Ghana, the EPA Five-Year Strategic Plan (2011-2015) proposed activities covering policies, institutions, legal reforms, and environmental assessment and legal compliance. However, legal compliance (and compliance with EIAs in particular) remain a challenge.

The fourth set of governance issues pertains to the interface between science and policy. Several countries have established mechanisms that can ensure the latest science underpins policy. This includes, for example, Chile where there has been a reliance on modelling that emphasises the net economic benefits of any proposed plans based on science. They also emphasise the fact that social benefits can be harnessed that are up to 5 times as large as the economic benefits deriving from reduced PM and health impacts. In Norway, policymakers draw upon a 'multiple-benefit methodology' that analyses GHGs and SLCPs in short and long terms.

Information pertaining to these four governance categories was shared during an opening workshop. Before and during that workshop a survey was conducted to determine the relative importance of specific issues under the four key governance categories in improving integration between air pollution and climate change. Following the survey, focus group discussions were held to identify possible interventions that might be most useful to strengthen performance on need areas in the Thai context. The following paragraphs summarise some of these findings.

The survey was shared in connection with the kickoff workshop of the SNAP project in 2021. In total 79 people responded to the questions indicating a range of important interventions falling into and across the four governance categories summarized above. To verify the survey results subsequently focus group discussions were held to further explore the responses given across the four categories of governance. The results were clear; according to the survey and confirmed (and elaborated) by focus group discussions the two most important interventions In Thailand to better address co-benefits between climate and air-pollution were the following:

1. Improve coordination between the pollution control department (PCD) and other agencies with different administrative portfolios.

2. Improving coordination between national agencies and local (or regional) governments

These two points were top runners and clearly spell out the need for improving horizontal and vertical integration. This need was closely followed by priorities to expand opportunities for civil society to participate in policy and planning, and the need to ensure consultations between (government) agencies before releasing regulation that affects other agencies. The following figure summarises this information.

It is clear that, based on the examples in the beginning of this section, that there is room for improving institutional coordination and coherence to bolster cooperation between and within government agencies as well as with other stakeholders in the Thai context. One of the possible interventions to improve institutional coordination and coherence that the project articulated was that the Thai government establish an interagency task force with members from the PCD, the Office of Natural Resources and Environmental Policy and Planning (ONEP), Thailand Greenhouse Gas Management Organization (TGO), Office of Transport and Traffic Policy and Planning (OTP), Department of Industrial Works (DIW), Ministry of Agriculture and Cooperatives (MAoC), Ministry of Higher Education, Science, Research and Innovation (MHESI), local governments, and civil society organizations. The taskforce could consist of a technical working group and a policy working group. The technical working group would work on harmonizing data and reporting, it could use the LEAP model and other integrated assessment models to identify solutions that address climate and air-pollution to be included in Thailand's NDC. The policy working group would then work on linking solutions to relevant policies (including shipping and aviation), and also communicate benefits of policy proposals to the public to garner public support for co-benefit policies.

The interagency task force could also develop and hold trainings on integrated assessments to build capacity among stakeholders. It was also pointed out that the task force should use clear, simple and consistent language to deliver information on health, employment, income and climate co-benefits to the public. It could also expand distribution channels by involving "influencers" to help spread information about benefits to the "new generation" through Facebook, Tik Tok, Twitter, Instagram etc.

9. Conclusions and Recommendations to increase air pollution and climate change mitigation in Thailand

The integrated air pollution and climate change mitigation assessment presented in this work has identified a clear set of policies and measures, which, if implemented could reduce toxic air pollutant emissions by between 15% and 70% by 2030 and 2050. These emissions reduction will contribute to significantly improving public health, by improving air quality outdoors and indoors and alleviating the air pollutant health impacts in Thailand, which experiences the 5th largest number of premature deaths from air pollution exposure every year currently. At the same time, the implementation of the policies and measures included in this integrated air pollution and climate change mitigation assessment can contribute to Thailand achieving its international climate change commitments, including the targets set in its Nationally Determined Contribution and Thailand's contribution to the Global Methane Pledge.

However, the emission reductions and air pollution and climate change benefits outlined in this report will remain potential reductions unless actions are taken to operationalise the findings of this report and to undertake actions that lead to the implementation of the policies and measures identified and evaluated as part of this assessment. There are several actions that can be taken within national and provincial level institutions to contribute to integration of air pollution and climate change planning, and to further implementation of priority mitigation measures. These actions are identified in this report as key recommendations resulting from this integrated air pollution and climate change mitigation assessment.

Recommendation 1: Enhance Thailand's National Air Quality Planning

This integrated assessment of air pollution and climate change highlights a set of specific mitigation measures that can achieve substantial improvements in ambient air pollution, and household exposure to air pollution. These mitigation measures should be integrated into the next update to Thailand's air quality management plans to ensure that the measures most effective at reducing air pollution nationally are identified as priorities within the key air quality management planning document in Thailand. Specifically, the priority measures to take forward are:

- Reducing open burning of agricultural residues
- Reducing open burning of solid waste
- Switching households to cooking using clean fuels and more efficient biomass stoves
- Euro V and VI vehicle emission standards for all vehicles
- Industrial emission controls, especially particle filters

Recommendation 2: Develop Regional Clean Air Plans with region-specific priority measures

The regions in Thailand also have a responsibility for improving air quality for their citizens. This report shows that there are specific measures, with quantified emission reductions that can be the basis for the development of regional clean air plans. The key national measures were broadly also identified as the priority mitigation measures for each region, and therefore regional Clean Air Actions Plans that commit to their implementation could be the basis for achieving clean air within each Province. To do so, the following steps could be taken to develop the regional Clean Air Plans:

- Identify a key coordinating institution at regional Level to have ownership for the development, endorsement, launch and implementation of a Clean Air Plan
- Establish a planning process at the regional level involving all key stakeholders to obtain buy-in to Provincial Clean Air Plan development
- Using the integrated air pollution and climate change mitigation assessment presented in this report, identify a clear set of mitigation measures with quantified benefits for air quality in each Province endorsed and agreed by stakeholders at regional Level

- In consultation with key stakeholders, develop implementation pathways for the key mitigation measures that outline concrete steps to facilitate their implementation. These steps should cover the financing, infrastructure, regulations, legislation, enforcement, communication, incentivising and other types of actions necessary to increase implementation of the priority actions in each region.

Recommendation 3: Enhance Thailand's NDC with key climate and clean air measures

The integrated air pollution and climate change mitigation assessment is relevant not only for air pollution planning, but can also provide the basis for updates to Thailand's Climate Change Planning to increase local benefits achieved alongside Thailand's GHG mitigation commitment. This assessment demonstrates that a package of mitigation measures could reduce emissions of GHGs like carbon dioxide by over 30% in 2050 compared to a baseline scenario. This can therefore make a substantial contribution to achieving Thailand's overall climate change mitigation target, outlined in Thailand's NDC and long-term strategy.

Countries that have signed the Paris Agreement are committed to updating their NDCs every five years. Therefore, by 2025, Thailand will submit an updated NDC. This integrated air pollution and climate change mitigation assessment provides the basis for this NDC update in a way that will also achieve substantial health benefits from Thailand's climate change plans. CCAC SNAP (2019) outlines four opportunities as to how countries can update their NDCs through actions to reduce air pollution and mitigate climate change (Figure 38).

This assessment provides the basis for Thailand to commit to more ambitious climate change mitigation actions through each of the four opportunities identified in CCAC SNAP (2019). Mitigation measures included in the assessment include those that target methane emission sources, and could reduce methane emissions by X% in 2030 compared to a baseline scenario, and Hydroflurocarbons, providing the basis to update Thailand's NDC with additional actions on methane and HFCs (Opportunity 1). A broader set of measures included in this assessment, across the household, transport, and electricity generation sectors simultaneously reduce black carbon (Opportunity 2), carbon dioxide and other air pollutants (Opportunity 3). Their integration in the NDC would ensure that achieving Thailand's climate change commitment would be achieved alongside improving the health of Thailand's population.

Finally, updating Thailand's NDC to include the priority measures from this integrated air pollution and climate change mitigation assessment could align the NDC with air quality plans and strategies if this assessment is also used in the development of national and provincial plans and strategies, creating alignment across plans and strategies affecting emissions across major source sectors (Opportunity 4). This alignment could facilitate more efficient air pollution and climate change planning. For example, progress could be jointly tracked on air pollution and climate change planning, and updates to the integrate air pollution and climate change mitigation assessment could be the basis for updating of NDCs and air pollution plans.

Figure 38: Four opportunities to enhance Nationally Determined Contributions through actions that reduction SLCPs and improve air quality.

Recommendation 4: Enhance Methane Action in Thailand to achieve multiple benefits

The Global Methane Pledge commits participants to work together to achieve a global 30% reduction in global methane emissions compared to 2020 levels by 2030 (European Commission and United States of America, 2021). The Global Methane Pledge does not specify what contribution countries and sectors should make to achieving this goal. Currently the contribution of countries and sectors is difficult to determine due to the inconsistent way in which countries describe methane mitigation within their climate change plans (e.g. NDCs). As a result, countries are encouraged to develop methane action plans, outlining methane mitigation measures, emission reductions, and implementation pathways to increase the clarity by which methane emission reductions are communicated by countries.

This integrated air pollution and climate change mitigation assessment provides the basis for the development of a methane action plan for Thailand, even though Thailand is not currently participating in the Global Methane Pledge currently. The mitigation measures implemented in key methane emitting source sectors show that Thailand could reduce 35% of methane emission by 2030, contributing to the global achievement of the Global Methane Pledge. Key mitigation measures that achieve this reduction, and the implementation of which could be the basis for a methane action plan, are:

- Methane emission reductions from livestock enteric fermentation
- Intermittent aeration of rice paddy fields
- Fugitive oil and gas emission reductions
- Landfill gas capture

Recommendation 5: Accelerate implementation of priority measures

This assessment not only identified the priority mitigation measures that could achieve the largest benefits for air pollution and climate change mitigation, it also identified the main barriers to implementation of these measures, and assessed the impact of these barriers in slowing the achievement of multiple air pollution and climate change benefits. The assessment showed that implementation of mitigation measures without significant barriers could avoid 3,100 premature deaths per year by 2030. However, if barriers, including economic, technical, capacity and social barriers, are significant enough to delay implementation of key mitigation measures, then the expected emission reductions are less than half those achieved without significant barriers. This reduces the reduction in population-weighted $PM_{2.5}$ concentrations, and reduces the health benefits from integrated air pollution and climate change action to 1,300 avoided premature deaths per year, only~1/3 of the maximum achievable health benefit from implementation of all policies and measures. This emphasises the need to ensure that solutions to overcome barriers outlined in Chapter 5 are identified and implemented quickly to ensure fast implementation of the priority mitigation measures, and achievement of health benefits in Thailand.

Recommendation 6: Integrate air pollution and climate change emission inventories for tracking progress

This assessment highlights that air pollution and climate change can be tackled through the implementation of a common set of actions which directly impact emissions contributing to both issues. The assessment provides an evaluation of the mitigation measures that have impacts on both issues, identifying those with the largest benefits. Going forward, it is necessary to demonstrate that, when these mitigation measures are implemented they are actually achieving the air pollution and climate change benefits that this assessment identifies as possible from their implementation. To do so effectively and efficiently could include the development and updating of an integrated air pollution and climate change emission inventory. There is substantial overlap in the methods and data necessary to quantify and track progress on air pollutant and greenhouse gas emissions. Therefore, it can be more efficient to set up a common, integrated system for the quantification and reporting of air pollutant and greenhouse gas emissions. Such systems have been developed in multiple countries, including those in Europe for reporting under the Convention on Long-Range Transboundary Air Pollution (CLRTAP), and other countries within the Climate and Clean Air Coalition Support National Action & Planning initiative (SNAP).

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