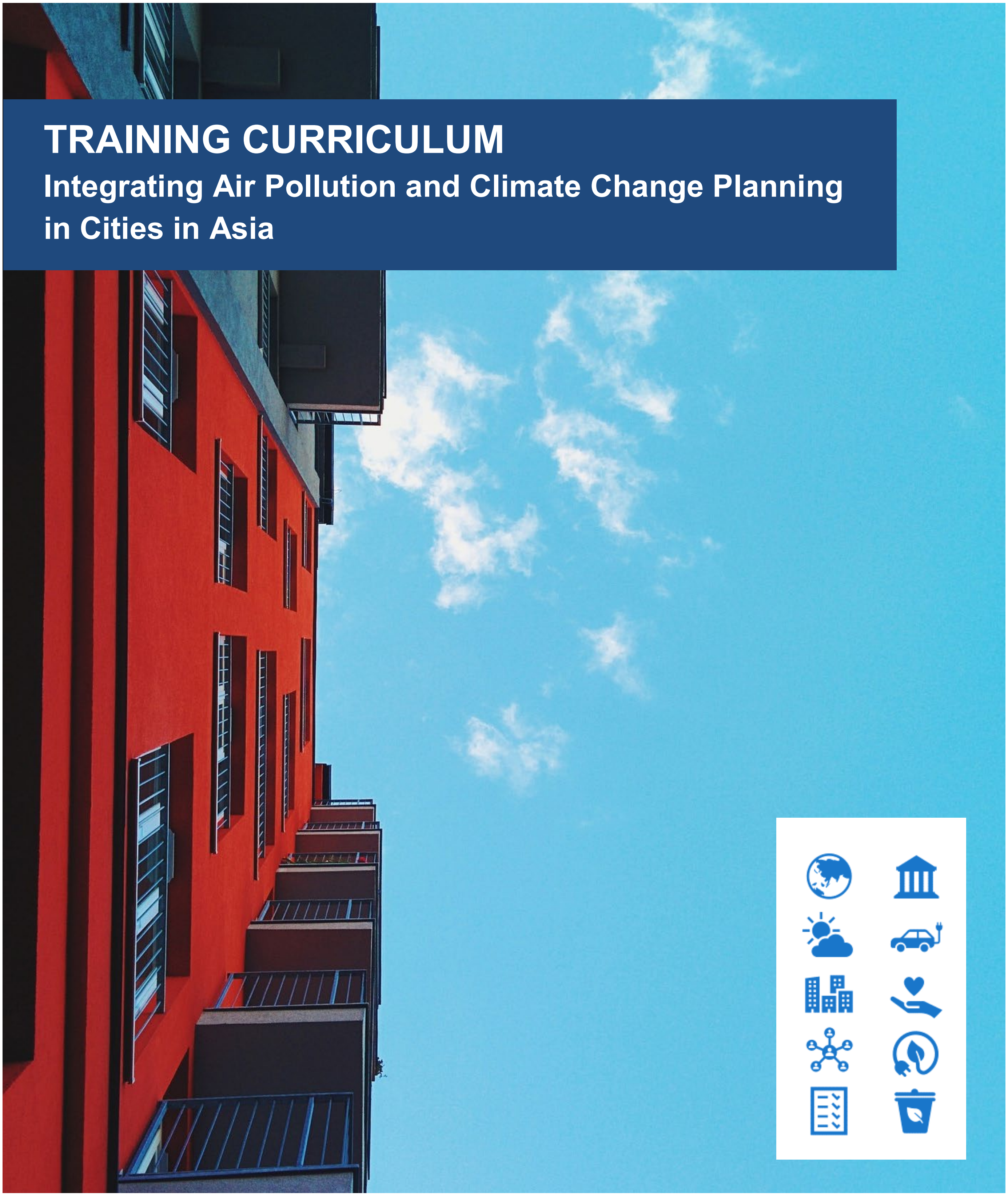
CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

TRAINING CURRICULUM

Integrating Air Pollution and Climate Change Planning in Cities in Asia



Delivered by: CLEAN AIR ASIA · ICLEI Local Governments for Sustainability EAST ASIA · IGES Institute for Global Environmental Strategies

Contents

I. Introduction: Integrating Air Pollution and Climate Change Planning in Cities

With more than half the world's population classified as urban, whether the world achieves global climate change goals increasingly rests on cities. Yet, many policymakers at the city level place clean air and public health before mitigating climate change. Fortunately, since emissions contributing to air pollution and climate change often come from the same sources, urban policymakers could potentially improve air quality and public health while also mitigating climate change. As cities in Asia often suffer from serious air pollution and related health problems as well as make sizable contributions to the changing climate, few regions could benefit more from integrating air pollution and climate change planning.

The main purpose of this training curriculum is to familiarize urban policymakers in Asia with knowledge and tools needed to strengthen the integration between air pollution and climate change planning. Though the case studies provided herein come chiefly from Asia and the United States (California and New York), other regions will likely find its content useful and some lessons transferable. This is partially because addressing both air pollution and climate challenges in integrated planning can save time and money. It is also because a failure to take into account relationships between air pollution and climate change can lead to interventions that have undesirable socioeconomic and environmental side effects.

For many policymakers in cities, however, integrating air pollution and climate change planning is easier said than done. There are at least three sets of knowledge and capacities that policymakers will need to take integrated air pollution and climate change planning forward.

1. **Understanding core concepts**: policymakers will understand different perspectives on what are called "co-benefits" from integrated air pollution and climate change planning.
2. **Assessing benefits and identifying solutions**: policymakers will receive practical examples of emissions inventories and health impacts assessment to estimate air quality, climate change and other benefits, as well as how those tools can support their decision making.
3. **Cases illustrating how to strengthen policies and institutions**: policymakers will receive concrete case studies (California, New York, Tokyo, Seoul, and Beijing) of the policy and institutional changes that can successfully work across air pollution, climate change, and related concerns as well as strengthen multi-sector and multi-level implementation of solutions.

The information presented is supplemented by training materials that could be used for workshops (see appendix for English and Chinese slides). The curriculum and the training materials meant to offer a broad overview of key themes; a deeper dive into some topics, especially modelling and tools, is possible by following the links to related resources.

II. Understanding core concepts

At the most fundamental level, the integrated planning featured in the curriculum involves addressing air pollution and climate change through single, rather than separate, planning processes. As will be discussed throughout these materials, this can be difficult. Integrated planning will often require familiarizing politicians and policymakers with new concepts such as co-benefits or short-lived climate pollutants (SLCPs). It will also involve equipping technical staff with the tools to identify the mix of technologies and policies that deliver climate, air quality and health benefits. Finally, it also requires that policymakers and technical staff are aware of the institutional and policy reforms as well as technological changes that are needed to advance more integrated air pollution and climate change planning. Decision making tools (section 3) and cases for policies and institutions (section 4) will be discussed in greater detail in later sections of these training materials. This section will concentrate chiefly on core concepts as well as some solutions to air pollution and climate change.

Objective

At the end of the section, participants will be able to:

- Understand the importance of integrated air pollution and climate change planning for cities;
- Define different perspectives on co-benefits (including how an air pollution perspective emphasizes SLCPs); and
- Identify solutions that can strengthen the integration between air pollution and climate change planning in cities.

A useful starting point for working on these objectives involves looking at the ultimate aim of integrated and climate planning. The end result of bringing these two processes together are "co-benefits." For reasons that will become apparent later, the term "co-benefits" is defined differently by different stakeholders.

In the context of these materials, "co-benefits" refers to all the benefits generated by a policy or plan that mitigates climate change while at the same time achieving other development priorities. These additional benefits can range from new jobs to improved technologies to even time savings (i.e. in the case of a new public transport system). For these materials, co-benefits that will be featured are the multiple benefits from mitigating climate change, controlling air pollution, and improving public health (UNEP, 2019).

The figures in Box 2.1 offer several illustrations of the concept of co-benefits. As can be seen from the figures, the key to co-benefits are actions or interventions that both mitigate climate change and improve air quality. One of the reasons for the multiple illustrations in Box 2.1 is there are different views on co-benefits. Such views can be roughly broken down into a climate change perspective (that varies between developed and developing countries) as well as an air pollution perspective co-benefits that involves SLCPs.

Box 2.1: Defining Co-benefits

There have been three main perspectives on "co-benefits" that have developed since researchers conceived of the term more than thirty years ago. Understanding a 1) climate, 2) development, and 3) air pollution perspective on co-benefits is important for urban policymakers as different definitions of the term can affect policy and technology choices in cities.

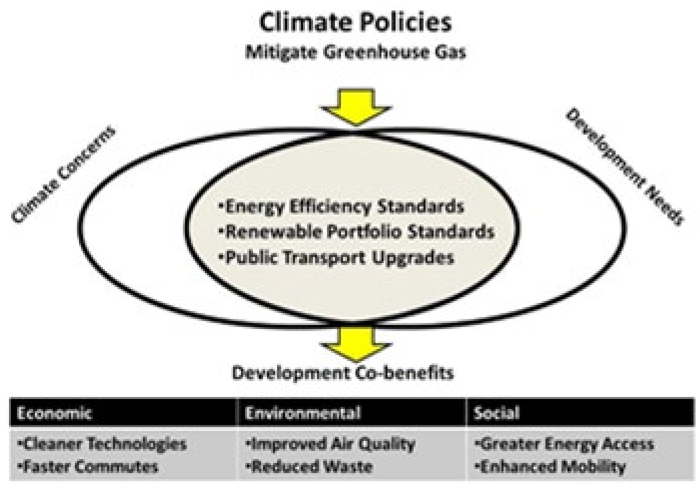


Figure 2.1: A Climate Perspective on Co-benefits

1. **Climate perspective (Figure 2.1):** Initially, a ***climate perspective*** on co-benefits referred to the additional *development benefits* of *GHG mitigation policies* chiefly in *developed countries*. A GHG mitigation policy in a developed country such as a carbon tax or emissions trading scheme could deliver "development co-benefits," ranging from improved air quality to cleaner technologies to better jobs. These additional benefits could limit concerns policymakers had about the costs of investing in GHG mitigation, especially since the GHG mitigation benefits were global, long-term, and uncertain.

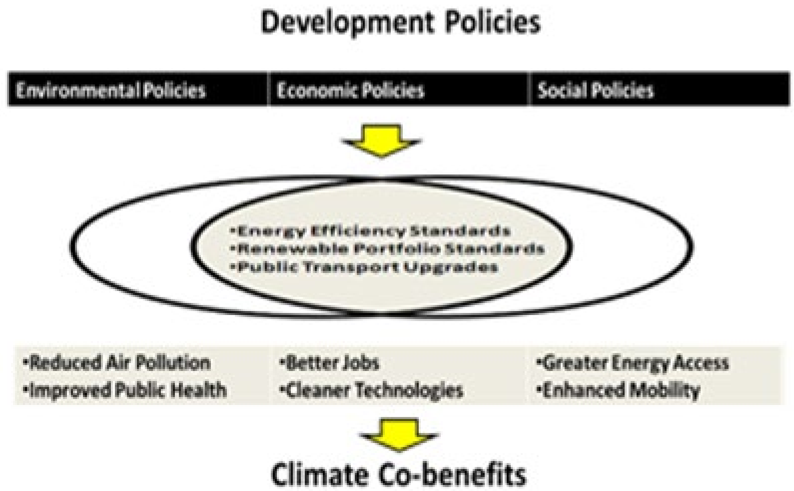


Figure 2.2: A Development Perspective on Co-benefits

2. **Development perspective (Figure 2.2):** Approximately 15 years ago, a ***development perspective*** on co-benefits emerged as the concept attracted more interest from *developing countries*. According to this perspective, co-benefits referred to the *additional GHG mitigation benefits* or *climate co-benefits* of *development policies* (including a range of environmental, economic, and social policies) in chiefly developing countries. These policies could mitigate GHGs even if their chief goal was not controlling climate change. This view underlined that development policies with climate co-benefits could not only limit concerns about the costs of GHG mitigation but also attract climate finance to help meet development needs.

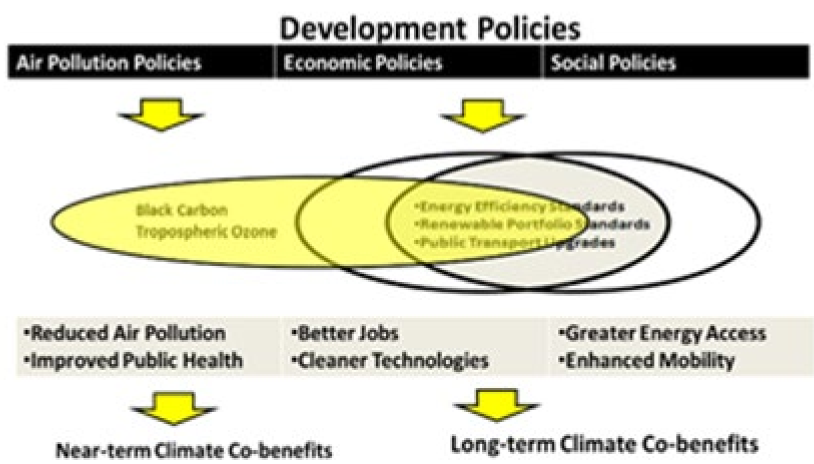


Figure 2.3: An Air Pollution Perspective on Co-benefits

3. **Air pollution perspective (Figure 2.3):** Slightly more than ten years ago, an **air pollution *perspective*** on co-benefits took shape based on research showing the

effects some air pollutants have on the climate in the near-term. At the time, the term short-lived climate pollutants (SLCPs) was coined to refer to *air pollutants* such as *black carbon, tropospheric ozone, and methane* that warm the climate in the *near-term* while causing air pollution. Some air pollution as well as economic and social policies could mitigate SLCPs, avoiding a warmer climate in the near term as well as improving public health and crop outputs.

(Source: Zusman and Miyastuka, 2015)

To better appreciate the differences between these approaches, it is helpful to provide a brief review of key air pollutants, SLCPs and GHGs.

2.1 An Overview of Air Pollutants, SLCP, and GHGs

An air pollutant is any substance in the air that has an adverse effect on human health or the environment. Criteria air pollutants is a term used for the six common air pollutants identified by the World Health Organization (WHO). These are the pollutants that policymakers usually regulate and/or use as air quality indicators. Table 2.1 lists the six criteria air pollutants, their sources and impacts.

Table 2.1. List of criteria pollutants

Main Criteria Air Pollutants	Impacts	
	Health	Environmental
Particulate Matter (PM) ➢ Mixture of solid and liquid particles in the air ➢ Size range varies, categorized based on particle aerodynamic diameter: coarse (PM_{10}, ≤10µm diameter); fine ($PM_{2.5}$, ≤ 2.5µm diameter) and ultrafine PM (≤ 0.1µm diameter) ➢ Sources can be natural (e.g. volcanic eruptions, forest fires) or man-made combustion processes and emission sources (e.g. industries, vehicles, burning, etc.) ➢ Primary PM are emitted directly by sources while Secondary PM form through chemical reactions in the air	➢ Respiratory and cardiovascular hospitalizations, diseases, and deaths ➢ Impaired central nervous system and child cognitive development ➢ Risk factor for Type 2 Diabetes ➢ Birth defects and reproductive disorders ➢ Lung cancer	➢ Reduced visibility (haze) ➢ Warm or cool climate depending on PM composition ➢ Cause damage to built structures ➢ Affect diversity of ecosystems by impacting health of organisms ➢ Cause imbalance in ecosystems by influencing nutrient transport, water pH, crop damage

Nitrogen oxides (NO_x) ➢ Includes nitrogen dioxide (NO_2) and nitrogen oxide (NO) ➢ Highly reactive gas that forms PM and ozone ➢ Main source are fuel-burning processes and facilities (e.g. power generation, industries, transport and household emissions)	➢ Irritation of respiratory system ➢ Development and aggravation of respiratory diseases (i.e. Asthma), leading to infections and hospitalizations ➢ Can affect liver, lungs, spleen, blood	➢ Reduced visibility (haze) ➢ Damage to sensitive ecosystems and crops ➢ Formation of acid rain that affects organisms, ecosystems, and built structures ➢ Nutrient pollution (eutrophication) in water environments
Sulfur dioxide (SO_2) ➢ Can form sulfur oxide (SO_x) compounds and PM ➢ Pungent, colorless gas that comes from sulfur-containing processes and fuels ➢ Emitted by volcanic eruptions but main source is fossil fuel combustion	➢ Causes headache, discomfort, and difficulty in breathing ➢ Development and aggravation of respiratory diseases (i.e. asthma, chronic bronchitis), leading to infections and hospitalizations ➢ Can affect liver, lungs, spleen, blood	➢ Reduced visibility (haze) ➢ Damage to sensitive ecosystems and crops ➢ Formation of acid rain that affects organisms, ecosystems, and built structures ➢ Nutrient pollution (eutrophication) in water environments

Carbon monoxide (CO) ➢ Colorless, odorless gas that can be fatal in high concentrations ➢ By-product of combustion processes (burning) ➢ Main sources are fossil fuel combustion processes such as transport emissions and industries, as well as cooking-related fuel burning	➢ Reduced circulation of oxygen, resulting in dizziness, confusion, unconsciousness, comatose, and death when exposed to very high concentrations (CO poisoning) ➢ For individuals with heart disease, exposure to very high levels can cause chest pains	➢ Indirectly affects climate by influencing formation of GHGs (ozone)
Ground-level (Tropospheric) Ozone (O_3) ➢ Ozonein the upper part of the Earth's atmosphere (stratosphere) serves as the ozone layer that protects the earth from UV rays, but O_3 is considered a pollutant if found near the ground (troposphere) due to its health impacts ➢ Ground-level ozone is formed through reactions of NOx and volatile organic compounds (VOCs), in the presence of heat and sunlight	➢ Causes shortness of breath, coughing, sore throat, difficulty in breathing, inflamed airways ➢ Development and aggravation of respiratory/lung diseases (i.e. asthma, chronic bronchitis, emphysema, COPD), leading to infections and hospitalizations	➢ Smog formation ➢ Damage to and reduced growth rates of crops and vegetation ➢ Warms the atmosphere (a GHG)

Lead (Pb) ➢ Hazardous heavy metal pollutant ➢ Main sources are industries related to mining and metals processing, smelters, incinerators and leaded fuel	➢ Adverse effects on the nervous, kidney, immune, reproductive, developmental, and cardiovascular systems (Pb poisoning) ➢ Exposed infants and children may experience neurological effects (learning and behavioral problems, lower IQ)	➢ Affect diversity of ecosystems by impacting health and survival of organisms ➢ Prolonged impacts due to persistence in the environment (can stay for years in soils and sediments)

(Source: Clean Air Asia, 2020 (compiled from Climate and Clean Air Coalition (2011), European Commission (n.d.), Health Effects Institute (2019), IPCC (2013),North Carolina Climate Office (n.d.), Prarther, et. al. (2001), US EPA (2018), World Health Organization (n.d.))

Greenhouse gases (GHGs) are gases in the atmosphere that absorb infrared radiation from the earth's surface and release most of that radiation back to the earth's surface. Through this process, GHGs trap heat inside the earth's atmosphere and are the chief cause of long-term global heating. Table 2.2 lists the main GHGs based on definitions derived from various sources.

Table 2.2. List of GHGs

Main Greenhouse Gases (GHGs)	**Impacts**	
	Health	Environmental
Carbon dioxide (CO_2) ➢ Most abundant GHG in the atmosphere (excluding water vapor) ➢ Occurs naturally in the environment and crucial in maintaining the carbon cycle ➢ CO_2 levels have dramatically increased in the atmosphere at the onset of fossil fuel combustion during the industrial period ➢ Other manmade sources include deforestation (limits carbon sequestration), biomass burning and other fuel-dependent processes (industries and transport) ➢ Can stay in the atmosphere for up to 200 years	➢ In very high concentrations, CO_2 can displace oxygen and nitrogen in the air, which can lead to headaches, dizziness, inability to concentrate, numbness, unconsciousness, increased heart rate, elevated blood pressure, seizures, and potentially coma	➢ Main cause of human-induced climate change ➢ Acidification of aquatic ecosystems which can lead to coral bleaching
Methane (CH_4) ➢ Flammable gas emitted by agricultural, livestock and waste emissions, including via decay of organic wastes ➢ Other main sources include mining/production, processing and use of natural gas and coal	➢ Direct inhalation of CH_4 can lead to dizziness and headache ➢ One of the key precursors of O_3, indirectly impacting health in the same way as O_3	➢ Second to CO_2 in its contribution to climate change ➢ Has 28 times the warming impact of CO_2 ➢ Also classified as a short-lived climate pollutant

➢ Can stay in the atmosphere for about 12 years		
Nitrous oxide (N_2O) ➢ Occurs naturally in the environment and crucial in maintaining the nitrogen cycle ➢ Main sources of emissions are industries, powerplants, agriculture (fertilizer), wastewater treatment ➢ Can stay in the atmosphere for about 121 years	➢ Irritation of respiratory system ➢ Development and aggravation of respiratory diseases (i.e. Asthma), leading to infections and hospitalizations ➢ Can affect liver, lungs, spleen, blood	➢ Has around 265 times the warming impact of CO_2 ➢ Formation of smog
Fluorinated Gases ➢ Includes Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur hexafluoride (SF_6), and Nitrogen trifluoride (NF_3) ➢ Main sources are industrial processes, both manufactured and used as substitutes for phased-out CFCs and halons used as coolants, refrigerants, insulating foams and aerosol propellants, etc.	➢ Irritation of eyes and respiratory system	➢ Warming impact can be more than 20,000 greater than that of CO_2 ➢ HFCs are also classified as a short-lived climate pollutant

➢ Can stay in the atmosphere for up to thousands of years		
Ground-level (Tropospheric) Ozone (O_3) ➢ Ozone in the upper part of the earth's atmosphere (stratosphere) serves as the ozone layer that protects the earth from UV rays, but O_3 is considered as a pollutant if found near the ground (troposphere) due to its health impacts ➢ Ground-level ozone is formed through reactions of NOx and volatile organic compounds (VOCs), in the presence of heat and sunlight ➢ Stays in the atmosphere from a few hours to a few weeks (short-lived)	➢ Cause shortness of breath, coughing, sore throat, difficulty in breathing, inflamed airways ➢ Development and aggravation of respiratory/lung diseases (i.e. asthma, chronic bronchitis, emphysema, COPD), leading to infections and hospitalizations	➢ Smog formation ➢ Damage to and reduced growth rates of crops and vegetation ➢ *Also classified as a criteria air pollutant, and as a short-lived climate pollutant

(Source: Clean Air Asia, 2020; Climate and Clean Air Coalition, 2011; European Commission, n.d.; Health Effects Institute, 2019; IPCC, 2013; North Carolina Climate Office, n.d.; Prarther, et. al., 2001; US EPA,2018; World Health Organization. n.d.)

SLCPs refer to gases and particles that contribute to warming and have a lifetime from a few days to approximately 10 years. In some cases, SLCPs overlap with the air pollutants and GHGs such as methane (CH_4). They include black carbon, tropospheric ozone and its precursors CO, non-methane volatile organic compound (NMVOC) and NO_X, CH_4 and some HFCs.

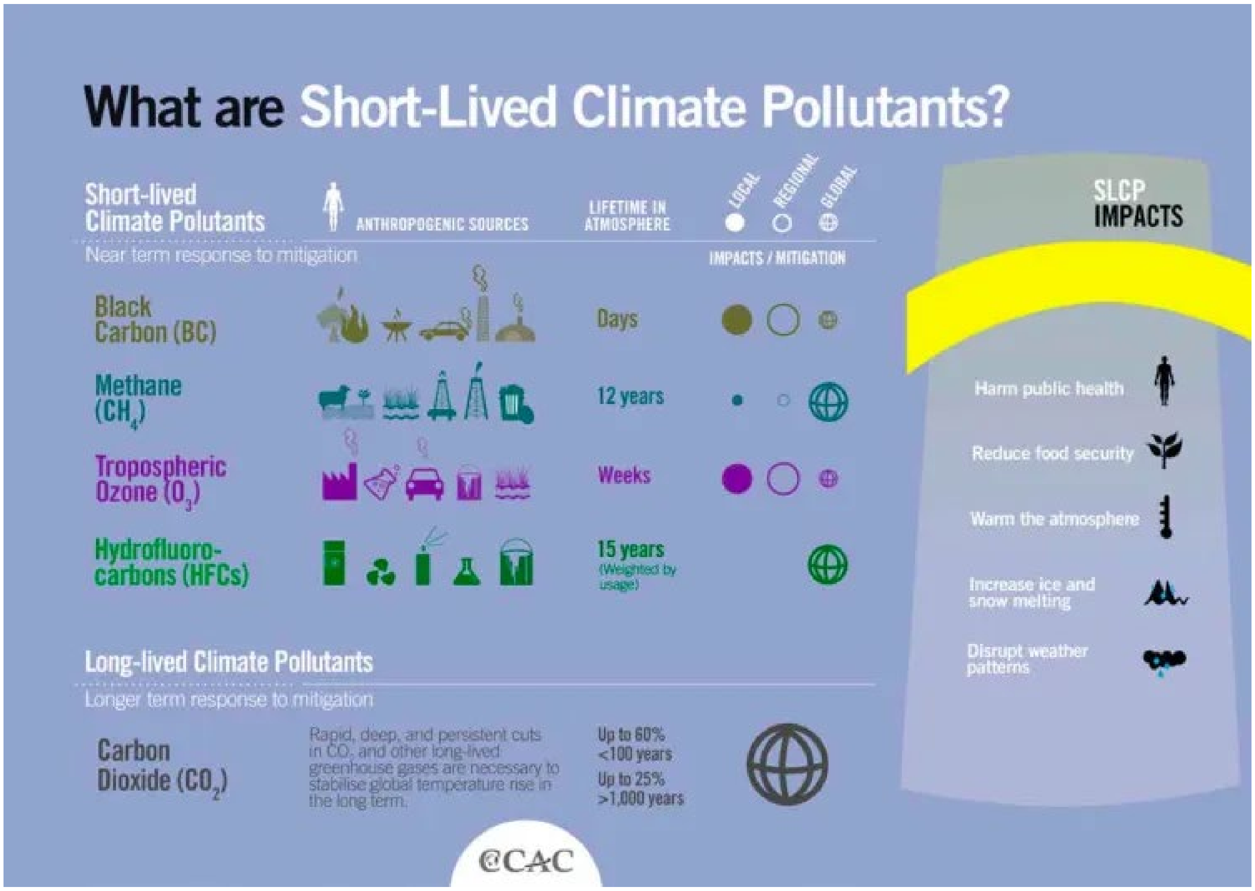


Figure 2.4: Defining Short-Lived Climate Pollutants
(Source: CCAC, 2015)

SLCPs are powerful climate forcers that, though they remain in the atmosphere for a much shorter period than CO2, have the potential to warm the atmosphere more than CO_2. It should be borne in mind, however, that these impacts are not always straightforward (as discussed for the example of black carbon in Box 2.2).

Box 2.2: The Climate Impacts of Black Carbon

Black carbon is an aerosol generated from the incomplete combustion of fossil fuels and biomass. Black carbon is also an indivisible component of $PM_{2.5}$. The impact of $PM_{2.5}$ on the climate depends on the several factors.

One factor involves organic carbon or white carbon. Like black carbon, organic carbon is also a part of PM2.5. In contrast to black carbon, organic carbon reflects radiation and cools the atmosphere, reducing near-term warming. In real world settings, PM2.5 emissions consist of both black and organic carbon. The ratio of the black to organic carbon from a given source is an important indicator of whether mitigating that source will have a warming (positive forcing) or cooling impact (negative forcing) on the atmosphere. Black carbon-rich sources such as diesel engines tend to have far more black carbon than organic carbon and therefore lead to warming. Burning of biomass can have a greater share of OC to BC and therefore lead to more cooling.

Another factor influencing the warming of black carbon involves cloud formation. The creation of clouds from the emissions of $PM_{2.5}$ (and black carbon) can also cause the reflection of radiation. The creation of clouds can offset some of the warming from even black carbon-rich sources of $PM_{2.5}$.

A final factor affecting the warming of black carbon involves regional climate changes. In this case, emissions of PM2.5 increase the intensity of rainfall, leading to sizable and dangerous changes in precipitation patterns. In specific regions, particulate pollution can disrupt the climate.

(Sources: Jacobson, 2001; Bond, 2013; Boucher et al, 2013; Aamaas et al. 2018; Nakajima et al, 2020.)

Outside of the climate impacts, the impacts of the SLCPs on air quality are straightforward: most SLCPs are also dangerous air pollutants that have harmful effects on health, ecosystems and agricultural productivity (UNEP, 2019).

Table 2.3. List of SLCPs

SLCPs	Impacts	
	Health	Environmental
Black Carbon (BC) ➢ Has a size of around 100 nanometers, and can be a key component of fine and ultrafine particulate matter air pollution, especially in areas with high combustion activities. Also called 'soot' ➢ Formed through the incomplete combustion of fossil fuels, organic materials, and other fuels ➢ Mainly emitted by anthropogenic sources such as industries, transport sector, and other burning processes (cooking, agriculture) ➢ Has a lifetime of 4-12 days in the atmosphere	➢ Its ultrafine size allows penetration of the lungs and transport of toxic components into the bloodstream ➢ Similar to health impacts associated with PM2.5, BC exposure can lead to respiratory and cardiovascular diseases hospitalization, and premature death (e.g. bronchitis, respiratory infections, pneumonia, aggravated asthma, stroke, heart attack, cancer)	➢ Absorbs light thus warming the environment by converting incoming solar radiation to heat ➢ Warming impact for BC is 900 (120 to 1,800 range) over a 100-year timescale. ➢ Affects cloud formation, regional circulation, and rainfall patterns ➢ Increase melting of snow and glacier ➢ Strains ecosystems (e.g. impacts agriculture yield)

Methane (CH_4) ➢ An odorless and flammable gas. Anthropogenic emissions make up 60% of global methane emissions. These primarily come from three sectors: fossil fuels, agriculture and waste. ➢ Can stay in the atmosphere for about 12 years	➢ Methane has indirect health effects, mainly by acting as a key precursor for tropospheric ozone which has severe health effects.·	➢ Second GHG to CO2 in its contribution to climate change ➢ Has 28-36 times the warming capacity of CO2 over a 100-year time scale.
Hydrofluorocarbons (HFCs) ➢ Main sources are industrial processes, used as substitutes for phased-out CFCs, HCFCs, and halons manufactured and used as coolants, refrigerants, insulating foams and aerosol propellants, etc. ➢ HFCs generally have a lifetime of a few days to many years.	➢ HFCs only have low potential for human toxicity and has no significant health risk under normal conditions (usually very low levels of exposure)	➢ Widely used HFCs (HFC-134a) – have a lifetime of 13.4 years and a 100-year GWP of 1,300

Ground-level (Tropospheric) Ozone (O_3) ➢ O3 in the upper part of the Earth's atmosphere (stratosphere) serves as the ozone layer that protects the earth from UV rays, but O3 is considered as a pollutant if found near the ground (troposphere) due to its health impacts ➢ Ground-level O3 is formed through reactions of methane, NOx and non-methane volatile organic compounds (NMVOCs), in the presence of heat and sunlight ➢ Stays in the atmosphere from a few hours to a few weeks	➢ Cause shortness of breath, coughing, sore throat, difficulty in breathing, inflamed airways ➢ Development and aggravation of respiratory/lung diseases (i.e. asthma, chronic bronchitis, emphysema, COPD), leading to infections and hospitalizations ➢ Globally, ozone accounts for 1 out of every 9 deaths due to COPD	➢ Smog formation ➢ Damage to and reduced growth rates of crops and vegetation ➢ *Also classified as a criteria air pollutant, and as a short-lived climate pollutant

(Source: Bond et al., 2013; Clean Air Asia, 2020; Climate and Clean Air Coalition, 2011; European Commission, n.d.; Health Effects Institute; 2019, 2020; Hodnebrog et al.; 2013; IPCC, 2013; Janssen et al., 2012; Kecorius et al., 2017; Myhre et al., 2013; North Carolina Climate Office, n.d.; Saunois et al., 2020; Tsai, 2006; Prarther et. al., 2001; US EPA, 2018; World Health Organization, n.d.; Wiedensohler et al., 2012)

2.2 Toward a Mix of Solutions

The discussion of impacts can help bring together the previous points regarding different perspectives on co-benefits (see Box 2.1). Unifying these different perspectives requires recognizing that many of the key criteria air pollutants described above and GHGs are emitted from similar sources. For example, power-plants, industries, and vehicles emit both criteria air pollutants and GHGs. The air pollutants emitted from these sources can have direct impacts on human health and the environment while contributing to **long-term** climate change.

At the same time, many of the most significant sources of black carbon and other SLCPs typically come from a different set of smaller diffuse sources than the power plants or industries that are the main sources of GHGs. Key SLCP sources include, for instance, diesel vehicles or the open burning of waste. Moreover, SLCPs can have direct impacts on human health and the environment while contributing to **near-term** climate change.

Because of the difference in sources and time scales of impacts, policymakers will need to adopt a **mix** of technologies and policies that are consistent with both this climate-centred and air pollution-perspective on co-benefits (Bowerman, 2013; Melamed, Schmale, and von Schneidemesser, 2016). It will also be important to adopt a mix of technologies and policies consistent with these views for at least three additional reasons:

- One reason is that efforts to reduce GHGs can often also curb emissions of sulfate pollutants that cool the atmosphere in the short-term. When those cooling sulfates pollutants are removed from the atmosphere, they create additional short-term warming (Westervelt, 2015). The best way to compensate for this additional warming from the removal of this cooling layer is to reduce SLCPs.
- Another reason is that a mix of policies and technologies is needed is that some conventional control pollution technologies and measures curb emissions of criteria pollutant at the end-of-the pipe. These policies and technologies do not reduce, and may increase, energy consumption as well as GHGs. Again, it will be important to offset these increases in GHGs with policies and technologies that mitigate long-term climate change (Asian Co-benefits Partnership, 2012).
- A final reason that a mix is needed is that the same end-of-the-pipe controls may also counteract or remove the cooling sulfates mentioned previously. Again, there is a need to offset the added warming with SLCP technologies and measures (Westervelt, 2015).

The need to mix different types of solutions sits at the core of a recent report entitled *Air Pollution in Asia and the Pacific: Science-Based Solutions* (UNEP, 2019). The report demonstrated that air pollution solutions fit into three categories:

1. Conventional controls (that do not achieve co-benefits): this involves time-tested, end-of-pipe equipment installed on power plants and vehicles.
2. Next stage controls that achieve co-benefits from mitigating SLCPs: this involves regulating sources that have not traditionally been the focus of the air pollution community, including farms and new industries.
3. Development priority measures that achieve co-benefits from mitigating GHGs: this involves introducing and scaling new technologies that create changes in energy systems and infrastructure (UNEP, 2019).

Table 2.4. 25 Clean Air Measures

Asia-wide application of conventional measures	
Post-combustion controls	Introduce state-of-the-art, end-of-pipe measures to reduce sulphur dioxide, nitrogen oxides and particulate emissions at power stations and in large-scale industry
Industrial process emissions standards	Introduce advanced emission standards in industries, e.g., iron and steel plants, cement factories, glass production, chemical industry, etc.
Emission standards for road vehicles	Strengthen all emission standards; special focus on regulation of light- and heavy-duty diesel vehicles
Vehicle inspection and maintenance	Enforce mandatory checks and repairs for vehicles
Dust control	Suppress construction and road dust; increase green areas
Next generation Asia-specific air quality measures that are not yet major components of clean air policies in many parts of the Asia Pacific	
Agricultural crop residues	Manage agricultural residues, including strict enforcement of ban of open burning
Residential waste burning	Strictly enforce bans of open burning of household waste
Prevention of forest and peatland fires	Prevent forest and peatland fires through improved forest, land and water management and fire prevention strategies
Livestock manure management	Introduce covered storage and efficient application of manures; encourage anaerobic digestion
Nitrogen fertilizer application	Establish efficient application for urea, use urease inhibitors and/or substitute with, for example, ammonium nitrate

Brick kilns	Improve efficiency and introduce emission standards
International shipping	Require low sulphur fuels and control of particulate emissions
Solvent use and refineries	Introduce low solvent paints for industrial and do-it-yourself applications; leak detection; incineration and recovery
Measures contributing to development priority goals with benefits for air quality	
Clean cooking and heating	Use clean fuels – electricity, natural gas, liquefied petroleum gas (LPG) in cities: LPG and advanced biomass cooking and heating stoves in rural areas; substitution of coal by briquettes
Renewables for power generation	Use incentives to foster extended use of wind, solar and hydro power for electricity generation and phase-out the least efficient plants
Energy efficiency for households	Use incentives to improve energy efficiency of household appliances, buildings, lighting, heating and cooling; encourage roof-top solar
Energy efficiency standards for industry	Introduce ambitious energy efficiency standards for industry
Electric vehicles	Promote use of electric vehicles
Improved public transport	Encourage a shift from private passenger vehicles to public transport
Solid waste management	Encourage centralized waste collection with source separation and treatment, including gas utilization
Rice paddies	Encourage intermittent aeration of continuously flooded paddies

Wastewater treatment	Introduce well managed two-stage treatment with biogas recovery
Coal mining	Encourage pre-mining recovery of coal mine gas
Oil and gas production	Encourage recovery of associated petroleum gas; stop routine flaring; leakage control
HFC refrigerant replacement	Ensure full compliance with the Kigali amendment

(Source: UNEP, 2019)

The abovementioned report was not only useful for identifying concrete technical and non-technical measures that fit into these categories which can help policymakers identify options that could help achieve co-benefits in their cities. The next section will discuss some of the tools that can assist policymakers with identifying options that have the greatest potential for co-benefits across and within key sectors.

III. Assessing Co-benefits and Identifying Solutions

Understanding core concepts and possible solutions is arguably the first step in integrating air pollution and climate change planning. A critical second step involves using emissions inventories (EI) and decision-making tools to determine what kinds of technologies and behavioral changes can bring reductions in multiple pollutants and GHGs in a particular city. This section has several objectives related to this next step. It also seeks to achieve the below objectives with specific case studies for emissions inventory development in Santa Rosa and electric vehicles in Pasig in the Philippines, waste emissions quantification for four cities in Southeast Asia (Nay Pyi Taw, Myanmar, Nonthaburi, Thailand, Jambi, Indonesia and Kampong Chhnang, Cambodia), as well as assessment of health impacts in Bangkok.

Objectives

At the end of the section, participants will be able to:

- Understand the process for developing an emissions inventory and health impacts assessment so as to quantify co-benefits and identify solutions capable of achieving those benefits
- Understand how some tools can be used to identify solutions capable of achieving co-benefits.

3.1 Emission inventories

Identifying solutions for integrating air pollution and climate change planning often requires developing an EI. An EI is a comprehensive listing of the amount of different pollutants or GHGs that are emitted from a fixed area's emissions sources over a specified period of time. Having an accurate assessment of what are frequently called an inventory's baseline emissions is essential for not only understanding the apportionment of pollution from key emission sources but also identifying control measures.

Though constructing an EI is critical for source apportionment and identifying controls, it is not easy. Depending upon the preferred level of accuracy, building an EI can consume significant amounts of time and resources. One of the key variables influencing the amount of time and resources is the quantity and quality of data; the types and amount of existing data will often affect the methodology adopted to build the EI.

This section offers a simple overview of data needed for an EI. More detailed steps for gathering and organizing relevant data can be found on Clean Air Asia's IBAQ Programme Learning Portal. The "Development of Source and Emissions Database" provides a step-by-step guide for building an emissions inventory database while guidance for "Integration of Criteria Pollutants and GHG/SLCP Emissions Inventory". Briefly, the integration of EI development for criteria pollutants and GHGs/SLCPs is useful environmental policymakers and air quality managers as this translates to time and financial savings while arriving at more systematic and holistic solutions.

The process of constructing an EI begins by mapping sources both criteria pollutants and GHGs/SLCPs and identifying agencies or groups within the city that could provide the necessary data in building an integrated database. The next step involves the assessment and shortlisting of tools that are appropriate in analyzing both climate change and air pollutant emissions. The last and most crucial step is the analyses and dissemination of results; this last step requires that end-users of the integrated EI become familiar with the concept of co-benefits and how this can be used for policy and decision making.

There are two approaches to gathering the activity level data that is central to constructing an EI. The top-down approach uses available “high-level” data such as national statistics for population and energy or fuel consumption to approximate activity levels. This top-down approach is preferable when there is a lack of local activity data and resources are limited to gather such data. In contrast, the bottom-up approach estimates emissions using finer-grained activity data from, for example, household or transport surveys. Identifying the approach to be used affects the kind of data assessment and the collection process. It also has implications for the selection of tools to be used to contribute to decision making. Table 3.1 provides an overview of the broad pollution and sector specific categories for EI development (Clean Air Asia, 2020).

Table 3.1. Data Requirements for Emissions Inventory Activity Data

Pollution source	Existing or relevant pollution sources	Activity data required (minimum)	Data gathering method
Point Source	Heavy industry and manufacturing facilities	Fuel use (type, amount); Equipment (type, fuel); Pollution control devices; Actual emissions data	Utilize activity data extracted from Self-Monitoring Reports (SMRs), 3rd party tests, and Continuous Emissions Monitoring System (CEMS) submitted by the industries/ facilities/ establishments to Environment Ministry
	Establishments located within the study zone		
Area Source	Residential activities	Household fuel use (type, amount); waste production and burning; solvent use	Perform household survey or collect census data from Statistics Office

	Commercial activities	Equipment/ cooking fuel use (type, amount); waste production and burning; solvent use	Perform household survey or collect data from Environment or Trade Ministry
	Crop residue open burning	Amount of biomass burned	Utilize data from City Agricultural Office
	Agricultural sector activities such as fertilizer use and animal manure management	Fertilizer use (type and amount); Manure production (can be estimated through number of livestock)	Utilize data from City Veterinary/Agricultural Office
Mobile Source	On-road vehicles	Vehicle data (count and classification) passing through streets	Perform classified vehicle volume count in collaboration with City Traffic Management and Enforcement Office
		Travel time and delay data; Time and speed profile	Perform travel time and delay studies with City Engineering Office/ Traffic Management and Enforcement Office
		Database of registered public utility vehicles in the city	Utilize data from the Transport Ministry or the City Traffic Management and Enforcement Office

(Source: Clean Air Asia, 2020a)

The other critical component of an EI are emissions factors. Emissions factors estimate how much pollution or GHGs are generated from combusting different forms of energy, biomass or waste. Emissions factors are multiplied by activity data to arrive at levels of emissions. Ideally, locally appropriate emissions factors are used in constructing an EI. However, often default data is used when locally-appropriate emissions factors are lacking.

In recent years, many organizations have developed decision making tools that can support the development of an EI. The tools can also use data from the EI to quantify the co-benefits of different policies and measures from controlling pollution and mitigating climate change. Some of these tools focus on a specific sector such as transport or look only at the impacts of different kinds of controls on health impacts. Others can work across multiple sectors and then incorporate an additional module or set of functions to allow the user to translate the estimation of changes in emissions and air quality into health impacts. Table 3.2 describes several decision making support tools and their unique features and functions (Clean Air Asia and UN Environment, 2019).

Table 3.2.Decision Making Support Tools

Tool		**Weblink**	**Description**	**Developer**
ABC Emission Inventory Manual	Atmospheric Brown Cloud Emission Inventory Manual	http://www.rrcap.ait.asia/Publications/ABC%20Emission%20Inventory%20Manual.pdf (free access)	Used to quantify the emissions of air pollutants that lead to the formation of haze and atmospheric brown clouds	Asian Institute of Technology (AIT) through UNEP
COPERT 5	Computer Programme to calculate Emissions from Road Transport	https://copert.emisia.com/ (free access)	Used to compile the mobile source portion of the CORINAIR annual emissions inventories	European Union
EDGAR	Emission Database for Global Atmospheric Research version 4.2	http://edgar.jrc.ec.europa.eu/ (free access)	Provides global past and present-day anthropogenic emissions of greenhouse gases and air pollutants from combustion and non-combustion sources per country	Joint Research Centre of the European Commission, in collaboration with the Netherlands Environmental Assessment Agency

EEA - EU EMEP/CORINAIR	European Monitoring and Evaluation Programme/ Core Inventory of Air Emissions	https://www.eea.europa.eu/themes/air/emep-eea-air-pollutant-emission-inventory-guidebook/emep (free access)	Collects, manages, maintains, and publishes official annual national inventories	European Union
EPA - AIR CHIEF	Clearinghouse for Inventories and Emissions Factors	https://www.epa.gov/chief	EI system by the US EPA; Uses AP-42	US Environmental Protection Agency
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies	http://gains.iiasa.ac.at/models/ (needs registration)	Provides estimates of emissions, for analyzing co-benefits of reduction strategies for air pollution and greenhouse gas	International Institute for Applied Systems Analysis
GAPF EI Manual	Global Atmospheric Pollution Forum Emission Inventory Manual	https://www.sei.org/projects-and-tools/tools/gap-global-air-pollution-forum-emission-manual/ (contact H. Vallack for access)	Manual was initially prepared for use in Northeast Asia and has been modified for use by the Malé Declaration countries of South Asia and the Air Pollution Information Network for Africa (APINA)	Stockholm Environment Institute (SEI), International Union of Air Pollution Prevention Association (IUAPPA), which coordinate the Global Atmospheric Pollution Forum (GAPF)

HBEFA	Handbook of Emission Factors for Road Transport	http://www.hbefa.net/e/index.html (for purchase)	Provides emission factors in g/km for the most current vehicle categories (Personal cars, Light Duty Vehicles (LDV), Heavy Duty Vehicles (HDV) and motorcycles), differentiated according to emission standards (Euro 0 to Euro VI) and different traffic and vehicle distributions	Environmental agencies of Germany, Switzerland and Austria, with support from Sweden, Norway, France and the EC Joint Research Centre
IVE Model	International Vehicle Emissions Model	http://www.issrc.org/ive/ (needs registration)	Estimates emissions of key urban pollutants, toxic substances and GHGs for passenger cars, trucks, buses three-and two-wheelers, in different fuels	International Sustainable Systems Research Center (ISSRC)
LEAP-IBC	Long-range Energy Alternatives Planning – Integrated Benefits Calculator	https://www.sei.org/publications/leap-ibc/ https://energycommunity.org/default.asp?action=IBC (needs registration)	Calculates emissions inventories and pollutant concentrations, project future emission trends, evaluate alternative mitigation scenarios, provide estimates on the health and climate impacts, crop yield loss	Stockholm Environment Institute (SEI), US EPA, and University of Colorado, with support from UN Environment and the Climate and Clean Air Coalition
MEIC	The Multi-resolution Emission Inventory for China	http://meicmodel.org/	Provides national emissions estimates in China for 2008 and 2010	Tsinghua University, Beijing, China

MOVES	Motor Vehicles Emission Simulator	https://www.epa.gov/moves (free access)	Emissions modeling system that estimates emissions for mobile sources (cars, trucks, motorcycles) for criteria air pollutants, greenhouse gases, and air toxics	US Environmental Protection Agency
NMIM-NONROAD	National Mobile Inventory Model	https://www.epa.gov/moves/how-install-national-mobile-inventory-model-nmim-windows-machine (free access)	Computer app used to estimate current and future emissions for non-road equipment	US Environmental Protection Agency
SIM-air	Simple Integrated Model for Better Air Quality	http://www.urbanemissions.info/tools/	Suite of tools to examine emissions, ambient air quality, health and control measures in a scenario approach	UrbanEmissions.info
REAS	Regional Emission inventory in Asia version 2.1	https://www.nies.go.jp/REAS/ (free access)	Regional emissions inventory and emission projection trends in Asia, for fuel combustions in power plants, industry, transport, and domestic sectors	National Institute for Environmental Studies and Asia Center for Air Pollution Research, Japan
TREMOD	Transport EMission estimation MODel	https://www.ifeu.de/en/methods/models/tremod/ (free access)	Used to describe motorized transport with regard to its energy consumption, emissions, activity of passenger and goods vehicles, trip lengths and frequencies	Institute for Energy and Environmental Research (Germany)

VERSIT+	VERSIT+	https://www.tno.nl/media/2451/lowres_tno_versit.pdf (free access)	Used to predict vehicle fleet emission and energy use factors that are representative for real-world driving conditions	Netherlands Organisation for Applied Scientific Research (TNO)
WebFIRE	*also under AIR CHIEF	https://cfpub.epa.gov/webfire/ (free access)	EPA's online emissions factor repository, retrieval, and development tool	US Environmental Protection Agency
WHO: RIAS	Rapid Inventory Assessment Technique	https://apps.who.int/iris/bitstream/handle/10665/58750/WHO_PEP_GETNET_93.1-A.pdf;jsessionid=363C506186E0A7942105291AE097DFC4?sequence=1 (free access)	A guide which discusses rapid inventory techniques and approaches for formulating environmental control strategies	World Health Organization

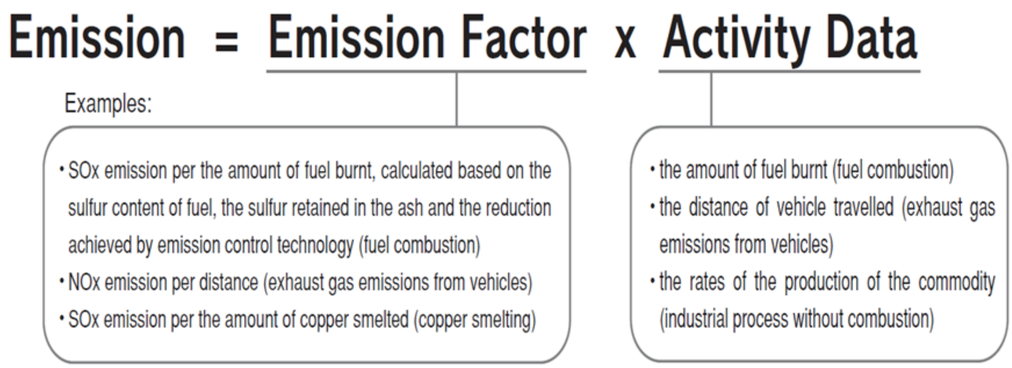
Constructing an EI and conducting a co-benefits analysis requires both technical expertise as well as experience. While interested readers and technical staff are encouraged to seek out that expertise and experience, the remainder of the chapter presents case studies to outline some of the main steps, results and challenges to estimating co-benefits.

3.2 Case study 1: Emissions Inventory for Air Pollutants, GHGs and SLCPs for Santa Rosa City, Philippines (Adapted from Clean Air Asia, 2020)

The first case study focuses on the city of Santa Rosa. In 2020, Clean Air Asia, together with the University of the Philippines – National Center for Transportation Studies, developed an EI for the city with co-funding from the Santa Rosa City Environment and Natural Resources Office (CENRO) and Mitsubishi Motors Philippines Corporation. The project contributed to longer-term efforts of establishing an air quality management system and developing a clean air action plan.

One of the factors that helped the project move forward was the active involvement in the EI's development of the Santa Rosa government's Core Team for the Clean Air Program. The Core Team is an inter-agency group composed of representatives from the environment, planning, health, traffic management and other relevant departments that facilitated cooperation on air pollution issues.

In building the EI, emissions were calculated as a product of emission factor and activity data. The basic formula was as follows:



By applying this formula, participants in the project built an EI that covered criteria pollutants, GHGs, and SLCPs from area, point, and mobile sources (see Table 3.3 for the more specific sources related to area, point, and mobile sources). By estimating baselines for each of these pollutants, co-benefits from pollution control measures could be calculated from the city's proposed clean air action plan. The inclusion of GHGs and SLCPs in the EI also enabled the clean air action plan to be further expanded into a climate and clean air action plan.

Table 3.3.The Scope of Santa Rosa's Clean Air Action Plan

Pollutants covered	**Types of pollution sources included**
Pollutants covered in the EI are criteria pollutants, greenhouse gases (GHGs) and short-lived climate pollutants (SLCPs). Criteria pollutants include: ➢ Particulate matter with a diameter of 10 micrometers (μm) or less (PM_{10}) ➢ Particulate matter with a diameter of 2.5 micrometers (μm) or less ($PM_{2.5}$) ➢ Carbon monoxide (CO) ➢ Sulfur dioxide (SO_2) ➢ Nitrogen dioxide (NO_2) ➢ Non-methane volatile organic carbon (NMVOC) GHGs include: ➢ Carbon dioxide (CO_2) ➢ Nitrous oxide (N_2O) ➢ Methane (CH_4) SLCPs include: ➢ Black Carbon (BC)	Emission sources in the EI were classified as Point, Area, or Mobile Sources. **a) Point sources** are stationary sources that can be identified individually at a given location. These are typically present in large manufacturing or production facilities that have confined chimney or stack emission points. These can include boilers, generator sets, furnaces, and other large combustion systems being operated in the area. **b) Area source** emissions are air pollutants emitted over a relatively large area. These are usually produced within households and commercial establishments through activities involving cooking, open burning, solvent use and many others. **c) Mobile sources** are vehicles and equipment generating air pollution that move or can be moved from place to place. In Santa Rosa City, mobile sources are mostly comprised of motorized road vehicles.
Period covered: 1 year (2019)	

An additional feature of the Santa Rosa EI was that identifying the main sources of emissions per pollutant allowed for the results to be mapped. This mapping, in turn, showed the location of dominant pollution sources with respect to residential areas and vulnerable populations. This information was then used to prioritize which pollution sources should be controlled to minimize impacts on vulnerable people and communities.

The main findings of the EI were that PM_{10} is mainly produced by mobile sources, specifically, motorcycles and tricycles. At the same time, CO_2 emissions were estimated only for area and mobile sources in which mobile sources, specifically cars and motorcycles, were found to be the dominant source. The use of liquified petroleum gas (LPG) as cooking fuel from residential areas also contributed to CO_2 emissions. Similar to $PM_{2.5}$ emissions, the BC emissions were only calculated for area sources.

Table 3.4. T Results of the Santa Rosa Emissions Inventory

Source	$PM_{2.5}$	PM_{10}	CO	SO_2	NOx
Area	7.74	33.96	216.71	399.51	59.52
Point	68.83	227.74	45.61	793.78	226.97
Mobile	73.10	737.48	10533.01	285.62	955.85
TOTAL	**149.67**	**999.18**	**10795.33**	**1478.91**	**1242.35**
Source	**NMVOC**	**CO_2**	**N_2O**	**CH_4**	**BC**
Area	761.36	34961.82	1.15	35.69	3.94
Point	4.73	215314.68	1.63	11.40	11.72
Mobile	4125.26	97631.91	10.63	37.73	17.63
TOTAL	**4891.35**	**347908.41**	**13.41**	**84.82**	**33.29**

Figure 3.1 shows the share of each source to the total emissions. The bulk of the CO_2, NMVOC, NO_x and PM_{10} emissions can be attributed to mobile sources. SO_x emissions come chiefly from point sources while $PM_{2.5}$, N_2O, CH_4, and BC emissions come from area sources.

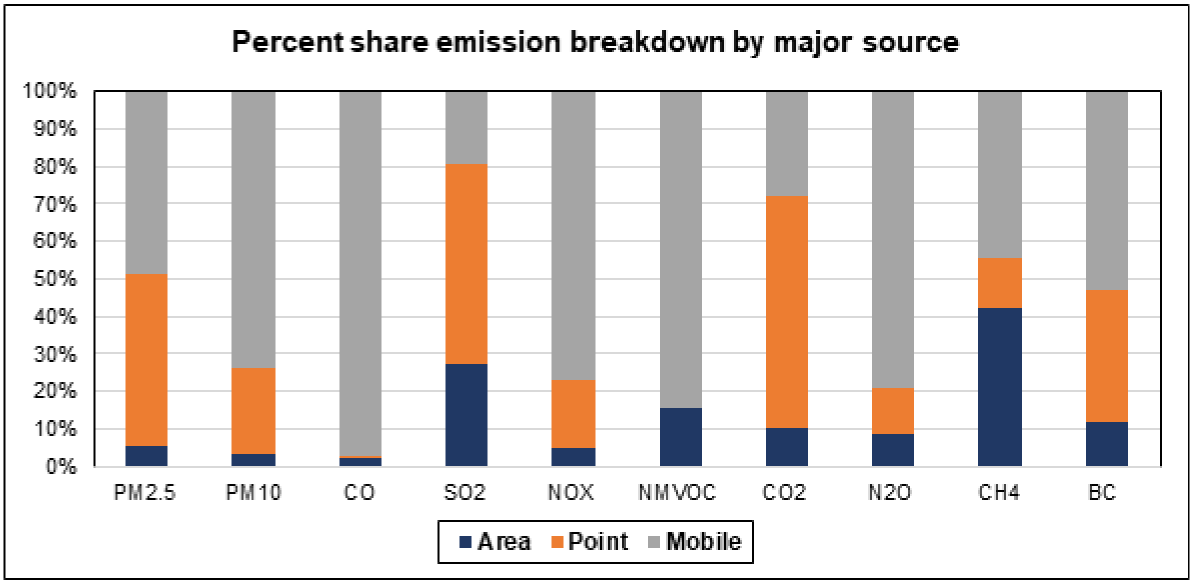


Figure 3.1: Percent share emission breakdown by major source
(Source: Clean Air Asia, 2020b)

The emission estimates generated for Santa Rosa City were further broken down into the different source sub-categories under **Point**, **Area**, and **Mobile Sources**. As an example, the emissions for the different vehicle types under mobile sources are shown below.

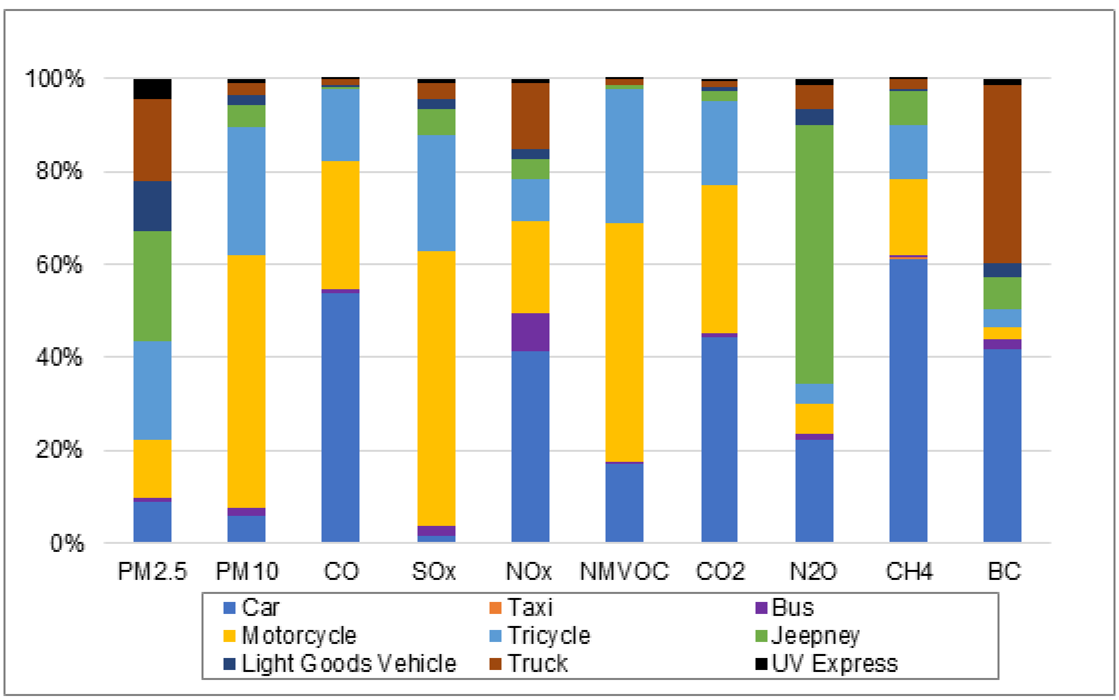


Figure 3.2: Percent share emission breakdown per pollutant
and vehicle type under Mobile Sources (Source: Clean Air Asia, 2020b)

The results of the EI were used as a basis for identifying priority control measures in Santa Rosa's climate and clean air action plan. As mobile sources were found to be the dominant sources of emissions most of the pollutants (PM10, CO, NOx, N2O, CH4, BC and NMVOC), the city focused on improving the inspection and maintenance (through the vehicle testing and apprehension program), improving public transportation and promoting walking and biking as modes of transportation.

While constructing Santa Rosa's EI was a useful exercise, it was not without its difficulties. Some of the main difficulties involved the lack of available data and insufficient data collection methods. However, as these limitations were considered in the project scoping, these challenges were not insurmountable: notably, the data collection method took a bottom-up approach and utilized household and commercial establishment surveys for area sources as well as vehicle counting for mobile sources. Another limitation was the dependence of available data from the Regional Environmental Management Bureau for the point or stationary sources. Records shared with Clean Air Asia showed that there were facilities currently operating within the city without the activity data needed to compute emissions. This resulted in an underestimation of emissions from this category.

Moving forward, one of the recommendations for the Santa Rosa and similarly motivated projects is that data collected through surveys be incorporated into regular or annual city department activities. For example, activity data for residential establishments can be obtained as part of the city planning and development office community-based monitoring system or the city's waste characterization surveys avoiding the need to conduct separate surveys activity data from commercial and point sources can also be required as part of the information that needs to be provided during application of business permits for relevant city offices.

3.3 Case study 2: Electric Tricycle Replacement Scheme in Pasig City, Philippines (Adapted from IGES and Clean Air Asia, 2014)

An important source of emissions in many rapidly motorizing cities in the Philippines are gasoline-powered tricycles. In this case study, the city government of Pasig, in cooperation with the Tricycle Operators and Drivers Association of San Nicolas (SNTODA), implemented a project in 2014 to replace 26 units of gasoline-powered tricycles with electric tricycles. The city government provided support to replace the gasoline-powered tricycles through a zero-interest loan, which the drivers agreed to pay back on a weekly basis. The tricycle operators, in turn, were required to turn over their old units to ensure that these were replaced and properly scrapped without additional gas-powered units being added onto the fleet.

The project was intended to result in reduced emissions as part of the Philippines' Nationally Appropriate Mitigation Actions (NAMA). NAMAs was a term that referred to the set of mitigation actions that countries pledged to the United Nations Framework Convention on Climate Change (UNFCCC) prior to the Paris Agreement. With the Philippines ratifying the Paris Agreement in 2019, the country's NAMA has been updated as a Nationally-Determined Contribution (NDC), reflecting the Philippines' commitment to reduce national emissions and adapt to the impacts of climate change.

To estimate the emissions of multiple sources, Clean Air Asia used the Transport Emissions Evaluation Models for Projects (TEEMP). TEEMP is a set of excel-based tools that can be used to evaluate the GHGs, air pollution, and other impacts of a suite of different transportation projects and interventions. The TEEMP tools were developed by Clean Air Asia and Institute for Transportation and Development Policy (ITDP) for initially evaluating the emissions impacts of the Asian Development Bank's (ADB) transport projects, but were later applied for a wider range of transportation interventions (CAA, 2011).

Co-benefits resulting from fuel consumption savings and CO2 emissions reduction were calculated by comparing a reference scenario with the old gasoline tricycles still in operation against a project scenario with the electric tricycles replacing the gasoline units. Emissions for both scenarios were calculated by multiplying activity data by emission factors. Activity data was based on the vehicle kilometers traveled by the vehicles; the emission factors were based on the type of technology used (i.e. gasoline-fueled tricycle and electric-powered tricycle connected to the main electricity grid).

The results of this analysis showed that the intervention would deliver several co-benefits. These included improvements in air quality within the routes covered by the electric tricycles; reduction in total energy consumption; lower CO_2 emissions; improvements in road safety and congestion from the replacement of older vehicles; reduced risks of breakdown while in operation; potential improvements in the total take-home pay of the drivers and operators of the tricycles; and lower noise pollution.

Among these co-benefits, it was possible to use the data mentioned in the previous section and TEEMP vehicle replacement tool to estimate reductions in tCO_2 emissions. The results of the calculations revealed that the reference scenario produced an average of 46.05 tons per year, while the project scenario generated an average of 9.74 tCO_2/year. The estimated average tCO_2 savings was therefore 36.31(IGES and CAA, 2014).

Table 3.5. Estimated Reductions in tCO2 annually from the Pasiq Electric Tricycle Project

	Average per year	**Average/year/unit**
Reference Scenario	46.05	1.77
Project Scenario	9.74	0.37
Savings	36.31	1.4

Figure 3.3 below depicts the tCO_2 per year emissions for 20 years (the solid line is the reference scenario and the yellow dotted line is the project scenario), while Figure 3.4 shows the avoided tCO_2 emissions per year.

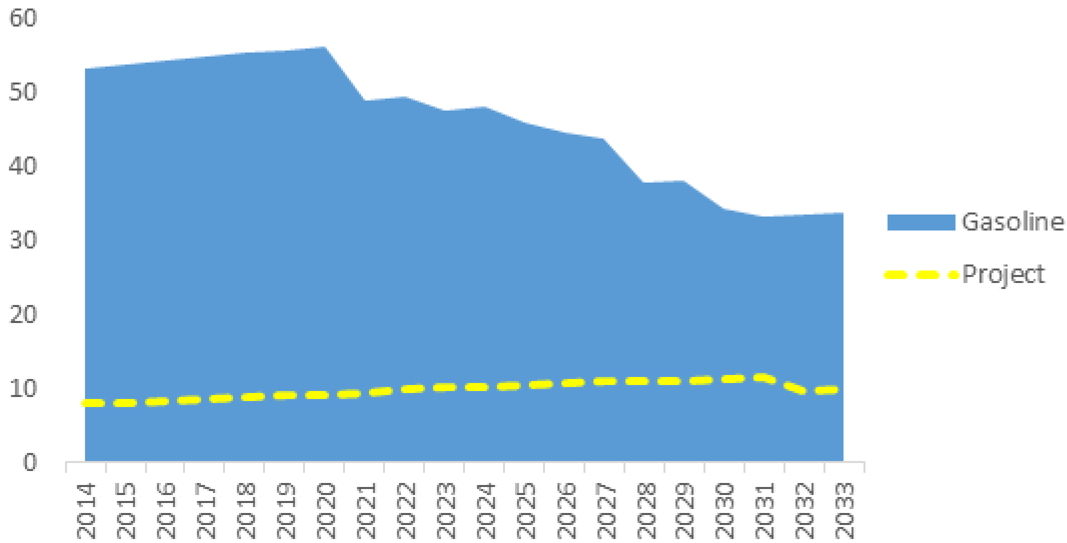


Figure 3.3: tCO2 per Year (Dynamic Scenarios Setting)
Source: IGES and Clean Air Asia, 2014

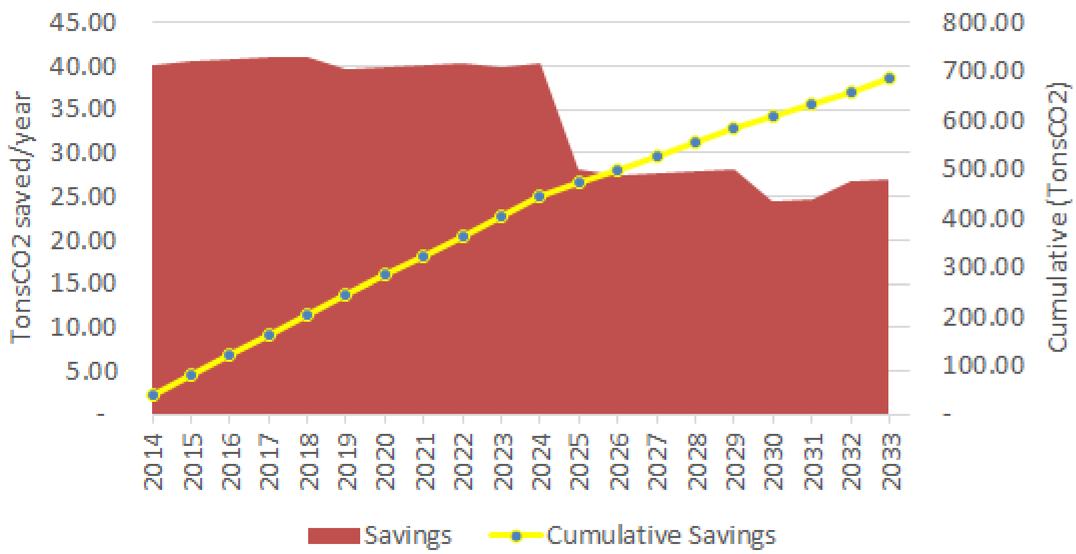


Figure 3.4: tCO2 avoided per Year
(Source: IGES and Clean Air Asia, 2014)

TEEMP also has features that make it possible to estimate financial savings. In this case, there were positive financial savings (from fuel, replacement and maintenance) from 2016 onwards as shown in Figure 3.5 below. [1] The savings are calculated from a project start date of 2014. The calculations assumed that the maximum life of the vehicles will be 18 years, hence by 2032, there would be a sudden drop in the projected savings. By this time, the electric vehicles were also assumed to be replaced by new units.

It is important to underline that the project did not estimate reductions in air pollution--though this could have been done by using emissions factors for different pollutants. Similarly, the project did not consider the quantification of economic benefits from reduced morbidity and mortality from air pollution. Given these limitations in the scope of the study, the benefits calculated resulting from the electric tricycle project may have been underestimated.

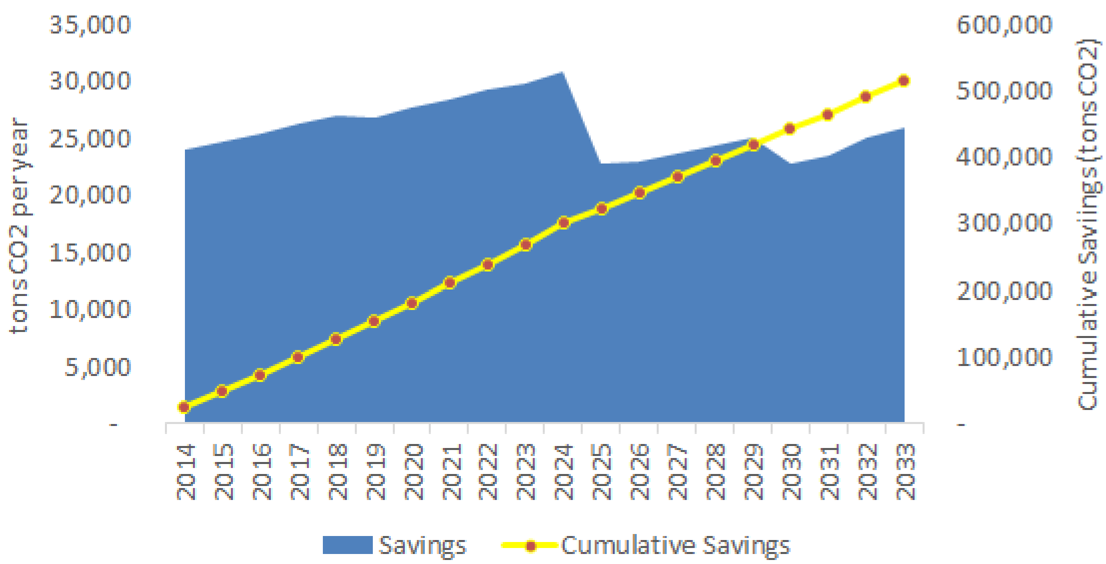


Figure 3.5: Fuel savings (USD) per Year
(Source: IGES and Clean Air Asia, 2014)

[1] Annual maintenance costs are assumed to be 10% of the vehicle cost.

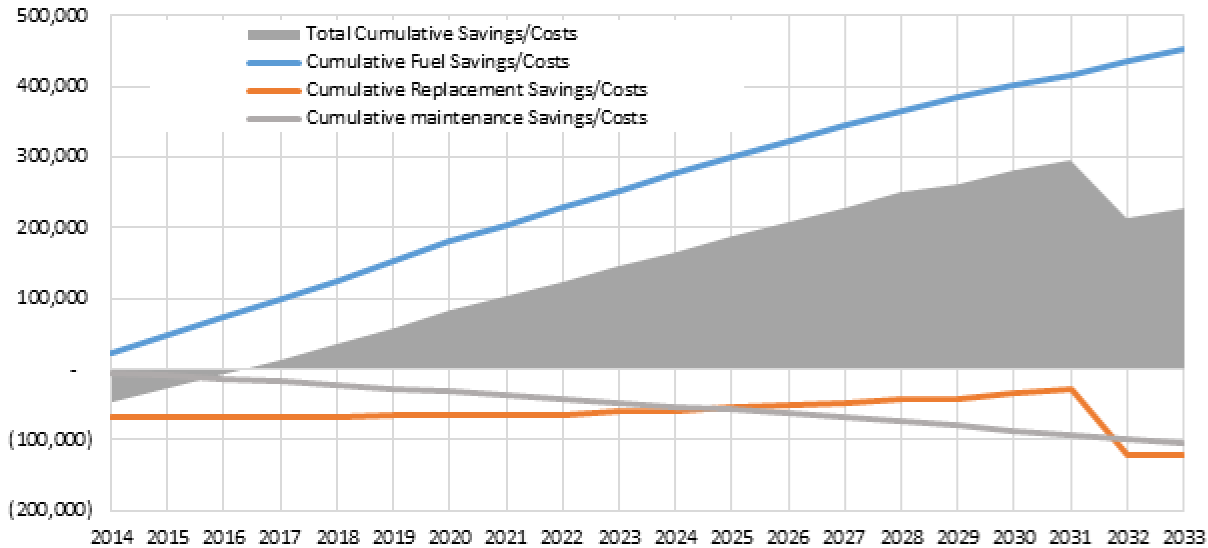


Figure 3.6: Total cumulative savings from 2014 to 2033
(Source: IGES and Clean Air Asia, 2014)

Though the co-benefits for this particular project were not huge, they could increase with scaling of electric vehicles. At the time of the project, Pasig intended for this intervention to serve as pilot to test the electric tricycle technology's applicability to local conditions. Assuming there were no significant problems with the pilot, plans were made to widen the adoption of the electric tricycles. To understand the possible impacts of these plans, TEEMP was used to run a scenario assuming a 50% electric tricycle share for the city's total tricycle fleet. The calculations assumed that the number of units would remain the same. To reach the 50% target in 20 years, an additional 205 units needed to be replaced every year with an annual growth rate of 16% for the next 20 years. The graph below shows the number of tricycles requiring replacement based on these projections.

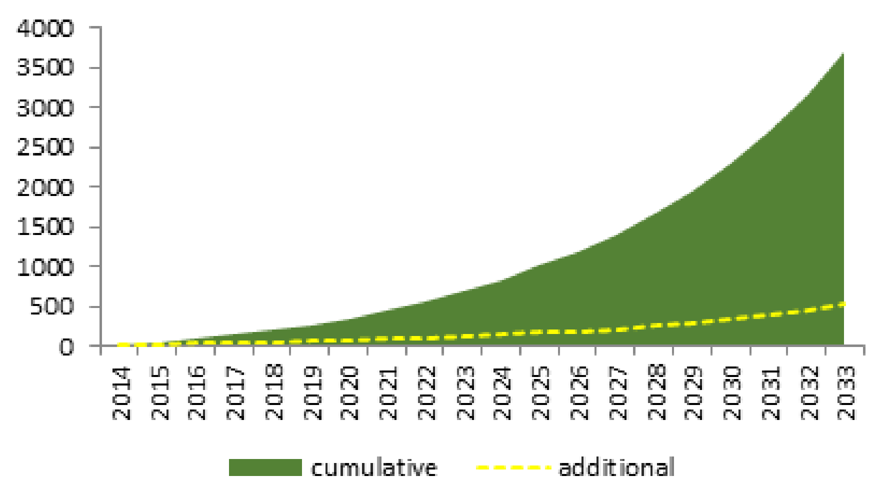


Figure 3.7: Electric tricycle replacements per year
(Source: IGES and Clean Air Asia, 2014)

If the above targets were met, an average reduction of 1,426 tCO_2 savings every year was achievable.

Table 3.6. tCO2 per Year – Roll-out Scenario (IGES and Clean Air Asia, 2014)

	Average per year	**Average/year/unit**
Reference Scenario	1890.17	1.67
Project Scenario	463.95	0.41
Savings	1426.22	1.25

The figure below shows the yearly CO_2 emissions for both the project and reference scenarios (in tons/year).

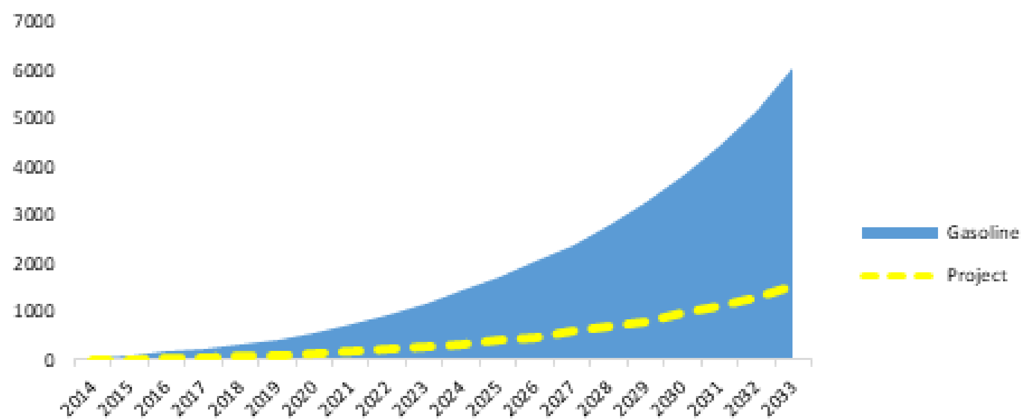


Figure 3.8: tCO2 per Year (Roll-out Scenario)
(Source: IGES and Clean Air Asia, 2014)

The same scaled-up projections also could deliver significant financial and fuel savings. In this case, TEEMP showed that it was possible to save approximately 834 thousand liters of gasoline per year (20-year average), which equates to an average of 5.2 million USD per year for 20 years. This 20-year period analysis demonstrates that it is only after eight years (by 2022) that the savings will accrue, considering replacement costs, maintenance costs and fuel costs. This is because the replacement costs are quite high, and a few years were needed before these can be offset by fuel savings.

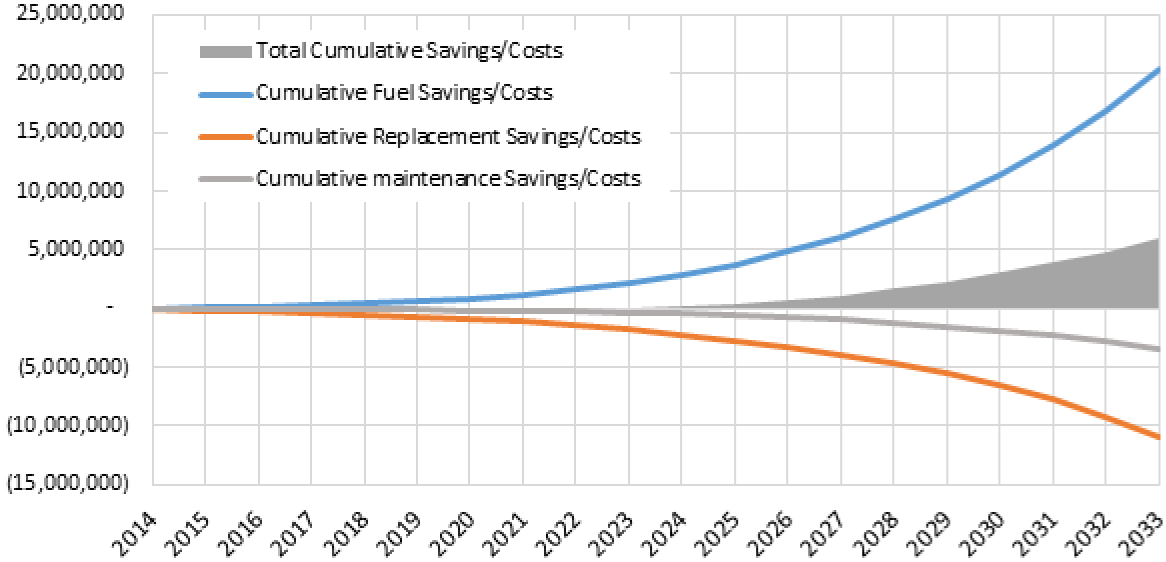


Figure 3.9: Cumulative Costs/Savings (USD) – Roll-out
(Source: IGES and Clean Air Asia, 2014)

An obvious question--which also related to the discussion in Chapter 4--is whether the plans to implement the project at scale ultimately materialized. In the years since the modeling, two electric tricycle-related projects were led by the city. In 2015, 200 units of electricity tricycles were deployed by the city under the *Easy Pondong Pangnegosyo* (Affordable financing to support livelihoods) Program. The city mayor also led the turnover of 33 electric tricycles to various barangays (communities) and some government offices in December 2017 in line with the city's advocacy to fight air pollution and promote sustainable transportation (Clean Air Asia, 2020c). It was unclear whether and to what extent these follow-up actions aligned with those using TEEMP. Moreover, no additional information is currently available on the implementation of a monitoring plan to validate the estimated benefits from the original intervention.

As is the case with analysis of co-benefits in many contexts, the results of the tools such as TEEMP depend on the accuracy of the reference and project scenarios. Every effort was made to develop realistic scenarios, but there are certain contingencies that are difficult to capture in a modelling environment (i.e. the decision of the mayor to purchase vehicles). Moreover, as this calculation was performed prior to project implementation, a monitoring plan that assesses the calculation of actual emissions would be desirable. The success of implementing the monitoring plan also largely depends on accurate record-keeping from the tricycle operators. This would likely require providing incentives for tracking progress.

3.4 Case study 3: Application of Emission Quantification Tool (EQT) to Measure Emissions from the Municipal Solid Waste (Adapted from CCAC and IGES, 2014)

Municipal solid waste represents a fast-growing source of air pollution and climate change in many of Asia's rapidly developing cities. The following case study reviews how an emissions quantification tool (EQT) was used to assess waste-related emissions from a project supported by the CCAC in Nay Pyi Taw, Myanmar, Nonthaburi, Thailand, Jambi, Indonesia and Kampong Chhnang, Cambodia. The Institute for Global Environmental Strategies (IGES), together with the Institut für Energie- und Umweltforschung (IFEU, Institute for Energy and Environmental Research), developed the EQT for this and other similarly motivated projects.

The EQT is a user-friendly tool that allows decision makers to calculate emissions of SLCPs and GHGs from different stages of the waste cycle: from waste generation to collection and transport to recycling to treatment and final disposal (See Figure 3.10) (Premakumara et. al., 2018; Nirmala and Premakumara, 2018). In then enables decision makers to compare the impacts (i.e. tonnes of CO2-eq) of business-as-usual and policy scenarios as well as track changes in emissions over time. The EQT is useful because it can help fast-growing cities overcome common waste management challenges (limited budgets, staff, and equipment) and improve planning by clarifying the impacts of possible interventions.

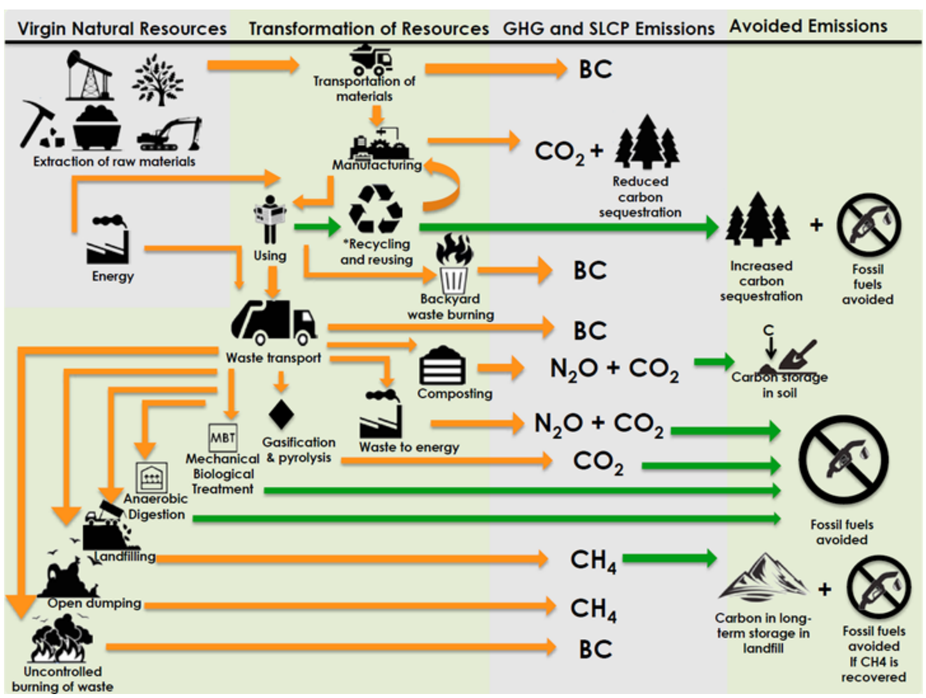


Figure 3.10: GHG and SLCP Emissions across the Waste Cycle

Table 3.7 provides per capita waste generation rates for the four featured cities. As demonstrated in Table 3.7, the amount of per capita waste ranged from 0.32 to 1.77 kg/capita/day in the four cities. Nonthaburi, Thailand (1.77 kg) recorded the highest levels of waste, a figure that is still far below developed countries.

Table 3.7. Per capita waste generation in the four case study cities

Description	Nay Pyi Taw	Nonthaburi	Jambi	Kampong Chhnang
Country	Myanmar	Thailand	Indonesia	Cambodia
GDP per capita (USD), 2017[7]	1,256	6,595	3,846	1,384
Per capita waste generation (kg/day)	0.52	1.77	0.53	0.32

As illustrated in Figure 3.11, organic waste (food and garden waste) was the largest source of waste across the cities, accounting for upwards of 40-80% of total volume. Residual waste, including recyclable materials (plastic, paper, metal and glass), represented roughly 10-25% of that total volume.

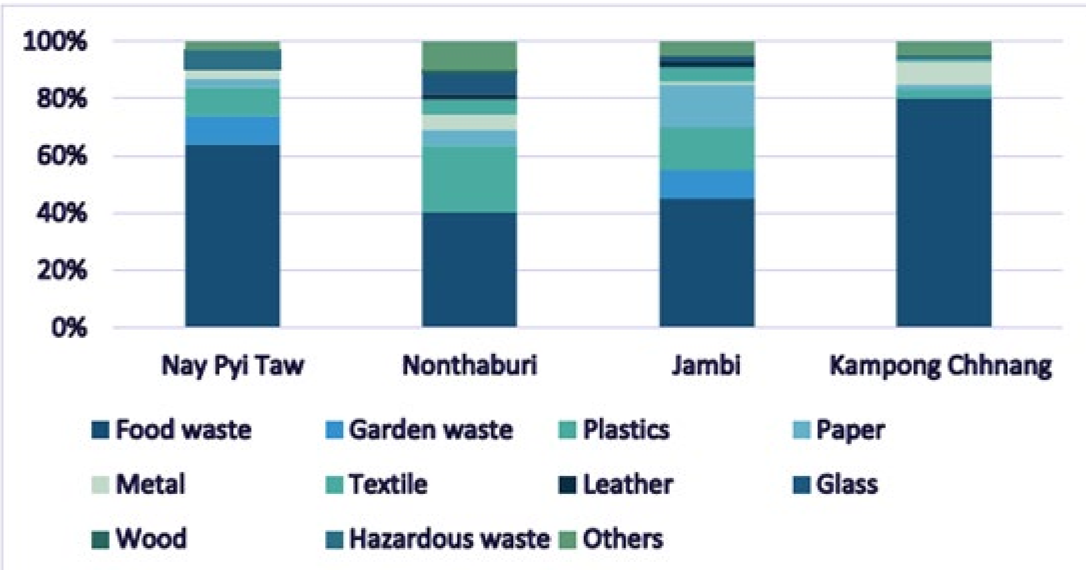


Figure 3.11: Waste composition in the four case study cities

Waste collection rates varied among the four cities, with the lowest levels of service in Kampong Chhnang (24%). House-to-house collection and communal collection, conducted by motorised waste vehicles, small trucks or handcarts at curbside or designated collection points, were the most common waste collection methods in all four cities. The informal sector delivered important waste services in Nay Pyi Taw, Jambi and Kampong Chhnang. With the exception of Nonthaburi (which has a sanitary landfill), open dumping was the most common disposal method; at least 90% of the waste was dumped in open disposal sites without proper environmental measures such as leachate treatment, gas treatment or other necessary safety controls in Nay Pyi Taw, Jambi and Kampong Chhnang.

The EQT help arrive at several important findings that informed plans in the four cities. First, final disposal activities contributed the highest levels of emissions, namely CH_4 and CO_2 from waste decomposition in open dumping sites. Second, open burning of solid waste—used to remove 30-50% of uncollected waste in the cities—was responsible for a significant source of black carbon emissions. Third, fossil fuel combustion from waste collection, transportation and other operational activities contributed sizeable amounts of CO_2, NO_x and black carbon, as well as $PM_{2.5}$ emissions. Fourth, composting was found to provide a viable approach for reducing organic waste from disposal sites and reducing pollution. Finally, the recovery of resources and avoidance of conventional material production processes meant that recycling offered the greatest GHG and SLCP emissions-saving potential in all the surveyed cities.

Based on the above results and a series of training workshops, the four cities developed several strategies and actions to reduce GHG and SLCP emissions. These included diverting organic waste from landfills and open dumpsites through segregated collection, processing and treatment methods, such as composting and anaerobic digestion. Another set of options focused on promoting the capture, recovery, and/or utilisation of CH_4 generated at sanitary landfill sites. A third category of interventions concentrated on prohibiting waste burning. The last set of actions centered on improving the efficiency of waste collection services through community and informal sector engagement, optimisation of waste collection routes, and the use of cleaner vehicles. Figure 3.12 compares the climate impact mitigation potential of current waste management activities in the four cities against a scenario based on the above actions. As suggested by that figure, the proposed actions could achieve significant emission reductions.

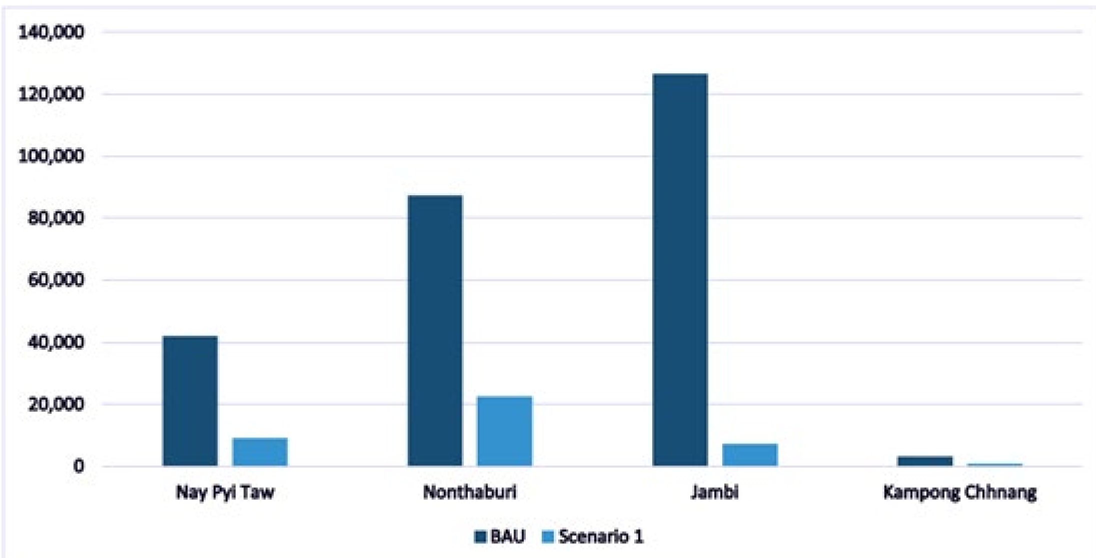


Figure 3.12: Comparative analysis of climate impacts in BAU and proposed scenario (tonnes of CO2-eq)

3.5 Case study 4: Health impact study in Bangkok, Thailand

The development of Bangkok, the capital of Thailand, as a global megacity could give rise to a number of environmental threats. Arguably the most costly of these threats is air pollution. According to an executive summary released by the National Statistical Office Thailand (2010), the Thai Pollution Control Department indicated that pollution had increased to levels that are considered unsafe--with $PM_{2.5}$ concentrations rising at an alarmingly harmful rate. As increases in non-accidental mortality and excess risks were observed during the recent years, there are growing concerns about the harmful impacts of not only PM2.5 but also NOX, SO2, O3, and PM10.

A study entitled “An Assessment of Annual Mortality Attributable to Ambient PM2.5 in Bangkok, Thailand” conducted by Fold, Allison, Wood, Thao, Bonnet, Garivait, Kamens, and Pengan in

2020 looks into annual mortality associated with PM2.5 in Bangkok based on available air quality monitoring data from 2012 until 2018. The objectives of the study were to 1) generate missing PM2.5 data through interpolation of existing PM2.5 and PM10; 2) determine the linkage between PM2.5 and meteorological parameters; 3) identify relative risks and resulting concentration-response coefficients for all-cause, cardiopulmonary, and lung cancer mortalities; and 4) estimate the annual mortality resulting from PM2.5 pollution with a tool called BenMAP-CE.

Figure 3.13 below shows the workflow of the study.

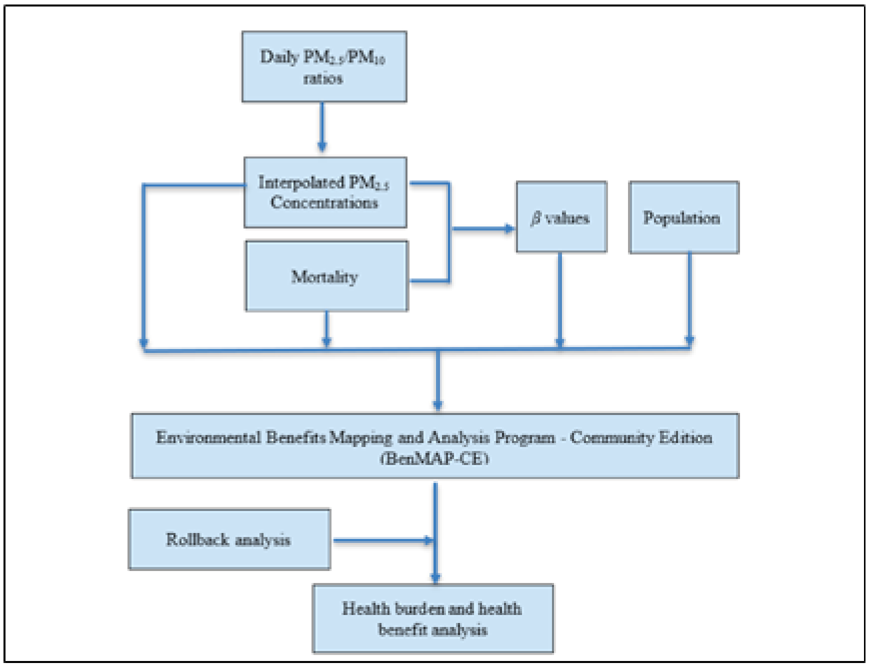


Figure 3.13: Workflow of the study procedure

To determine the mortality attributed to ambient PM2.5 concentrations, BenMAP-CE was used. This is a Geographic Information System (GIS)-based tool that estimates the health impact and corresponding economic value resulting from changes in air pollution levels. BenMAP-CE utilizes a health impact function, incorporating air quality monitoring data, population data, baseline incidence rates, and effect estimate to calculate health impacts quantified in terms of the change in mortality incidence rate resulting from the change in air pollution level. This is calculated using the following equations:

Equation 1: Concentration-response (C-R) coefficient

$$\boxed{\beta = \frac{ln(RR)}{\Delta PM2.5}}$$

Equation 2: Change in incidence Rate

$$\boxed{\Delta Y = Y_0\,(1 - e^{-\beta\,\Delta PM_{2.5}}) * pop}$$

In the first equation, relative risk (RR) refers to the ratio that compares the mortality of a $PM_{2.5}$ exposed group to the mortality of an unexposed group. C-R stands for the concentration-response coefficient and is used to gauge strength of the relative risk for a similar change in $PM_{2.5}$ exposure (ΔPM2.5). The change in $PM_{2.5}$ exposure is used to project the mortality reduction from an ambient value attributed to a certain target or standard. The C-R coefficient is then used in the second equation in order to calculate the change in incidence rate as a function changes in $PM_{2.5}$ exposure or concentration.

The results of the study are organized into 1) interpolated PM2.5 data, 2) correlation between PM2.5 and meteorological conditions, 3) health Benefit Analysis, and 4) uncertainty of the Analysis. This case study will only focus on the findings of health benefit analysis.

Figure 3.14 shows the original $PM_{2.5}$ and PM_{10} data from 2012 to 2018 as well as the interpolated concentrations compared with the WHO Air Quality Guideline Values and the Thailand annual standard values.

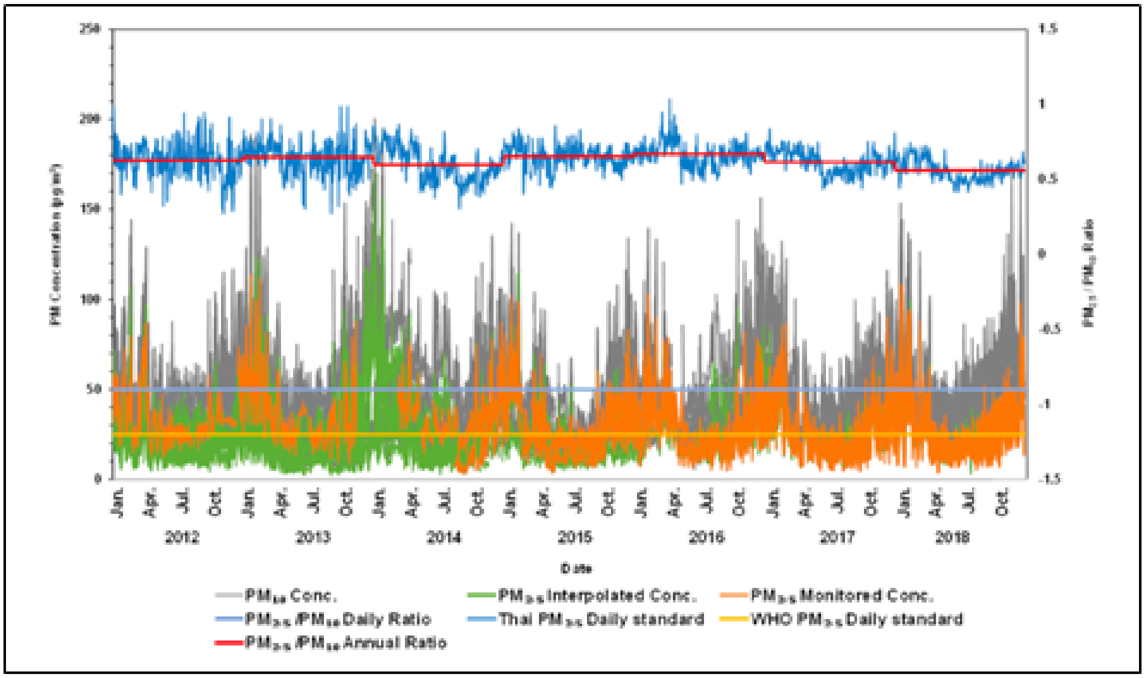


Figure 3.14: Daily average PM2.5 and PM10 concentrations, and PM2.5/PM10 ratios during 2012-2018

Table 3.8 shows the health burden resulting from anthropogenic $PM_{2.5}$ levels above the background concentration of 2.15 μg/m3 in Bangkok using values calculated from this study. The health burden is comprised of 4,240 non-accidental mortalities, 1,317 cardiopulmonary deaths, and 370 lung cancer mortalities.

Table 3.8. Health burden and avoided deaths in 2016 resulting from compliance with the Thai National Ambient Air Quality Standards (NAAQS) and the World Health Organization (WHO) guidelines

Health Endpoint	Health Burden	Thailand Standard 25 μg/m^3	WHO Guideline 10 μg/m^3
	Deaths * (95% CI)	Avoided Deaths * (95% CI)	Avoided Deaths * (95% CI)
Mortality, non-accidental	4240 (1219–6938)	1393 (593–2691)	3159 (893–5248)
Mortality, cardiopulmonary	1317 (1065–1551)	360 (284–434)	959 (769–1140)
Mortality, lung cancer	370 (175–530)	102 (45–156)	270 (125–397)

* Specific for age 30–99.

The table also shows the benefits in terms of the number of avoided deaths when the Thailand annual standard of 25 μg/m3 as well as the WHO annual guideline of 10 μg/m3 are met. The numbers demonstrate that compliance with the more stringent WHO annual standard is estimated to reduce premature mortality three times as much compared to meeting the Thai standard. Meeting the Thai annual standard of $PM_{2.5}$ will result in 25% reduction in premature mortality, while compliance with WHO annual guideline is estimated to lead to a 71% reduction in premature mortality each year.

As the first health impact study looking into annual mortality and $PM_{2.5}$ exposure in Bangkok, the findings demonstrated significant benefits of improving PM2.5 concentrations from existing levels towards meeting Thai annual standards and the WHO guideline values. The number of reduced premature deaths can be used to quantify economic benefits of air quality programs. Furthermore, the study recommended that additional research be carried to understand further concentration-dose responses using values specific to Bangkok as well as determining the effect of meteorology in PM2.5 analysis.

III. Strengthening Policies and Institutions

Previous sections provided an overview of core concepts and introduced decision-making tools that can help policy makers identify solutions capable of delivering co-benefits. For many cities, understanding these key concepts and using these tools will be necessary but not sufficient steps to achieving co-benefits. An additional set of needed changes involves the policies and institutions that can align government agency and other stakeholder interests behind integrating air pollution and climate change.

This alignment is needed for a few reasons. Firstly, failing to consider both air pollution and climate change concerns can result in policies that are beneficial for air quality but not climate (or vice versa). This can potentially have adverse impacts on the environment while also misallocating resources and increasing implementation costs. A related possibility is that relevant policies and institutions may *not* offer the financing, technologies, capacity building and other forms of enabling support needed for the widespread implementation for often small-scale transport, waste, or energy solutions. Lacking such support, it may be challenging to achieve the kinds of scalable reductions in GHGs and SLCPs often estimated with assessment models and decision-making tools (UNEP, 2019).

Discussing policy and institutional reforms needed for scalable change, however, can become an exercise that is too conceptual and abstract for policymakers. To lend more concreteness to this discussion, this section draws on actual examples from in and outside Asia. The case studies follow a standard format—moving from essential background to key barriers to success factors—to demonstrate the varying approaches subnational governments have adopted to bring together the air pollution and climate change agendas. The cases begin with the state of California and then move to New York and Seoul, Tokyo, concluding with Beijing.

Objectives

At the end of the section, participants will be able to do the following:

- Discuss policy and institutional reforms that subnational governments have adopted to align the air pollution and climate change agendas
- Identify policy and institutional reforms that can support this alignment in their own city.

4.1 California's institutions and planning processes

While California is a US state and not a city, it offers arguably the most instructive example of a subnational government working on air pollution at the same time as climate change. California's growing vulnerability to climate change is one of the key reasons it has many lessons to offer other subnational governments. In recent years, this vulnerability has increased to the point where state policymakers regularly confront droughts, wildfires, heatwaves, reduced snowpack, and other extreme weather events. These impacts place a heavy burden on California's economy and people.

Wildfires—which have increased in recent years—is one of the best-known examples of how climate change is affecting California. Warmer spring and summer, reduced snowpack, and earlier spring snowmelt create longer and more intense dry seasons that increase moisture stress on vegetation and make forests more susceptible to severe wildfires. CAL FIRE, the California Department of Forestry and Fire Protection, reported that the acres burned by wildfires grew steadily from 25,438 in 2010 to 822,794 in 2018, although a sharp decrease happened in 2019 (Figure 4.1). In 2020, total 9,639 wildfire incidents burned 4,177,856 acres of forest, caused 31 fatalities, and destroyed 10,4888 structures in California (Figure 4.2). In addition, increasing wildfires emitted air pollutants and caused heavy smog, threatening public health in California.

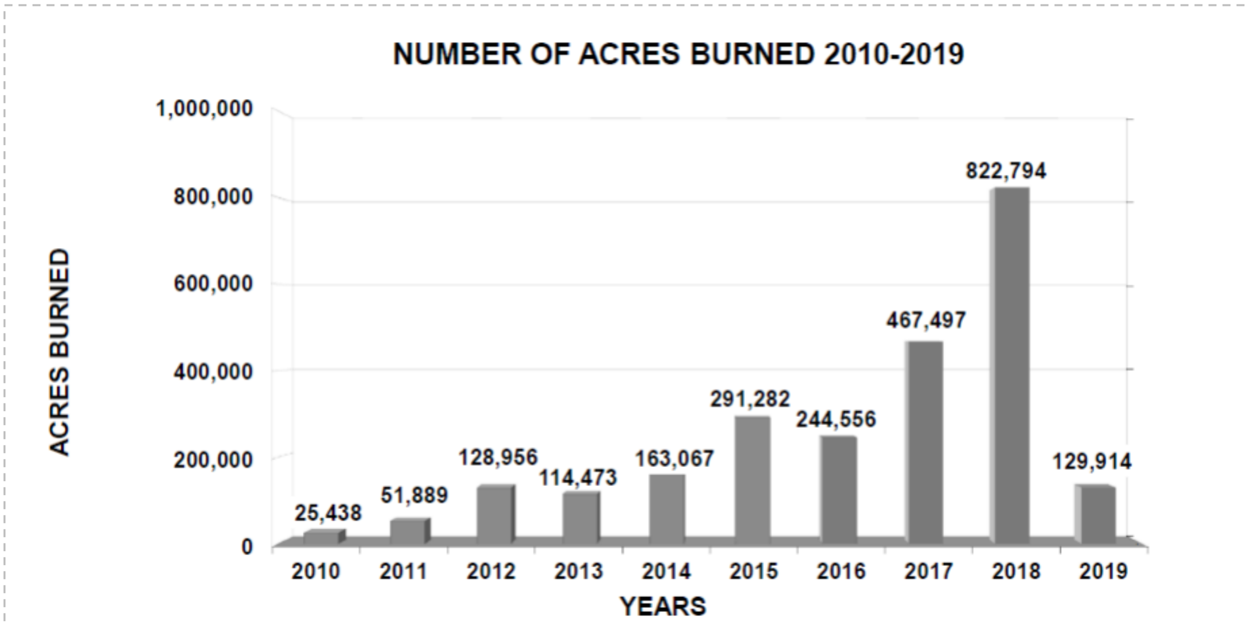


Figure 4.1: Number of acres burned 2010-2019 in California
(Source: CAL FIRE, n.d.)

Figure 4.2: A summary of all 2020 wildfire incidents in California, including those managed by CAL FIRE and other partner agencies (Source: CAL FIRE, n.d.)

California also has a keen and long-running interest in controlling air pollution. Due to high levels of transportation-related emissions in sprawling cities such as Los Angeles, California's urban air quality frequently exceeds national standards. These exceedances and their impacts on health and infrastructure are the main reason that California has been given the right to set state-level emissions standards that are more stringent than national standards.

The growing exposure to climate change and long-running experience with air pollution is arguably behind California's pioneering efforts to tackle climate change and air pollution together. Some of that recognition has resulted in policies that aim to regulate emission sources that contribute to both problems. It has led to reforms to consider the social dimension of air pollution and climate change in relevant policies and institutions (CARB, 2017a).

The agency leading the effort on air pollution and climate change is the California Air Resources Board (CARB). CARB was created in August 1967 with the goal of addressing air pollution through "a unified, statewide approach" (CARB, n.d.). Under the *Assembly Bill 32 (AB 32 or the Global Warming Solutions Act of 2006)*, CARB was assigned responsibilities for GHG emission reduction in 2006. As shown in Figure 4.3, to handle this responsibility CARB was placed in charge of a Climate Action Team made up of 18 relevant agencies that were tasked with bringing down GHG emissions to 1990 levels by 2020. In addition to placing CARB in this lead position, a decision was also made to create an Environmental Justice Advisory Committee that would work with communities and civil society on social justice issues related to AB 32. Yet a third important decision involved the establishment of an Economic & Technology and Advancement Committee to provide analysis and recommendations on the design and implementation of *AB 32* (CARB, 2018).

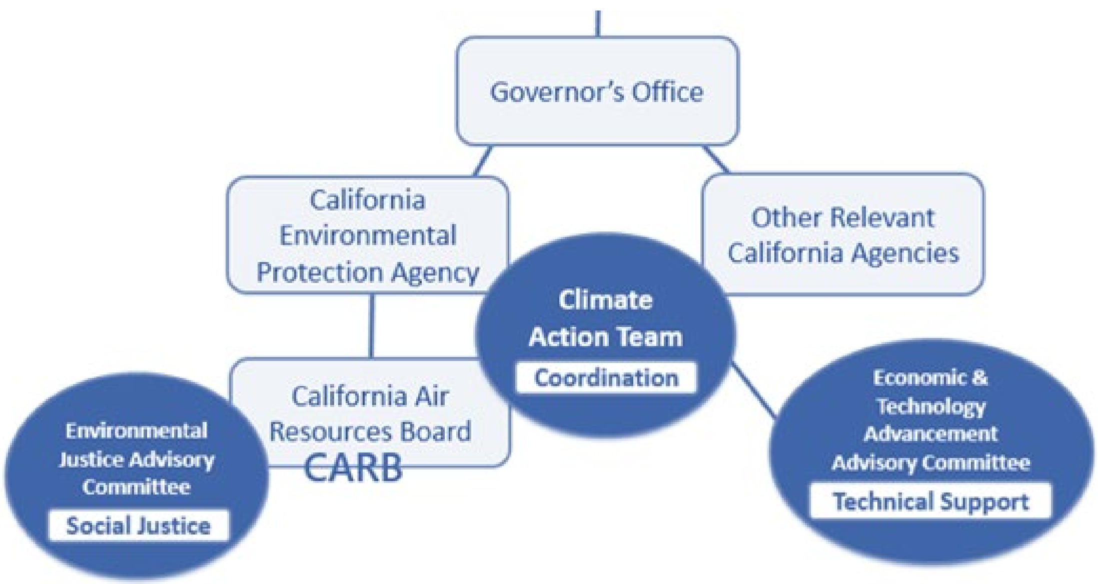


Figure 4.3: Institutional arrangement of air quality and climate change management in California (Source: IGES)

The institutional *structures* described above helped to strengthen the integration of air pollution and climate concerns. The decision-making *process* was also designed in a manner that facilitated this integration. The process was guided by a long-term mitigation goal as well as the development of a more flexible scoping plan that set out detailed targets in different sectors for the near term. The scoping plan was also adopted a few years before the AB 32's reduction targets came into force. This allowed for public comments on the plan while giving businesses sufficient lead time to prepare for required reductions. Some businesses were also motivated to act early before these legal restrictions were enforced and capture first mover advantages in relevant markets by changing technologies or production processes.

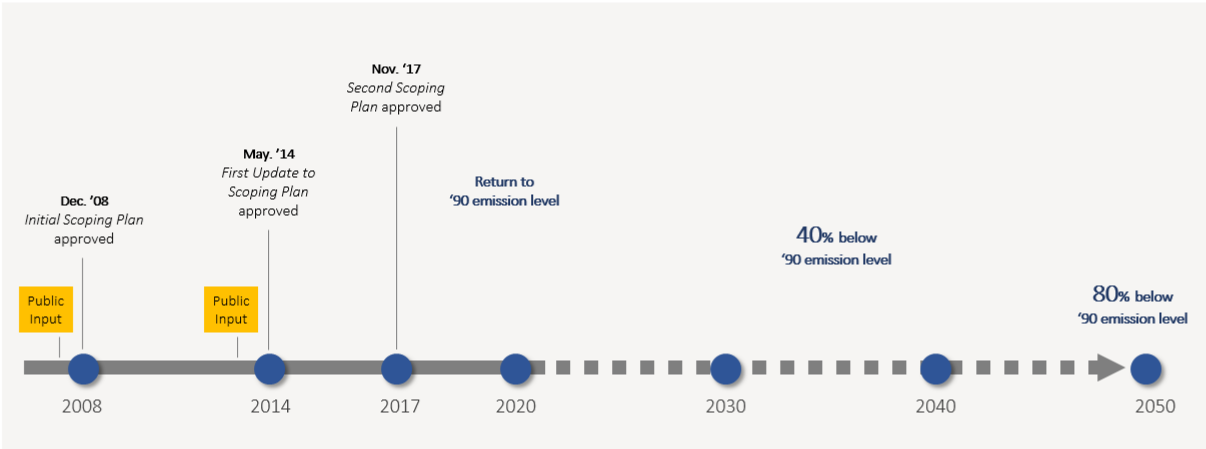


Figure 4.4: AB32 climate change scoping plan

Both the previously discussed structure and process also established a solid foundation for additional more targeted strategies and actions. For example, CARB worked with related agencies on a sector-specific Forest Carbon Plan and Sustainable Freight Action Plan. In a move that was particularly relevant to these materials, CARB further developed a first-of-its-kind *Short-Lived Climate Pollutant Strategy* at the subnational level that would feed into a *Second Scoping Plan for AB 32.* This second plan would come to be known as the *2017 Climate Change Scoping Plan* outlining comprehensive approaches to achieving its GHG emission reduction targets.

This new strategy was an important milestone since it marked the first time that CARB and contributing agencies sought to achieve synergies and avoid trade-offs between air quality, climate change, and other development priorities. A similarly motivated effort was made to ensure coherence between existing policies and strategies and the *2017 Climate Change Scoping Plan*. This would help avoid a situation wherein the Scoping Plan worked at cross purposes with, for example, a state-level industrial policy that promoted an increase in SLCPs or GHGs (CARB, 2017a).

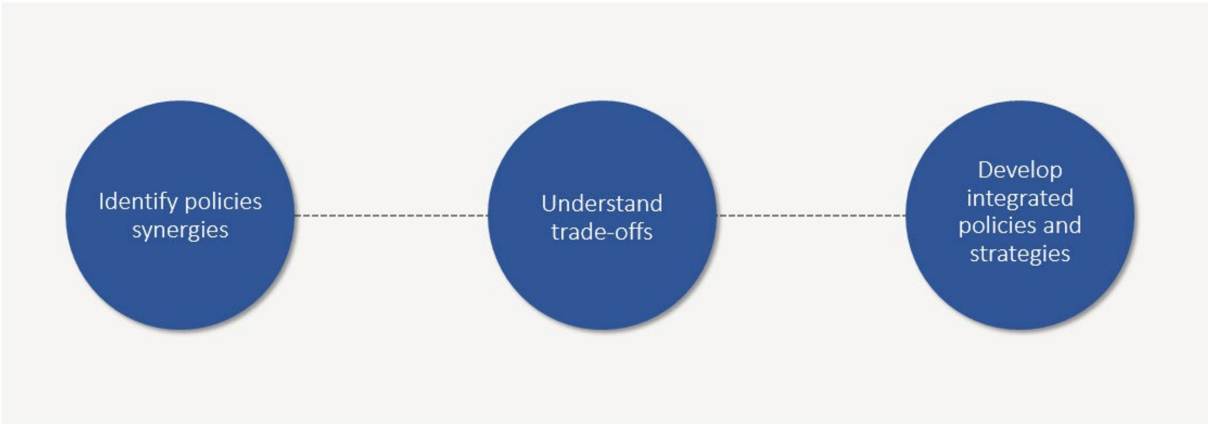


Figure 4.5: The process of developing integrated policies and strategies

The practical implementation of AB 32 encountered formidable challenges in balancing climate change mitigation and environmental justice concerns. Though efforts were made to engage the public, some communities, especially disadvantaged groups, continued to feel that their opinions received little consideration in practice. In 2017, California established Assembly Bill 617 (AB 617) to provide an unprecedented level of support for public engagement in developing comprehensive community-level policies. AB 617 includes new regulatory authority and funding to expand local air quality monitoring systems to better diagnose and monitor local air pollution hotspots (Fowlie et al., 2020).

Another bill to support California's GHG reduction and sustainable development is Senate Bill 375 (SB 375), the Sustainable Communities and Climate Protection Act. SB375 requires regional metropolitan planning organizations in California to develop Sustainable Communities Strategies (SCS) to reach their climate and air quality goals. Under this strategy, the core approach to integrate GHG emissions and air pollutants reduction in curbing the vehicle mile traveleds (VMT).

The implementation of SB 375 includes the following key activities:

-
- Focusing housing and job growth within existing urbanized areas.
- Utilizing infill opportunities to conserve natural resources and farmlands.
- Investing in expanded transit networks and service frequency.
- Investing in biking and walking infrastructure.
- Investing in transportation demand management, such as carpool/vanpool, carshare, and parking supply management.
- Planning homes at a range of densities and affordability levels near job centers.

Incentives are available to encourage local governments to implement projects under SCSs. Local governments themselves are facing increasing public awareness and call on climate change and sustainable development. California also provides financial incentives by linking SCSs actions with funding opportunities. For example, local governments implementing SCSs programs have priorities for selecting regional transportation program funding and California Climate Investments program funding (CARB, n.d.).

An additional reason California represents an instructive example is it has also worked with cities to achieve air quality and climate goals. To illustrate, in California's Bay Area (an area that includes San Francisco and Oakland) the Bay Area Air Quality Management District issued the *Bay Area 2017 Clean Air Plan: Spare the Air · Cool the Climate.* This plan seeks to protect public health through air quality improvement and climate change mitigation. The District began with the long-term vision for buildings, transportation, production and consumption in the Bay Area by 2050. It then decided on a multi-pollutant strategy that would help achieve these visions by addressing ozone, PM2.5, other toxic pollutants, and GHGs (Figure 4.6) (Bay Area Air Quality Management District, 2017).

Figure 4.6. The Bay Area Multi-Pollutant Strategy
(Source: Bay Area Air Quality Management District, 2017)

California's successful integration of climate change and air pollution issues can be attributed to several factors. One factor includes strong commitment from the state's political leadership. AB 32 and the supportive institutional reforms began to take shape when Arnold Schwarzenegger was Governor. Importantly, this commitment remained strong even after the person and party occupying the governor's office changed. The political commitment at the highest level has arguably shielded AB 32 from the kinds of opposition to climate change witnessed at the national level in the United States. At the same time, the opposition from the federal government to climate change has not helped California--and may explain why it offers an example that may be more useful outside than inside the United States.

4.2 New York - Long-term Urban Sustainability Strategy

In recent years, New York has been one of a growing number of cities in the United States to pursue a more sustainable development path. A clear example of this pursuit was the passage of *OneNYC 2050: Building a Strong and Fair City (OneNYC 2050*). As its name implies, *OneNYC*

2050 is a plan released in 2019 intended to guide New York's development for 30 years. As a forward-looking development strategy, *OneNYC 2050* not only presents a vision for a desirable long-term future but outlines eight goals and 30 initiatives that will help achieve those aspirations.

Importantly for the sake of this curriculum, both air pollution and climate change are featured in the strategy. Their inclusion is reflected in targets that aim to lower ambient concentrations of PM2.5 to 7.85 μg/m3 while eliminating GHGs by 2050. *OneNYC 2050* also contains specific activities to help achieve its air pollution and climate change targets. These activities are linked to additional targets focusing on healthy lives, a liveable climate, and efficiency mobility.

A VIBRANT DEMOCRACY	1.	Empower all New Yorkers to participate in our democracy
	2.	Welcome new New Yorkers from around the world and involve them fully in civic life
	3.	Promote justice and equal rights, and build trust between New Yorkers and government
	4.	Promote democracy and civic innovation on the global stage
AN INCLUSIVE ECONOMY	5.	Grow the economy with good-paying jobs and prepare New Yorkers to fill them
	6.	Provide economic security for all through fair wages and expanded benefits
	7.	Expand the voice, ownership, and decision-making power of workers and communities
	8.	Strengthen the City's fiscal health to meet current and future needs
THRIVING NEIGHBORHOODS	9.	Ensure all New Yorkers have access to safe, secure, and affordable housing
	10.	Ensure all New Yorkers have access to neighborhood open spaces and cultural resources
	11.	Advance shared responsibility for community safety and promote neighborhood policing
	12.	Promote place-based community planning and strategies
HEALTHY LIVES	13.	Guarantee high-quality, affordable, and accessible health care for all New Yorkers
	14.	Advance equity by addressing the health and mental health needs of all communities
	15.	Make healthy lifestyles easier in all neighborhoods
	16.	Design a physical environment that creates the conditions for health and well-being
EQUITY AND EXCELLENCE IN EDUCATION	17.	Make New York City a leading national model for early childhood education
	18.	Advance equity in K-12 opportunity and achievement
	19.	Increase integration, diversity, and inclusion in New York City schools
A LIVABLE CLIMATE	20.	Achieve carbon neutrality and 100 percent clean electricity
	21.	Strengthen communities, buildings, infrastructure, and the waterfront to be more resilient
	22.	Create economic opportunities for all New Yorkers through climate action
	23.	Fight for climate accountability and justice
EFFICIENT MOBILITY	24.	Modernize New York City's mass transit networks
	25.	Ensure New York City's streets are safe and accessible
	26.	Reduce congestion and emissions
	27.	Strengthen connections to the region and the world
MODERN INFRASTRUCTURE	28.	Make forward-thinking investments in core physical infrastructure and hazard mitigation
	29.	Improve digital infrastructure to meet the needs of the 21st century
	30.	Implement best practices for asset maintenance and capital project delivery

Figure 4.7: AQ and CC integration in OneNYC 2050 (released in 2019)

The quantitative and qualitative goals associated with activities in Figure 4.8 recognize that air pollution and climate change often share similar sources and solutions. This realization is, for instance, reflected in goals on air pollution and climate in the city action plan where transportation/mobility and energy are recognized as contributing to both problems. Meanwhile, the livable climate goal targets and the efficient mobility goal aim to achieve climate and air quality benefits with energy and transport-related activities. Another notable feature of *OneNYC 2050* demonstrating a different form of integration is its healthy lives activities; these activities explicitly aim to address the interactions between air- and climate-related health impacts.

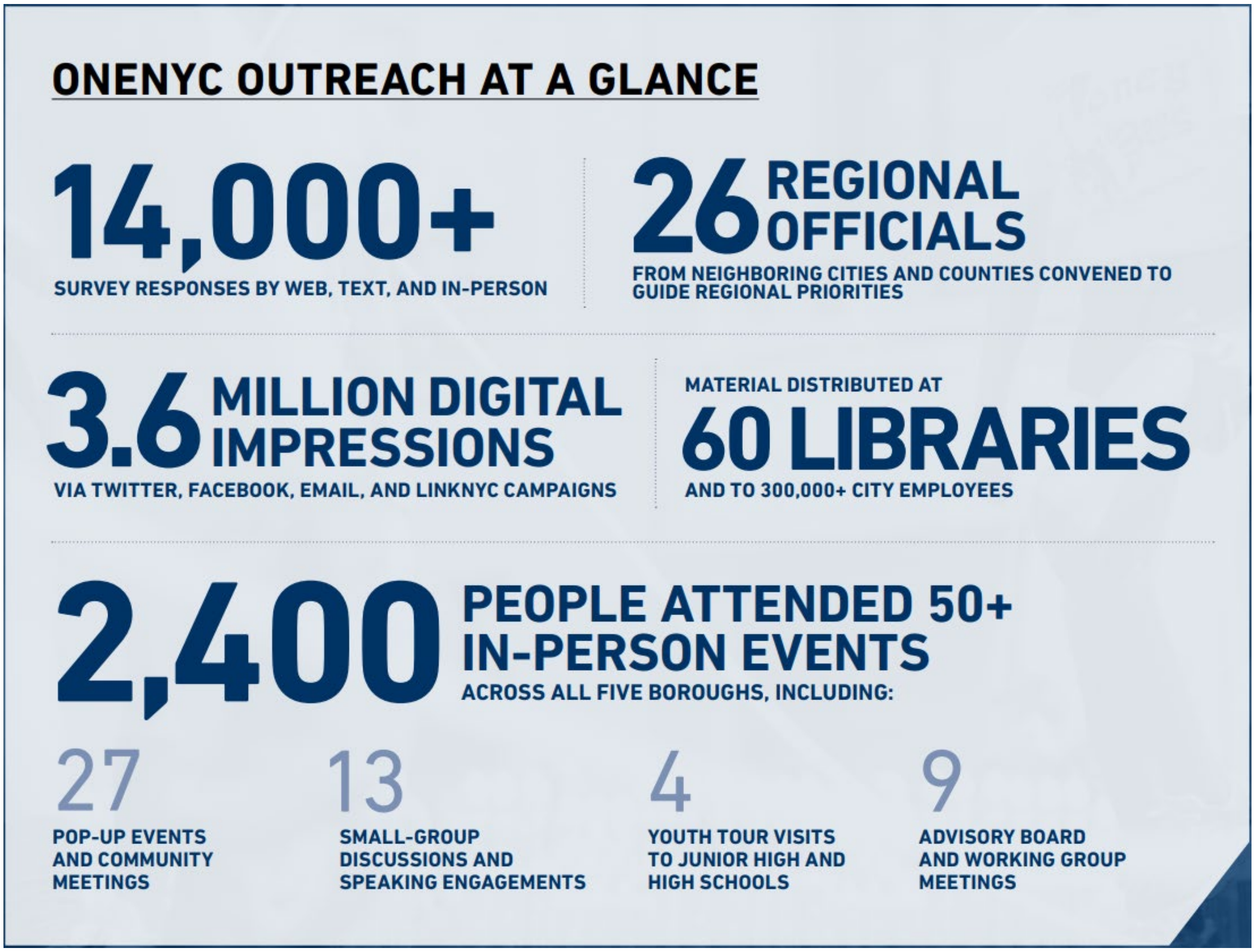


Figure 4.8: OneNYC 2050 outreach at a glance (released in 2019)

Above and beyond the design of OneNYC, there are several factors that contributed to the process of developing the program. In particular, New York emphasized a participatory and inclusive approach to urban planning that sought inputs from various stakeholder groups through a wide range of different channels and media. New York further aimed to communicate in numbers the levels and types of participation. In comparison to California, both the inclusion and communication elements are even more prominent in New York. This, in turn, helped to strengthen the connection between not only clean air, climate change, and health but other (possibly more tangible) livelihood issues.

Though the experience with OneNYC has been largely positive, it also encountered some challenges. One of the main hurdles has been on securing sufficient levels of resources to implement the programme. According to the Independent Budget Office, dating back to the 1980s, New York has seen a reduction in financial support from the federal government. This has meant it relies more heavily on local taxes and revenues to underwrite city-level activities. It further remains to be seen whether there will be sufficient resources to carry forward plans following the recovery from the COVID-19 pandemic. Similar to California, New York might have to fight an uphill battle with the federal government to pursue ambitious climate change goals.

4.3 Seoul - Recognizing Co-Benefits

Starting with several actions to reduce both criteria pollutants and GHGs, co-benefits have become an emerging priority in Seoul, South Korea. Seoul’s interest in achieving these benefits may have not been intended initially as actions focused chiefly on climate change or air quality. Yet the benefits from working on both issues in parallel have become increasingly recognizable in several of the programs described below.

Some of the main programs that have helped deliver co-benefits focused first and foremost on abating air pollution. These include the city’s efforts to improve and replace fuels to lower mobile source emissions as well as the development of low emission zones (LEZ). Other similarly motivated programs have sought to curb personalized motorized transport by expanding green spaces. Yet a third set of examples has sought to replace inefficient technologies. The most successful of these efforts began since 2008 when the city started to adopt a low NO_x burners program that subsequently resulted in the replacement of more than 2,800 conventional burners, contributing to sharp reductions in NO_x and CO_2 while saving energy and more than KRW 220 billion revenue over a ten year period.

Other programs in Seoul have taken climate change as the main entry point. Many of the actions fitting this characterization were conceived as part of Seoul’s comprehensive energy management plan or One Less Nuclear Power Plant (OLNPP). Formulated shortly after the Fukushima triple disaster, the OLNPP was so-named because it was intended to save the amount of energy that could be generated by a nuclear power plant. The OLNPP’s first phase lasted two years (2012-2014), during which it managed to bring about a reduction in 1 GW/ 20 million TOE energy demand. The second phase (2014-2020) of OLNPP aimed to double first phase reductions and achieve 20% energy self-sufficiency (Seoul Solution, 2018). These programmes benefited from Seoul’s mayor’s commitment to climate change who served as a Chair of the World Mayors Council on Climate Change (WMCCC).

While the two sets of programs outlined above were effective from either an air pollution or a climate perspective, it was only during the ICLEI World Congress in April 2015 that Seoul clearly indicated its intention in integrating climate change and air quality. As articulated in the declaration of the *Promise of Seoul: Taking Actions against Climate Change*, this was to be achieved through a comprehensive management system that addressed both GHGs and air pollution (one of the 11 promises committed by Seoul). In order to fulfill the promises, 10 action areas have been proposed for implementation.

Figure 4.9. Tasks and action plan areas of Promise of Seoul (Source: Promise of Seoul, 2015)

In the context of co-benefits, the Action Plan on Air Quality ensured mobile sources were incorporated into the city's climate change plan. These benefits were pursued by promoting an eco-friendly driving culture among citizens, business and government agencies. Specifically, activities with the relevant 2030 target were defined as follows:

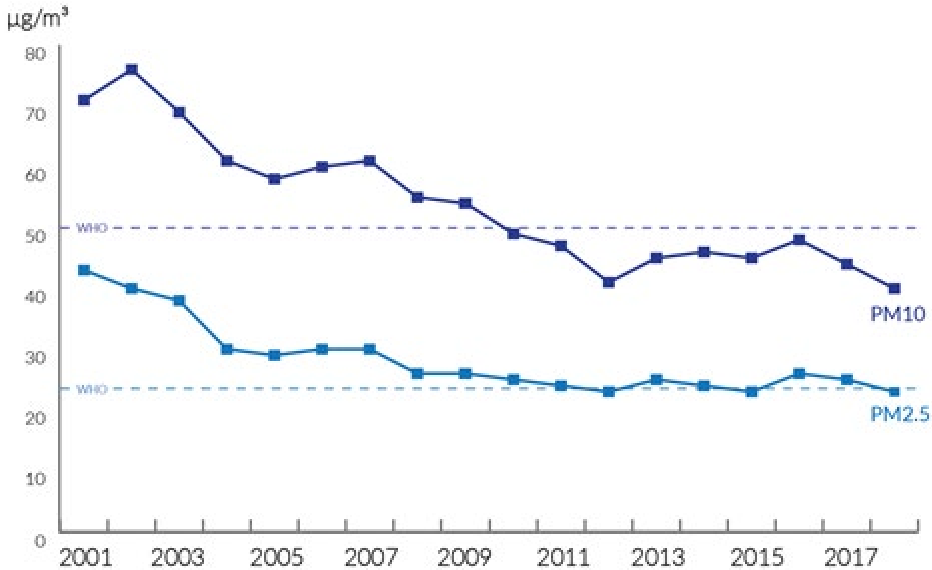
1. Promote an environmentally-friendly driving culture: 10,000 persons will have participated in experience-based education for eco-friendly, economic driving
2. Facilitate low carbon, eco-friendly modes of transport: the distribution of electric vehicles will reach 2,600,000 and that of hybrid vehicles will be reduced to 100,000
3. Build domestic and international cooperation and implementation system responding to climate change: 50 low-emission zone with monitoring system will be established, and the capital will continue to operate international forum on improving air quality in Northeast Asia to foster regional cooperation
4. Make Seoul a safe city against Fine Particles: the City will meet the WHO standard of $PM_{2.5}$, which is 15 $\mu g/m^3$, and low emission projects will be carried out to the 60,000 forecasted number of diesel vehicles, especially on old models

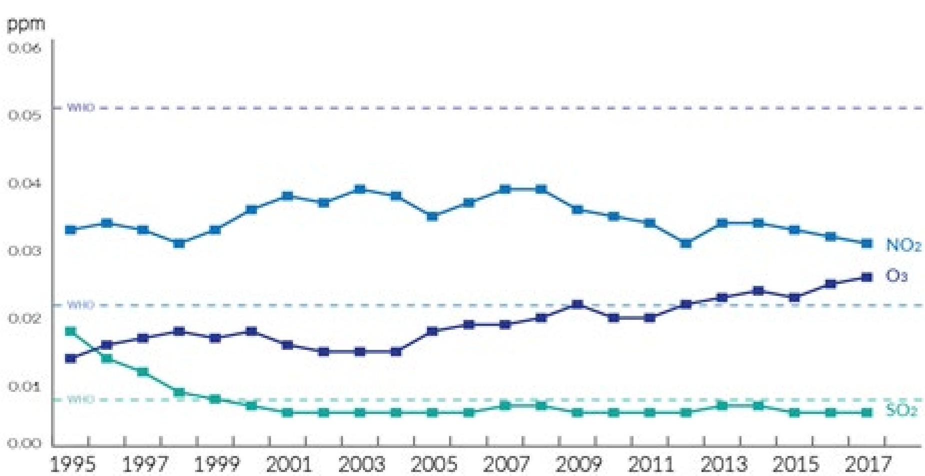
Across the *Promise of Seoul*, a recurring theme has been strong and active public participation. For many years, Seoul has emphasized the importance of working with citizens not as passive recipients but active providers of knowledge. For example, in the case of boiler replacement, Seoul's governments informed citizens of the advantages and disadvantages of eco-friendly condensing boilers (that discharged only one-eighth of the levels of $PM_{2.5}$ as regular boilers). Boiler producers were also encouraged to proactively promote their eco-friendly boilers. In the

Promise of Seoul, the most important rationale “Citizen Involvement Matters the Most” is clearly stated in the first page of this high-level guiding document. Citizen involvement would be emphasized early and often; this also involved the government establishing citizen-led evaluation groups to engage and take forward citizen proposals and ideas (SMG, 2015).

Box 4.1: Reducing air pollution in Seoul

Due to many of the reforms described in this section, emissions of many of the key pollutants have fallen or not increased in Seoul over the past decade. For instance, the annual average of PM_{10} and $PM_{2.5}$ remained at 2012 levels – $40\mu g/m^3$ and $23\mu g/m^3$ respectively. Another encouraging sign is that the concentrations of SO_2 have remained below WHO standards since 2001. Less encouraging has been the fluctuations in NO2 levels that have been above WHO standards as well as ozone level has been increasing although remaining below WHO standards.





Given that climate change and air pollution often share similar sources, there is scope for further integration in Seoul’s household, commerce, and the transport sectors. These sectors represent the greatest sources of energy consumption as well as criteria air pollutants. Strengthening integration of climate and air pollution concerns would also necessitate coordination between relevant institutions and policies.

4.4 Tokyo - Control of Diesel Emissions from Mobile Sources

In the 1990s, increases in mobile source emissions of PM led to sharply escalating concerns over the risk of respiratory diseases and cancer in Tokyo, Japan. Research from that period showed that diesel vehicles, although accounting for only 20% of the total vehicles in Tokyo, were responsible for the majority of PM emissions, including BC. As noted previously, BC is one of the SLCPs with impacts on near-term climate change and air quality.

To help curb these emissions, the Tokyo Metropolitan Government (TMG) initiated the “Say No to Diesel Vehicles” campaign in 1999. The TMG also rolled out an *Ordinance on Environmental Preservation to Secure the Health and Safety of Citizens of the Tokyo Metropolitan Area* in December 2000. This was soon followed by the introduction of a low sulfur diesel fuels and mandates on the installation of diesel particulate filters (DPF)[2] for trucks, buses and other large diesel-powered vehicles across the Greater Tokyo Area in 2003. Diesel vehicles that did not meet emission standards were either restricted from entering that area, needed to be replaced with cleaner vehicles, or mandated to be equipped with reduction devices (Bureau of Environment, TMG, 2018a). To facilitate the implementation of these regulations for resource-constrained businesses, the TMG also provided loans or subsidies for small and medium sized enterprises to purchase low-emission vehicles (TMG, 2003). This package of policies and measures led to significant improvements in air quality and sharp reduction of PM in Tokyo (Figure 4.11). They also motivated other parts of Japan as well as the national government to adopt similar policies and measures with comparable ends in mind.

[2] DPFs require low sulfur fuels to function properly.

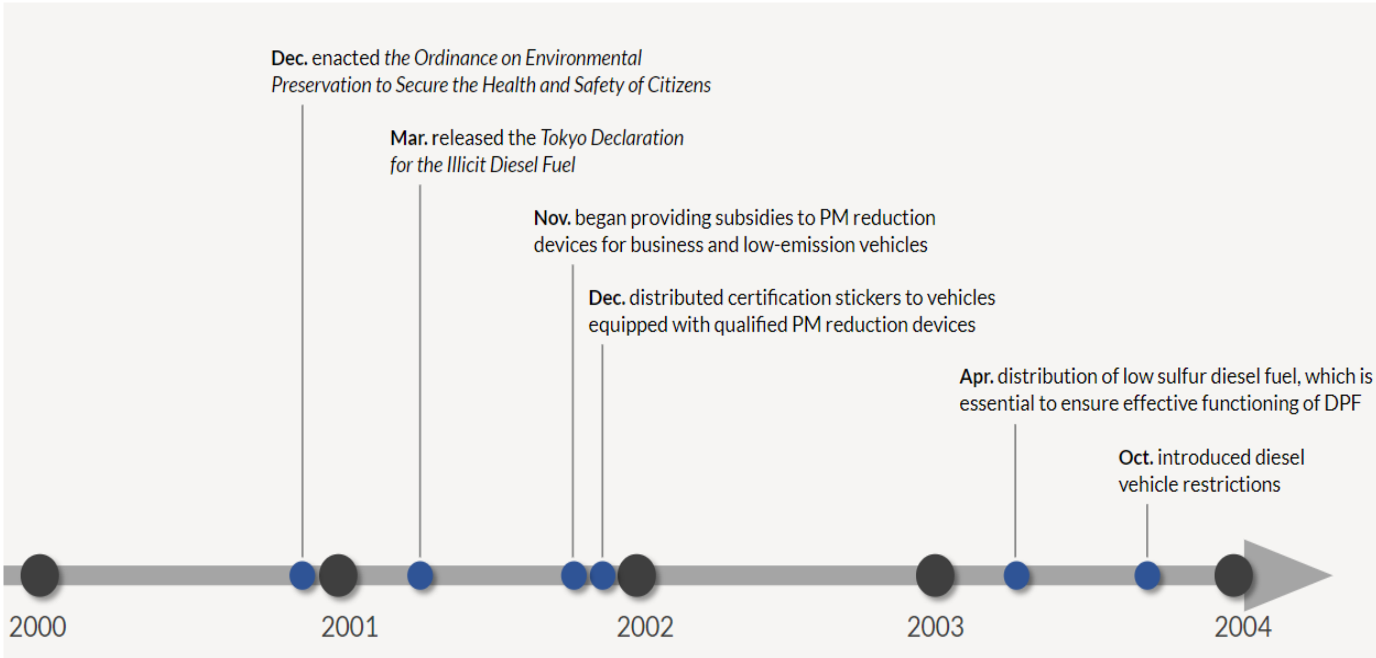


Figure 4.10: The development of policies on diesel vehicles in Tokyo

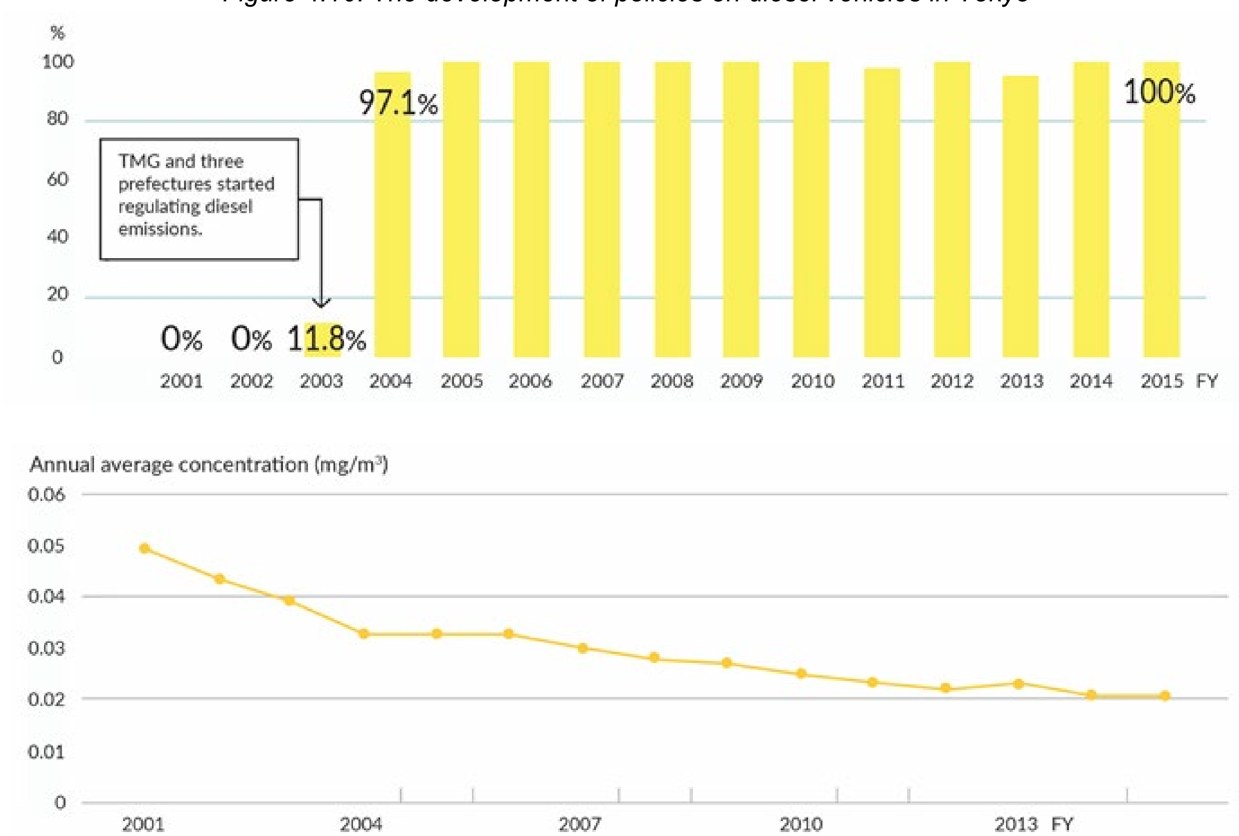


Figure 4.11: Environmental standards on and achievement of vehicle control during 2001-2015

In the years that followed Tokyo's diesel regulations, the city government would begin to focus more on reducing emissions of CO_2 and other criteria air pollutants from mobile sources. For example, between 2011 and 2015 TMG introduced the Vehicle Emission Reduction Program that requested approximately 1,700 businesses submit a Vehicle Emission Reduction Plan aimed at mitigating both GHGs and air pollutants. The encouraging results of this first phase led to a second phase (2016-2020) where 1,5000 businesses were required to work on the promotion of eco-driving (an approach to driving that aims to reduce fuel consumption) in addition to purchasing hybrid vehicles (Bureau of Environment, TMG, 2018a).

There are a number of factors that contributed to the success of the TMG initiatives. Firstly and somewhat surprisingly, the absence of regulations at the national level combined with far-sighted leadership to bring about policy changes at the city level. Tokyo's mayor launched the diesel programme because he felt the need to compensate for the absence of national standards and policies on diesel-powered vehicles. The second set of success factors involved extensive business consultation and promotion campaigns led by the TMG. The city made concerted efforts to engage the users of 20 vehicle types across 3,800 businesses, including 2,000 large enterprises, prior to the piloting of 2003 diesel vehicle control measures (Bureau of Environment, TMG, 2018b). A similar approach to business consultations and engagement was also a defining feature of the Vehicle Emission Reduction Program (Bureau of Environment, TMG, 2018a). The third set of success factors involves the level of regional cooperation among cities in the Greater Tokyo Area. While Tokyo proper played a leadership role, it worked closely with surrounding prefectural and city governments that are home to businesses that depend heavily on access to Tokyo when, for example, determining the number of diesel vehicles entering the city.

The TMG's forward strides were not without challenges. Some of the main challenges included ensuring a diverse range of vehicles that needed to be outfitted with the aforementioned DPF and the difficulties of conducting emission measurements over the course of the actual operation of the vehicles. Yet another difficulty involved the different techniques required to reduce NOx at the same time as PM.

4.5 Beijing - Co-Control Approach

Beijing's struggles with air pollution have been well chronicled. However, in recent years, the city has enjoyed success reducing emissions of several pollutants. As of 2019, for example, four air pollutants—SO_2, NO_x, PM_{10} and CO—reached national level 2 standards. At the same time, there is still room for improvement on $PM_{2.5}$ and ozone; levels of both pollutants remain above national 2 standards (BMEEB, 2020a). Even as Beijing has stepped up efforts to control air pollution, city leaders have become more aware of the impacts of climate change such as heat waves and flooding (Zhang et al., 2019). These impacts are anticipated to be particularly great in Beijing as the city has a significant amount of infrastructure that is vulnerable to the effects of a warmer climate (Hu, 2016).

In both Beijing and other cities in China, there have been past efforts to align the air pollution and climate agendas. These efforts are part of a larger co-control approach that has been discussed in various forms for more than a decade in China. Over the past two years, Beijing has become even more interested in how co-control of air pollution and climate could be tailored to its needs.

One of the reasons for this recent rise in interest is the recognition that clean energy policies—which have been strongly supported by the national government—can help achieve air quality goals. To some extent, this realization dates back to China's 11th Five-Year Plan (FYP) when policymakers recognized that efforts to achieve energy intensity targets were also helping to achieve SO_2 targets. In more recent years, the realization of the potential for energy and other policies to help improve air quality has led to more coordinated efforts to promote clean energy as well as structural reforms that can bring down emissions of some pollutants. For example, a central sub-plan of the 13th FYP is the *Energy Production and Consumption Reform Plan (2016-2030)*, which contains both a CO2 emission target and PM2.5 reduction target. These targets are then linked to roadmaps for lowering emissions of $PM_{2.5}$ to 35 μg/m3 in Beijing-Tianjin-Hebei and its Surrounding Areas to reduce $PM_{2.5}$ concentration (UNEP, 2019). To help achieve these goals, Beijing evaluated the mitigation potential of 32 policies measures in seven categories and redoubled efforts to address emissions from coal-fired boilers, residential fuel use, and mobile sources (UNEP, 2019).

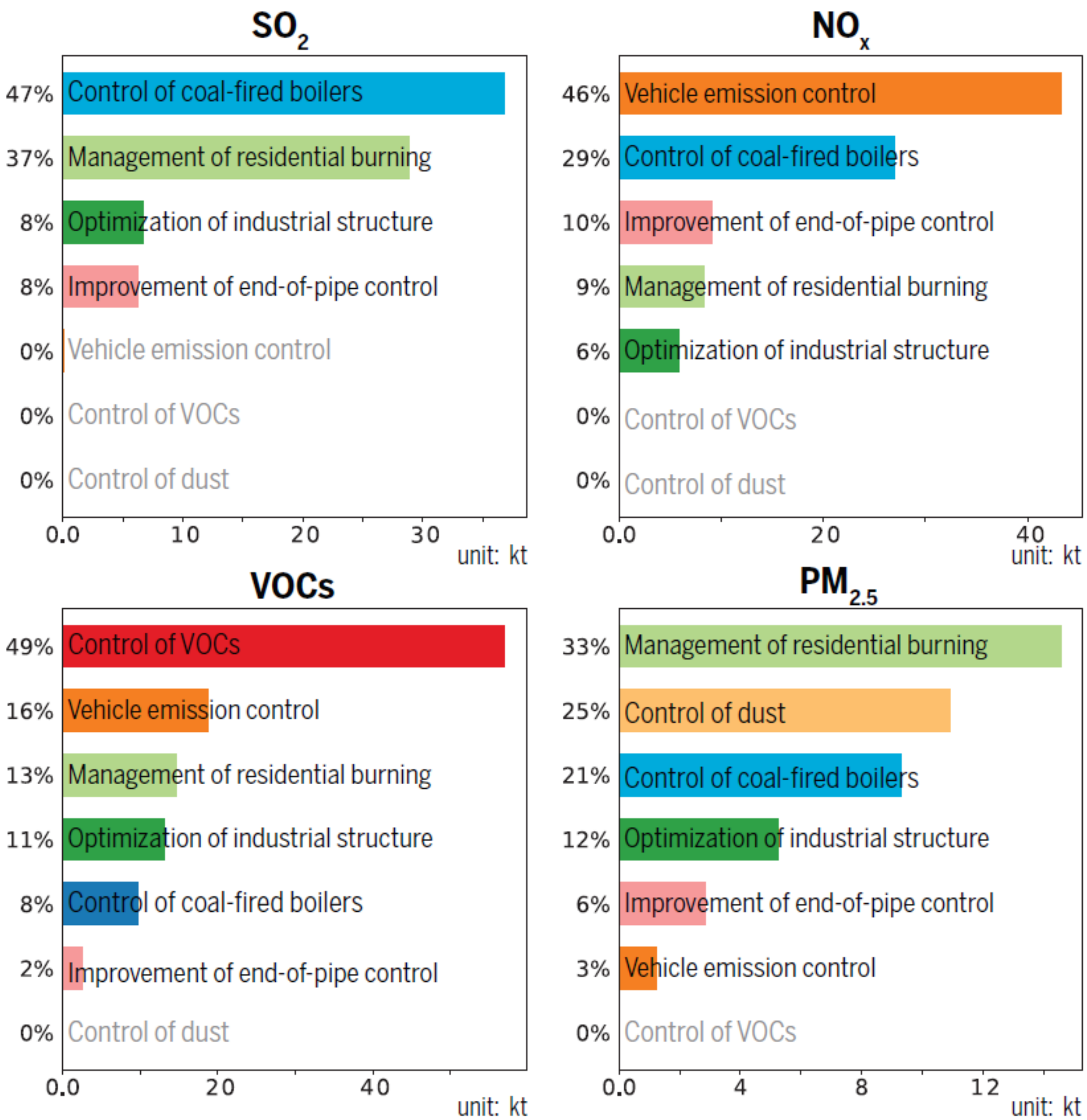


Figure 4.12: Contribution of measures to the reduction of major pollutant emissions in Beijing during 2013-2017 (Source: UN Environment, 2019)

Another factor contributing to the growing interest in co-control is a decision to place the climate change portfolio under the then recently reformulated Ministry of Ecology and Environment (MEE). Mitigating climate change was previously the chief responsibility of the National Development and Reform Commission (NDRC). The reshuffling of responsibilities happened first at the national level; but, as is common practice in China, cities are required to undertake reforms mirroring those at the national level. This has meant that the Beijing Municipal Ecology and Environment Bureau (BMEEB) is now tasked with both managing air quality and mitigating climate change. Reflecting its new responsibilities, the BMEEB is now seeking to enhance air quality and thereafter pursue a second goal of reducing CO2 (BMEEB, 2020b).

Figure 4.13: The reformulation of BMEEB bearing air quality management and climate change responsibilities

A third set of factors behind the growing interest in co-control in Beijing and other cities involves the performance evaluation system. Traditionally, city mayors are evaluated based on their ability to achieve targets set at the national level. While these targets once focused chiefly on levels of economic development or foreign direct investment, there has been a welcomed effort to include energy and environmental targets as part of the evaluation criteria. Performance on these criteria can determine whether a local leader is promoted or demoted—for example, to lead another city or to occupy a national level position. As such, the inclusion of both energy and air pollution targets in the criteria has generated strong incentives for local leaders to seek cost-effective ways of achieving not just one but multiple delegated targets under the FYPs. These incentives are not unique to Beijing but they are arguably even stronger given its status as the national capital and pioneer in numerous policy areas.

Last but not least and as implied elsewhere in this section, Beijing is understandably regarded as a leader on many national and cross-regional efforts in China. This reputation has been particularly important when it comes to interventions aimed at curtailing pollution from Beijing-Tianjin-Hebei and its surrounding areas. Because this region consists of the most polluted cities in China, the central government has placed an emphasis on regional cooperation that could have implications for co-control. To illustrate, regional cooperation was at the core of past efforts to reduce air pollution such as during the 2008 Olympic Games, the 2014 Asia-Pacific Economic Cooperation (APEC) Summit and the 2015 China Victory Day Parade. Central government-led cooperation has also been the centerpiece of efforts to arrest dangerous levels of PM2.5 when the State Council formed the *Coordination Group for Air Pollution Prevention and Control in Beijing-Tianjin-Hebei and Surrounding Areas* in 2013. It was similarly part of the motivation behind the formation of a Leadership Group in 2018 (Figure 4.13) led by the Vice Premier Han Zheng with support of the Minister of Ministry of Ecology and Environment and mayors/governors across the region (He et al. 2018). Using these regional frameworks, the national government has gradually increased regulatory measures. These have included the *Strengthened Measures on Air Pollution Prevention and Control in Beijing, Tianjin and Hebei Act* that sets out annual PM2.5 reduction targets in all involved cities and provinces since 2016 (UN Environment, 2019;BMEEB, 2020c).

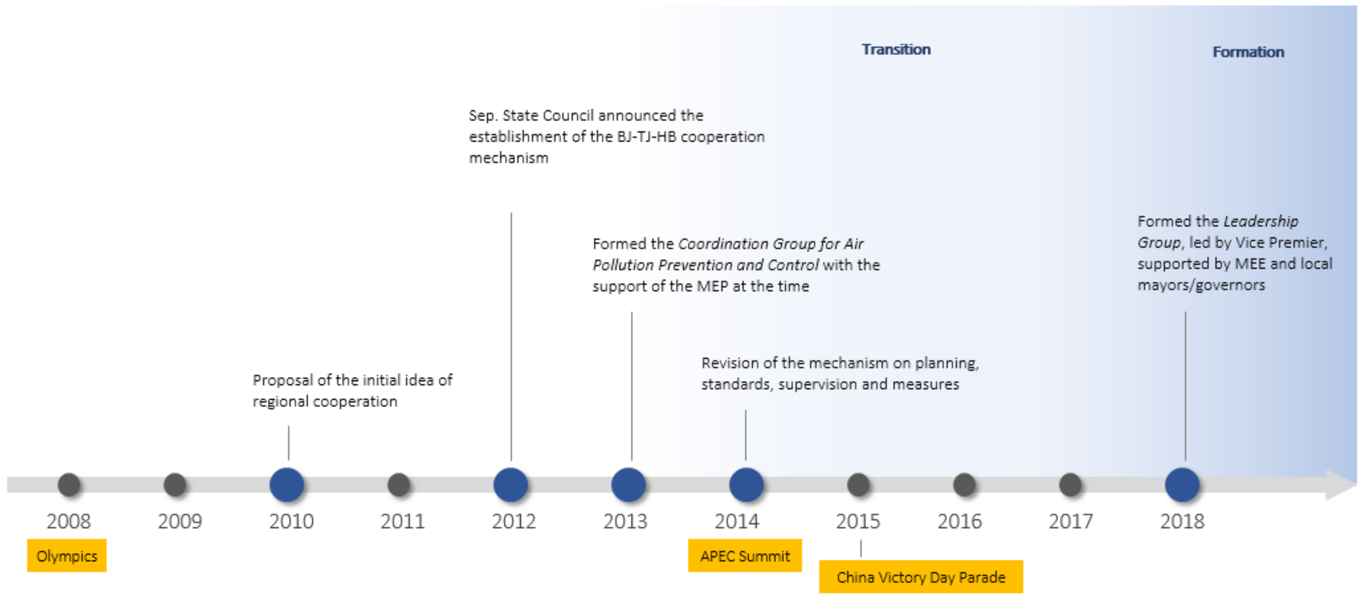


Figure 4.13: The evolution of Beijing-Tianjin-Hebei regional cooperation mechanism

A key success factor in the Beijing case is the top-down approach that is found in many policy decisions in China. The Chinese leadership maintains considerable influence over the direction of policies and design of institutions. When the leadership decides to change in policy or alter an institution, municipal governments follow. This can create a sense of certainty and reduce the time involved in introducing new approaches. Beijing also has arguably benefited from its status as national leader and the performance evaluation system that have placed a premium on working on both air pollution and climate change.

These success factors, to some extent, may also be seen as limitations. A possible drawback of top-down decision-making is there can be limited room for adaptation and contextualization. This can be particularly difficult if there are limits of local resources to achieve national goals. There also may be more rigidity in the institutions to new ways of thinking and outside-the-box solutions.

4.6 Summary and conclusion

In summary, cities are following different approaches and using varying entry points to integrate air pollution and climate change. This section has shown approaches range from building cross-sectoral planning into relevant institutions (California) to making air quality and climate change part of a city's sustainability strategies (New York) to following national mandates (Beijing) to discovering co-benefits through narrower interventions that grow into broader initiatives (Seoul or Tokyo) (Table 4.1). The section has also shown that entry points also varies some cities starting with conventional air pollution controls and others beginning with more forward looking (next stage) options or development priorities. Moreover, while there is significant diversity across the cases, there are several success factors and challenges that appear across different cities and regions. These include the following:

1. Strong and proactive leadership (often with an underlying political motivation)
2. Effective coordination across institutions charged with air pollution, climate and other relevant sectoral portfolios
3. Vertical integration of national goals into city planning processes
4. Local innovation in response to national rules (with some potential for scaling)
5. Multi-stakeholder engagement and targeted public communication

Table 4.1. Comparison of integrated approaches and entry points in California, New York, Seoul, Tokyo and Beijing

	Approach / Entry Points	**Conventional controls**	**Next stage measures**	**Development priority**
California	Integrated planning approach at State level			✓
New York	Integration at city long-term strategy			✓
Seoul	Co-benefits recognition from both AQ and CC aspects		✓	
Tokyo	Diesel vehicle control to co-control AQ and CC	✓		
Beijing	Central government-driven co-control		✓	

IV. References

Aamaas B., Lund MT, Myhre G, Samset BH, Stjern CW, Kallbekken S (2018) The climate impacts of current black carbon and organic carbon emissions. CICERO Report 2018:08.

Bay Area Air Quality Management District. 2017. Spare the Air · Cool the Climate: A Blueprint for Clean Air and Climate Protection in the Bay Area. https://www.baaqmd.gov/~/media/files/planning-and-research/plans/2017-clean-air-plan/attachment-a_-proposed-final-cap-vol-1-pdf.pdf?la=en

BMEEB. 2008. Strengthen Hig-Emitting Vehicles Pollution Prevention and Control, Promote Air Quality Imrprovement in the Capital.

BMEEB. 2018. Inauguration of BMEEB. http://sthjj.beijing.gov.cn/bjhrb/index/xxgk69/zfxxgk43/fdzdgknr2/xwfb/841698/index.html

BMEEB. 2019a. Beijing to Print, Issue and Implement the 2019 Action Plan for Pollution Prevention and Control, Overall Plan for Air, Water and Soil Protection Tasks in 2019. http://sthjj.beijing.gov.cn/bjhrb/index/xxgk69/zfxxgk43/fdzdgknr2/xwfb/845618/index.html

BMEEB. 2019b. Notice of Beijing's Early Implementation of the China 6 Vehicle Emission Standards. http://sthjj.beijing.gov.cn/bjhrb/index/xxgk69/zfxxgk43/fdzdgknr2/shbjgfxwj/1750455/index.html

BMEEB. 2020a. Beijing Ecology and Environment Statement 2019. http://sthjj.beijing.gov.cn/bjhrb/index/xxgk69/sthjlyzwg/1718880/1718881/1718882/1791057/2020051111183160595.pdf

BMEEB. 2020b. BMEEB 2019 work summary and 2020 work plan. http://sthjj.beijing.gov.cn/bjhrb/index/xxgk69/zfxxgk43/fdzdgknr2/ghjh44/1744756/index.html

BMEEB. 2020c. Significant Achievements in Ecological and Environmental Protection Breakthroughs via Strengthening Jing-Jin-Ji Regional Co-Control. http://sthjj.beijing.gov.cn/bjhrb/index/xxgk69/zfxxgk43/fdzdgknr2/xwfb/1702213/index.html

Boucher, O. Randall, D. Artaxo, P. Bretherton, C. Feingold, G. Forster, P. Kerminen, V.-M. Kondo, Y. Liao, H. Lohmann, U. et al. The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Internet], Cambridge University Press (2013), p. 2013

Bond, T.C., Doherty, S.J., Fahey, D.W., Forster, P.M., Berntsen, T., DeAngelo, B.J., Flanner, M.G., Ghan, S., Kärcher, B., Koch, D. and Kinne, S., 2013. Bounding the role of black carbon in the climate system: A scientific assessment. Journal of geophysical research: Atmospheres, 118(11), pp.5380-5552.

Bowerman, N.H., Frame, D.J., Huntingford, C., Lowe, J.A., Smith, S.M. and Allen, M.R., 2013. The role of short-lived climate pollutants in meeting temperature goals. Nature Climate Change, 3(12), pp.1021-1024.

Bureau of Environment, TMG. 2018a. Diesel Vehicle Control. https://www.kankyo.metro.tokyo.lg.jp/en/automobile/diesel.html

Bureau of Environment, TMG. 2018b. Diesel Vehicle Control Introduction in Chinese. https://www.kankyo.metro.tokyo.lg.jp/en/automobile/diesel.files/Control_zh.pdf

CAL FIRE. (n.d.). 2020 Fire Season. Retrieved January 11, 2021, from https://www.fire.ca.gov/incidents/2020/

CAL FIRE. (n.d.). 2019 Wildfire Activity Statistics. 51.

CARB (n.d.). What are Sustainable Communities Strategies? | Retrieved January 11, 2021, from https://ww2.arb.ca.gov/our-work/programs/sustainable-communities-program/what-are-sustainable-communities-strategies

CARB. 2017a. California's 2017 Climate Change Strategy. https://ww3.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf

CARB, 2017b. Short-Lived Climate Pollutant Reduction Strategy. https://ww2.arb.ca.gov/sites/default/files/2018-12/final_slcp_reduction_strategy_w_appx_march2017%20Final%202017.pdf

CARB. 2018. Assembly Bill 32 Overview. https://ww3.arb.ca.gov/cc/ab32/ab32.htm

CARB. n.d. History. https://ww2.arb.ca.gov/about/history

Clean Air Asia. (2020a). Integrated Programme for Better Air Quality in Asia City Solutions Toolkit. Retrieved from: https://learning-cleanairasia.org/city-solutions-toolkit/

Clean Air Asia. (2020b). Emissions Inventory for Santa Rosa City, Philippines Report. Unpublished.

Climate & Clean Air Coalition. (2011). Short-lived climate pollutants. https://www.ccacoalition.org/en/content/short-lived-climate-pollutants-slcps

CCAC and IGES. (2019). Development of City Action Plans to Reduce GHGs and SLCPs from MSWM in Southeast Asia, CCAC & IGES, 2019

European Commission. (n.d.). Cleaner air for all. https://ec.europa.eu/environment/air/cleaner_air/#air%20pollutants

Fold, N., Allison, M., & Wood, B. (2020). An Assessment of Annual Mortality Attributable to Ambient PM2.5 in Bangkok, Thailand. Int. J. Environ. Res. Public Health 2020, 17(19), 7298. Retrieved from: http://doi.org/10.3390/ijerph17197298.

Fowlie, M., Walker, R., & Wooley, D. (2020). Climate policy, environmental justice, and local air pollution. 27.

Han, H. 2018. The Plan for Institutional Reform of the State Council. The Xinhua News Agency. http://www.gov.cn/xinwen/2018-03/17/content_5275116.htm

He, W., Zhang, W., Wang, S., Chai, F., Li, H., Zhang, J., Wnag, H., Hu, J. 2019. Implementation and Suggestions on Improvement of Jing-Jin-Ji Regional Cooperation on Air Pollution

Prevention and Control Mechanism. Environmental Science Research, 10: 1696-1703. DOI 10.13198/j.issn.1001-6929.2019.09.06. http://www.huanjing100.com/p-9943.html

Health Effects Institute. (2020). State of Global Air 2020. Special Report. Boston, MA:Health Effects Institute

Health Effects Institute. (2019). State of Global Air 2019. Special Report. Boston, MA:Health Effects Institute

Hodnebrog, Ø., Etminan, M., Fuglestvedt, J., Marston, G., Myhre, G., Nielsen, C., Shine, K. & Wallington, T. (2013). Global warming potentials and radiative efficiencies of halocarbons and related compounds: A comprehensive review. Reviews of Geophysics. 51. 300-378. 10.1002/rog.20013.

Hu, X. 2016. Where Will Climate Change Impact China Most? https://www.weforum.org/agenda/2016/04/where-will-climate-change-impact-china-most/

Institute for Global Environmental Strategies and Clean Air Asia. (2014). Reduction in CO2 Emissions through an Electric Tricycle Replacement Scheme in Pasig City, Philippines: An MRV Demonstration Study.

IPCC, 2013: Climate /k Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp. Accessed from https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_all_final.pdf

Jacobson, M. Z. Global direct radiative forcing due to multicomponent anthropogenic and natural aerosols. Journal of Geophysical Research-Atmospheres 106, 1551-1568 (2001).

Janssen, N., Gerlofs-Nijland, M., Lanki, T., Salonen, R.O., Cassee, F., Hoek, G., Fischer, P., Brunekreef, B. and Krzyzanowski, M.(2012). Health Effects of Black Carbon 2012, World Health Organization. ISBN 978 92 890 0265 3

Kampa, M. & Castanas, E., 2008. Human health effects of air pollution. Environmental Pollution, 151(2), pp. 362-367.

Kecorius, S., Madueño, L., Vallar, E., Alas, H., Betito, G., Birmili, W., Cambaliza, M., Catipay, G., Cayetano, M., Galvez, M.C., Lorenzo, G., Müller, T., Simpas, J., Tamayo, E., & Wiedensohler, Alfred. (2017). Aerosol particle mixing state, refractory particle number size distributions and emission factors in a polluted urban environment: Case study of Metro Manila, Philippines. Atmospheric Environment, 170, 169-183. DOI: 10.1016/j.atmosenv.2017.09.037

Kim, E., Jeon, S., Lee, J., Park, Y., Lee, D. 2012. Local Adaptation Plan to Climate Change Impact in Seoul: Focused on Heat Wave Effects. Journal of Environmental Impact Assessment, 21(1).

Ma., W. 2018. From NDRC to MEE, What are the Responsibility Changes of the Climate Change Department? China Times. Beijing, China. https://new.qq.com/omn/20181031/20181031A18VU6.html

Melamed, M.L., Schmale, J. and von Schneidemesser, E., 2016. Sustainable policy—Key considerations for air quality and climate change. Current opinion in environmental sustainability, 23, pp.85-91.

Menikpura, S.N.M, Premakumara, D.G.J, 2018, Emission Quantification Tool (EQT) for

Estimation of GHGs/SLCPs from Solid Waste Sector – Version II, IGES, Japan

Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Nakajima, T., Ohara, T., Masui, T., Takemura, T., Yoshimura, K., Goto, D., Hanaoka, T., Itahashi, S., Kurata, G., Kurokawa, J.I. and Maki, T., 2020. A development of reduction scenarios of the short-lived climate pollutants (SLCPs) for mitigating global warming and environmental problems. Progress in Earth and Planetary Science, 7(1), pp.1-21.

National Statistical Office Thailand. (2010) Executive Summary: The 2010 Population and Housing Census. National Statistical Office Thailand: Bangkok, Thailand.

National Atmospheric Emissions Inventory. (2020, April 27). Greenhouse gases. https://naei.beis.gov.uk/overview/ghg-overview

North Carolina Climate Office. (n.d.). Greenhouse gases. https://climate.ncsu.edu/edu/Greenhouse

Prather M, Ehhalt D, Dentener F, Derwent R, & Grubler A (2001). Atmospheric chemistry and greenhouse gases. In: Climate Change 2001: The Scientific Basis, Third Assessment Report. IPCC: Working Group I of the Intergovernmental Panel on Climate Change. ISBN 0521-01495-6. https://www.ipcc.ch/site/assets/uploads/2018/03/TAR-04.pdf

Premakumara, D.G.J, Menikpura, S.N.M, Singh, R.K, Hengesbaugh, M, Magalang, A.A, IIdefonso, E.T, Valdez, M.D.C.M, Silva, L.C, 2018, Reduction of Greenhouse Gasses (GHGs) and ShortLived Climate Pollutants (SLCPs) from Municipal Solid Waste Management (MSWM) in the Philippines: Rapid review and Assessment, Waste Management, 80, 397-405

Saigusa, N. 2011. Tokyo Metropolitan Government's Efforts to Control Diesel Vehicle Emissions. https://www.japanfs.org/en/news/archives/news_id030817.html

Saunois, M., Stavert, A., Poulter, B., Bousquet, P., Canadell, J., Jackson, R., Raymond, P., Dlugokencky, E., Houweling, S., Patra, P., Ciais, P., Arora, V., Bastviken, D., Bergamaschi, P., Blake, D., Brailsford, G., Bruhwiler, L., Carlson, K., Carrol, M. & Zhuang, Q. (2020). The Global Methane Budget 2000–2017. Earth System Science Data. 12. 1561-1623. 10.5194/essd-12-1561-2020.

SMG. 2015. Promise of Seoul: Taking Actions against Climate Change.

Seoul Solution. 2015. Low NOx Burners : The Solution to Reduce Emission of Air Pollutants and Conserve Energy. https://seoulsolution.kr/en/node/3389

Seoul Solution. 2018. New Renewable Energy: One Less Nuclear Power Plant. https://seoulsolution.kr/en/node/3363

The City of New York. 2019. OneNYC 2050: Building a Strong and Fair City. https://onenyc.cityofnewyork.us/wp-content/uploads/2020/01/OneNYC-2050-Full-Report-1.3.pdf

TMG. 2003. In Introducing Diesel Vehicle Control. https://www.kankyo.metro.tokyo.lg.jp/en/automobile/diesel.files/diesel_vehicle.pdf

Tsai, W. (2006). An Overview of Environmental Hazards and Exposure Risk of Hydrofluorocarbons (HFCs). Chemosphere. 61. 1539-47. 10.1016/j.chemosphere.2005.03.084.

UN Environment 2019. A Review of 20 Years' Air Pollution Control in Beijing. United Nations Environment Programme, Nairobi, Kenya.

UNEP. 2019. Synergizing action on the environment and climate: good practice in China and around the globe.

UNEP-WMO. 2011. Integrated assessment of black carbon and tropospheric ozone: summary for decision makers." UNEP, Nairobi, Kenya.

United States Environmental Protection Agency. (2019, December 18). Criteria air pollutants. https://www.epa.gov/criteria-air-pollutants

Westervelt, D.M. Horowitz, L.W. Naik, V. Golaz, J.-C.Mauzerall, D.L. . Radiative forcing and climate response to projected 21st century aerosol decreases. Atmos Chem Phys, 15 (2015), pp. 12681-12703

Wiedensohler, A., Andrade, M., Weinhold, K., Müller, T., Birmili, W., Velarde, F., Moreno, I., Forno, R., Sanchez Barrero, M., Laj, P., Ginot, P., Whiteman, D.N., Krejci, R., Sellegri, K., & Reichler, T. (2018). Black carbon emission and transport mechanisms to the free troposphere at the La Paz/El Alto (Bolivia) metropolitan area based on the Day of Census (2012). Atmospheric Environment. 194. 10.1016/j.atmosenv.2018.09.032.

World Health Organization. (n.d.). Ambient air pollution: Pollutants. https://www.who.int/airpollution/ambient/pollutants/en/

Zhang, M., Liu, Z., & van Dijk, M. P. (2019). Measuring urban vulnerability to climate change using an integrated approach, assessing climate risks in Beijing. PeerJ, 7, e7018. https://doi.org/10.7717/peerj.7018