Asia Pacific Clean Air Partnership

The Effects of COVID-19 on Clean Air and a Healthy Climate in Asia's Cities

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The Effects of COVID-19 on Clean Air and a Healthy Climate in Asia's Cities

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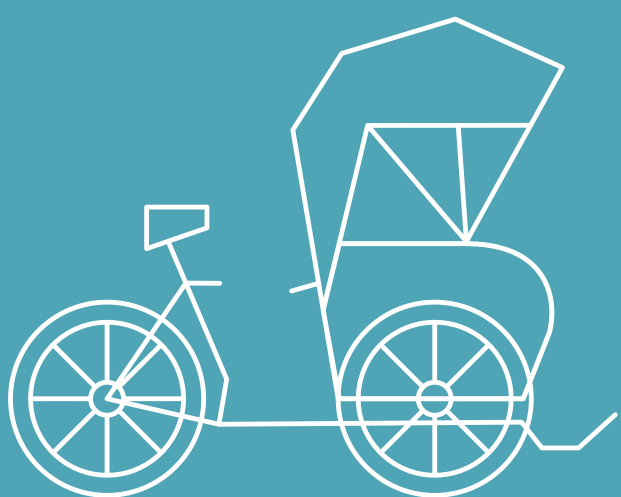


INTRODUCTION

1.

Introduction: The Effects of COVID-19 on Clean Air and a Healthy Climate in Asia's Cities

1.1 Background

On 11 March 2020, the World Health Organization (WHO) declared that COVID-19 was no longer a regional health threat but a global pandemic. Shortly thereafter, much of the world adopted social distancing, movement restrictions, and lockdowns to slow COVID-19's spread. Many cities subsequently saw sharp reductions in energy consumption and motorized transport drive down air pollution and greenhouse gas (GHG) emissions. Though COVID-19 was a tragedy of epic proportions, it came with a silver lining: many cities enjoyed cleaner air.

These visible signs of improvement found support in data. For example, the World Meteorological Organization (WMO) pointed to a 10 to 40 per cent reduction in mean $PM_{2.5}$ levels in East and South Asia during 2020 (WMO 2021). These reductions may also have been timely. The WHO suggested improved air quality could have lowered the burden of COVID-19 in polluted areas because unclean air exacerbates susceptibility to the virus (WHO 2021b). But even as evidence that the pandemic improved air quality and health was growing, there were also concerns about sustaining these gains.

To some extent, green stimulus programs and related policies answered these concerns. Many governments invested in sustainable transport, renewable energy, energy efficient industries, and green infrastructure as part of stimulus programs. Some countries backed these efforts with stronger climate and clean air policies as well as institutional reforms. Studies underlined these efforts could prove transformative. The promise of long-term changes could be found in work that estimated a possible reduction of 25 percent in GHGs by 2030 from a green, low carbon recovery (UNEP 2020). The creation of 191 million new jobs and US$3.6 trillion of additional revenue through nature-positive solutions by 2030 echoed a similar sentiment (WEF 2020).

Though the worst of COVID-19 appears to be over, it also raises important questions about COVID-19's immediate and then longer-term impacts on urban air quality. To understand both sets of impacts, the United Nations Environment Programme (UNEP) Asia Pacific Office, the Institute for Global Environmental Strategies (IGES), the Ministry of Environment, Sri Lanka, and the National Institute of Technology, Bandung, Indonesia developed a study on how COVID-19 affected air quality. Part of the study examined effects across several cities in Asia and the Pacific; a more in-depth set of reviews explored connections in Colombo, Sri Lanka; Jakarta, Indonesia; and Kawasaki, Japan. the Asia-Pacific Clean Air Partnership and UNEP's Sida fund supported this work and helped align its contributions to several related initiatives and programs.

1.2 The Air Quality Impacts of COVID-19 in Select Asian Cities

The WHO estimates that air quality in 97 per cent of the cities in low- and middle-income countries have air quality exceeding safe levels. Nonetheless, many cities experienced significant improvements in air quality during COVID-19. While these improvements occurred in many parts of the world, they were particularly notable in Asia. Data from different Asian cities (see Figure 1-1) underlines that many of the key sources of pollution—ranging from industry, transportation, construction, and road dust—fell during this period.

To understand the extent of the improvements in Asia, air quality data for 13 cities were collected from the World Air Quality Index Portal (World Air Quality Index 2020) for the period January to June 2020 (COVID-19). That data was then compared against the previous year (2019). The intertemporal analysis showed the surveyed cities experienced a significant decline in PM_{10} and $PM_{2.5}$ concentrations during COVID-19. More concretely, across the surveyed cities there was between a 22-65% reduction in PM_{10} and $PM_{2.5}$. The data also demonstrated that NO_2 and SO_2 concentrations fell between 10-60% and 25-60% respectively.

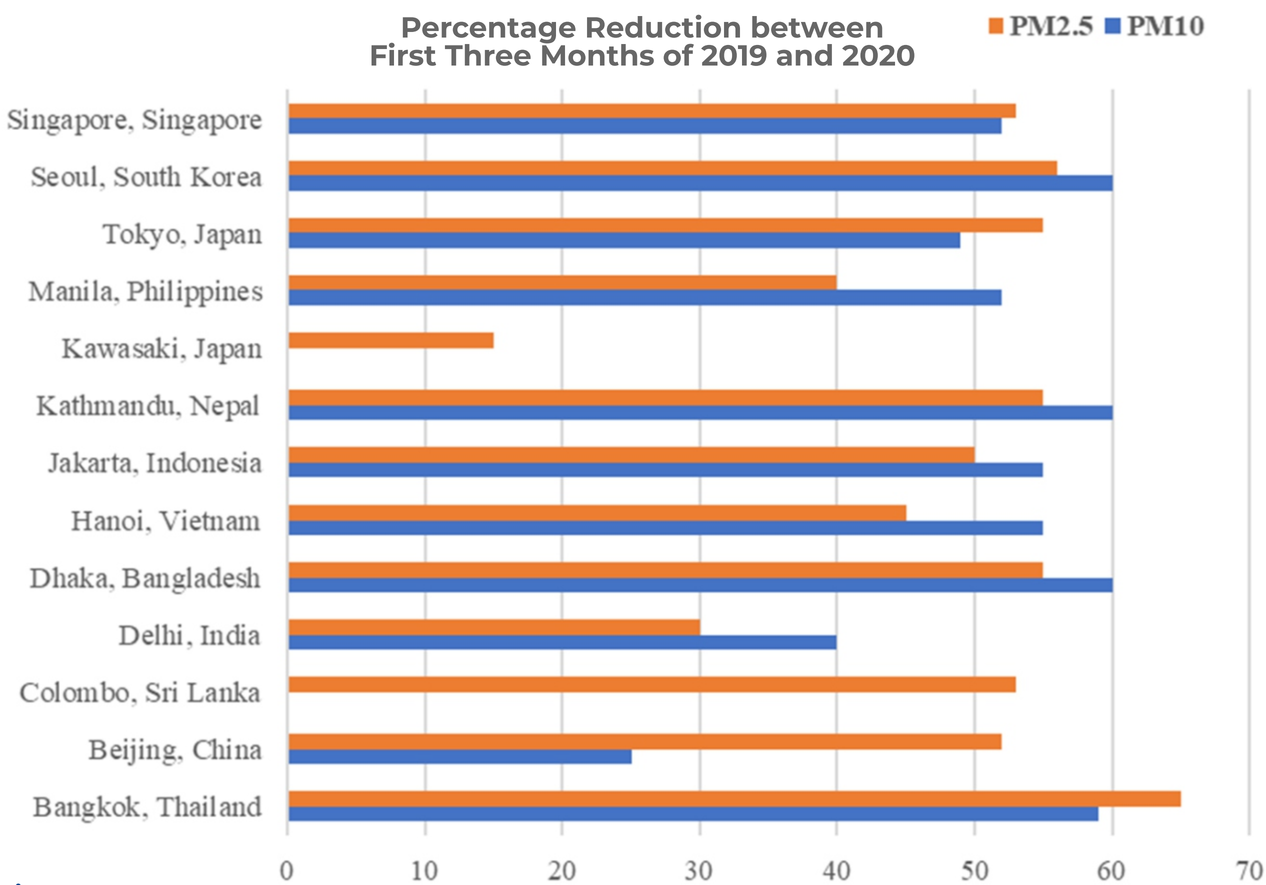


Figure 1-1.
Percentage Reductions in $PM_{2.5}$ during COVID (January-June, 2020) Compared to Pre-COVID (January-June, 2019)

Sampun Design Studio

Importantly, the improved air quality likely helped to protect health when the virus was becoming more serious. Several studies underlined the potential for lockdowns and cleaner air to decrease annual mortality rates (Myllyvirta and Dahiya 2020; Sharma et al. 2020). Researchers also reported linkages between air pollution and COVID-19 related mortality during the winter (Gupta et al. 2020; Liang et al. 2020; Zhao et al. 2020). A related line of work suggested potentially positive impacts on socioeconomic and gender equity. These effects may stem from the fact that about 91% of premature mortality due to air pollution occurs in low- and middle-income countries, with the most significant impacts felt in Southeast Asia and the Western Pacific (WHO 2021a).

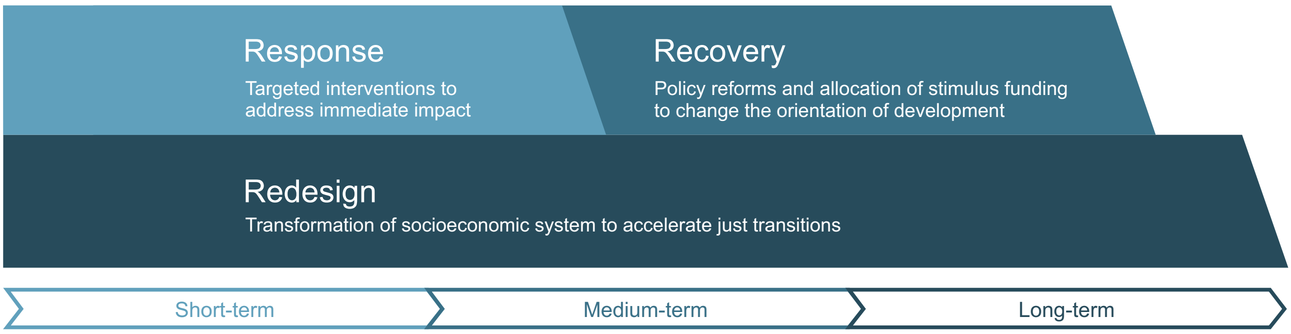
While there were indeed many signs of improved air quality and health, not all of the news was good. One of the worrying set of data points was that PM_{10} concentrations remained above 2019 WHO guidelines (45 μgm^{-3}) for many of days in the previously surveyed 13 cities. These exceedances were most common in Delhi (100%), Beijing (56%), Dhaka (40%), and Seoul (31%) where air quality was above recommended levels for more than 30% of the relevant days. Even more troubling was that $PM_{2.5}$ concentrations were greater than the 2019 WHO (15 μgm^{-3}) in all cities. Arguably the biggest question revolved around whether shutting down economies was a sustainable solution to air pollution and related environmental challenges.

1.3 Sustaining Air Quality Improvements in the Wake of COVID-19

As often occurs in crises, COVID-19 opened an opportunity for many cities to adopt—or strengthen—responses to air pollution and related environmental challenges. A critical issue is whether those initial responses contributed to a broader long-term strategy that could retain air quality gains and achieve other goals. The potential for more transformative changes was great due to "green" recovery packages that would go beyond stimulating the economy. Many of the packages aimed to promote sustainable transportation, electric mobility, advanced energy and clean technologies. Some of these efforts could potentially have even longer lasting effects on infrastructure and policymaking institutions.

To help assess the possible effects across different cities in Asia, this chapter employs a simple analytical framework developed by IGES that organizes COVID-related interventions in terms of their substantive and temporal scope. That is, it classifies interventions of whether they intended to address the immediate health-related effects or had the potential to build back better by making infrastructure and institutions more environmentally sustainable. The three types of interventions in this framework are defined below.

1. **Response** refers to actions to address the pandemic, including mandates for masks, social distancing, teleworking, and lockdowns. From an environmental point of view, emergency measures to deal with the health impacts of the pandemic are an essential response measure.
2. **Recovery** refers to broader programs (economic stimulus, etc.) aimed at stimulating a depressed economy and employment. From an environmental perspective, not just any recovery, but a green recovery is critical. Such a programme would include provisions for tackling air pollution, climate change and other environmental challenges.
3. **Redesign** is a strategy to transform industry, infrastructure, and institutions with the chief motivation to improve the post-COVID economy and society in the long run. Promoting decarbonization is essential for this category. Increasing societal resilience to pandemics like COVID-19 is equally critical (Finch et al. 2022; Zusman, Kawazu, André Mader, et al. 2020).



One way of using this framework is to see how the interventions from the 13 previously reviewed cities fit into the different categories. Table 1.1 presents the results of using that framework to organize different interventions from the 13 select cities. While there exists considerable variation across the cities, some common themes can be seen even across a cross section of experiences.

Table 1-1 :
Using the Triple R Framework to Organize Interventions

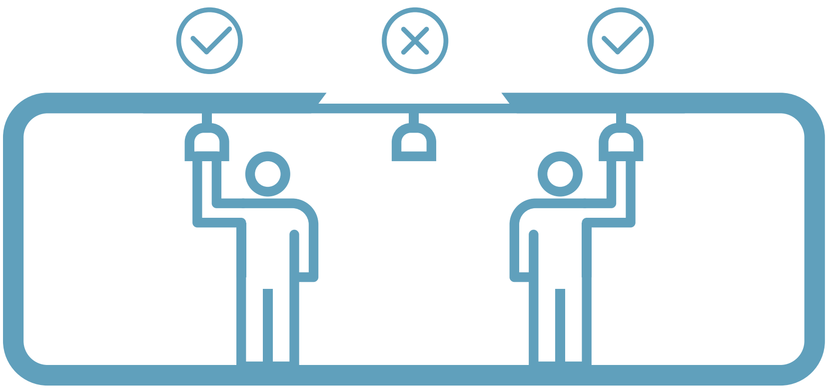
City	Response	Recovery	Redesign
Bangkok, Thailand	• Masking restrictions, social distancing, teleworking, etc. • Thai baht (THB) 45 billion was released for healthcare services. • Health insurance premium deductions increased to THB 25,000 from THB 15,000.	• Started COVID response and recovery plan for health, industrial, and agricultural sectors. • Liquidity for boosting entrepreneurs, SME loan restructuring, monetary policy, etc. • Up to THB 100 billion in soft loans for tourism operators.	• THB 217 billion for SMEs. • THB 500 billion for SMEs' liquidity. • 3-year action plan (2020 – 2022) to mitigate air pollution in Bangkok. • 1.05 million electric vehicles (EV) will be made available by 2025 to reduce gasoline demand and improve air quality.
Beijing, China	• Masking restrictions, social distancing, teleworking, etc. • 1.2 trillion Chinese Yuan (CNY) for epidemic prevention and control measures.	• CNY 100 billion to recover the agriculture sector. • Launched COVID response and recovery plan for health and industry. • Allocated 4 trillion Chinese Yuan (CNY) to stimulate the economy and industrial sector.	• 300 billion Yuan for small and medium-sized enterprises. • A comprehensive action plan to mitigate autumn and winter air pollution. • Started winter air pollution campaign to clear smog-laden skies.
Colombo, Sri Lanka	• Masking restrictions, social distancing, teleworking, etc. • Implemented several health safety guidelines and took steps to control COVID. • Provided US$217.57 million in loans for the COVID-19 Emergency Response and Health Systems Preparedness Project.	• Started COVID response and recovery plan for health, industrial, and agricultural sectors. • Interest-free advance payment of Sri Lankan Rupee (LKR) 10,000 to all low-income and vulnerable households. • Rs. 400 Million for COVID-19 affected people.	• Introducing electric vehicles to reduce air pollution. • Clean Air 2015 Action Plan and the Transport plan. • Promoting green buildings to reduce CO_2 emission.
Delhi, India	• Masking restrictions, social distancing, teleworking, etc. • Indian Rupee (INR) 23,220 crore for setting up pediatric health facilities to deal with any COVID-19 emergency. • INR 93,869 crore to give free foodgrains.	• Industries opened with 50% capacity to generate employment. • INR 150,000 crore for SMEs, including the healthcare sector and loans to travel agencies. • INR 14,775 crore as fertilizer grant to achieve green recovery after the pandemic.	• INR 20 lakh crores for 'Atma Nirbhar Bharat' or a 'self-reliant India.' • INR 6.29 lakh crore to stimulate the economy and industrial sector. • National Clean Air Programme to mitigate air pollution to reduce 20% to 30% PM concentrations by 2024. • Implementation of the winter action plan. • Installed two smog towers • Engagement of 300 low-floor electric buses.
Dhaka, Bangladesh	• Masking restrictions, social distancing, teleworking, etc. • USD91 million for informal sector workers; health insurance of 5-10 lakh Bangladeshi Taka (BDT) for health workers (doctors, nurses, and others). • 25-50 Lakh BDT in case of death.	• A special honorarium of USD12 million for bankers, health workers, and others. • 300 billion BDT for banks to provide working capital loan facilities to affected industries	• 200 billion BDT for working capital loan facilities to SMEs. • 200 billion BDT for Employment generation activities. • Promotion of 15% eco-friendly vehicles by 2030. • Announced electric vehicle framework for sustainable transport by 2026.

City	Response	Recovery	Redesign
Hanoi, Vietnam	• Masking restrictions, social distancing, teleworking, etc.	• About USD70 per month for employees. • Started COVID response and recovery plan for health, industrial, and agricultural sector.	• Reduced corporate income tax for SMEs. • Cut environmental protection tax on jet fuel. • Reducing vehicle registration fees by 50 percent. • Adopting Electric Vehicle policy to reduce air pollution.
Jakarta, Indonesia	• Masking restrictions, social distancing, teleworking, etc. • Indonesian Rupiah (IDR) 97.26 trillion for healthcare.	• IDR 243.33 trillion is used for Social Protection, like the staple food program, the pre-employment card program, etc.	• Indonesian Rupee (IDR) 18.45 trillion for vaccines, health facilities, and infrastructure, laboratories, research and development. • IDR 123.46 trillion for SMEs. • Promoting the use of CNG for public buses and increasing the use of electric buses and micro-powered electric transportation.
Kathmandu, Nepal	• Masking restrictions, social distancing, teleworking, etc. • Health sector emergency response plan	• Tourism organizations provided daily or monthly wages to their workers. • Allocating Nepalese Rupee (NPR) 122 billion for vaccines under FY 2021-22 budget. • Economic support package for SMEs. • Abolishing excise duty on the import of EVs, reduced customs duty	
Kawasaki, Japan	• Masking restrictions, social distancing, teleworking, etc. • Enacted various response measures following the state of emergency that aimed at improving the health and wellness of its residents with environmental implications. • Adopted and extended programmes promoting bicycling that helped ease commuting and limit exposure to infection.	• Announced multiple stimulus packages for socio-economic recovery. • In addition to healthcare and support for businesses, such as tax breaks for small businesses. • Transferred Japanese Yen (JPY) 100,000 and JPY 10,000 additional financial support per child per household were offered.*	• Kawasaki Carbon Zero Challenge was approved in November of 2021 to achieve a 100% reduction in carbon dioxide (CO_2) emissions by 2050. • Adopted Hydrogen Strategy for the Realization of a Hydrogen Society. • Eco-friendly buildings under Kawasaki City Main Government Building Reconstruction Basic Plan.
Manila, Philippines	• Masking restrictions, social distancing, teleworking, etc.	• Allotted 200 billion Philippine pesos (PHP) (US$3.9 billion) for low-income households badly affected in the COVID-19 crisis. • PHP 205 billion for 18 million low-income families under the recovery plan.	• Provided 1.3 trillion pesos to help the economy recover from the coronavirus pandemic over the next four (4) years. • Started electric vehicles for under a sustainable transport plan. • Replacing regular tricycles with 100,000 e-tricycles. • Department of Energy estimates gasoline consumption to be reduced by 561,000 barrels a year or 260,000 tons of carbon dioxide emissions by the use of e-tricycles.
Tokyo, Japan	• Masking restrictions, social distancing, teleworking, etc. • Announced YEN YEN4690.5 billion for healthcare services and Research and Development of new drugs and vaccines.	• All the residents, regardless of nationality, received a Special Cash Payment of YEN 100,000. • Local governments will compensate the accommodation fees for those who could not afford housing fo three months. • The emergency recovery plan to cope with COVID-19 with a total outlay of YEN234.2 trillion.	• Announced 117 trillion yen as an additional economic stimulus package for SMEs. • The Tokyo Metropolitan Government (TMG) adopted a new environmental master plan with progressive milestones in 2016. • Introduced a long-term target plan to reduce the concentration of photochemical oxidant to 0.07 ppm or less at all monitoring stations by FY2030. • In addition, the plan aims to achieve 100% national PM2.5 air quality standards by FY2024.

City	Response	Recovery	Redesign
Seoul, South Korea	• Masking restrictions, social distancing, teleworking, etc. • Announced 2.3 trillion won for medical institutions and funding quarantine efforts • Announced South Korean won (KRW) 4.4 trillion won to purchase COVID-19 vaccines, boost immunization, and increase coronavirus testing.	• Announced 160 trillion KRW for various economical packages for health, industrial and agricultural sectors. • 33 trillion KRW ($29.2 billion) as a supplementary budget to provide pandemic relief to households, aid small businesses, and create jobs.	• South Korea doubled its economic rescue package to 100 trillion KRW ($80 billion) to save companies hit by the coronavirus • The plan is to move towards a net-zero society by supporting current policies such as reducing greenhouse gas emissions by 2030. • The plan is to have renewables account for 20% of the country's generation capacity by 2030. • The Government has plans to reduce emissions from the transportation sector by 43% by 2022 and to increase the number of environmentally friendly cars, including electric and hybrid cars, by 2 million by 2022.
Singapore, Singapore	• Masking restrictions, social distancing, teleworking, etc. • Under the 2021 budget, Singapore Dollar (SGD) 4.8 billion was allocated towards public health and safe re-opening measures, • The quarantine Order Allowance Scheme allowed self-employed individuals or employers whose employees were enforcing quarantine orders to receive SGD per day.	• The Government has announced a $133 million COVID-19 Drivers Relief Fund for taxi and private hire car drivers during the budget. • Provided S$90 million for tourism recovery support • The Government set aside S$320 million to grant tourism credits to Singaporeans to drive local spending for Singapore's eateries, shops, hotels, and leisure attractions.	• Announced SGD 60 billion (~42.4 billion USD) to help businesses stay afloat, keep jobs, and protect livelihoods. • The National Environment Agency introduced the Commercial Vehicle Emissions Scheme (CVES) for all new and used imported Light Goods Vehicles (LGVs), Goods-cum-Passenger Vehicles (GPVs), and small buses, all with maximum laden weight (MLW) not exceeding 3,500kg, from 1 April 2021 to 31 March 2023.

Based on the data presented in Table 1.1, a few interesting patterns emerge. For instance, the Table 1.1 shows that all of the cities introduced responses that aimed to protect the health of their citizens. It further illustrates most focused on well-known physical distancing and masking that may have also reduced exposure to air pollution.

In addition, many of the cities also adopted recoveries that brought resources to industries and businesses—though it is often unclear whether these were targeting recoveries or green recoveries. Finally, the redesign of infrastructures and institutions was often a missing piece of the puzzle, raising doubts about the lasting effects of near-term targeted interventions and stimulus spending.



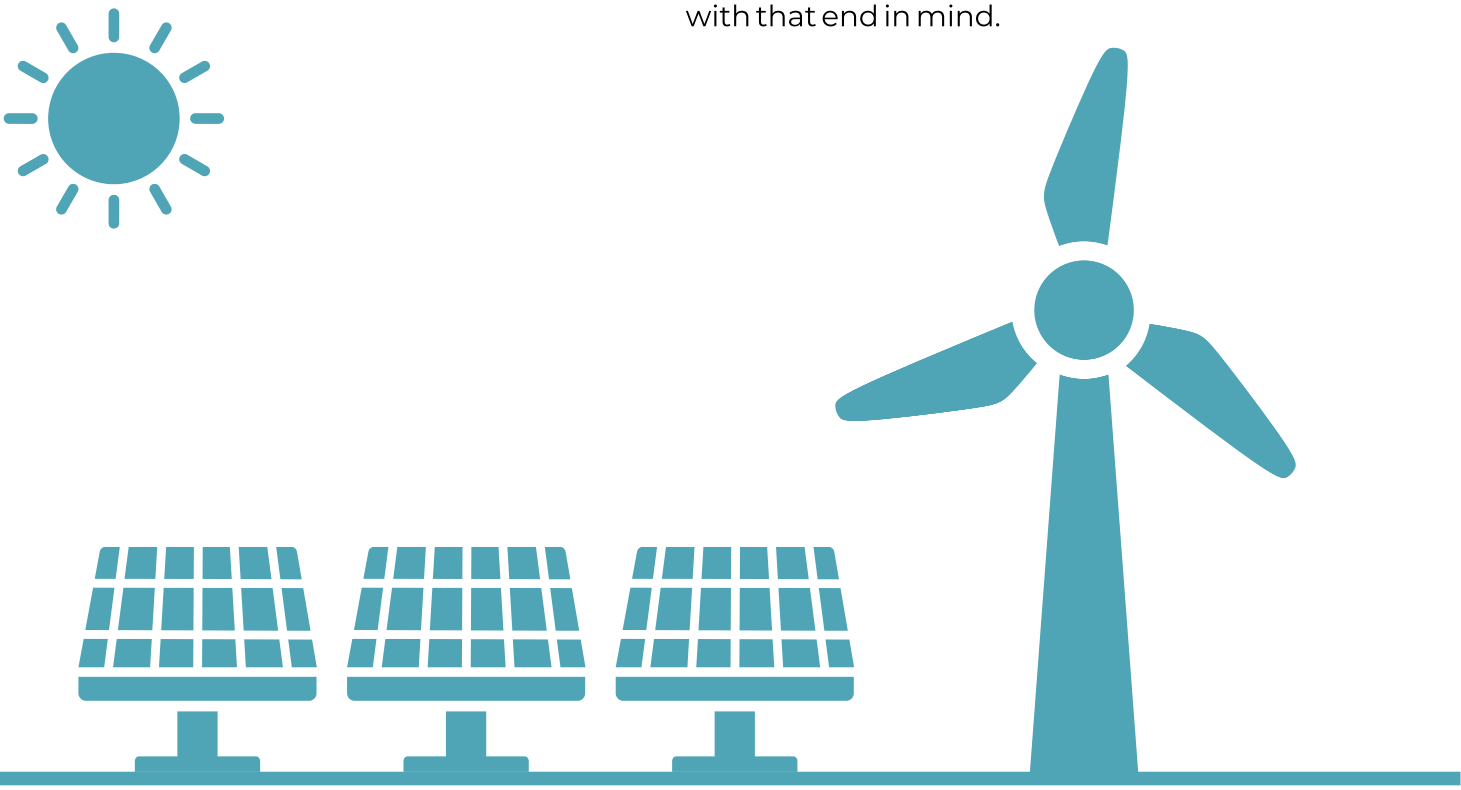
1.4 Conclusion

This chapter has shown that air quality in many parts of Asia improved during the COVID-19 compared to previous years. The improvements stemmed from lockdowns and work-from-home programs to control the transmission of COVID-19. During these restrictions, traffic volume and energy consumption declined while the environment experienced its own recovery. Though there were indeed signs of environmental progress, some of the results were less positive. For example, $PM_{2.5}$ concentrations were still above the WHO guidelines in many cities. Moreover, there was limited evidence that cities were thinking about long-term structural changes to their socioeconomic systems that would sustain these gains. The opportunity to build back better may have been missed.

As the world looks to a post-COVID era, it will be important to learn lessons from the pandemic. One of the clearest lessons is that environmental considerations should be taken on board across all sectors and different types of interventions. It also apparent that the “Redesign” of infrastructure and institutions should feature more prominently in government decisions. An encouraging sign is that that COVID-19 has offered some concrete examples of how to support these “Redesign” efforts and they need not only be relevant to a pandemic. Some recommendations in this regard include the following:

- Building low or zero-emissions public transportation systems as a substantial number of people rely on public transportation and better access to rail, buses, and paratransit transportation modes improves mobility.
- Funding and integration of bike lanes and walkways into urban transportation – the COVID-19 pandemic has increased the use of bike lanes and walkways, further emphasizing the importance of better integrating these modes into public transport and public space.
- Promoting not the adoption of clean technologies in energy and industrial sectors but structural changes to their management and oversight that facilitates their spread within and across sectors
- Including health related concerns in national/regional pollution control policies/regulations and pushing for alignment with international guidelines, including integration of air and health into nationally determined contributions that countries pledge to outline their climate actions.
- Strengthening horizontal and vertical integration within and between structures to address air pollution and climate change,

Another more positive sign is that looking more closely at the experience of particular cities may also offer insights into interventions that could sustain improvements in air quality. The succeeding chapters offer these more focused reviews of Kawasaki, Japan; Colombo, Sri Lanka; and Jakarta, Indonesia with that end in mind.



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2

The Effects of COVID-19 on Air Quality and Climate Planning in Kawasaki, Japan

2.

The Effects of COVID-19 on Air Quality and Climate Planning in Kawasaki, Japan

The COVID-19 pandemic has been a source of previously unimaginable suffering. With death tolls over 7 million globally, the pandemic effects will be felt worldwide for generations. Meanwhile, in Japan—the country that is the focus of this chapter—the number of lives lost has been slightly above 74,000 (WHO 2023). Though lower than many other countries, the pandemic effects in Japan will also be remembered for generations.

As is often the case with unforgettable tragedies, opportunities have emerged from the crisis. Many of these opportunities involve the effects that COVID-19 has had on air quality, public health, and climate change in cities. For cities ranging from Delhi, India, to Sao Paolo, Brazil, the lockdowns from the pandemic brought reductions in transport and industrial-related air pollution (Gupta et al. 2020; Krecl et al. 2020; Magazzino, Mele, and Schneider 2020; Rodríguez-Urrego and Rodríguez-Urrego 2020). Subsequent socioeconomic recovery efforts may have also led to infrastructure investments and industrial and institutional changes that could help lower emissions of greenhouse gases (GHGs) over the long-term . For instance, the United Nations Environment Programme's (UNEP) Emission Gap Report found that a green recovery could cut CO_2 by 25 percent from 2030 levels and place the world on the back on a 2 C° pathways . Yet, if some of the positive impacts of COVID 19 are to be truly transformative, it will be important to share the experiences of many cities.

The main goal of this chapter—one of three city-level case studies—is to help share lessons from Kawasaki, Japan. Toward that end, the chapter has three main objectives. First, the chapter examines the effects COVID-19 had on air quality in Kawasaki and responses aimed at limiting the adverse effects of air pollution on health. Second, the chapter explores how Kawasaki set the stage for a recovery that could help build back better while also lowering emissions of GHGs with air quality co-benefits. Third, the chapter highlights how some industrial and institutional redesigns can help make the city more sustainable in the long-term.

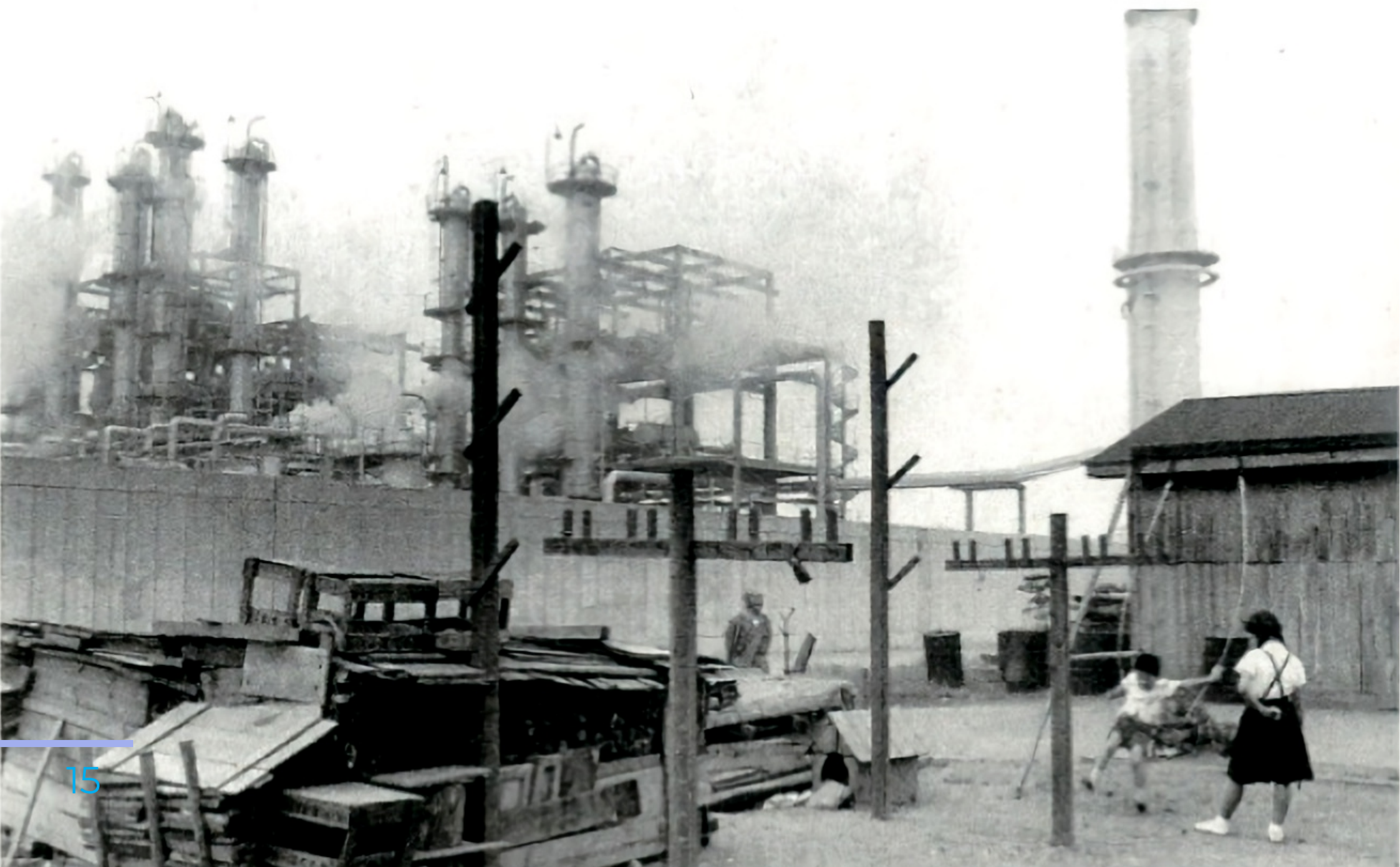
The chapter is divided into four sections to help meet these objectives. The next section (section 2) provides a brief overview of the city of Kawasaki, Japan, noting that it has seen many conventional pollutants drop considerably as the city has tightened emissions controls over the past four decades. The third section uses the Triple R framework to summarize some of the interventions that Kawasaki in the wake of COVID-19. The final section highlights five critical take-aways and areas for mutually beneficial learning between Kawasaki and other cities.

2.1 Overview of Kawasaki

Kawasaki is a city of more than 1.5 million people located on Japan's Eastern Pacific seaboard, along the Tama River in Kanagawa prefecture. The city covers an area of 144.35 km^2, stretching across a wedge of narrow terrain sandwiched between Yokohama and Tokyo. The average age of a Kawasaki resident is 43.6 (2019), and the average annual income is a little more than 4,200,000 yen (2018) (approximately 37,500 US dollars).

Two discernible trends mark Kawasaki's early industrial history. Due to its favorable location, Kawasaki became a heavy industrial center that helped fuel Japan's recovery from World War II. As pollution levels climbed during the early stages of Japan's post-war recovery, the national government devote considerable effort to curb harmful emissions from industries. Initially, much of the emphasis was placed on requiring industries to install end-of-the-pipe control technologies to limit sulfur dioxide (SO_2) emissions. More recent years have seen more attention to improving energy efficiency and adopting environmentally sustainable technologies to restructure the city's industries (Kanada et al. 2013).

Figure 2-1.
An Illustration of Pollution Levels in Kawasaki in the 1960s
Source: Kawasaki, 2020b



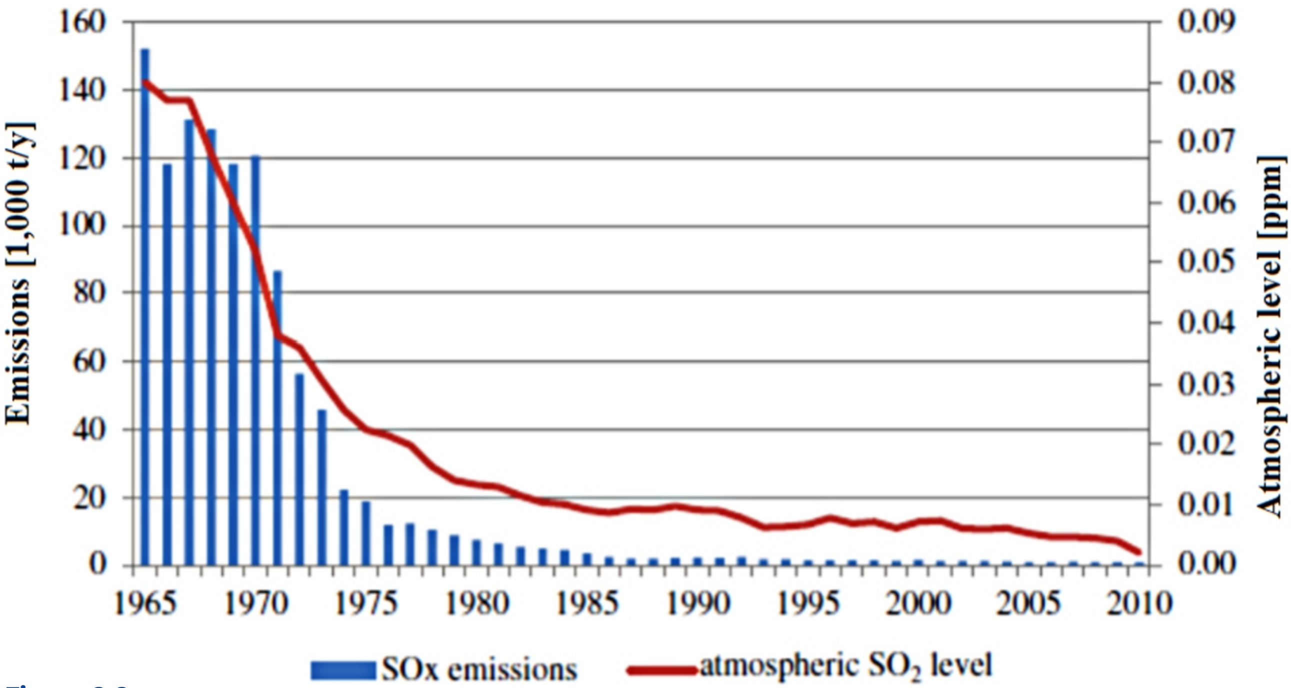


Figure 2-2.
Trends in Sulfur Dioxide Emissions in Kawasaki
Source: Kanada et al., 2013

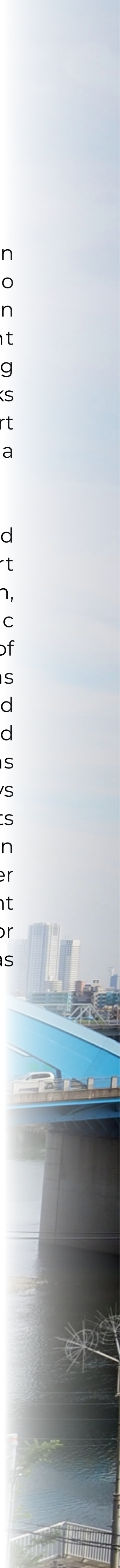
Perhaps because of the progress regulating conventional pollutants, there have not been recent source apportionment studies of the entire city of Kawasaki. However, a new study on the source apportionment of ultrafine ($PM_{0.1}$), fine ($PM_{2.5}$), and coarse particles (PM_{10}-$PM_{2.5}$) for an urban-industrial area in Kawasaki found that the automobile exhaust (30 percent) and the coal combustion (related to steelworks) (24 percent) were the main sources of ultrafine particulate during the winter. During the summer, fuel combustion (39 percent) and automobile exhaust (11 percent) were the main contributors to these emissions (Fujitani et al. 2021).

As part of these more recent efforts to bring down these emissions with broader structural changes (see also discussion of "Redesign" later in this chapter), Kawasaki has sought to attract companies with a global business outlook. These efforts have resulted in more than 400 research and development institutions in various fields such as information communication technology (ICT), electronics, machinery, and biotechnology deciding to locate in Kawasaki. The same efforts have also meant that the employee composition ratio of academic and development research institutes is the highest among the major cities in Japan. Science parks such as Kanagawa Science Park support advanced technology development and a wide range of entrepreneurial activities.

Air quality in Kawasaki has also benefited from well-connected public transport systems. Like many other cities in Japan, residents rely heavily on public transportation to get to and from places of work and business—though there has been a slight decrease in bus use discussed later in the chapter. The publicly funded Japan Railways (JR) Nambu Line runs through the city, and five private railways cross the Nambu Line. Kawasaki residents also use a modern bus system to get to train stations and local in-city travel. The number of standard passenger cars, kei cars (light automobiles also known as ultra mini or microcars), and motorcycles in Kawasaki as of 2020 are presented in Table 2-1.

	Car	Motorcycle	Kei Car (light automobile)	
Private	331,297	16,825	75,857	423,979
Business	14,901	9	3,912	18,822
Sum	346,198	16,834	79,769	346,198

Table 2-1.
Number of Motor Vehicles in Kawasaki
Source: Kawasaki, 2020



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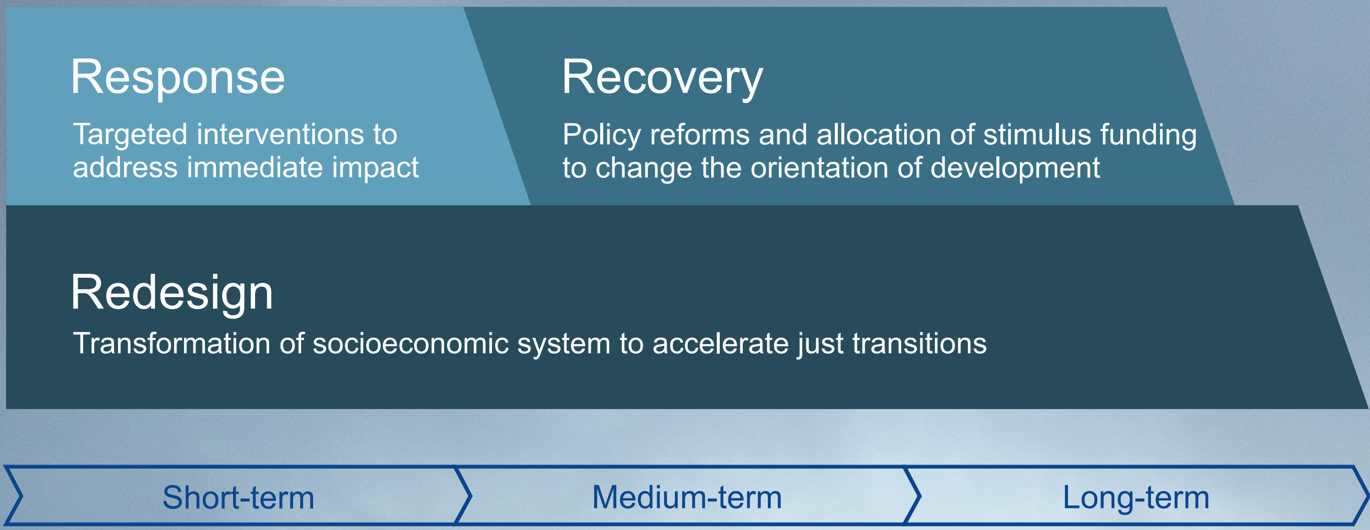


2.2 The Triple R Framework

As with many parts of the world, COVID-19 has had a pronounced impact on socio-economic development in Kawasaki. These impacts have, in turn, led the national and city government to adopt immediate response measures and efforts aimed at socioeconomic recoveries and long-term redesigns of infrastructure and institutions.

To help organize Kawasaki's actions, the chapter will use the Triple-R Framework. The framework is so-named because it classifies interventions into three categories that operate at different time scales: 1) Response; 2) Recovery; and 3) Redesign (see Chapter 1 for a definition of the different types of interventions).

In addition to helping to organize interventions, the framework suggests that capturing complementarities between the different Rs in the framework can bring about lasting changes to energy, transportation, and industrial systems needed for a sustainable future. Coherence between the Rs is therefore desirable for decision-makers employing the framework (Anon 2020; Finch et al. 2022; Janardhanan et al. 2021; Zusman, Kawazu, André Mader, et al. 2020).

Tomáš Malík. 2019

2.2.1 Response

The impacts of COVID-19 have been felt in waves in Japan, with the numbers of infected individuals rising and falling with major peaks (see Figure 2-3 for data on infections in Kawasaki). With each successive wave, the national government has declared a state of emergency and encouraged residents and businesses to take appropriate measures to safeguard health. Importantly, and in contrast to many other countries, there has not been a formally mandated lockdown or restriction on travel; however, many companies and places of businesses have become more flexible, allowing workers to telecommute. In addition, especially during the state of emergency, there was a significant drop-off in commuting and non-essential travel.

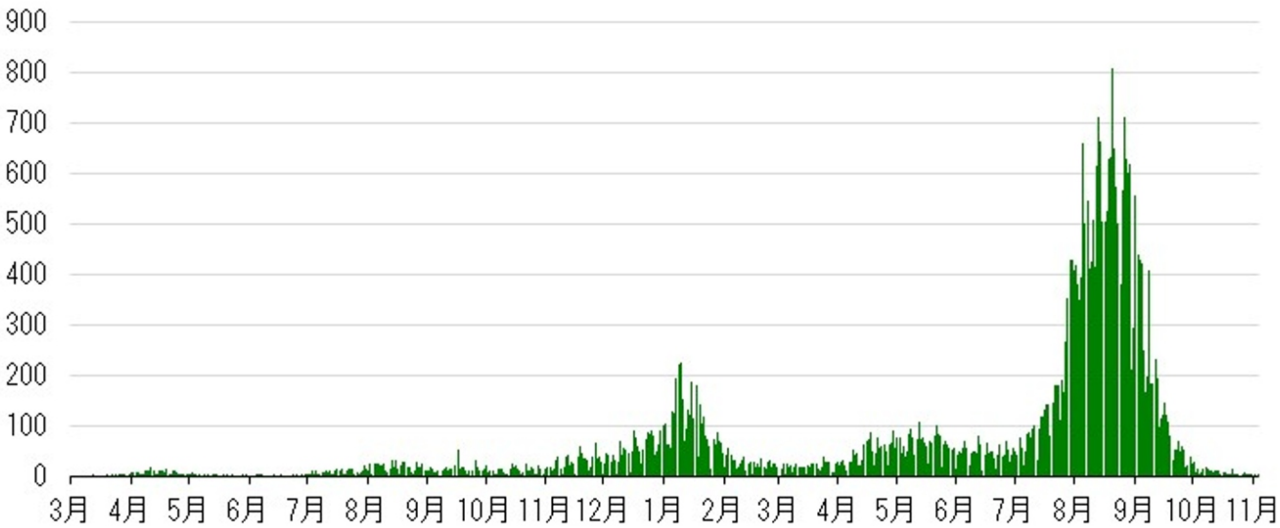


Figure 2-3.
Number of COVID-19 Infections in Kawasaki 2020-2021
Source: Kawasaki, 2021

While more research is needed on the precise causes, there have also been modest improvements in air quality in Kawasaki following the initial waves of COVID-19. This is evident in Figure 2-4, which displays monthly ambient concentrations of $PM_{2.5}$ and NOx for 2017 through 2020. In 2020, during the first wave, the levels of $PM_{2.5}$ were lower than three previous years in four of the five months since the onset of COVID-19. In addition, there was an approximately 15% average reduction in $PM_{2.5}$ between 2019 and 2020 for the same four months. Meanwhile, NOx levels were lower than the previous three years in all five months following the first wave of COVID-19. Though the precise causes of these changes require additional research, even modest reductions in $PM_{2.5}$ can have beneficial effects for health that are important during the spread of a virus (Feng et al. 2016). For instance, the World Health Organisation (WHO) recently updated its air quality guidelines for the first time since 2005 to reflect a growing body of scientific evidence showing that air pollution damages human health at even lower concentrations than thought previously (WHO 2021c).

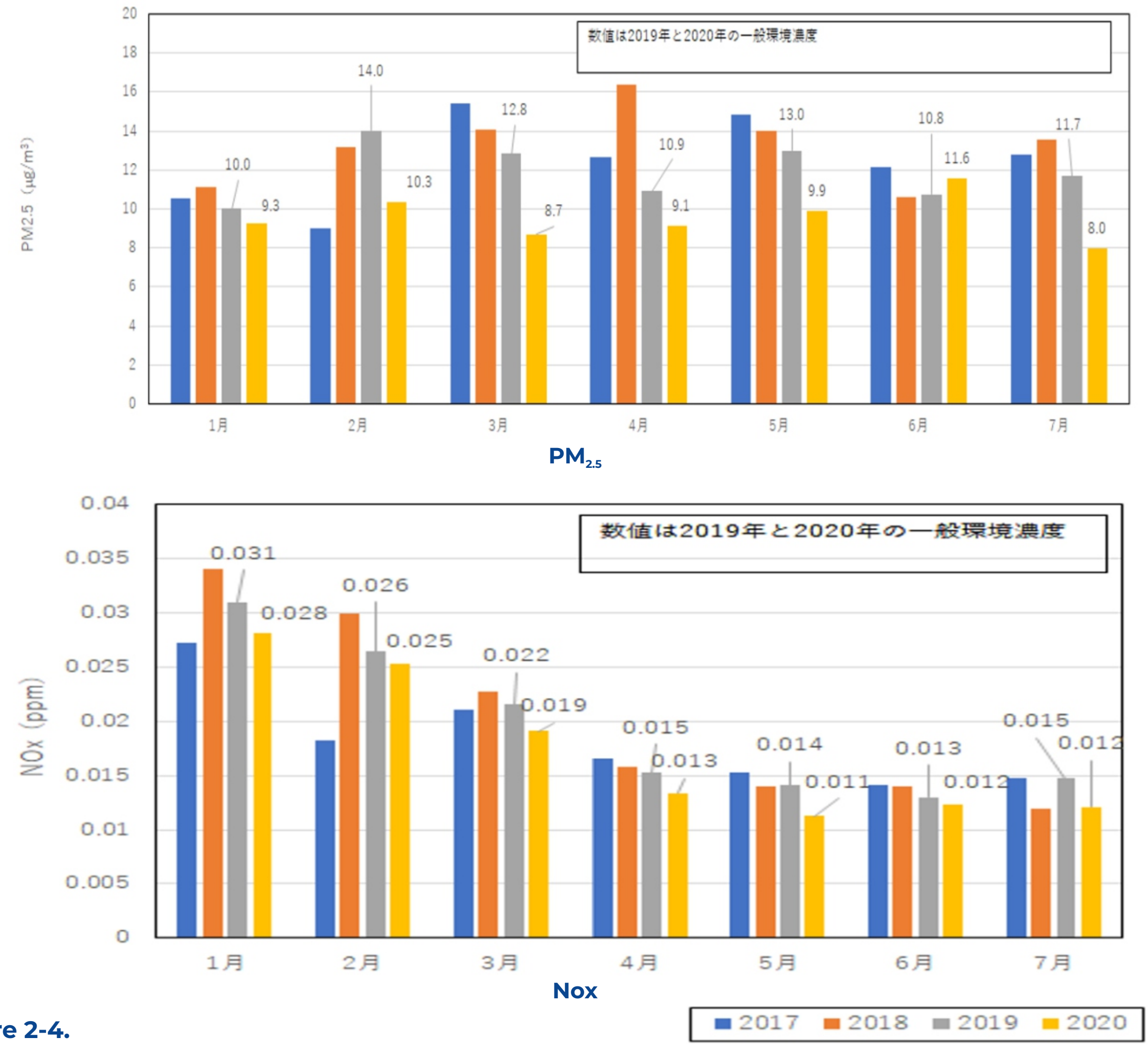


Figure 2-4.
$PM_{2.5}$ and NOx Concentrations in Kawasaki
Source: Kawasaki, 2020

In addition to experiencing some improvements in air quality that have helped lessen strains on health, Kawasaki has also enacted other response measures following the state of emergency to improve the wellness of its residents with environmental implications. Many of these efforts have focused on public transport. In terms of public transport, bus companies have been required to adopt infection prevention measures such as sterilizing straps and handrails and increasing ventilation. In addition, measures have been taken to improve employee and passenger security with requirements on mask-wearing and requests to use public transport during off-peak times and limit conversation. Outside of public transport, the city has also promoted reforms to secure the workplace. This includes encouraging workers to avoid the three “dense” (sealed, dense, close) (See Figure 2-5) as well as other precautionary interventions focusing on mask-wearing, hand washing, and ventilation (Ministry of Health Welfare and Labor-Japan 2021).

Figure 2-5.
Poster Illustrating COVID-19 Prevention Measures in Kawasaki
Source: Ministry of Health Welfare and Labor-Japan, 2021

Kawasaki has also adopted and extended programs promoting bicycling that helped ease commuting and limit exposure to infection. Under the "Kawasaki City Bicycle Utilization Promotion Plan, the city has sought to "promote urban development that utilizes bicycles that are safe, secure, attractive and energetic." This plan was initiated in March 2019 with five shared cycling demonstration ports. In the wake of COVID-19, decisions have been made to improve the bicycle traffic environment and to implement the Kawasaki city cycle network plan intended to cover 213 km by 2029 March. In a similarly motivated effort, the city has pledged to subsidize businesses for keeping bicycle parking areas intact.

2.2.2 Recovery

The second component of the Triple-R framework is recovery. The recovery element of the Triple-R framework involves stimulating the economy. Yet, as shown below, Japan's recovery also injected new momentum in climate policies at the national and local levels.

Following COVID-19, the Japanese government adopted multiple stimulus packages. In addition to healthcare and business support, those packages also consisted of fiscal policies such as tax breaks for small businesses. Further, teleworking was promoted, transfers of 100,000 JPY from the government and as much as 10,000 JPY additional financial support per child per household were offered (KPMG 2020a, 2020b).

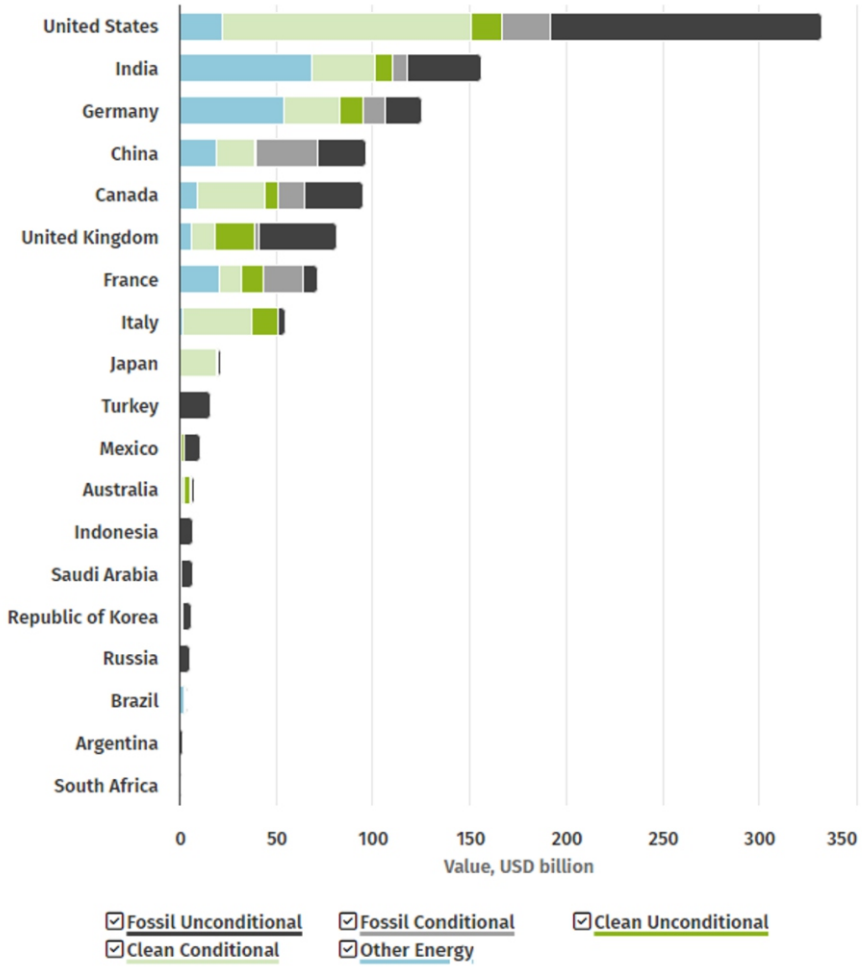
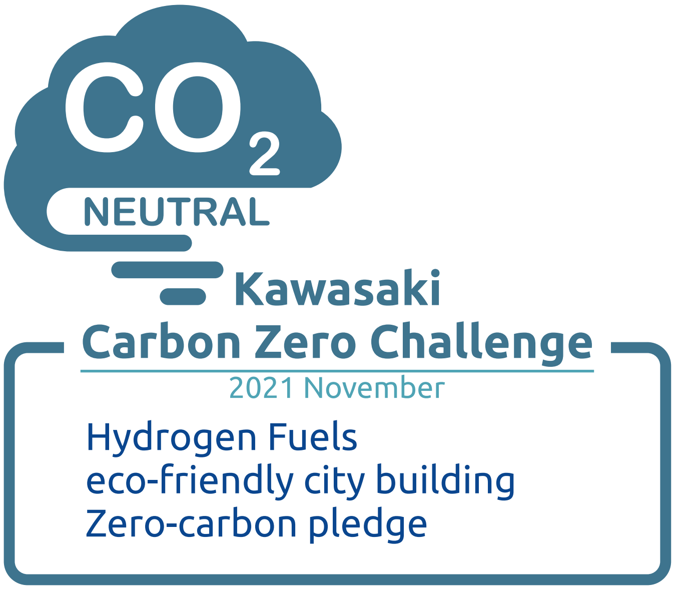


Figure 2-6.
Energy Policy Tracker on Green Stimulus
Source: Energy Policy Tracker, 2023

Many national efforts also aimed for not simply a recovery but a green recovery. As suggested in Figure 2-6 above, most of the resources offered to the energy sector in Japan were for potentially clean energy (although much of the allocated resources do not include environmental safeguards, which is why it is labelled "clean conditional" (IISD et al. 2021). The provision of these resources was arguably one of the reasons that cities in Japan were willing to adopt more ambitious climate policies in the wake of COVID-19. Many of the reviewed policies and actions in this section were considered even before COVID-19. However, these policies and actions have gained additional momentum as city policymakers have sought to capitalize on political and financial support for a green recovery.



Bring CarbonDioxide (CO2) emission down to zero by 2050
& give rise to a sustainable recovery in Kawasaki

Arguably the highest-profile set of interventions that have benefitted from the recovery is the Kawasaki Carbon Zero Challenge (CZC) that the city approved in November of 2021. The CZC is a set of programmes that Kawasaki has adopted to achieve a 100% reduction in carbon dioxide (CO_2) emissions by 2050. The programme is intended to be implemented through both new and existing efforts to decarbonize Kawasaki. The following are among the CZC's main provisions:

- The year 2030 milestone is set as a mid-term target;
- The city's Mizonokuchi area is designated as a decarbonization model district where citizens will experience actions that contribute to decarbonization, such as recycling plastics and the promotion of electric vehicles and fuel cell vehicles;
- The city aims to use 100% renewable energy in major city public facilities; and
- The city will offer new support and evaluation methods for companies working toward decarbonization.

After 2022, Kawasaki also plans to revise its Global Warming Countermeasures Promotion Basic Plan--a plan adopted in 2010 and already revised once in 2018. The results of the CZC are likely to feed into the newly enacted 2022 plan.

2.2.3 Redesign

The final element of the Triple R framework is the redesign. Redesign is critical because some of the impacts of the response and recovery efforts could have limited effects without structural changes to infrastructure, industries, and institutions. A considerable amount of literature demonstrates that these structures can generate inertia that locks in energy and pollution-intensive development patterns (Barter 2004; Olsen et al. 2021; Unruh 2000). By the same token, crises such as COVID-19 and the resultant influx of funding can transform infrastructure, industries, and decision-making institutions and open sustainable development pathways over the long term (Unruh 2002).

Part of the efforts to achieve the redesign is channeled through the "Kawasaki Hydrogen Strategy for the Realization of a Hydrogen Society" originally adopted in 2015. That program--which has also gained added impetus in the wake of COVID-19--consists of five directions, three strategies, and eight projects. Collectively the strategy is intended to make Kawasaki into an "environmental and industrial future-oriented city" (see Figure 2-7). As also illustrated in Figure 2-7, the program aims to put in place the necessary technologies and infrastructure to promote hydrogen fuels and raise brand awareness and increase social acceptance. It is also consistent with Japan's broader efforts to promote the use of hydrogen as a clean fuel in other countries.

5 directions

- Promotion of hydrogen energy utilization, sophistication and high added value
- Reduction of environmental burden such as reduction of greenhouse gases
- Development of technology launching from hydrogen and creation of new industries
- Strengthening disaster prevention and improving safety and security through the utilization of hydrogen
- Expanding the spread of hydrogen in the lives of citizens and improving social acceptance

3 strategies

- Construction of hydrogen supply system [Entrance]
- Expansion of hydrogen utilization across multiple fields [Exit]
- Improving social awareness [Brand power]

8 projects

- Hydrogen BCP model
- Hydrogen BCP model at railway station
- Regional circulated hydrogen local production for local consumption model
- Fuel cell forklift introduction / clean hydrogen utilization model
- Packaged hydrogen station model
- CO2-free hydrogen filling / forklift utilization model demonstration project
- Demonstration project for practical use of fuel cell railway vehicles

Figure 2-7.
Kawasaki's Hydrogen Strategy
Source: Authors

Another example of the redesign that has gained additional support and some refinements in the wake of COVID-19 involves Kawasaki's main city building. Under the "Kawasaki City Main Government Building Reconstruction Basic Plan", approximately 47 billion yen (42 million US dollars) has been invested in disassembling the city's two main office buildings and constructing a new eco-friendly building (See Figure 2-8).

The building is designed to reduce CO_2 by maximizing the use of renewable energy and combining methods such as high-efficiency equipment, wood materials, and natural ventilation systems. Following COVID-19, plans have also been made to enable teleworking by creating flexible office seating plans in the new building.

Figure 2-8.
Kawasaki City Office Building Rendering
Source: Kawasaki, 2021

Another decision that will have a bearing on the city's redesign involves a company founded in Kawasaki more than 100 years ago, JFE Steel. JFE recently announced it would close the steelmaking processes in the Keihin industrial district in 2023. As a result, a large area of vacant land of 2.5 million square meters will be available. The city is now engaged in ongoing discussions of how Kawasaki city can take advantage of this opportunity to transform its traditional heavy industry into a green and clean technology hub (e.g., renewable energy and recycling technology). This transformation will nonetheless not be easy. One challenge is the employees who are likely to lose their jobs as a result of these structural changes. In addition, the company's blast furnace is located on an artificial island, Ogishima, and this island is not, generally speaking, a suitable environment for residential and commercial facilities. These challenges underline the difficulties and possible trade-offs from structural changes.

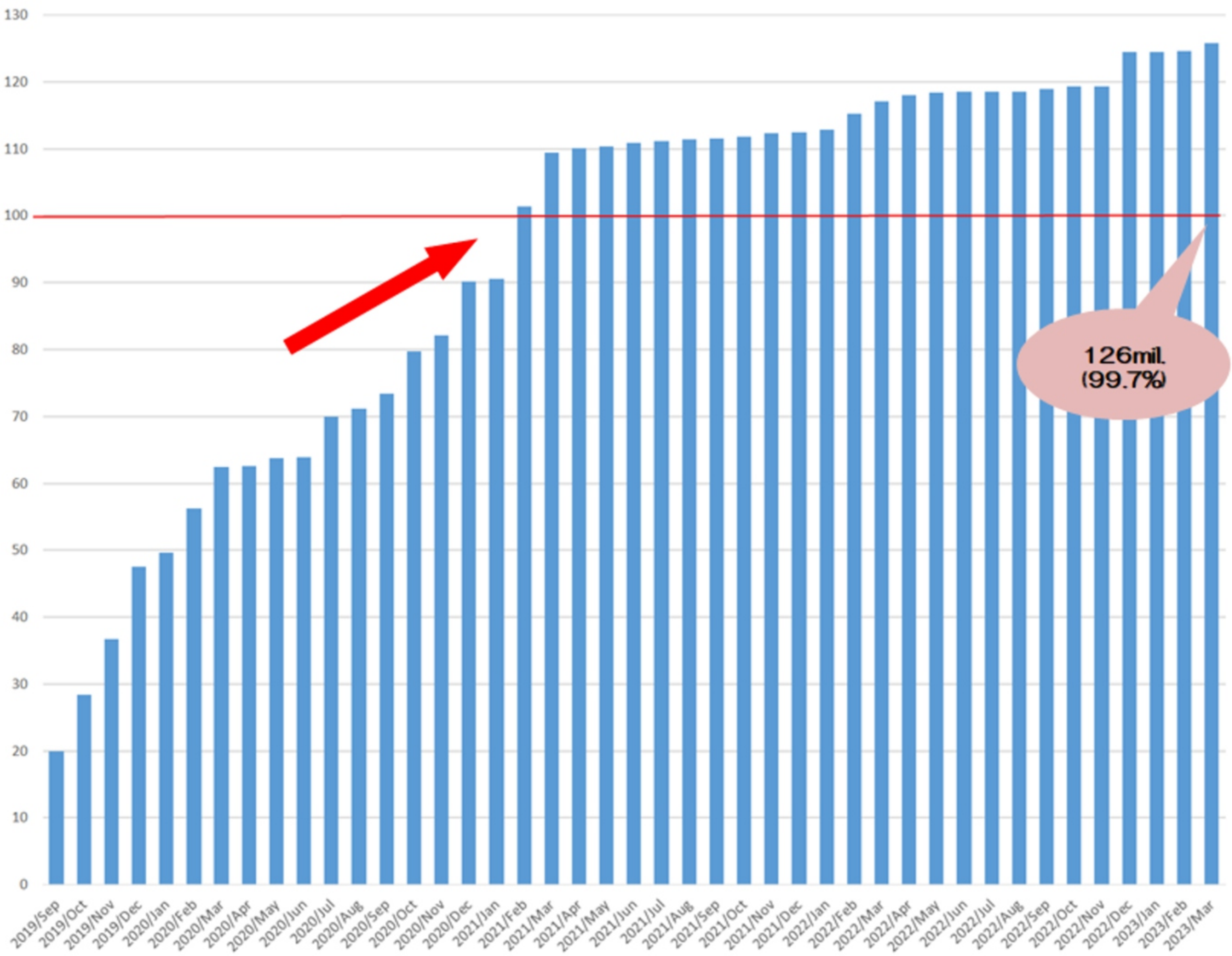


Figure 2-9.
Population of Cities in Net Zero Pledges
Source: Ministry of the Environment of Japan, 2023

A final set of governance and policy reforms that have gained traction in the wake of COVID-19 across Japan involve the effects of zero-carbon pledges on local-national institutional relationships. More than 930 city and local governments, accounting for more than 99% of the population, have made zero carbon pledges following COVID-19 and the announcement of national-level zero carbon targets (see Figure 2-9) (Ministry of the Environment of Japan, 2023). Many cities have done so with the expectation that some of the stimuli will help fund shifts in industry and other critical infrastructure. Significantly, these pledges and the potential for fiscal transfers could also strengthen institutional relationships between the national and local levels. The strengthening of these institutional relationships may also be complemented by redesign reforms aiming to engage diverse stakeholders in climate planning.

2.3 The Way Forward

This chapter has provided an overview of the air pollution and climate change policies that Kawasaki, Japan adopted (or strengthened) in the wake of COVID-19. It used the Triple R framework to help organize those interventions. In so doing, it suggested at least five take away points that could be relevant for cities outside Kawasaki.

1. Though Kawasaki has a long track record of successfully curbing industrial air pollution, the city still witnessed a reduction of approximately 15% in $PM_{2.5}$ concentrations over the previous year in the wake of COVID-19.
2. More research is needed on the precise causes of those reductions. At the same time, even slight declines in $PM_{2.5}$ can have beneficial effects on health that were arguably even more important to the well-being of Kawasaki's residents during the early spread of the virus.
3. Following Japan's first state of emergency, Kawasaki introduced an ambitious new net-zero target under its Kawasaki Zero Carbon Challenge. The presentation of this target set the stage for additional climate actions that are likely to have co-benefits for air quality. Climate led the way, but these reforms may improve air quality.
4. The key to achieving lasting reductions in CO_2 and air pollution in is the “redesign” of infrastructures, industries and institutions. Structural changes in each of these areas could lead to not merely reductions in CO_2 or air pollution but a more sustainable city.
5. One of Japan's less visible but potentially most meaningful “redesigns” is the strengthening of central-local relationships. The promise of the transfer of "green stimulus funds from national to local governments has been an incentive to increase the ambition of climate actions.

While Kawasaki is unique in many respects, some of the lessons learned from the above take home points could be shared more widely. For instance, its efforts to transition from a city that once managed air pollution through end-of-the-pipe technologies to energy-efficiency measures to more recent industrial redesign could be illuminating for cities contemplating similar transitions.

The fact that these transitions can occur while the city aims to make lifestyles and livelihoods more sustainable could be useful in many contexts Maximizing complementary changes to industrial and socioeconomic systems will be a growing priority for much of the world. Kawasaki is well situated to mentor other cities in that regard.

At the same time, learning could be a dynamic and interactive process where Kawasaki gains from the experiences of other cities as well. In this connection, one issue where Kawasaki may want to exchange experiences involves reductions in the use of public transport after the pandemic. The growing acceptance of teleworking has led to a reduction in commutes and use of public transport in Kawasaki. The relevant data underlines this reduction: public bus ridership fell by approximately 4 percent in Kawasaki between 2019 and 2020 (Kawasaki Transport Department 2021). Though not a major drop, there is scope for cities to learn from each other on how to make public transport attractive and safe following COVID-19.

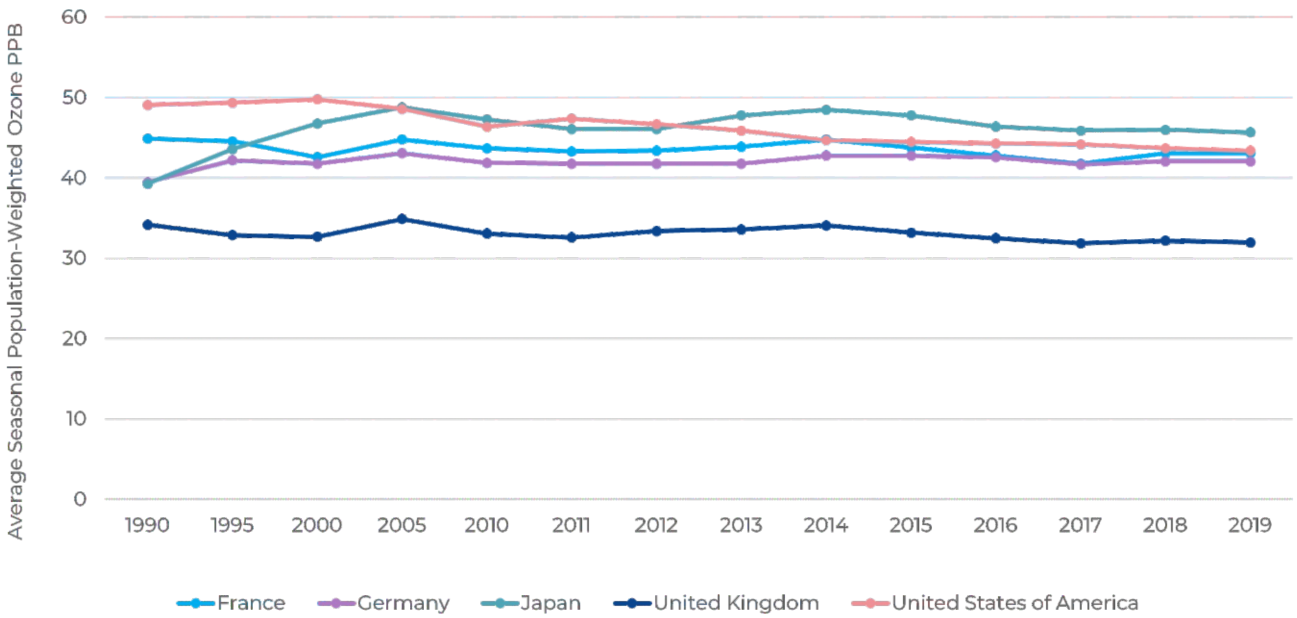


Figure 2-10.
Ozone Concentrations in Japan and Other OECD Countries
Source: Health Effects Institute, 2020

Another area that may be ripe for mutually beneficial learning involves tropospheric ozone (O_3) concentrations. In Japan, average measures of ozone concentrations have been higher than most Organisation of Economic Cooperation and Development (OECD) countries over the past decade (see Figure 2-10) (Health Effects Institute 2020). Kawasaki appears to have made some progress with a reduction in ozone days exceeding national standards over the past five years (World Air Quality Index 2021).

Nonetheless, there may be opportunities to discuss what has been behind that progress—and continuing challenges—on ozone. Such a discussion may be valuable in light of the COVID-19 because reductions in $PM_{2.5}$ in some countries can create conditions that lead to increases in ozone (Sicard et al. 2020).

The COVID-19 pandemic has had a devastating impact on the world, but it has also created an opportunity for cities to improve air quality and combat climate change. Kawasaki, Japan is a prime example of a city that has seized this opportunity. In the wake of the pandemic, Kawasaki experienced a significant improvement in air quality. This was due to a number of factors, including reduced traffic congestion, fewer industrial emissions, and increased public transportation use. The city also took advantage of the pandemic to accelerate its climate action plans, including a pledge to achieve zero carbon emissions by 2050.

Kawasaki's experience shows that the COVID-19 pandemic partially worked as a catalyst for positive change. By taking advantage of the opportunity to improve air quality and combat climate change, cities can create a healthier and more sustainable future for their residents. Cities can learn from each other's experiences. Other cities can learn from Kawasaki's experience by sharing best practices and collaborating on joint projects. By working together, cities can create a healthier and more sustainable future for all.

Didin Agustian Permadi
Muhayatun Santoso
Mila Dirgawati
Soni Pratamayudha

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3

The Effects of COVID-19 on Air Quality Planning in Jakarta, Indonesia

3.

The Effects of COVID-19 on Air Quality Planning in Jakarta, Indonesia

At the end of 2019, the discovery of the coronavirus in China would set in motion sweeping changes to economic and energy systems across the world. By early 2020, the World Health Organization (WHO) would hint at the size of those changes when it declared COVID-19 a global pandemic (WHO, 2020). This declaration would be followed by decisions from many countries to implement restrictions on social activity that reduced public mobility and fossil fuel consumption in key sectors. While these limitations hurt economic growth, they also helped the environment (Bhat et al. 2020; Janardhanan et al. 2020; Zusman, Kawazu, Mader, et al. 2020).

In terms of environmental health, air quality was arguably the area that saw the greatest improvement in COVID-19's wake. Research in Asia, for instance, showed the impacts of various COVID-19 related measures improved air quality in India, China, Indonesia and Malaysia (Abdullah et al. 2020; Chen et al. 2020; Mahato, Pal, and Ghosh 2020; Santoso et al. 2021). These gains were not limited to Asia, however. Air pollution also fell in Italy, Spain and USA by up to 30 percent according to another similarly themed study (Ahmad et al. 2020).

In Indonesia, more than 4 million confirmed cases of COVID-19 with more than 140 thousand deaths were reported during January 2020–October 2021 (WHO 2021d). Meanwhile, in Jakarta, Indonesia's capital, large scale social restriction (LSSR) would force the closure of public places and restrict public transport and travel. Following a pattern seen elsewhere in the world, Jakarta's provincial environmental protection agency and researchers also reported improvement of air quality during the implementation of the LSSR (DLH 2020; Santoso et al. 2021).

This chapter is intended to present information on the effects of LSSR implementation on Jakarta's air quality. The chapter also draws upon the notion "build back better" to identify strategies to sustain air quality gains in the post-pandemic era. The chapter is aimed at helping the government to evaluate the effects of the LSSR implementation and the associated benefits on air quality improvement, while raising public awareness of the need for sustainable solutions to air pollution.

3.1 Overview of Jakarta

Jakarta, Indonesia is located in a lowland with an average elevation of 7 meters above sea level (ASL). The area of Jakarta Province covers 662 km^2 with a water environment (sea) of 6,977 km^2. Jakarta Province is divided into five administrative cities and one administrative district. The province consists of Central, North, West, South and East Jakarta and one administrative district (Kepulauan Seribu).

The population of Jakarta from 2015 to 2020 has increased every year, where the highest population was nearly 10.5 million people with an annual population growth rate of 0.92 percent during the reporting period (Figure 3-1) (BPS DKI Jakarta 2021). In 2020, the population density in Jakarta was 14,555 peoplel/km^2 with the highest density in Central Jakarta at reached 18,603 people/km^2.

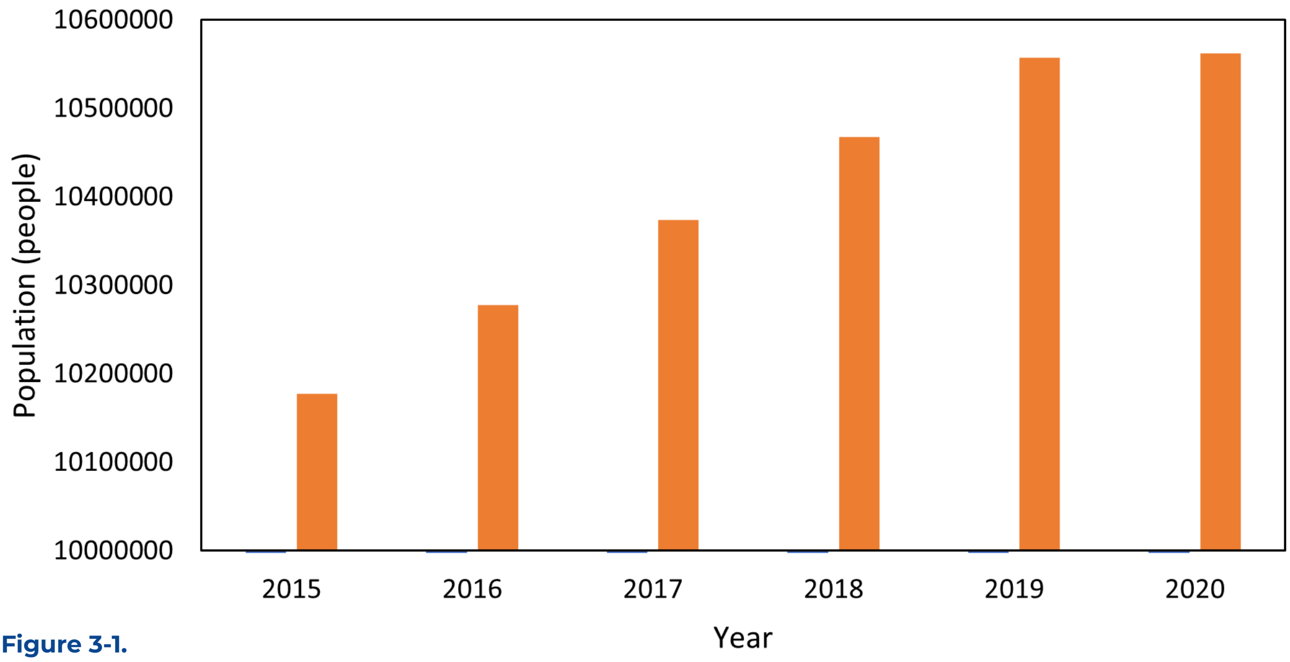


Figure 3-1.
Population Growth Between 2015 – 2020.
Source: BPS DKI Jakarta (2021)

The Gross Regional Domestic Product (GRDP) values for Jakarta province during the period of 2016 – 2020 are presented in Table 3.1. The table shows that the GRDP increased constantly from 2016 to 2019 but decreased in 2020 due to COVID-19.

The economic structure of Jakarta in 2020 was dominated by the wholesale and retail sectors and automotive with a contribution value of 16.62 percent during the 2016-2020 period (BPS DKI Jakarta 2021). In addition, the manufacturing and construction industry sectors also shared significant contribution of 11.4 percent from the total values of GRDP during the same period.

No.	Year	Gross Regional Domestic Product at Current Price (billion rupiah)	Gross Regional Domestic Product at Constant Prices (billion rupiah)
1.	2016	2,159,073	1,539,916
2.	2017	2,365,363	1,635,359
3.	2018	2,592,606	1,735,208
4.	2019	2,816,760	1,836,198
5.	2020	2,772,381	1,792,794

Table 3-1.
Gross Regional Domestic Product of Jakarta Province between 2016–2020
Source: BPS DKI Jakarta (2021)

3.1.1 Meteorological Conditions

The rainy season in Jakarta occurs from October to March, with the accumulation of monthly rainfall ranging from 87 – 1,000 mm (Table 3-2). The dry season follows from April to September with monthly rainfall intensity ranged from 12–151 mm. The highest monthly average temperatures occur May (29.7 °C), concurrent with the dry season. The lowest monthly rainfall is in February, coincident with the rainy months with high rainfall intensity (784–1,043 mm/month).

Month	Rainfall (mm)		Temperature (°C)	
	Kemayoran	Tanjung	Kemayoran	Tanjung
January	618	607	24-34 (28)	24.2 – 32.4 (28.3)
February	1.043	784	24-35 (27.7)	24.6 – 32.6 (27.9)
March	221	211	25-34.6 (28.6)	24.6 – 34 (28.7)
April	183	142	25-34.80 (29)	24.8 – 34 (29.5)
May	50	52	24.8 – 35.60 (29.6)	25.2 – 35.2 (29.7)
June	21	63	24.4 – 35 (29.5)	24.6 – 35.2 (29.6)
July	12	99	24.2 – 34.2 (28.9)	25 – 33.6 (29)
August	101	77	24 – 34.8 (29.1)	24.3 – 34.6 (29.3)
September	151	131	24 – 35 (29.3)	24.1 – 35 (29.4)
October	208	98	24 – 34.6 (28.8)	24.4 – 34.4 (29.1)
November	87	114	25 – 35.2 (29)	25 – 34.9 (29.1)
December	134	236	24.2 – 34.8 (28.1)	24 – 34 (28.1)

Table 3-2.
Rainfall and Temperature Data for Jakarta, 2020
Note: Numbers presented in the parentheses indicated the average values
Source: BPS DKI Jakarta 2021

3.1.2 Ambient Air Quality Monitoring

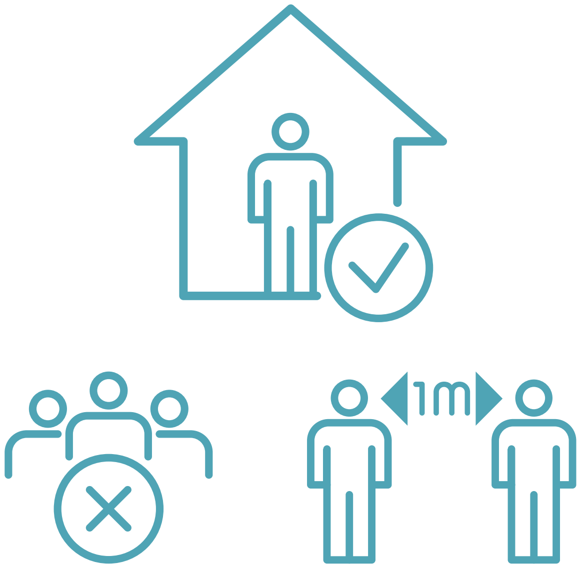
Currently, Jakarta has several continuous ambient air quality monitoring stations, and these are managed by different agencies such as the DLH, the Ministry of Environment and Forestry (KLHK), Meteorological Agency and Geophysics (BMKG), the United States embassy and an intensive aerosol monitoring (non-automatic, filter-based monitoring) by National Nuclear Energy Agency (BATAN). DLH manages five automatic monitoring stations located in the Jakarta Province namely DKI 1 (Bundaran HI, Central Jakarta), DKI 2 (Kelapa Gading, North Jakarta), DKI 3 (Jagakarsa, South Jakarta), DKI 4 (Lubang Buaya, East Jakarta) and DKI 5 (Kebon Jeruk, Central Jakarta). Parameters monitored at those stations are PM_{10}, $PM_{2.5}$ (since Jan 2019), CO, O_3, SO_2, NOx, non-methane hydrocarbon (NMHC), total hydrocarbons, CH_4 and the standard meteorological parameters. Continuous monitoring of PM mass uses the standard Federal Reference Method (FRM) Beta Attenuation (BAM) (Verewa F701-20 for PM_{10} and Horiba APDA- 138 371 for $PM_{2.5}$). Standard continuous gas analyzers have been used as follows: O_3 (HORIBA APOA-139 370), CO (HORIBA APMA-370), SO_2 (HORIBA APSA-370), and NOx (HORIBA APNA-370) (Santoso et al. 2021).

KLHK operates one station in the Gelora Bung Karno (GBK) sport complex with measured parameters of PM_{10}, $PM_{2.5}$, CO, O_3, SO_2, NO_2. BMKG manages one station located in the Northern part of Jakarta (Kemayoran) that monitors PM_{10}, total particulate matter (TPM), greenhouse gases (GHGs) (CO_2, CH_4, N_2O, SF_6), O_3, SO_2, NO_2. This site is also accompanied by the ground measurement of Aerosol Optical Depth (AOD) with a solar-powered CIMEL Electronique 318A sun photometer; this is part of the National Aeronautics and Space Administration (NASA), Aerosol Robotic Network (AERONET). Two stations have also been set up in the United States embassy monitor $PM_{2.5}$ concentrations using sensors since 2015 (Vital Strategies, 2019). An intensive particulate matter (PM) measurement using a filter-based using a Gent Stack Filter Unit (SFU) particle sampler which is capable of collecting particulate matter in $PM_{2.5\text{-}10}$ and $PM_{2.5}$ size fractions (Santoso et al. 2020). This site is located in DLH headquarter (Central Jakarta), and it has been used to monitor long term PM and compositions since 2010 (Santoso et al. 2020).

Richan Dwi Putra. 2021.

3.2 The Large-Scale Social Restriction Policy in Jakarta

The Ministry of Health (MoH) issued the Decree No. HK.01.07/MENKES/239/2020 regarding the LSSR in the DKI Jakarta Province to prevention actions on the COVID-19. The ministerial decree required the Governor's Decree to provide guidance on the technical implementation on the LSSR, especially for key sectors in the DKI Jakarta Province. Table 3.3 summarizes actions and goals taken to implement the Governor's Decree.



Sector	Guidance on the LSSR implementation		
	LSSR 1 (10 April – 3 June)	**Transition LSSR (4 June – 13 September)**	**LSSR 2 (14 September – 31 December)**
Health	100 percent operation & standard health procedure	50 percent operation & standard health procedure	50 percent operation & standard health procedure
Food			
Energy			
Communication and IT			
Finance			
Logistic			
Hotel			
Construction			
Strategic Industry			
Basic public service			
Daily consumption			
Recreation	Close		Close
Shopping malls	Normal/open		50 percent operation & standard health procedure
Married ceremony	Restricted only in government office		Restricted only in government office
Sport events	Close	Open	Close
Education	Close	Close	Close
Religious	Close	50 percent operation & standard health procedure	Open with 50 percent from the capacity
Other public facility	Close / no activity for more than 5 persons		Close / no activity for more than 5 persons

Table 3.3.
Summary of Regulation for LSSR Implementation in 2020
Source: Pergub 33 2020; Pergub 79 2020; and Pergub 88 2020.

3.3 What was COVID's Impacts on Emissions, Energy Use and Air Quality in Jakarta?

3.3.1 Energy Use Data

3.3.1.1 Industry

Fuel consumption data from the industrial sector in Jakarta Province was obtained for 2019-2020 and presented in Figure 3-2.

The data shows that manufacturing industries in Jakarta consume gas, diesel oil and coal for energy and other purposes. Annual fuel consumption for all type of fuels tended to decrease from 2019 to 2020. The reduction rate for gas consumption was 9 percent, while for diesel oil and gas the reductions were 23 percent and 33 percent, respectively. These reductions likely affected industrial emissions.

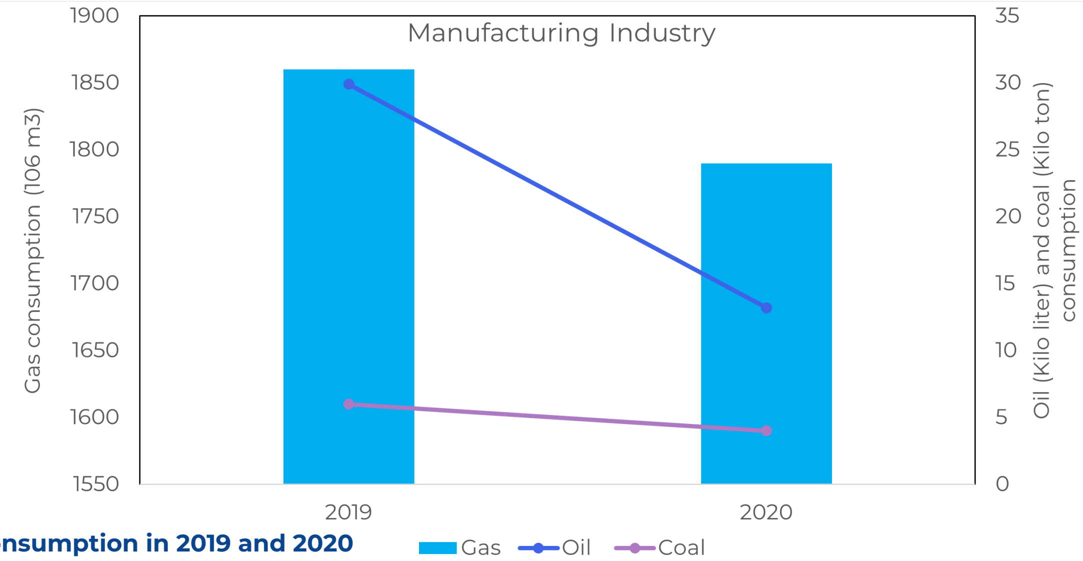


Figure 3-2.
Industrial fuel consumption in 2019 and 2020
Source: KLHK 2021

To estimate the magnitude of the reductions, emissions from manufacturing industries were quantified using the Atmospheric Brown Cloud Emission Inventory Manual (ABC EIM) EXCEL tool. The result of that analysis is presented in Table 3.4. Due to the reduction on the consumption of gas, diesel oil and coal, emission reductions (varying by species) ranged from 12 Ton/yr-11,000 Gg/yr.

Species	Emission (Ton/year)		Emission Reduction (Ton/yr)
	2019	2020	
NOx	58,485	45,275	13,210
CO	2,204,743	1,706,896	497,847
$PM_{2.5}$	52	40	12
CO_2	48,964,105	37,906,756	11,057,349

Table 3-4.
Impacts on Emissions in the Manufacturing Industry
Source: Author Analysis

3.3.1.2 Residential

The amount of LPG circulated to the household in Jakarta Province is presented in Figure 3-3 for January-March from 2019 through 2020. The media reported the trend of increasing LPG consumption at home; those estimates are broadly comparable to the data reported by the PT Pertamina Marketing Operation Region III. Data on the sales of non-subsidized LPG (5.5 and 12 kg) tended to increase by 3-4 percent while the subsidized LPG (3 kg) tended to slightly increase to around 1 percent. This could consequently lead to a modest increase in emissions from the residential cooking (using LPG).

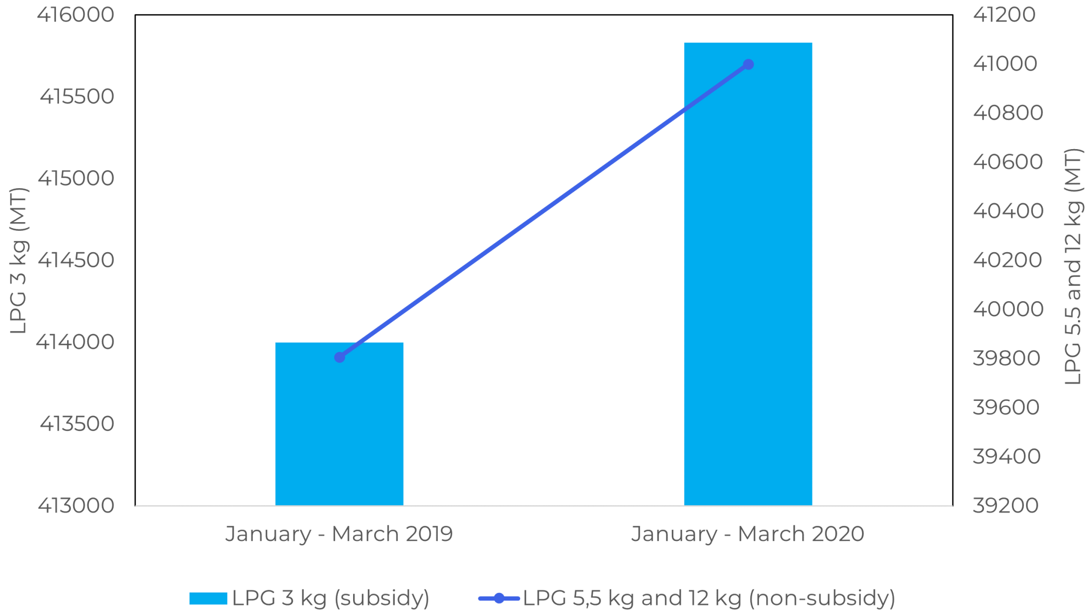


Figure 3-3.
LPG sale for the reporting period of January – March 2019 and 2020
Source: PT Pertamina MOR III 2021

Based on the reported increase in LPG fuel sales from households, emissions were estimated to be higher in the pandemic year of 2020 (see Table 3-5). Emissions increases (varied by species) from 3 Ton/yr – 36 Gg/yr due to the more intensive use of LPG in 2020.

Species	Emission (Ton/yr)		Emission increase (Ton/yr)
	2019	2020	
NOx	3,195	3,216	21
CO	6,752	6,798	46
$PM_{2.5}$	472	475	3
CO_2	5,409,367	5,445,437	36,070

Table 3-5.
Impacts on Emissions from Residential Energy
Source: Author Analysis

3.3.1.3 Power generation

During the LSSR implementation, the government strengthened its commitment to providing a stable electricity supply. However, the electricity demand for public facilities tended to fall during the LSSR and many power producers needed to adapt to the reduced demand by not running their plants less than 100 percent of the total capacity.

Consequently, many individual power producers (IPPs) limited their operation, leading to an unavoidable drop in fuel consumption. Figure 3-4 presents the fuel consumption of several power plants operated in Jakarta province during 2018-2020. The fuel consumption tended to fall significantly between 2019 to 2020; for instance, in two key power plants (Tanjung Priok POMU and Muara Karang Power Plants) there was a reduction of approximately 34 percent (gas), 33 percent high speed diesel (HSD) and 73 percent marine fuel oil (MFO).

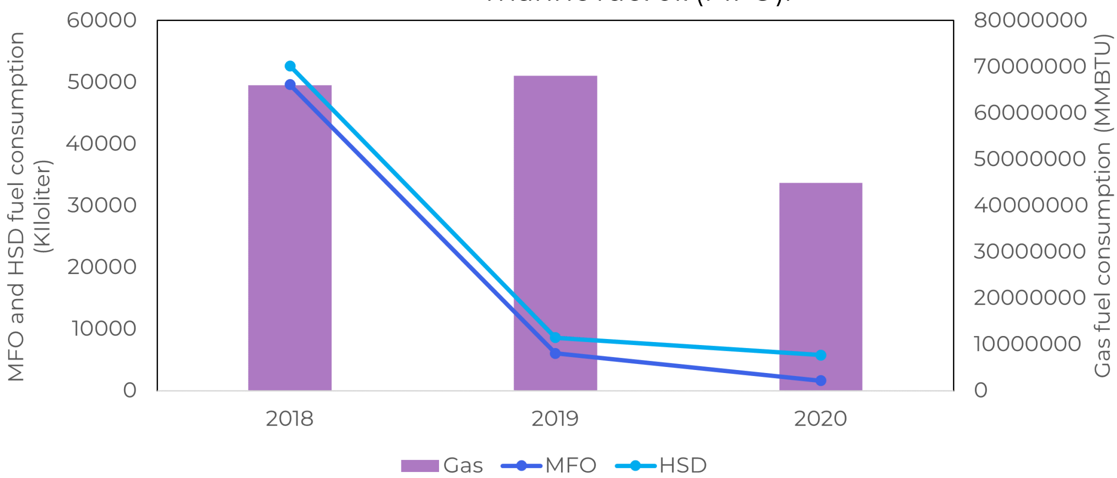


Figure 3-4.
Fuel Consumption from Power Plants for 2018-2020
Source: PT Indonesia Power 2020; PT PJB 2020; PT PLN 2020

Note that the reduction in demand and power generation likely led to a steep decrease in emissions from these plants and improvements in air quality. The emission reduction is suggested in Figure 3-4 and Table 3-5. In particular, Table 3-6 shows that emissions different pollutants fell by between 170 t/yr ($PM_{2.5}$) and 20,800 Gg/yr (Co_2).

Species	Emission (Ton/yr)		Emission Reduction (Ton/yr)
	2019	2020	
NOx	100,413	67,357	33,056
CO	9,145	4,827	4,318
$PM_{2.5}$	398	228	170
CO_2	42,808,552	22,005,845	20,802,707

Table 3-6.
Impacts on Emissions from Power Plants
Source: Author Analysis

3.3.1.4 Commercial

Much like industry, the commercial sector was also affected by the LSSR (Table 3-7). Figure 7 presents the changes in fuel consumption for oil and gas in the commercial sector in Jakarta Province between 2019 and 2020. Diesel oil consumption, which was used mainly for back-up generators, tended to decrease significantly while the supply of gas increased in 2020. The changes in fuel consumption likely affected emissions from the commercial sector in 2020 relative to 2019. The implications of theses shifts are presented in Table 3-7. That table shows emission reduction ranged from 3 ton/yr ($PM_{2.5}$) to 518 ton/yr (CO_2).

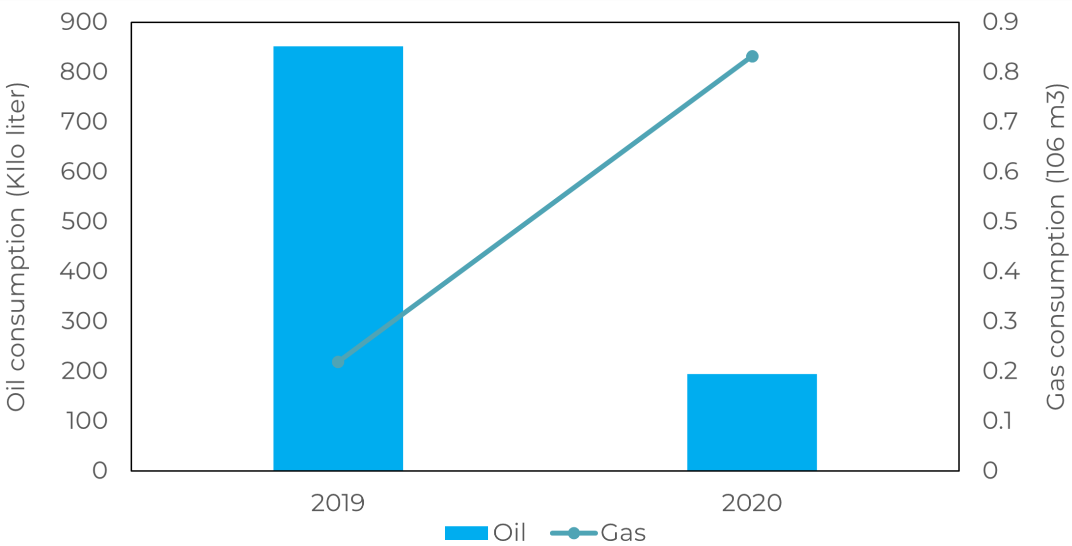


Figure 3-5.
Fuel Consumption for the Commercial Sector for 2019-2020
Source: Abdurrahman 2020

Species	Emission (Ton/yr)		Emission reduction (Ton/yr)
	2019	2020	
NOx	61	15,3	45,7
CO	13,2	4,17	9,03
$PM_{2.5}$	3,6	0,83	2,77
CO_2	2,700	2,182	518

Table 3-7.
Impacts on Emissions from the Commercial Sector
Source: Author Analysis

3.3.1.5 On-Road transportation

On-road transportation is a major contributor to air pollution in Jakarta. The LSSR limited on-road mobile transport, especially in major road network at the city.

The distribution of fuels, including gasoline and diesel oil in 2020 as compared to the year of 2018, are presented in Figure 3-6. There was an obvious decrease for both fuel distribution during 2020, a reduction that was likely due to the lower levels of mobility.

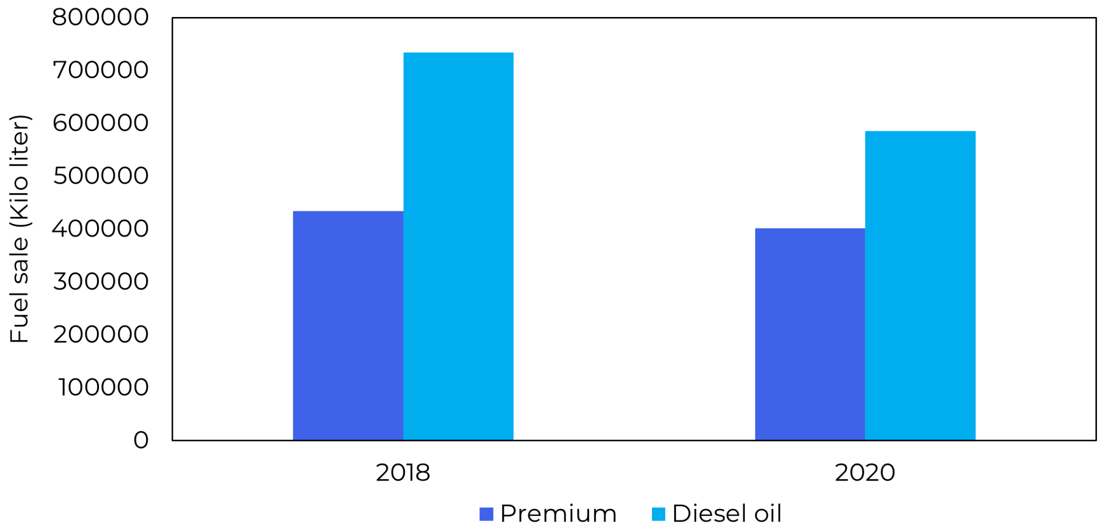
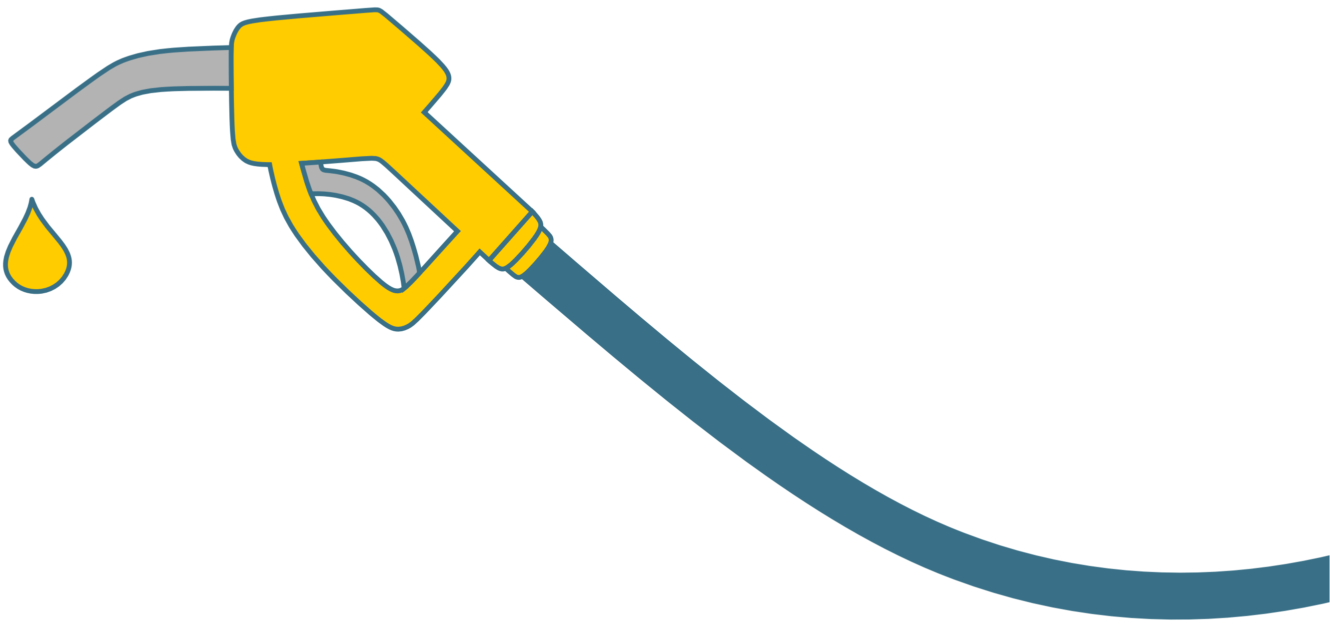
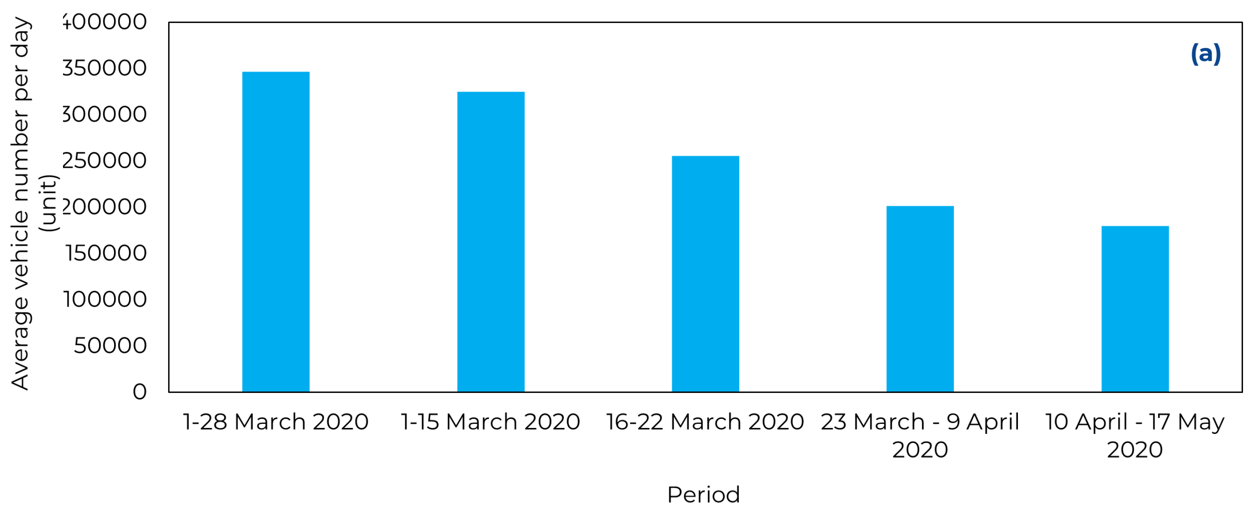


Figure 3-6.
Fuel Sales for On-Road Mobile Sources for 2018-2020
Source: BPH Migas 2018; PT Pertamina 2020



Traffic was less intense before and during the LSSR implementation as shown in Figure 3-7a. Traffic counting was done at three important road network in Jakarta: Cipete Raya, Bundaran Senayan, dan Dukuh Atas. Before 10 April 2020, the volume of traffic was between 325,000 –350,000 vehicle per day on all roads. That number dropped to only 180,000–255,000 vehicles per day during 16 March to 17 May 2020 (LSSR implementation).

The reduction in volume also likely affected average vehicle speeds on Cipete Raya, Bundaran Senayan, dan Dukuh Atas, during and after the first LSSR (see Figure 3-7b). The reduction in traffic intensity during the LSSR period was also correlated with the observed higher speed of vehicles. Before the LSSR, the average vehicle speed was only 16.3 km/hr but after the speed increased to between 17.2 – 20.2 km/hr.



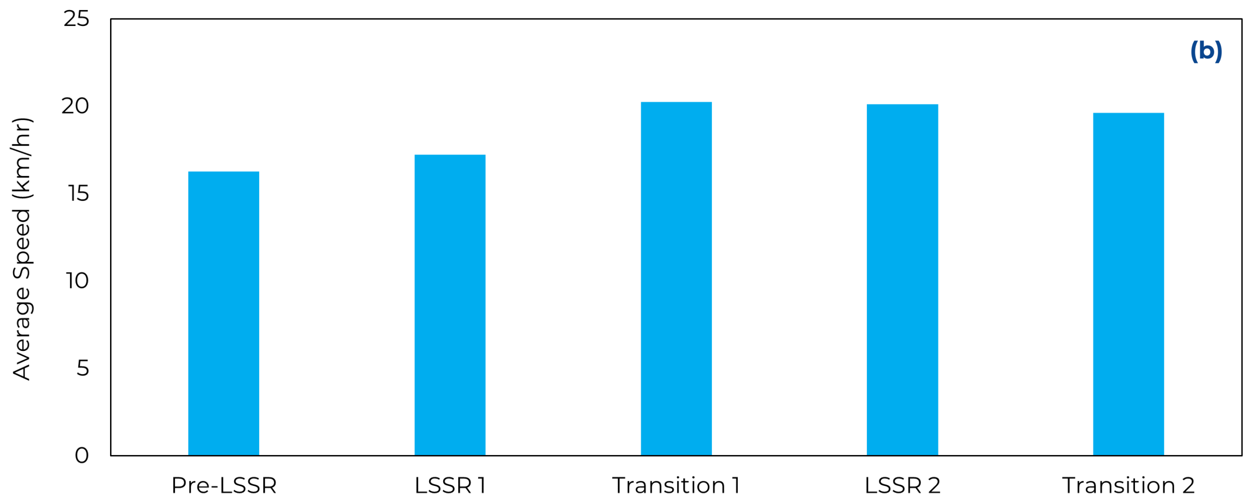
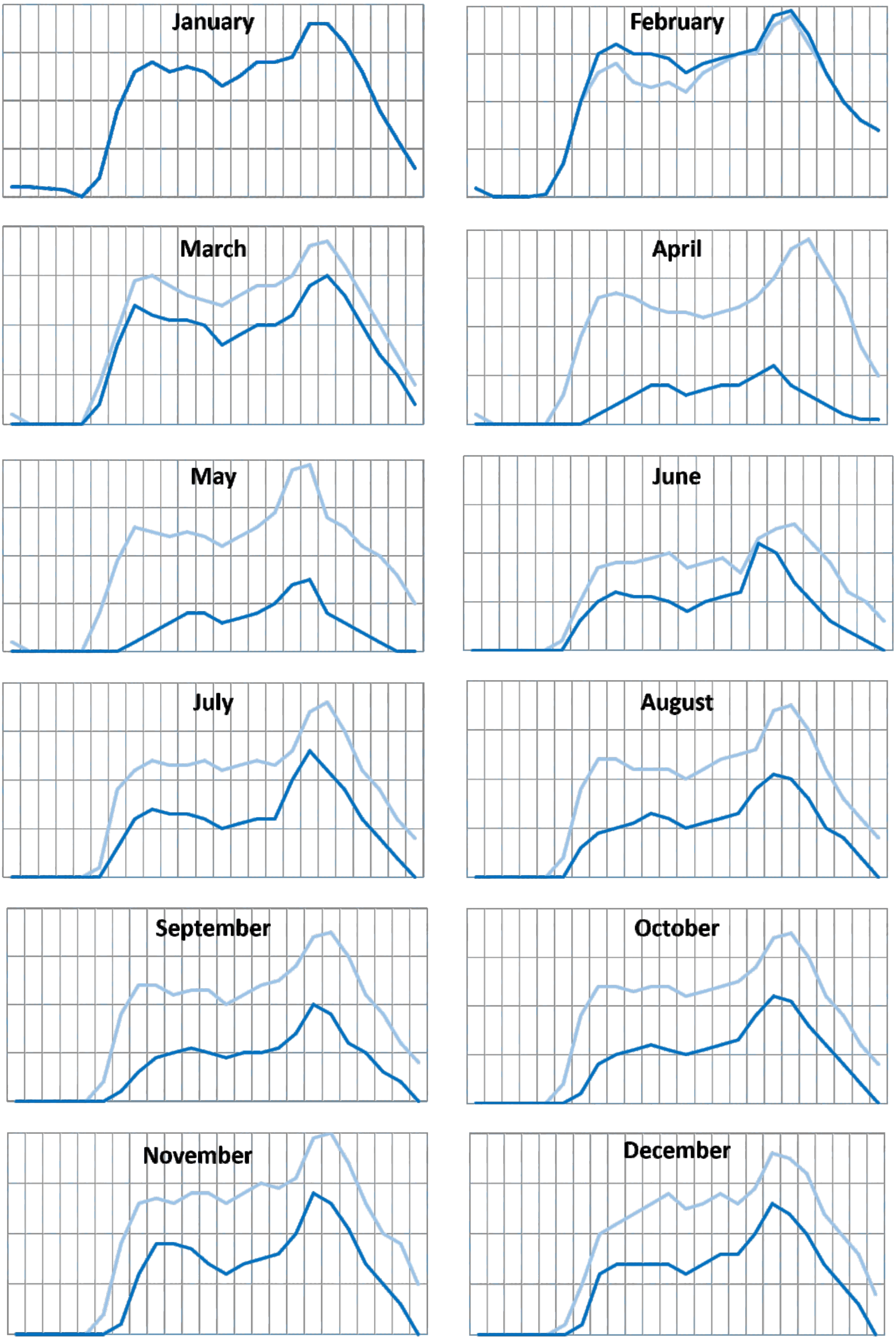


Figure 3-7.
Traffic-counting and Average Speed on Several Road Networks in Jakarta, 2020: a) Traffic Counting (vehicle/day), and b) Average Speed (km/hr)
Source: DISKOMINFOTIK 2021



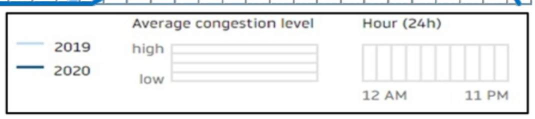


Figure 3-8.
Congestion Levels in Jakarta
Source: Tom Tom Indonesia 2021

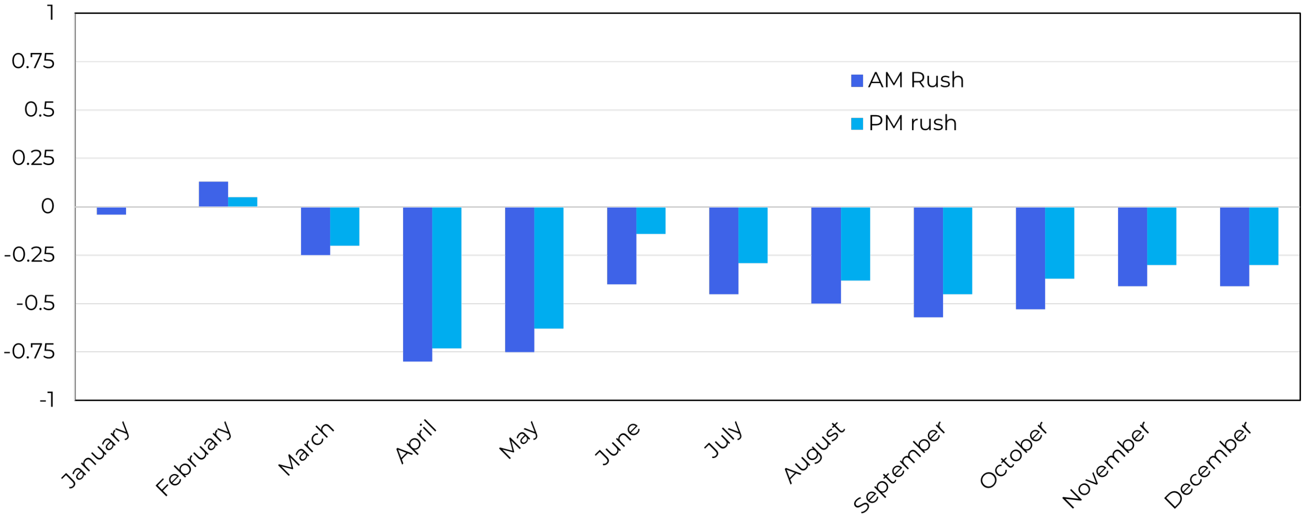


Figure 3-9.
Rush Hour Changes 2019-2020 in Jakarta
Source: Tom Tom Indonesia 2021

Another indication of the effects of the LLSR involved congestion levels. Average traffic congestion level data were taken for every month of 2019 and 2020 (Figure 3-9). During January–February, the congestion levels are relatively similar between 2019 and 2020, and even the level in February 2020 is higher than 2019. However, comparing those years, from March–December, there were significant reductions in traffic congestion in 2020 as compared to 2019. A remarkable reduction occurred in April and May 2020 when the first LSSR was initially implemented in Jakarta. Reductions in congestions throughout the pandemic year could also bring down emissions of air pollution.

Figure 3-9 presents the changes in morning and afternoon rush hours between 2019-2020 in Jakarta. In April-May 2020, there was reduction in amount of traffic during the morning rush hour of 75–77 percent and afternoon rush hour (60-70 percent) compared to similar months in 2019. Less significant albeit still sizable reductions were also seen in other months—except in period just before the LSSR (January and February 2020). The reductions in traffic also likely contributed to improvements in air quality.

3.4 The Impact of LSSR on Air Quality in Jakarta

3.4.1 Air Quality Monitoring Data

The ambient air quality monitoring data used for this study were obtained from several high-quality sources (see Figure 3-10). The chapter used three sources of ground-based monitoring data for Jakarta: 1) PM filter-based measurement (i.e. PM mass, carbonaceous and elemental compositions) at the DLH Headquarters; 2) BMKG site (North Jakarta) for PM_{10} and Aerosol Optical Depth (AOD) measured by sun-photometer equipment; 3) DKI 1 Bundaran HI for $PM_{2.5}$ and gases, and 4) KLHK GBK Sports Complex ($PM_{2.5}$ and Gases). In addition, the chapter also retrieved Terra Moderate Resolution Imaging Spectroradiometer (MODIS) Aerosol Optical Depth (AOD) to visualize the spatial distribution of column aerosol burden (https:// giovanni.gsfc.nasa.gov/ giovanni/).

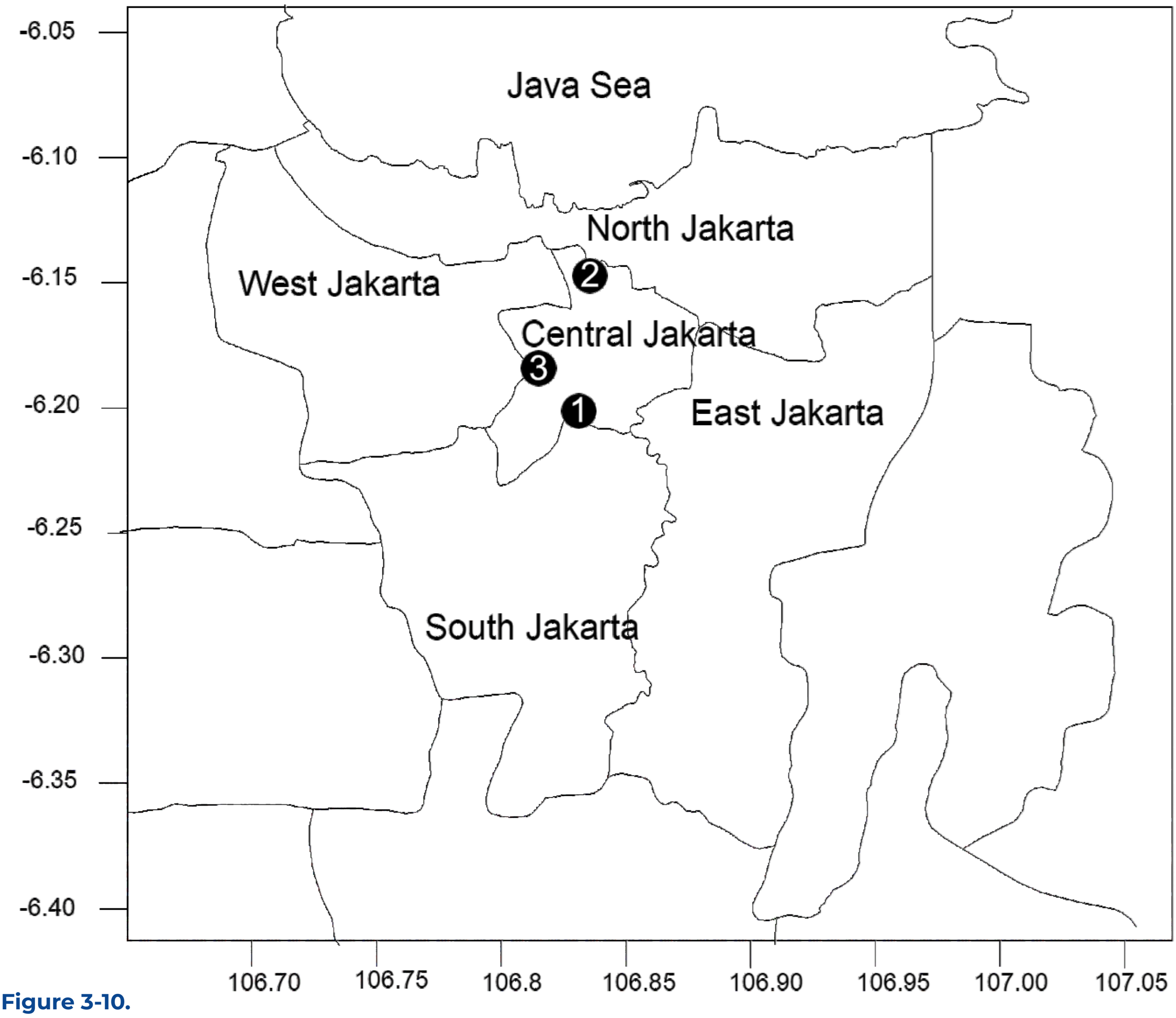


Figure 3-10.
Location of Air Quality Monitoring Stations Featured in this Chapter
Note: (1) DLH headquarters, (2) BMKG North Jakarta, and (3) DKI 1 Bundaran HI

3.4.2 Long Term Monthly Average PM

Long-term PM (both coarse and fine) and compositions monitoring data (filter-based) were obtained from station No. 1 (Figure 3-11) to investigate the impact of LSSR on PM air quality in Jakarta (Santoso et al., 2021). Monthly average concentrations of PM during the LSSR (March – May 2020) were compared with long-term averages for similar months (2010 – 2019). There was a clear reduction in $PM_{2.5}$ concentrations when comparing averages prior to COVID (21.4 μg/m^3) and the LSSR period (10.5 μg/m^3) (Figure 13-10a).

The main source of $PM_{2.5}$ was fossil fuel combustion; this drop was therefore arguably related to a reduction in the traffic and other combustion sources. This is also apparent in that the monthly average of $PM_{10-2.5}$ during the LSSR period were far lower than the long-term average (Figure 3-11b). The 2020 March concentration was only 10 μg/m^3 while the long-term value was 27 μg/m^3. Similar conditions were seen for April and May where the long-term average concentrations were more than double those from 2020. This comparison further underlines that the LSSR had significant effect on coarse and fine PM air quality in Jakarta.

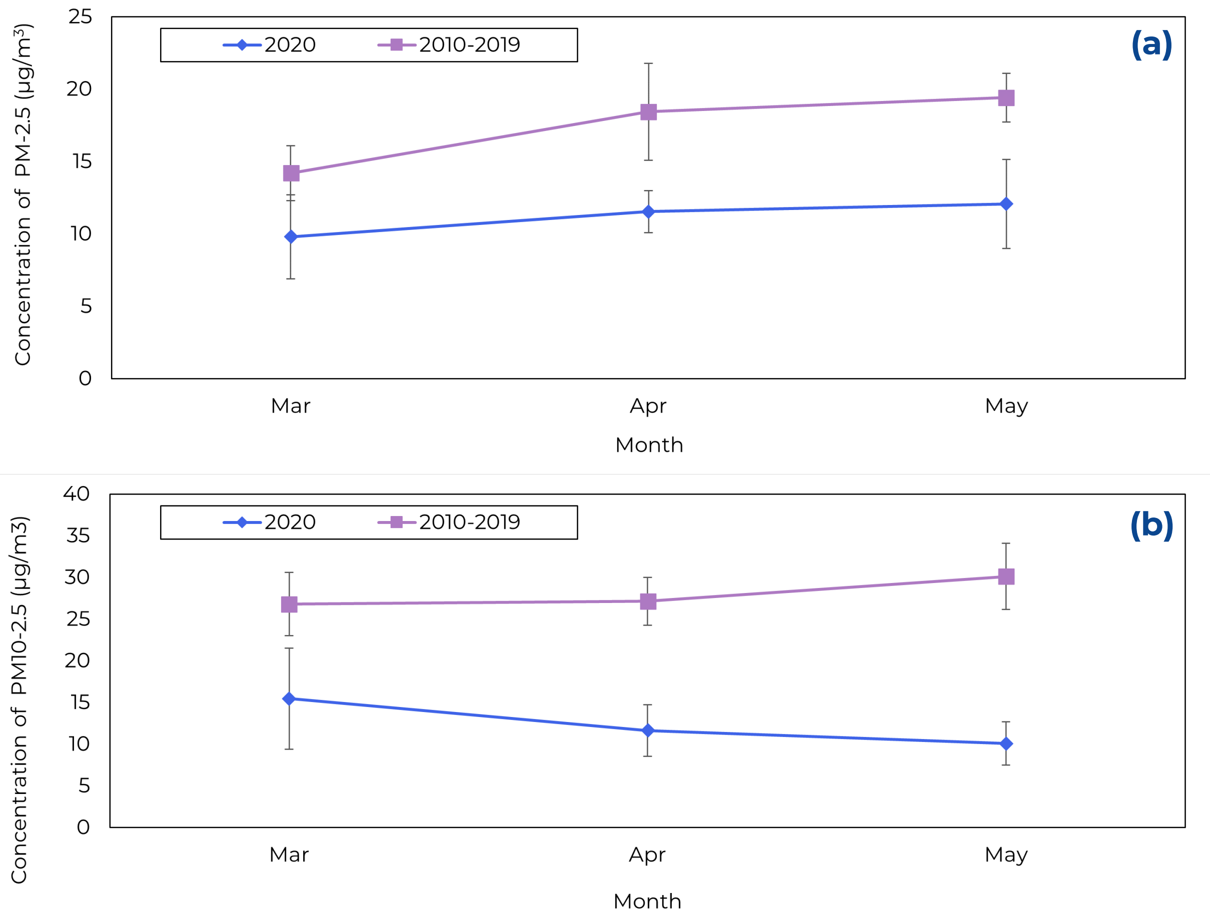


Figure 3-11.
Comparison of LSSR Period Monthly Averages and Normal Period Long Term Monthly Averages for Fine and Coarse PM in Jakarta, a) Fine PM, and b) Coarse PM
Source: Adapted from Santoso et al. 2021

3.4.3 Annual and Monthly Variations in Gases

The chapter compared the period average of SO_2, CO, O_3, and NO_2 concentrations prior to the LSSR (1st January – 15th March 2020) and during the LSSR (16th March – 31st May 2020). Similar data were also gathered for a similar time in 2019 and labeled pre-LSSR 2019 and LSSR 2019. The results are presented in Figure 3-12.

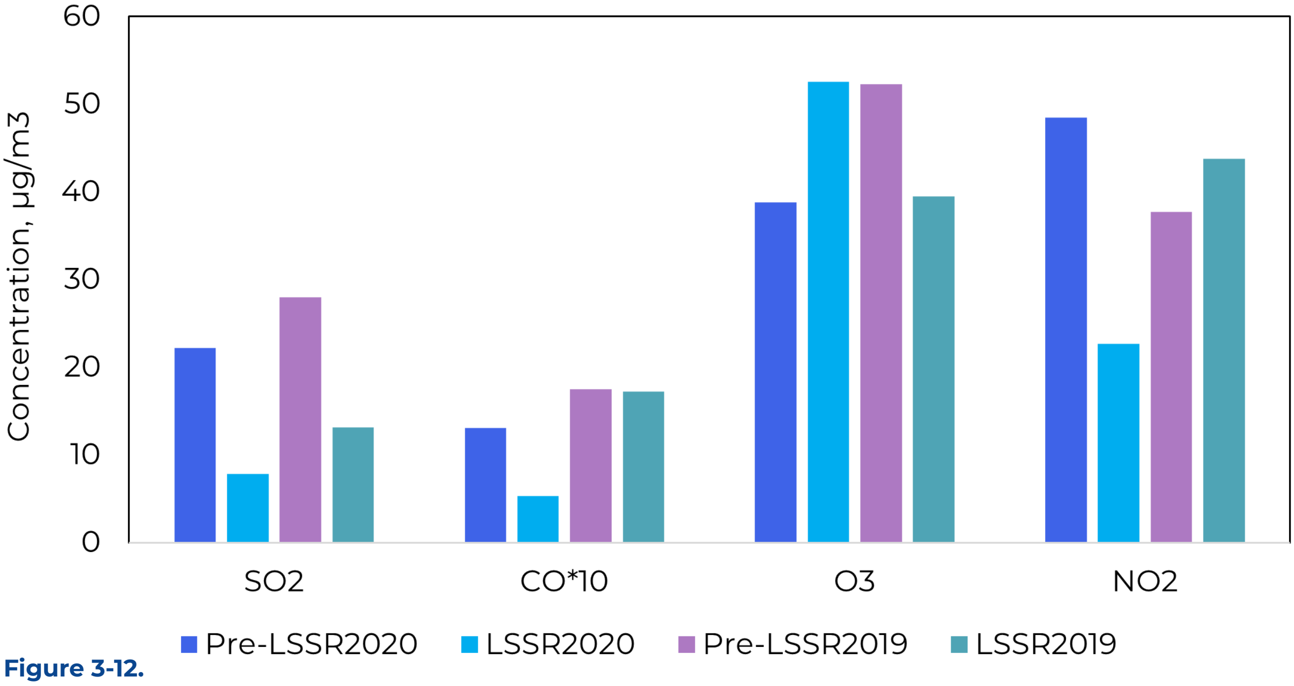
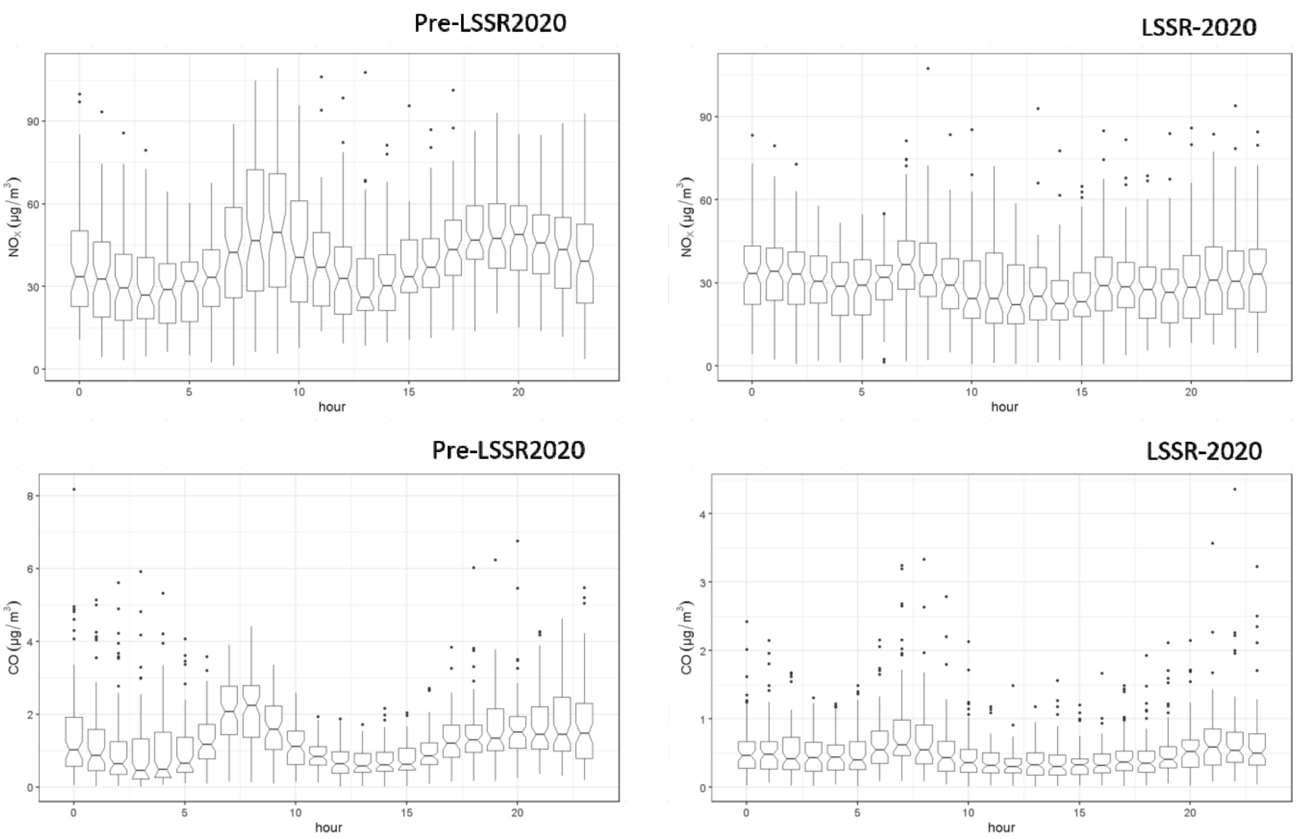


Figure 3-12.
Comparison of LSSR Period Monthly Average and Normal Period Long Term Monthly Average of SO_2, CO, NO_2, and Ozone Concentrations Recorded at DKI1 Stations
Source: Adapted from Santoso et al. 2021

The figures above illustrate that there were significant reductions in SO_2, CO, and NO_2 concentrations during the LSSR in 2020. This was likely due to the drastic reduction in traffic activity in Central Jakarta. These reductions are well captured by the monitoring data, and that seems to be affected by traffic emissions. In contrast, the chapter also found a slight increase of period average ozone concentration (secondary pollutant) during the LSSR 2020. The increase in ozone is likely is attributable to urban photochemistry. A reduction in primary NOx emissions led to less ozone titration and an increase in ozone (Santoso et al.2021).

3.4.4 Ground Based AOD vs. Satellite AOD

The turbidity of the atmosphere due to the anthropogenic and natural aerosol can be measured by what is known as aerosol optical depth (AOD). Ground-based observations of the AOD was recorded using sun-photometer that were placed in the BMKG site (Figure 3-13). Monthly and longer averages of (normal and LSSR period) AOD were constructed to assess these effects (see Figure 3-13). Overall, the monthly average AOD data observed during the LSSR period were higher than those from October – December 2019, but not higher than January and February 2020. However, the longer averages showed a clear reduction in the AOD during the LSSR period relative to the normal pre-COVID period. AOD measurement estimates the aerosol burden in a column of the atmosphere therefore it is not only affected by ground emissions but also meteorology in the upper air. The AOD is also able to be measured by satellite over a larger area of observation. A moderate resolution imaging spectroradiometer (MODIS) satellite instrument can provide AOD aerosol products from Terra MODIS (MOD04) and Aqua MODIS (MYD04).



Pre- and Post-LSSR 2020
Source:Adapted from Santoso et al. 2021

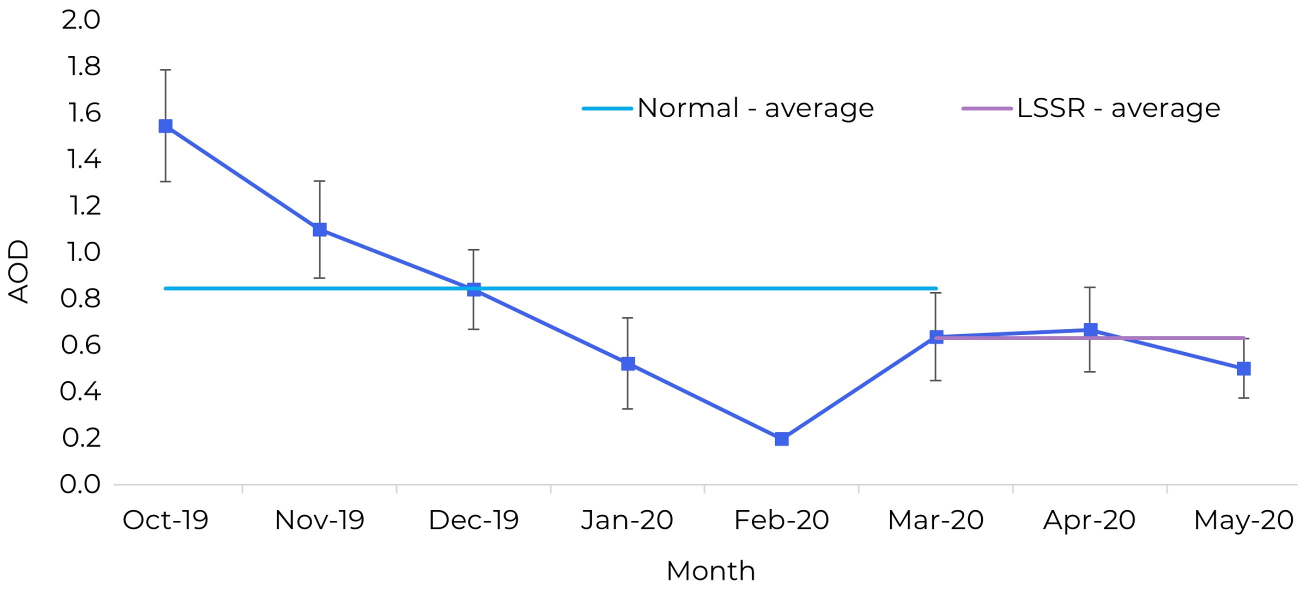


Figure 3-13.
Measurement of AOD by Sun-Photometer during October 2019–May 2020
Source: Adapted from Santoso et al. 2021

Monthly average MODIS AOD figures were extracted from NASA (https://giovanni.gsfc.nasa.gov/giovanni/) for the period of March - May 2020 (LSSR) and March – May 2019 (non-LSSR). The results from that data are presented in Figure 3-14. Consistently, the AOD value observed over Jakarta for the period of March – May 2020 were lower than the values in March – May 2019. The values ranged from 0.3-0.4 during the LSSR 2020 period while in 2019 showed a range of 0.4 – 0.5.

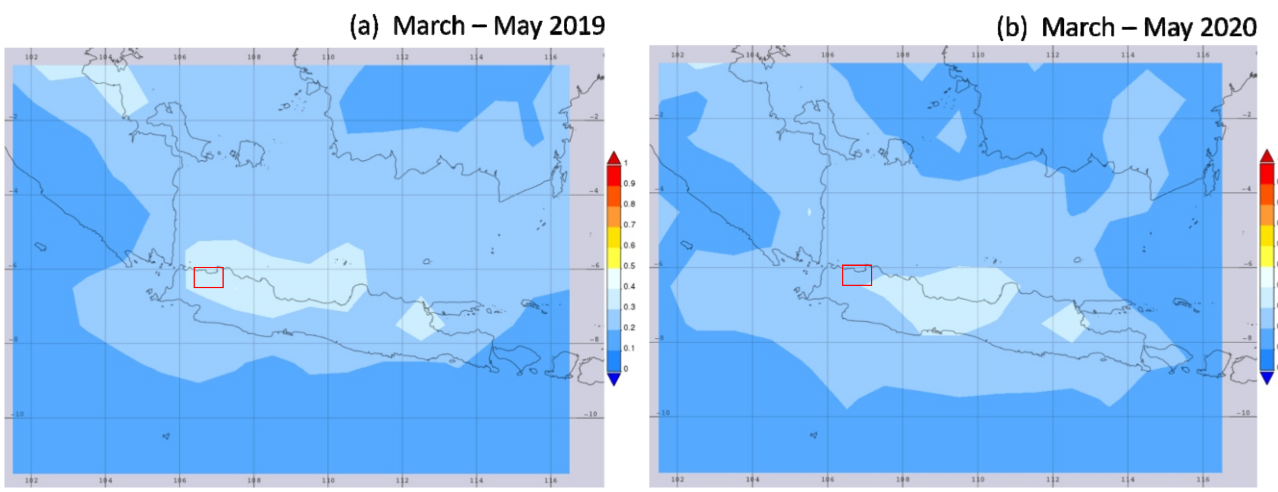


Figure 3-14.
Terra MODIS AOD for Different Periods in 2019 and 2020
Source: Adapted from Santoso et al. 2021

3.5 What Policy Responses and Behavioral Changes Led to Air Quality Improvements?

3.5.1 Policy Responses

The Indonesian government issued various policies to limit the effects of COVID-19. In fact, in total the government issued nine legal pronouncements, including four presidential decrees, two presidential regulations, a government regulation, and a presidential instruction (Roziqin, Mas'udi, and Sihidi 2021). Energy, transport and other sectoral policies also helped to protect health and limit the spread of COVID-19.

3.5.1.1 The Large-Scale Social Restrictions

The most prominent of these policies was the previously mentioned LSSR. Social distancing was initially introduced but it was not sufficient to stop the spread of COVID-19. LSSR was then adopted to move beyond social distancing. LSSR was based on Presidential Decree No. 11 of 2020, a decree involving the Establishment of Public Health Emergency and Government Regulation No. 21 of 2020. The provincial government also issued a Governor Decree to provide technical guidelines for LSSR's implementation. DKI Jakarta province issued 3 governor decrees on the detailed guidelines of LSSR. The LSSR differed from full lock down measures implemented in other countries. For instance, the LSSR included relaxed conditions such as the normal operation of international airports and harbors, public transport and inter-cities mobility.

LSSR helped to control the spread of COVID-19 in an area and at the same time it effectively reduced mobility in Jakarta. As noted previously, LSSR led to an improvement in ambient air quality as seen through a correlation between reduced traffic activity but the degree of improvement likely varied from one place to another. Therefore, the availability of complete air quality monitoring (temporal and spatial) is needed for to assess the impact of reduced public mobility. Air quality improvement can be one indicator of the successful implementation of the program. However, to sustain the air quality gains, it is important to translate the temporary improvements to more sustainable transport policies--for example, to reduce the total number of vehicle kilometer travelled (VKT) of private vehicles by shifting to public transportation.

> **LSSR led to an improvement in ambient air quality.**

In fact, LSSR is one example of policy response improved air quality in Jakarta over a relatively short period. This emergency response provided lessons learned on the benefits of LSSR on air quality, but other air quality management programs are needed to build upon that initial success. International support has been in place, for example, the collaboration between Bloomberg, Vital Strategies, Jakarta EPA under the "Toward Clean Air Jakarta" program. Several initiatives have been taken by the local government to deal with air quality such as the blue-sky program, regular air quality monitoring, etc. Moreover, the provincial government issued several air pollution regulations (see Table 3-8). In addition to existing regulations, there should bean enhancement in developing air quality management tools such as emission inventories, monitoring, modeling and health impact assessments. The result can serve as science-based evidence to drive the policy formulation, implementation and evaluation.

No.	Provincial government regulation	Air pollution control aspects
1	DKI Jakarta Government Regulation No. 2/2005 on Air Pollution Control	• Emission standards for stationary and mobile sources • The use and the sharing of information on air quality monitoring indexes • Prohibition of open waste burning; • Mandatory conversion of BBM (gasoline) to BBG (natural gas) for government operational vehicles and public transportation • Development of green open spaces • Implementation of Car Free Days • Emission permits for industries with routine evaluation, and emission taxes
2	Governor of DKI Jakarta Regulation No. 141/2007 on the Use of Natural Gas for Public Transportation and Operational Vehicles of the Regional Government	Conversion from gasoline to natural gas for public transportation and government operational vehicles
3	DKI Jakarta Government Regulation No. 5/2014 on Transportation	• Expansion and integration of public transportation • Periodic revitalization of public buses, the use of clean energy for public transportation, emission testing, and the application of congestion pricing
4	Governor of DKI Jakarta Instruction No. 66/2019 on Air Pollution Control	Measures to reduce air pollution including: • revitalizing old buses • Implementing odd-even policies and ERP • emission testing and use of new vehicles • improving pedestrian accessibility • controlling industrial emissions • increasing urban green area development • enforcing emission standard for point sources • transitioning to cleaner and renewable energy to reduce dependency on fossil fuel in several public facilities
5	Governor of DKI Jakarta Regulation No. 66/2020 on Vehicle Emission Testing	• Emission testing for both private and public vehicles once a year • Requirements for workshops to conduct emission tests and integrate emission test • Reports with the local tax payment system
6	The Decree of DKI Jakarta Governor No.670/2000 on the Determination of Emission Standard for Stationary Sources in DKI Jakarta	Emission standards for stationary sources including the processing industry and power plants

Table 3-8.
Air Pollution Regulations Issued by the Provincial Government
Source: Adapted from Bloomberg Philanthropies and Vital Strategies 2019

3.5.1.2 Energy Policies

The Ministry of Energy and Mineral Resources (MEMR) is responsible for energy policies in Indonesia. Several studies predicted that the COVID-19 crisis would significantly impact Indonesia's economic performance and its energy sector. One of the most affected sectors by the pandemic was the coal sector--with exports decreasing by more than 40 percent in the first two months of 2020 compared to the previous year. This motivated MEMR to issue regulations that would ease administrative and business procedures for mining. At the same time, the regulation was questioned by civil society groups as it would undermine Indonesia's commitment to reducing carbon emissions by 2030 to 25 percent (GSI, 2020). Decreasing electricity demand due to the pandemic impacted the financial status of the State Electricity Company (PT PLN), leading to the renegotiation of independent power producer contracts. To make investments more attractive, the MEMR issued a new regulation (No. 4/2020) that aimed to overcome several regulatory obstacles to renewable energy. The MEMR also included solar industry in the post-COVID-19 green recovery plans through tax incentives.

In Jakarta, LSSR implementation had other effects on energy use and demand. For instance, there was a 50 percent reduction in demand compared to the pre-COVID years. In fact, MEMR offered that the normal period the consumption of fuel oil increased by 2.7 percent annually while LPG increased rate at 5 percent per year. Responding to these problems, the government committed to secure energy supplies during COVID-19 pandemic. In this connection, the MEMR targeted four sectors, namely transportation, power generation, household, and industry (MEMR 2020). Note that these sectors were (and continue to be) major contributors to air pollution in Jakarta and other cities in Indonesia. But the pandemic tended to alter the energy consumption as discussed in the previous section. The sustainable supply of fuel oil, liquified petroleum gas (LPG), natural gas for various economic sectors became a government priority. Policy responses in the energy sector focused on the development of strategic projects to bring in more opportunities such as the Refinery Development Master Plan (RDMP) dan Grass Root Refinery (GRR) projects. Nationally, in the early 2020 fossil fuels and LPG consumption reduced by 13 percent as compared to the similar period in 2019 (MEMR 2020).

Other policy responses due to COVID-19 pandemic in the energy sector included the adjustment of the cost of natural gas for specific industries. There are 197 industries currently using natural gas and they have enjoyed the adjusted rate of 6 USD/MMBTU. This policy aimed at increasing the contribution to the national income as well as reducing air pollutants from the industrial combustion sector.

Another issue was the use of clean and renewable energy during the pandemic. In this area, the government targeted the conversion of diesel oil fueled power plants to natural gas for a total capacity of 1.7 GW at 52 locations. MEMR mandated PT PLN to conduct gasification project of the power generation industry and purchase liquefied natural gas (LNG) from PT Pertamina for the conversion of diesel oil fueled power plants. In February 2020, the government issued Ministry Decree No. 4/2020 on the amendment of government policy on the usage of cleaner and renewable energy in power generation in Indonesia. It regulates the build, own, operate (BOO) contract scheme, refused derived fuel of municipal solid waste, and electricity purchase scheme from PT PLN. Refineries were operated at the minimum operational threshold of 70 percent to cope with the demand reduction up to 30 percent (MEMR 2020).

As many of these energy policies were helping to approve air quality, specific air pollution regulations were issued through the governor instruction No. 66/2019 on air pollution control. It is worth noting that several measures were categorized in energy policies such as transition to cleaner and renewable energy to reduce dependency on fossil fuel. This regulation mandated the implementation of solar panel installation on the rooftops of school building, provincial government's buildings, and public hospitals in Jakarta. Other interventions that could help lower emissions involved the promotion of biofuel (B20 towards B30) as well as the LPG and CNG for public buses.

3.5.1.3 Transport Policies

As expected, the LSSR restricted public mobility due to the closure of public facilities, schools, and recreational areas. Several studies demonstrated the reduction in traffic volume as well as congestion levels during morning and afternoon rush hours in Jakarta (section 2.2.5). After the first wave of LSSR implementation, the provincial government also introduced odd-even number license plate policy. This policy is part of the Governor Instruction No. 66/2019 and it will be implemented as needed during big events. Other measures in the regulation included revitalizing old buses, electronic road pricing, emission testing and use of new vehicles.

During the LSSR, people were still allowed to use private vehicles, but the capacity was limited to 50 percent of passenger capacity. This policy applied to the public vehicles in Jakarta. A mask-on policy was also implemented for passengers. Eventually, a more relaxed policy was implemented that allowed 100 percent passenger if all of them were from the same domicile. Other modes of transport also introduced restrictions on maximum capacities.

3.5.2 Behavioral and Lifestyle Changes

3.5.2.1 Changes in Work Environments/ Work from Home

The Governor of DKI Jakarta applied LSSR due to the significantly increasing number of COVID-19 cases. 'Essential businesses that include energy, communication and IT, finance, logistics, hotels, industrial, basic necessities, public utilities, and government's strategic facilities were allowed to continue with certain restrictions and exempted from the LSRR. Moreover, these sectors were required to limit the number of people at workplaces at any time to less than 50 percent. Meanwhile, all non-essential businesses were required to implement mechanism to work from home for employees or limit the number of people at workplaces at any time not more than 25 percent. These attempts to slow down the spread of COVID-19 led to office/company closures and a sudden increase in working from home.

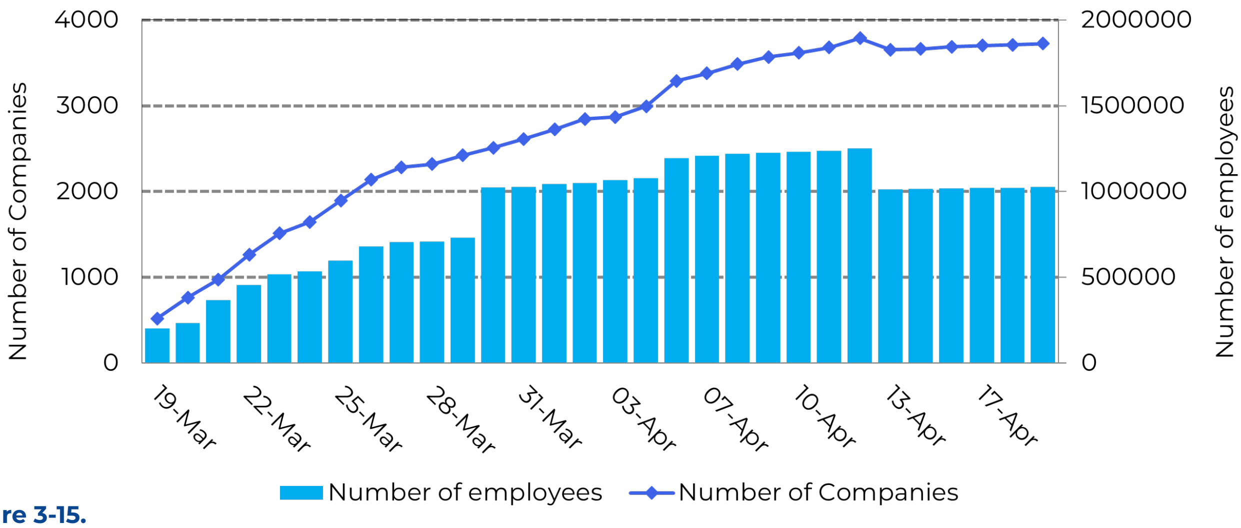


Figure 3-15.
Number of Companies Implementing Work from Home in Jakarta, 2020
Source: https://lokadata.beritagar.id/chart/preview/perusahaan-yang-menerapkan-wfh-jakarta-2020-1587382946#

The most significant change in behavior was working remotely. Early estimates suggested 60 percent of total inhabitants of Jakarta were working from home during the beginning of the pandemic. There were 3,725 companies implementing work from home measures in April 2020, accounting for 1,026,875 employees (Figure 13-15). Of those who worked from home, approximately one-third (34.3 percent) were employees of non-essential business sectors and the remaining 65.7 percent were from essential businesses.

3.5.2.2 Biking

Another change in behavior during the pandemic in Jakarta was that the citizens avoided commuting on crowded public transportation (particularly during peak hours) and turned to other modes of transport. Cycling or biking emerged as an alternative and allowed commuters to maintain social distancing while also increasing physical activity. Cycling in Jakarta took off, evidenced by the 30 percent increase in the number of bicycle sales compared to the same sales period last year. The increase occurred at the end of April when the government began to loosen LSSR (https://co.id/ekarina/berita/5f157dbd397ca/tren-gowes-kerek-penjualan-sepeda-to-30-selama-pandemi).

According to data from the Institute for Transportation and Development Policy (ITDP), on average, annual cycling numbers in the city increased five-fold. Specifically, the ridership in high-volume travel areas such as Dukuh Atas station along Jl. Sudirman increased by ten-fold on weekdays compared to the previous year (23 October and 6 November 2019) (ITDP 2020). Table 3-9 shows data on the annual increases in the number of cycling in five major road segments in Jakarta. As seen in the table, the average of number of bicycle usage in Sarinah increased four-fold in the period of 2019-2020, with the highest increase in Dukuh Atas.

Survey location	Direction	Annual Increment (2019 – 2020)
Sarinah	North – South	> sixfold
	South – North	>two-fold
Dukuh Atas	North – South	>two-fold
	South – North	>eleven-fold
Karet Sudirman	North – South	>seven-fold
	South – North	>two-fold
Gelora Bung Karno	North – South	>seven-fold
	South – North	>two-fold
Bundaran Senayan	North – South	Not available
	South – North	>five-fold

Table 3-9.
Annual Increase in the Amount of Cycling in Five Major Road Segments in Jakarta
Source: ITDP 2020

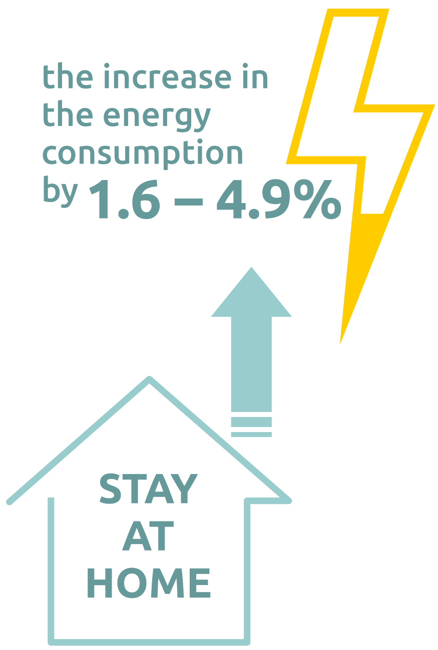
3.5.2.3 Traffic Volumes

The odd-even license plate policy aimed to reduce the use of public transportation and temporarily encourage switching to private vehicles to prevent the spread of COVID-19. The number of passengers of private cars of four-wheeled vehicles was limited from three to five passengers. The capacity of public transportation was also been limited to maintain distance between passengers; transportation permits for online motorcycle taxi were given for food or goods delivery services only. Policies implemented by the provincial government changed people's lives, and these changes have had an impact on community mobility. As a result, the daily traffic volume reduced from 346,462 units/day in March 2020 to 179,531 units/day in May 2020.

Meanwhile, the average vehicle speed on major roads slightly increased between pre-LSSR (16.2 km/hour) and LSSR-2 periods (21.0 – 21,5 km/hour). Traffic congestion from March to December 2020 were also lower than 2019 and changes in rush-hour were observed between March and December 2020. The increase in the average speed and reduction in the traffic congestion imply mobility fell for Jakarta citizens in inner-city streets from the initial period of COVID-19 to the LSSR period. This may suggest that policies implemented by the provincial government, particularly restrictions on activities in public places and implementing the school and work from home mechanism, altered mobility patterns and lifestyles. Various online platforms (i.e. food order, study, etc) reduced the need for motorized transport even after the relaxation of the LSSR policy (Irawan et al. 2022; Rizki et al. 2021).

3.5.2.4 Changes in Energy Use

The change in behavior and lifestyle due to the COVID-19 pandemic in Jakarta also affected the energy consumption. Since people spend more time at home, they used home office electronics as well as lighting, cooling, and kitchen appliances. However, the increase in the energy consumption by 1.6 – 4.9 percent or 2.3 – 6.9 million barrel of oil equivalent (BOE) for households was not significant due to concurrent decreases in people's purchasing power. On the other hand, the restriction of activities led to a decrease in energy consumptions in the industrial, commercial (office, bank, restaurant, and trading), and transportation sectors (BPPT 2020).



3.6 Recommendations

The report *Air Pollution in Asia and the Pacific: Science-based Solutions* recommended 25 solutions broken up into three categories to reduce air pollution in the Asia and the Pacific region (UNEP APCAP and CCAC 2019):

- Conventional emission controls focusing on emissions that lead to the formation of fine particulate matter ($PM_{2.5}$): end of pipe controls, emission standards, vehicle inspection and maintenance, dust control.
- Next-stage air-quality measures for reducing emissions that lead to the formation of $PM_{2.5}$ and are not yet major components of clean air policies in many parts of the region: prohibition of crop residue, waste open burning, forest management, livestock and fertilizer management, low sulfur fuel for shipping, etc.
- Measures contributing to development priority goals with benefits for air quality: clean cooking, renewables for power generation, electric vehicle, energy efficiency, solid waste management, etc.

As the world moves into a post-COVID era, these three categories offer a useful framework to organize efforts to sustain improvements in air quality. In particular, while Indonesia has already made progress with several conventional measures, the government should continue to strengthen their implementation. In addition, it will be critical that Indonesia places greater emphasis on adopting and scaling next stage measures in the second category. Finally, the government should not reverse course on the third category; support for renewables, electric vehicles, and energy efficiency will be especially important for transitions in the energy sector.

There is also scope to make stronger links between air quality and climate change. For instance, Indonesia would be well advised integrate some of the above 25 measures into the nationally determited contributions (NDCs). Further, there is also potential to harness the momentum from the COVID-era to contribute to improving regional air quality. Strengthening the design and implementation of the 25 solutions will help to some extent with these efforts. In a similar vein, Indonesia might also want to feature these solutions in discussions over the ASEAN Haze Agreement.

Above and beyond the 25 solutions, there are also opportunities to continue the more sustainable lifestyle changes. COVID-19 has altered citizen's perceptions on necessity of motorized transport with the advent of online platforms, hybrid meeting technology, work from home for non-office essential work, etc. These behavior changes should be sustained. This will require a sound understanding by policymakers as well as the citizens of the rationale for the policies and strategies implemented during the pandemic. It will also hopefully contribute to a broader and deeper understanding of what it means to live sustainably in a post-COVD world.

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4

The Effects of COVID-19 on Air Quality Planning in Colombo, Sri Lanka

4.

The Effects of COVID-19 on Air Quality Planning in Colombo, Sri Lanka

COVID-19 was first detected in Wuhan, China at the close of 2019. A few months later, COVID-19 had become a full-fledged global pandemic (WHO 2020). The impacts of the pandemic began to be felt in Sri Lanka in March 2020. As those impacts became more acute, Sri Lanka's government imposed a lockdown that brought most non-essential activities to a halt. The lockdown and related restrictions reduced motorized transport. It also led to a drop in harmful emissions and improved air quality in many parts of Sri Lanka.

The effects of COVID-19 on air quality in Sri Lanka were notable. Monitoring data showed a 15% and 25% reduction of $PM_{2.5}$ and PM_{10} levels toward the end of March 2020 compared to the same period in 2019. Though primary air pollutants such as $PM_{2.5}$, PM_{10}, NO_2, CO, SO_2 and VOCs fell during this time frame, secondary air pollutants such as O_3 and secondary $PM_{2.5}$ remained unchanged or increased. The fact that these emissions stayed the same or increased is likely attributable to an emission reduction in NOx and variations in meteorological conditions (Adam, Tran, and Balasubramanian,2021).

This chapter analyses the effect of COVID-19 on air quality in Colombo, Sri Lanka. It also recommends actions to sustain air quality improvements. It is hoped that the information presented herein can contribute to clean air solutions for Colombo and build a better future for all.

The chapter is divided into several sections that can help illustrate the above effects and form the basis for policy recommendations. The next section (section 2) describes the main sources of data that underpins the rest of the chapter.

4.1 Step 1: Gathering Data

The chapter follows a sequence of steps. This section summarizes the key sources of data that were used for the analysis.

4.1.1 Mobility Data

One of the main sources of data involved mobility. Mobility data was obtained from two sources: 1) lockdowns and social restriction measures; and (2) Google.

In terms of the first source, the chapter relied press releases for each lockdown and other restriction measure issued through the Government Information Department of Sri Lanka (Government Information Department, 2021). The press releases were studied, and relevant information was abstracted. In addition, other web-based sources were also gathered and analyzed to validate the information in the press releases.

Another source of mobility data came from Google. Google mobility data demonstrates movement trends by region and includes different categories of places (Google Mobility, 2021). The mobility data were created with aggregated, anonymized sets of data from users who have locations activated in their devices.

The baseline data for the mobility represents a median value from the 5-week period, starting from Jan 3rd, 2020. These data include several categories of locations, which have been divided with characteristics for purposes of social distancing guidance. The categories are as follows: workplace; residential; recreational, transit stations (i.e., subway, seaport, taxi stand, highway rest stop, car rental agency), parks, (public garden, castle, national forest, campground, observation desk); and grocery and pharmacy.

4.1.2 OXFORD Government Response Tracker Data

In tackling COVID-19, Sri Lanka also utilized the Oxford COVID-19 Government Response Tracker (OxCGRT) that collects systematic information on COVID-related policy measures. Different policy responses were tracked from January 1st, 2020 for more than 180 countries, including the 23 publicly available indicators listed in Table 4-1.

ID	Name	Type	Targeted/general?
Containment and closure			
C1	School closing	Ordinal	Geographic
C2	Workplace closing	Ordinal	Geographic
C3	Cancel public events	Ordinal	Geographic
C4	Restrictions on gathering size	Ordinal	Geographic
C5	Close public transport	Ordinal	Geographic
C6	Stay-at-home requirements	Ordinal	Geographic
C7	Restrictions on internal movement	Ordinal	Geographic
C8	Restrictions on international travel	Ordinal	No
Economic response			
E1	Income support	Ordinal	Sectoral
E2	Debt/contract relief for households	Ordinal	No
E3	Fiscal measures	Numerical	No
E4	Giving international support	Numerical	No
Health systems			
H1	Public information campaign	Ordinal	Geographic
H2	Testing policy	Ordinal	No
H3	Contact tracing	Ordinal	No
H4	Emergency investment in health care	Numerical	No
H5	Investment in COVID-19 vaccines	Numerical	No
H6	Facial coverings	Ordinal	Geographic
H7	Vaccination policy	Ordinal	Funding
Miscellaneous			
M1	Other responses	Text	No

Table 4-1.
Government Response Indicators Included in the OxCGRT
Source: BSG-WP-2020/032 Version 12 2020

For example, responses related to school closures, travel restrictions, vaccination policy, etc. These policy responses were recorded on a scale to reflect the extent of government action, and scores were aggregated into policy indices. This data is helpful for decision-makers and citizens to understand responses taken by the Government. Out of these 23 indicators aggregated, the OxCGRT summarizes them into four different indices: overall government response index; stringency index; containment and health index; and economic support index.

4.1.3 Health Data

Yet another set of data involved different health endpoints. The number of COVID-19 patients were obtained from daily reports from the Epidemiology Unit of the Ministry of Health, Sri Lanka (Epidemiology Unit-Sri Lanka, 2021). The data were collected from the first COVID-19 confirmed case in Sri Lanka to October 31st, 2021. In addition, the statistics for other diseases related to exposure to air pollution were also identified, including: respiratory diseases; heart disease; endocrine, nutritional, and metabolic diseases; diseases of the eye and adnexa; and neoplasms (i.e., cancers) (Eze 2015; Hedley 2002; WHO 2021c). This data was gathered for Colombo based on the ICD – 10 classifications from the Ministry of Health, Sri Lanka for the years 2019 and 2020.

4.1.4 Air Quality Data

The final set of data focused on air quality. Air quality monitoring located at the National Building Research Organization and Central Environmental Authority were used to assess changes in air quality for 2020 through October 2021. In 2020, three monitors were in operation in Colombo and one monitor was in operation in Kandy.

4.2 Step 2: Data Analysis

The second step focused on analyzing the data to determine if there was a correlation between COVID-19 restrictions, reductions in mobility, and improvements in air quality and health.

To begin this second step, hourly measurements of pollutants were converted to 24-hour average values. Time-series plots were developed to examine the time-dependent changes in pollutants from each monitoring station. Time segments were identified in which the distribution of $PM_{2.5}$ changed in terms of variance that then made it possible to use the change point analysis technique. The “changepoint” package in R was used for the above purposes. The changepoint segments were then temporarily connected with the implementation of lockdown policies using the Government Response Index for Sri Lanka and further validated by press releases. Amalgamating inferences were gathered by the above independent evaluations (changepoint analysis and observations on lockdown interventions), then the $PM_{2.5}$ time series were divided into pre-lockdown, lockdown, and post-lockdown segments. Further, the changes in air quality were quantified for each segment based on their means and the standard deviations.

Moving forward, the Google mobility index was then used to create six categories of changes in mobility patterns. To simplify the analyses, an average was taken for three of those categories (i.e., recreational, transit stations, and parks) and labelled “Recreational”. Finally, “Workplace”, “Residential”, “Recreational”, and “Grocery and Pharmacy” measures were plotted for 2020. A unit change in every daily index represents the change in personal mobility based on the strength of mobility restrictions.

The next part of the analysis involved the air quality data. Since the distribution of particulate matter ($PM_{2.5}$) at a given time is determined by the densities of vehicles, Google mobility indices were used to quantify the proportionate change in $PM_{2.5}$ concentration with a unit change in mobility patterns. With this context, two extremes of mobility were selected i.e., “Residential Mobility” and “Workplace Mobility” for the analysis to better describe the containment policies and their potential impact on the air quality.

The non-linear and potential lagged effect of the two mobility indicators were evaluated using Distributed Lag Non-Linear Models (DLNM) implemented in the R statistical platform. The DLNMs have the advantage over other regression models as they can estimate the risk of exposure at each exposure value over the space of lag accounting for the collinearity in data. The DLNMs were used to predict the risk of increase in the $PM_{2.5}$ concentration at each value of the mobility indicators regarding the risk at the baseline mobility (relative risk or the proportionate change).

The data sets from January 1st 2020 to August 29th 2021 were used to improve the robustness of the model estimates. It was predicted that a Quasi-Poisson distribution would allow for over-dispersion of the $PM_{2.5}$ data. Two models were developed for “Residential” and “Workplace” mobility to independently describe the effect of two mobility extremes. Lags used were only up to a maximum of two days based on the nature of the association between the temporal effect of vehicle emission and $PM_{2.5}$ values. A sensitivity analysis was conducted to evaluate parameter definitions and the model fit using Akaike Information Criterion (AIC) and residual diagnostic plots.

The changepoint analysis is a method developed to detect a segment or multiple segments of a time series having a statistically different mean or variance (or both) to the adjacent segment. The “changepoint” package in R was used to evaluate changes in the $PM_{2.5}$ measured at the Colombo meteorology monitoring station. This offered a useful technique to determine the size, timing, and possible causes of changes in time series data.

In sum, there were three main sub-steps taken to determine how COVID-19 lockdown interventions affected air quality in Colombo. First, there was an effort to identify periods where air quality changed; second an attempt was made to quantify changes in mean levels of air quality; and, finally, by relating the period with statistically significant impact on the lockdown policies.

The figure illustrates the daily variation of $PM_{2.5}$ values in Colombo meteorology monitoring station. The red horizontal lines show the segments having equal distribution (mean and variance) and the red numbers represent respective means. Year breaks are marked by vertical dashed lines. The dates in the horizontal axis represent the starting and ending points of each segment and year break.

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4.3 Step 3: Presenting Results

The third step entailed using the data to generate results. The first set of results employed descriptive statistics. This was followed by a using different methods to describe associations or correlations across the data. Finally, pollutant concentration reductions were quantified based on changes in mobility patterns.

4.3.1 Descriptive Statistics

4.3.1.1 Mobility Data

Once the first case of COVID-19 was reported, Sri Lanka adopted a range of different measures to minimize contact and social gatherings that could spread the virus. There were different levels of social restriction measures. These included (1) nationwide lockdown, (2) select area lockdowns, (3) social gathering restrictions, and (4) travel band restrictions across provinces, and nighttime lockdowns. Further, the lockdowns were relaxed in several areas. For example, Sri Lanka enforced a nationwide lockdown on March 20th, 2020. This regulation was enforced in all districts, except Colombo, Gampaha, Kalutara, and Puttalam on April 27th, 2021. The same lockdown was removed on May 5th, 2021 for all districts, except Colombo and Gampaha. Figure 4-1 shows the nationwide lockdown periods beginning with first confirmed case on January 27th, 2020 and then running to October 31st, 2021.

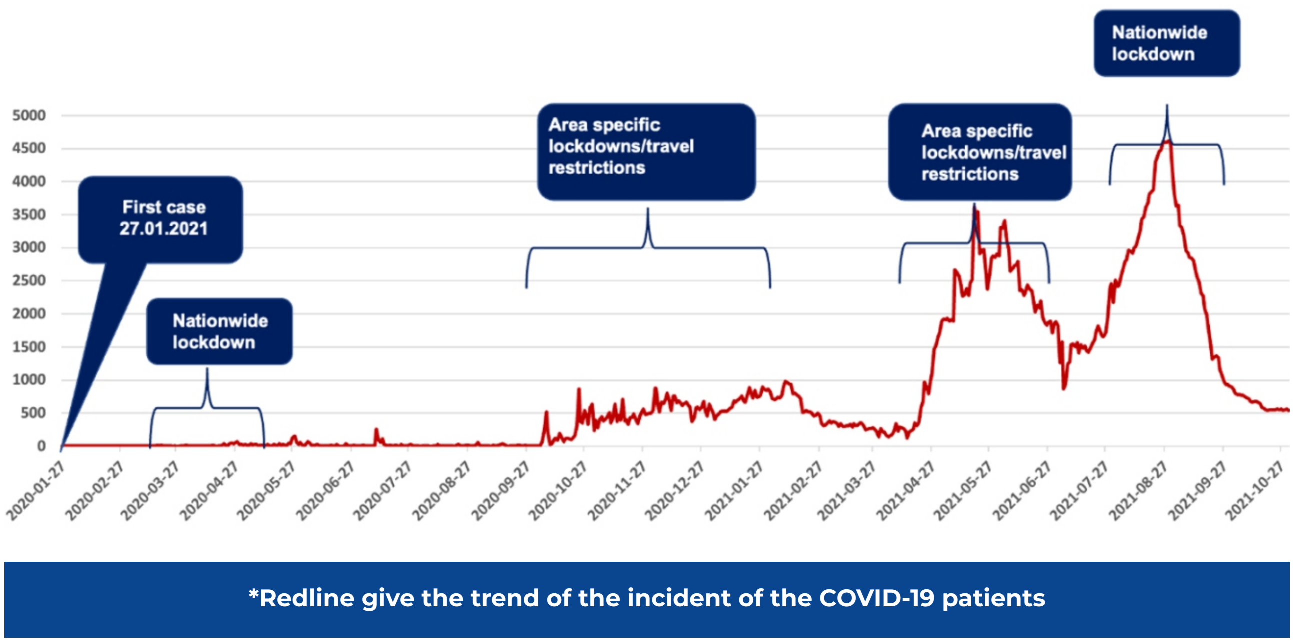

Figure 4-1.
Lockdown Periods during COVID-19
Note: Redline provides the trend in the incidences of COVID-19 patients

In addition to the nationwide lockdowns, Sri Lanka introduced different levels of social restrictions over time (see Figure 4-2).

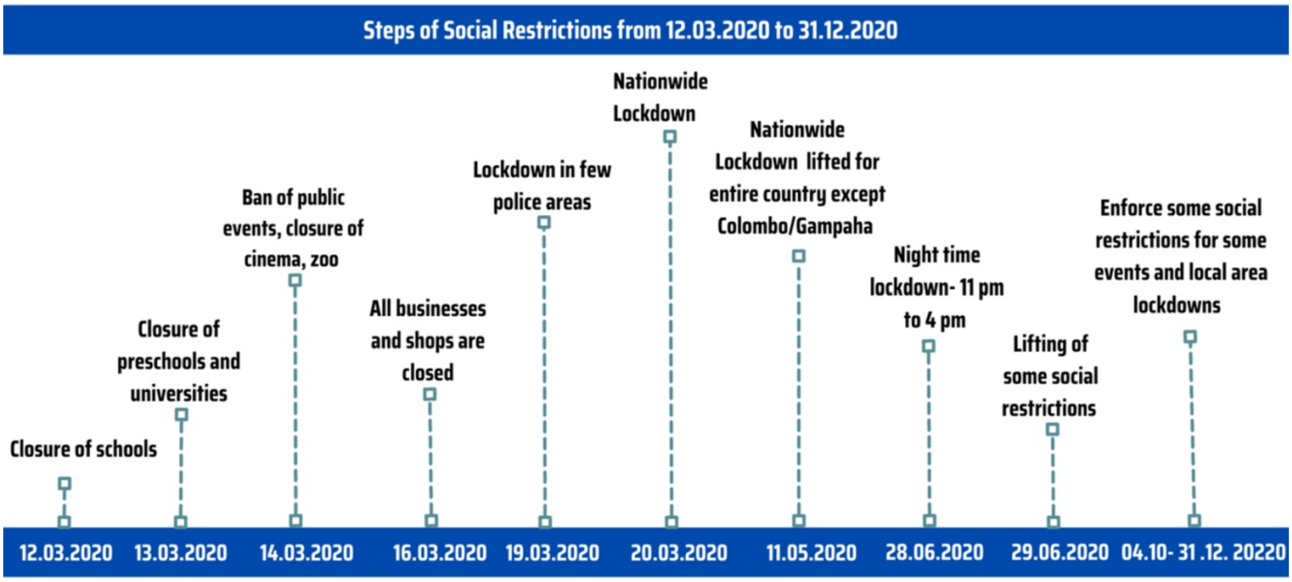

Figure 4-2.
Illustration of Different Levels of Social Restrictions in 2020

Another set of data from which it is possible to generate descriptive statistics was Google mobility data. Figure 4-3 presents that data, showing the residential mobility category increases or fluctuates above the other three categories (i.e., grocery and pharmacy, workplace, and recreational), where these three categories fall compared to their baseline values.

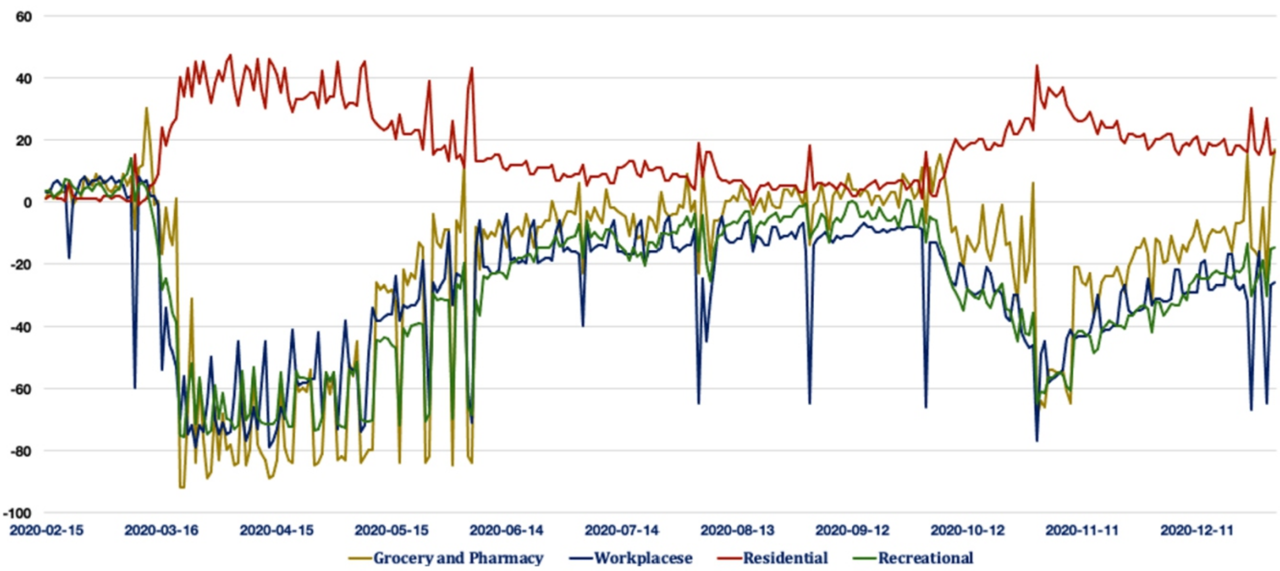

Figure 4-3.
Google Mobility Data in 2020

4.3.1.2 OXFORD Government Response Tracker Data

The stringency index is a composite measure based on nine different indicators, which include C1 to C8 and H1 as shown in Table 4-1. These indicators are rescaled to a value from 0 to 100 where 100 is the strictest. Figure 4-4 shows the stringency index of Sri Lanka from January 21st, 2020 to December 31st, 2020.

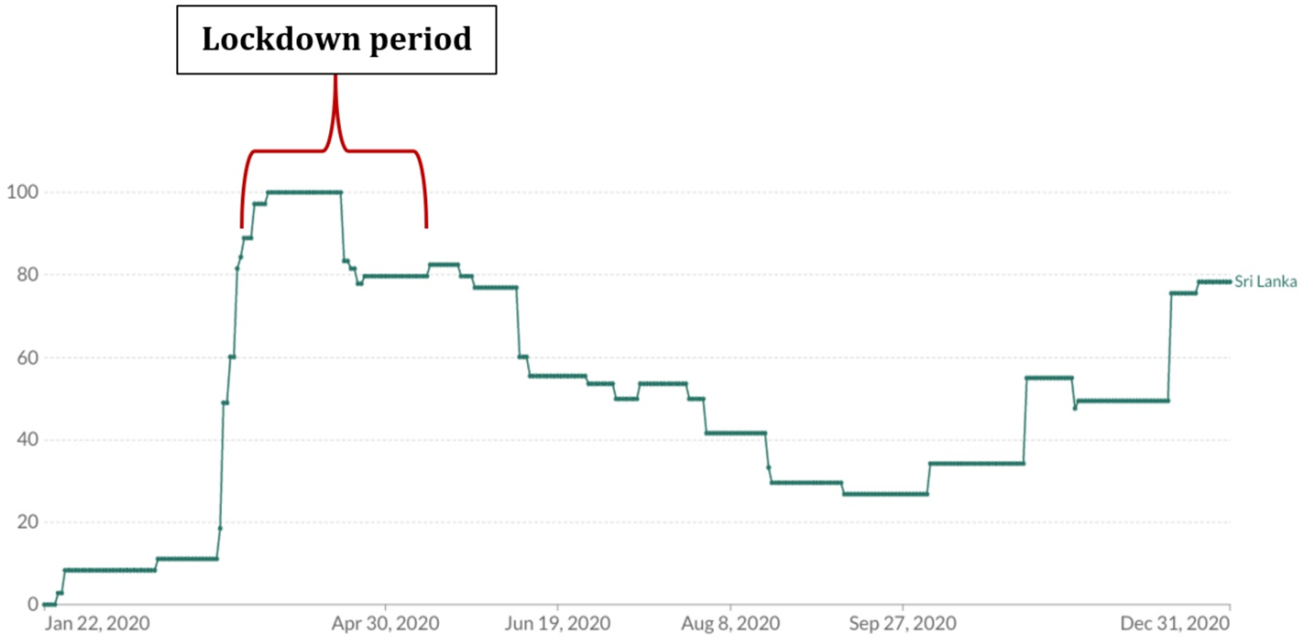

Figure 4-4.
Variation in the Stringency Index from January 21st, 2020 to December 31st, 2020

4.3.1.3 Health Data

The next set of data showing notable trends was the health data. The first confirmed case of COVID-19 (a Chinese tourist visiting Sri Lanka) was reported in Sri Lanka on January 27th, 2020. The first Sri Lankan COVID-19 patient was reported on March 10th, 2020. Local transmissions began to increase following these cases. Figure 4-5 shows the number of patients reported in Sri Lanka for 2020 and 2021. In the first wave on that figure, there were 3,396 cases reported, while 92,341 cases were recorded in a second wave, and 445,336 cases were reported in a third wave.

Figure 4-5.
Trends in COVID-19 Cases (Based on Reports from the Epidemiology Unit)

Another important data point, presented in Table 4-2, were admissions for other diseases compared for 2019 and 2020. It can be inferred from the trends in Table 4-2 that there is a major reduction in admissions to the hospitals in 2019 and 2020 for respiratory and cardiovascular diseases. This data, however, needs to be carefully interpreted. Moreover, health care accessibility changed in 2020 due to different health measures. This will be further explained in the discussion section.

Disease category	2019 Admissions	2020 Admissions
Diseases of the respiratory system (diseases such as asthma)	35121	14525
Diseases of the circulatory system (diseases such as ischemic heart diseases)	29021	25149

Table 4-2.
Hospital Admissions Data Comparison from 2019 and 2020
Source: Medical Statistics Unit, Ministry of Health

4.3.1.4 Air Quality Data

The final set of data involved air quality. Continuous air quality monitoring data was obtained from four air quality monitors for 2020. Furthermore, the air quality data for Sri Lanka's central environment authority was gathered up to August 29, 2021. Figure 4-6 presents $PM_{2.5}$ concentrations from 2020 and 2021 from three monitors in Colombo and Kandy.

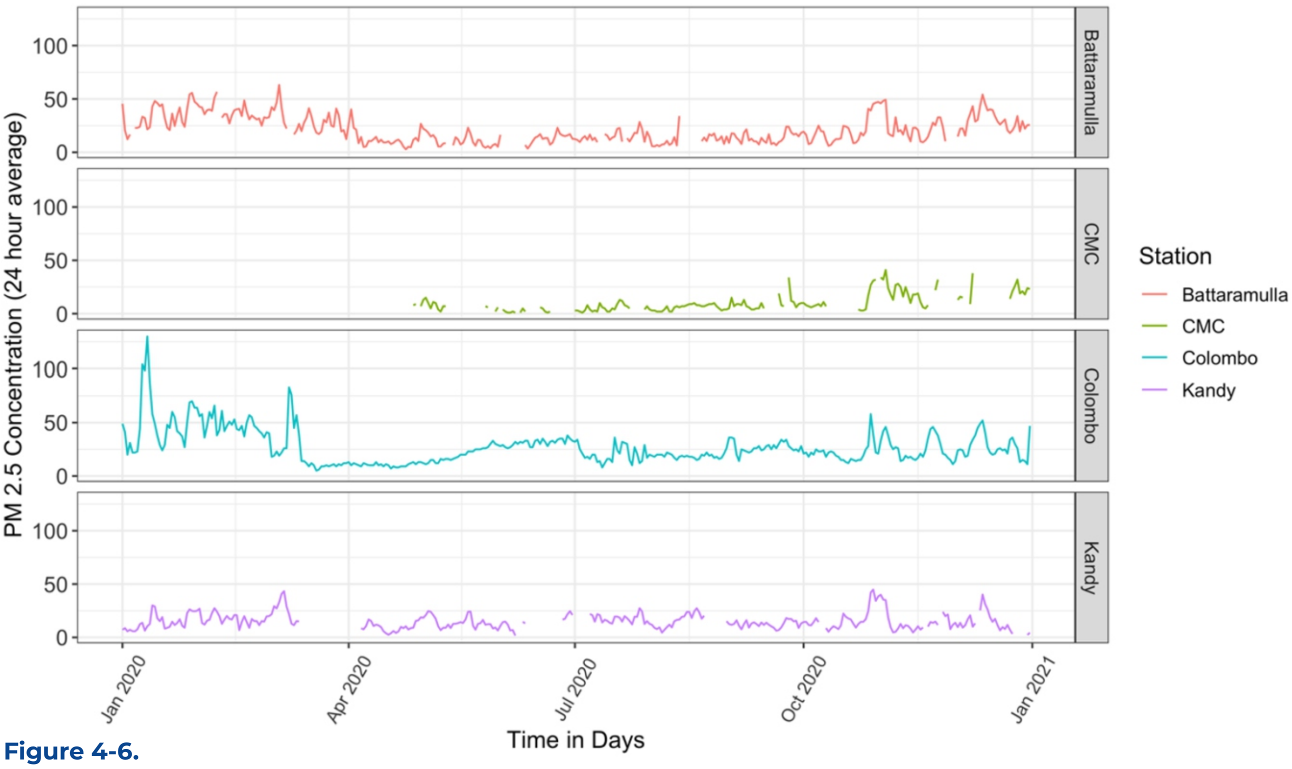

Figure 4-6.
24-Hour Average Concentration of $PM_{2.5}$ throughout 2020 (Data from all four monitors) X-Axis Represents Time in Days (from 1 January 2020 to 31 December 2020)

Figure 4-7 illustrates variations in 24-hour concentrations of $PM_{2.5}$, SO_2, and NOx over the year 2020 from the Central Environmental, Battaramulla. Similar to the $PM_{2.5}$ daily concentrations, the daily concentration pattern of the nitrous oxide and the sulfur dioxide concentration changed. However, the nitrous oxide followed a pattern similar to $PM_{2.5}$ concentration, while Sulphur dioxide concentrations became lower towards the end of the year.

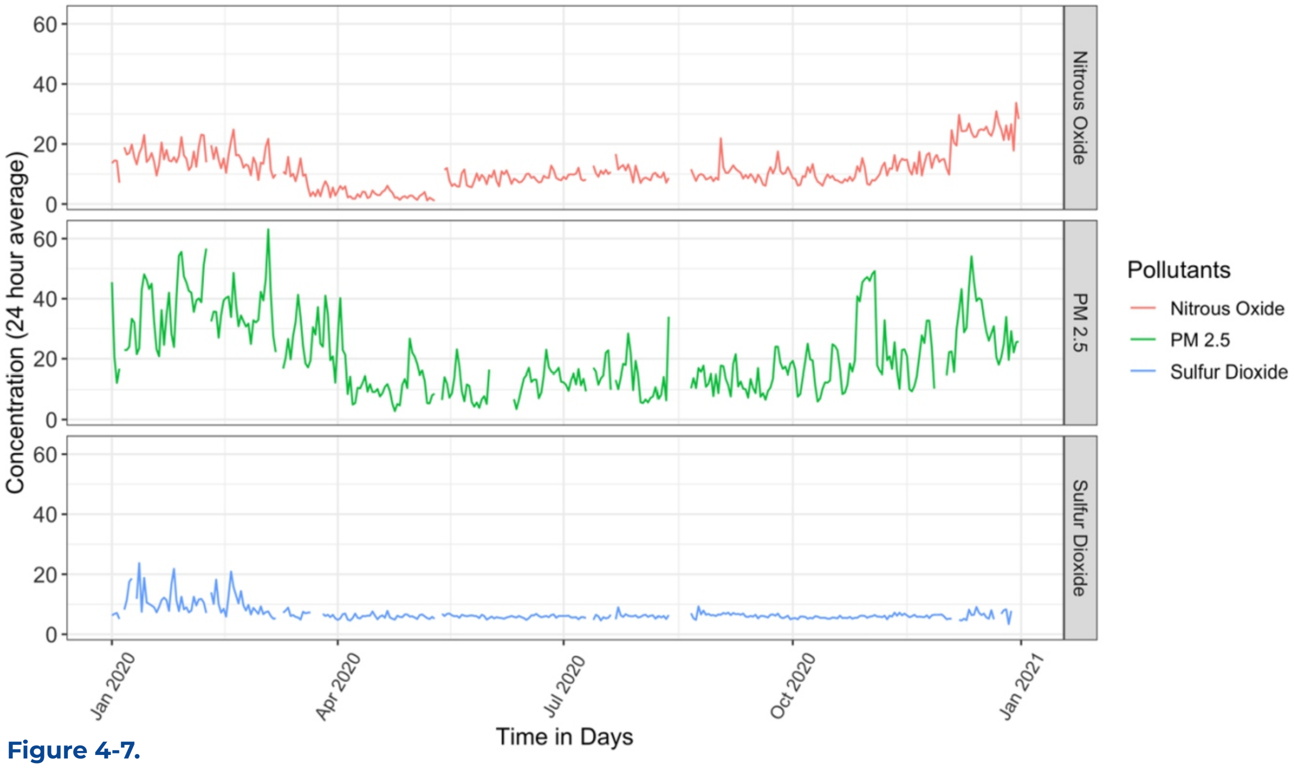

Figure 4-7.
Variations in 24-hour Concentrations of $PM_{2.5}$, SO_2 and NOx over 2020

Table 4-3 presents the annual average values of $PM_{2.5}$ for 2020.

Air Quality monitor	Mean (standard deviation)
Central Environmental Premises Battaramulla	21.0 (12.5)
Meteorology Department, Colombo	26.7 (15.94)
Municipal Council, Colombo	9.9 (8.4)
Kandy	15.0 (7.5)

Table 4-3.
Annual Average Values of $PM_{2.5}$

4.4 Air Quality Variations in the Pre-lockdown, Lockdown and Post-Lockdown Periods

The monitoring station from central environmental authority provide data on $PM_{2.5}$, SO_2, and NOx daily concentrations for 2020. The daily variations in this data for 2020 are illustrated in Figure 4-8. The lowest average $PM_{2.5}$ daily concentration of 15.6 μg/m^3 (Standard Deviation = 9.6) was reported during the first lockdown period that ran from 20 March to 11 May 2020. The data show that $PM_{2.5}$ daily concentrations during the post-nationwide lockdown (17.5 μg/m^3) were lower than before the nationwide lockdown (34.2 μg/m^3).

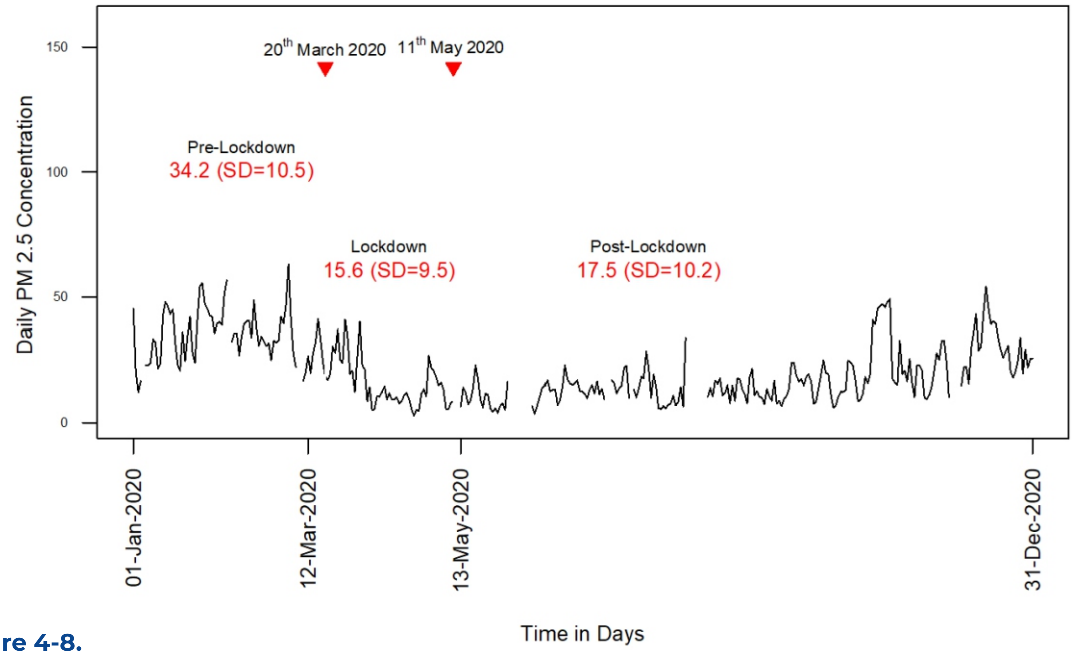

Figure 4-8.
Daily Variations in PM2.5 Concentrations over 2020 (Air Quality Monitoring Station Located at the Central Environmental Authority, Battaramulla)

The monitoring equipment at the Department of Meteorology, Colombo-7 provided the $PM_{2.5}$ daily concentrations for 2020. The daily variations in this data for 2020 are presented in Figure 4-9. That figure shows that the lowest average $PM_{2.5}$ daily concentration of 11.0 μg/m^3 (Standard Deviation = 2.2) was reported during the first nationwide lockdown. The $PM_{2.5}$ daily concentrations during the post-nationwide lockdown (24.4 μg/m^3) were again lower than before the lockdown (43.6 μg/m$^{3)}$.

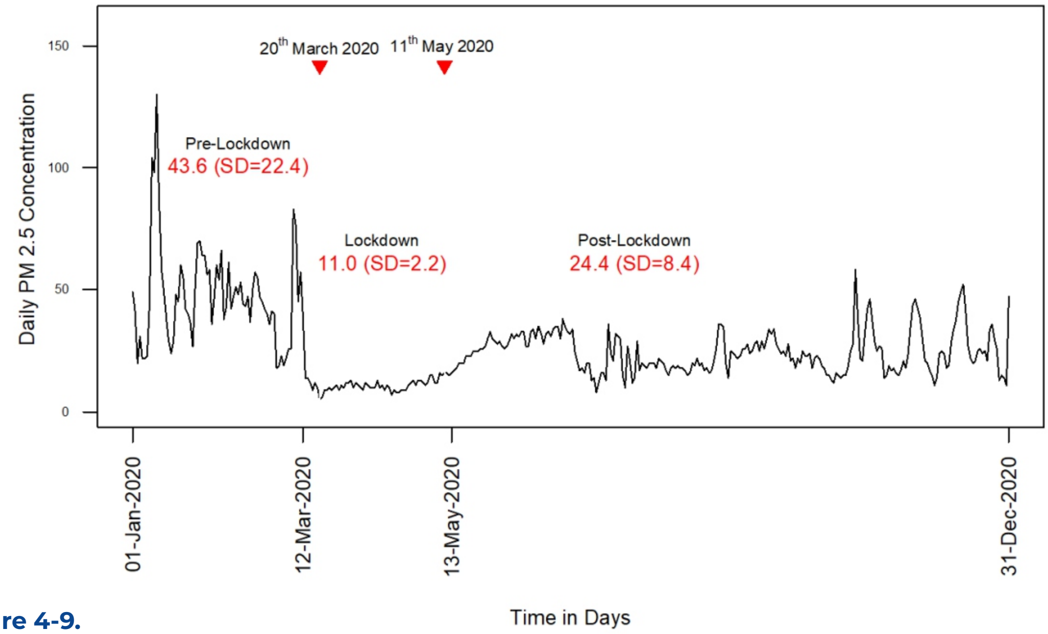

Figure 4-9.
Daily Variations in $PM_{2.5}$ Concentrations over 2020 (Air Quality Monitoring Station Located at the Department of Meteorology, Colombo)

The monitoring data from the Municipal Council, Colombo generated $PM_{2.5}$ daily concentration data for 2020. The daily variations in this data for year 2020 is provided in Figure 4-10. The lowest average $PM_{2.5}$ daily concentration of 7.9 μg/m^3 (Standard Deviation = 3.7) was reported during the first nationwide lockdown period of 20 March to 11 May 2020. The $PM_{2.5}$ daily concentration during the post-nationwide lockdown was 10.4 μg/m^3). However, this monitoring station lacks air quality data for the pre-lockdown period.

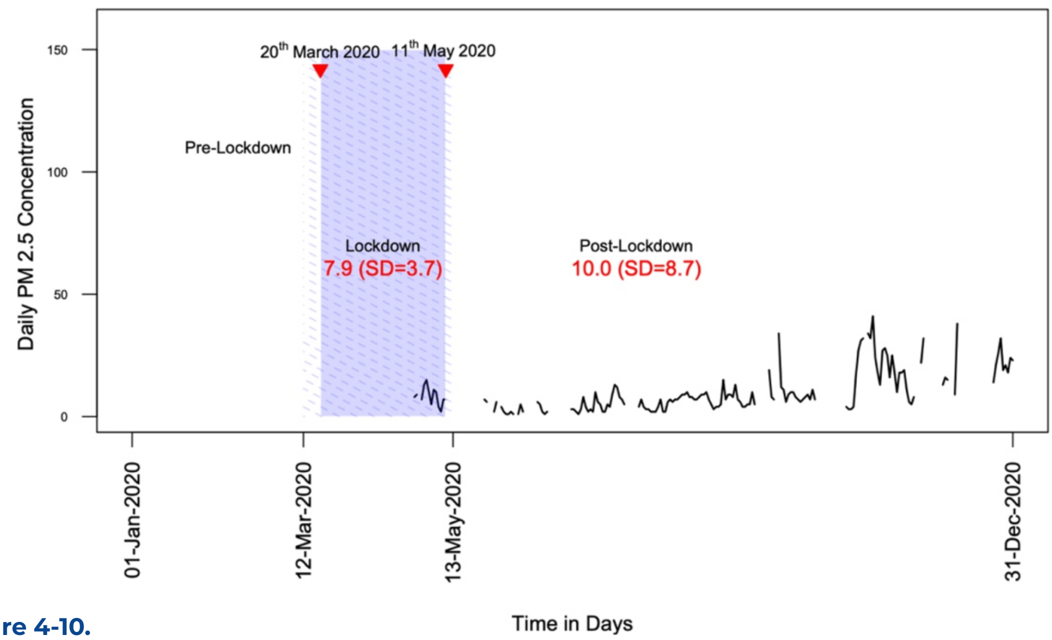

Figure 4-10.
Daily Variations in PM2.5 Concentrations over 2020 (Air Quality Monitoring Station Located at the Municipal Council, Colombo)

Daily air quality concentration data were acquired from three monitoring stations in Colombo and a station in Kandy. Similar patterns could be seen from all the surveyed stations (Table 4-4).

	Monitoring Station	Pre-lockdown Mean (SD)	Lockdown* Mean (SD)	Post-lockdown Mean (SD)
(1)	Central Environmental Authority Premises, Battaramulla, Colombo			
	PM_{10} (μgm^{-3})	56.5 (13.6)	25 (12.0)	30.5 (12.7)
	$PM_{2.5}$ (μgm^{-3})	34.2 (10.5)	15.6 (9.5)	17.5 (10.2)
	SO_2 (ppb)	9.9 (4.1)	5.9 (0.75)	6.0 (0.77)
	No_x (ppb)	14.7 (4.1)	3.3 (1.5)	11.8 (5.6)
(2)	Meteorology Department, Colombo			
	PM_{10} (μgm^{-3})	64.9 (28.0)	19.3 (3.5)	45.0 (14.6)
	$PM_{2.5}$ (μgm^{-3})	43.6 (22.4)	11.0 (2.2)	24.4 (8.4)
(3)	Municipal Council, Colombo			
	PM_{10}(μgm^{-3})	NA	21 (10.3)	28.2 (12.6)
	$PM_{2.5}$(μgm^{-3})	NA	7.9 (3.7) **	10.0 (8.7)
(4)	Kandy			
	PM_{10}(μgm^{-3})	42.0 (13.0)	33.1 (8.2)	37.8 (12.1)
	$PM_{2.5}$(μgm^{-3})	17.2 (7.9)	11.4(5.7)	14.9 (7.3)
	SO_2(ppb)	1.3 (0.48)	0.94 (0.41)	1.1 (0.71)
	NO_x(ppb)	9.5 (2.7)	3.5 (2.2)	9.6 (3.0)

*20.03.2020 to 11.05.2020
**Limited data availability

Table 4-4.
$PM_{2.5}$, SO_2 and NOx Daily Concentration over 2020

The air quality levels also decreased during the lockdown periods in 2021. For example, Figure 4-11 shows the daily concentration of $PM_{2.5}$ for the monitoring stations at the Central Environmental Authority, Battaramulla through 29 August 2021.

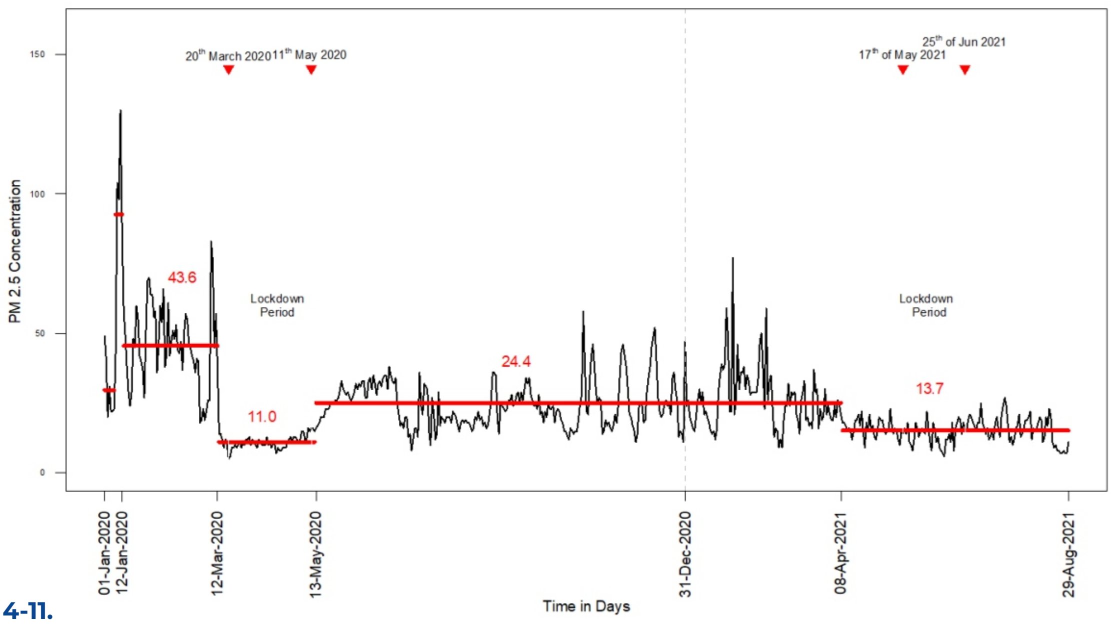

Figure 4-11.
Daily Concentrations of $PM_{2.5}$ from 2020 to 2021 (Air Quality Monitoring Station Located at the Central Environmental Authority, Battaramulla)

The daily $PM_{2.5}$ concentrations went down in both nationwide lockdown periods (i.e., nationwide lockdown period from the 20 March 2020 to the 11 March 2020, and the nationwide lockdown period from the 17 May 2021 to the 25 June 2021. Comparison of lockdown periods and the reported $PM_{2.5}$ levels are provided in Table 4-5 below.

Nationwide Lockdown period	20th March 2020 to 11th May 2020	17th of May 2021 to 25th of June 2021
Daily $PM_{2.5}$ concentration (µg/m³) (Standard Deviation)	11.0 (2.2)	13.7 (3.9)
Lockdown criteria	Most factories and governments and private sector services were not functioning. Travel restrictions were strictly followed.	Most of the factories, governments, and private sector essential services functioned. Travel restrictions were not stringent for those who attended the services and production sectors.

Table 4-5.
Comparing Two National Lockdowns

The mobility patterns can further explain the changes in the daily concentration of $PM_{2.5}$ during the lockdown periods. As shown in Figure 4-12, this can be further described with mobility patterns. Moreover, the residential mobility is lower, and the workplace mobility is higher in the nationwide lockdown from the 17 May 2021 to 25 June 2021 as compared to 20 March to 11 May 2020.

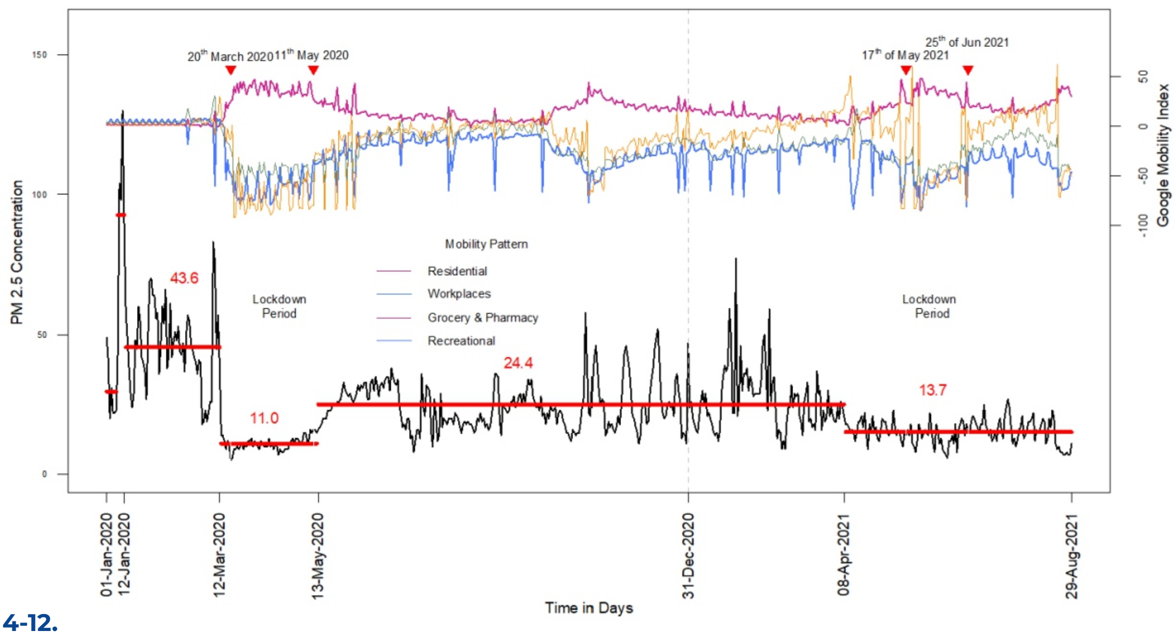

Figure 4-12.
$PM_{2.5}$, Mobility Patterns and the National Lockdown in 2020 and 2021

The variations in the daily concentration of $PM_{2.5}$ were compared across the pre-lockdown, lockdown, and post-lockdown periods. It can be surmised from that comparison that the daily variations of $PM_{2.5}$ are the highest in the pre-lockdown periods relative to the lockdown and post-lockdown periods. The variations of the daily concentrations of $PM_{2.5}$ in the post-lockdown period were higher than the lockdown period. These findings were similar across different air quality monitoring stations (Figures 4-13 and 4-14).

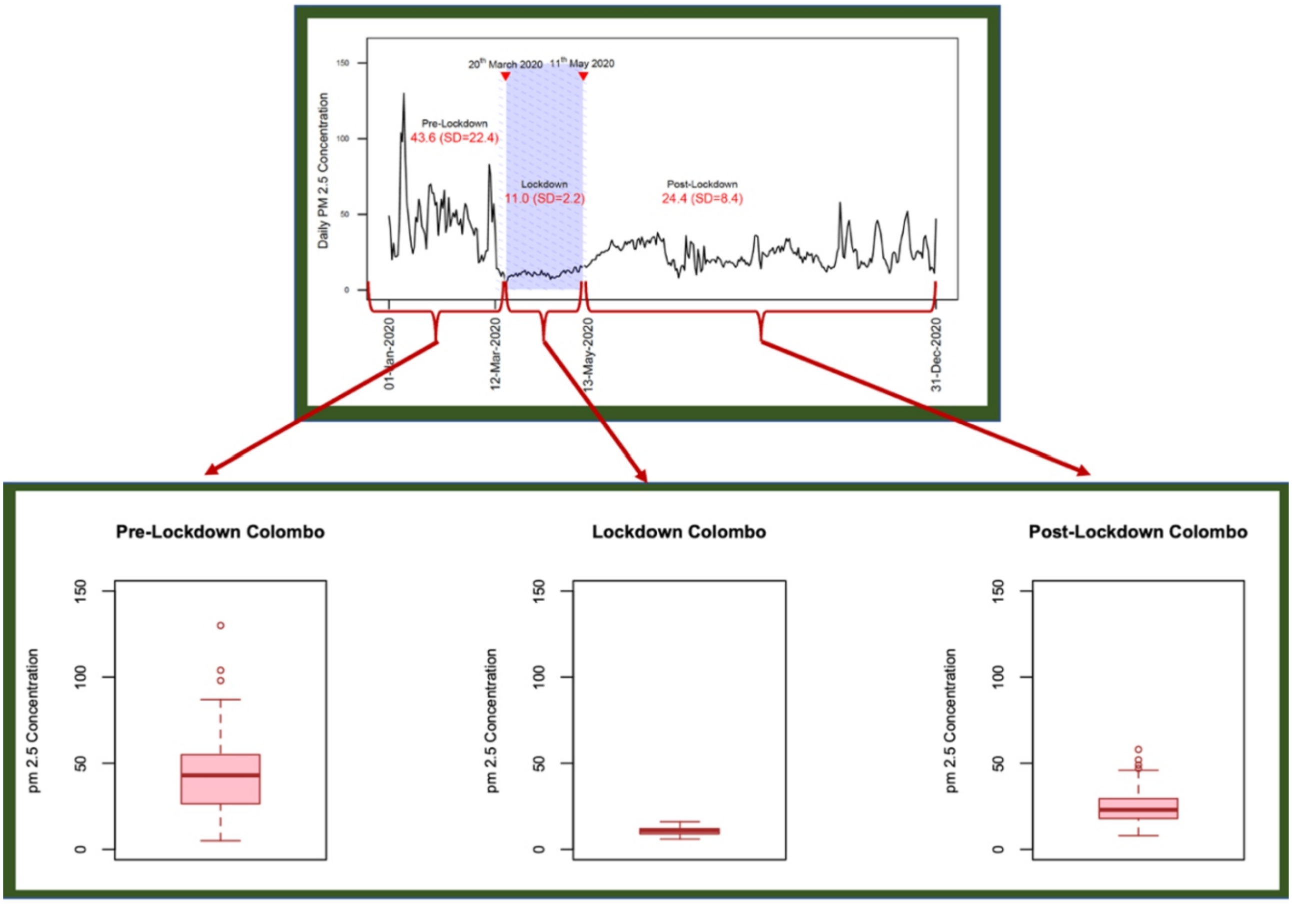

Figure 4-13.
$PM_{2.5}$ Daily Variability – Pre-Lockdown, Lockdown and Post Lockdown Period – 2020 Meteorology Department, Colombo

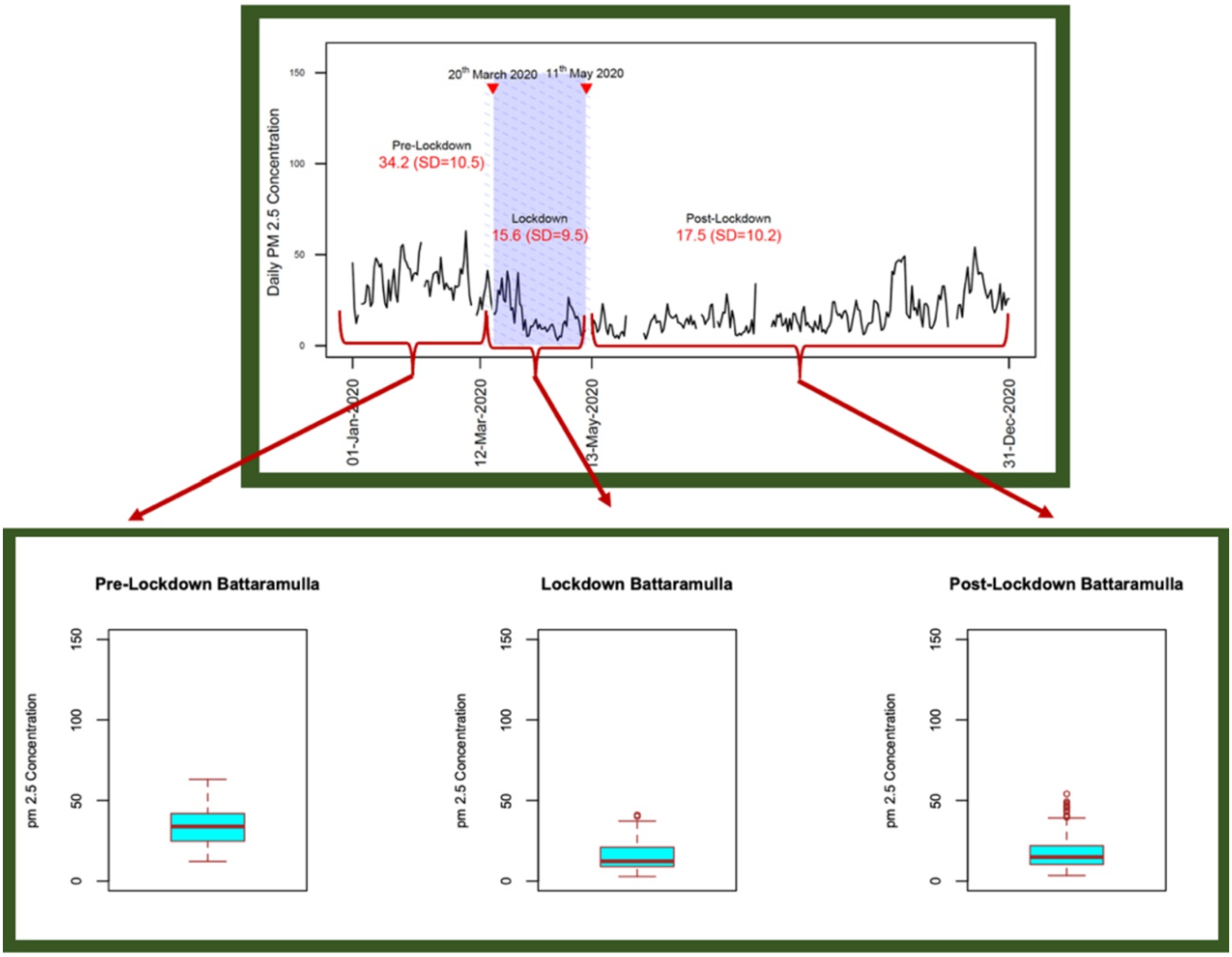

Figure 4-14.
$PM_{2.5}$ Daily Variability – Pre-Lockdown, Lockdown and Post Lockdown Period – 2020 Central Environmental Authority, Battaramulla

Daily changes in concentration of PM_{10} also showed a similar pattern to daily concentrations alterations of $PM_{2.5}$. Figure 4-15 provided the daily $PM_{2.5}$ and PM_{10} concentrations changes in 2020 recorded for the monitoring station at the Department of Meteorology, Colombo. Figure 4-16 presents $PM_{2.5}$, and PM_{10} mean concentration changes in pre-lockdown, lockdown, and post-lockdown periods for 2020 from the monitoring station at the Department of Meteorology, Colombo.

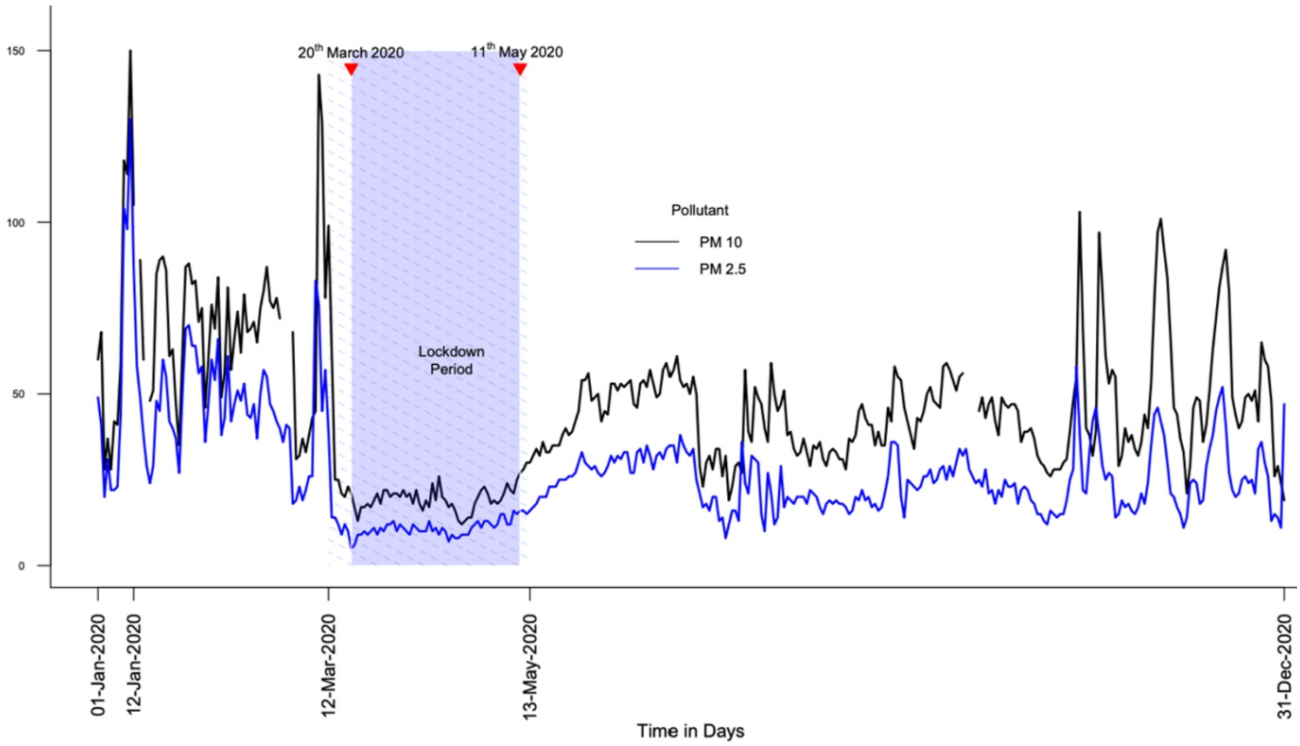

Figure4-15.
Daily $PM_{2.5}$ and PM_{10} Concentration Changes in 2020 at Monitoring Stations Located at the Department of Meteorology, Colombo

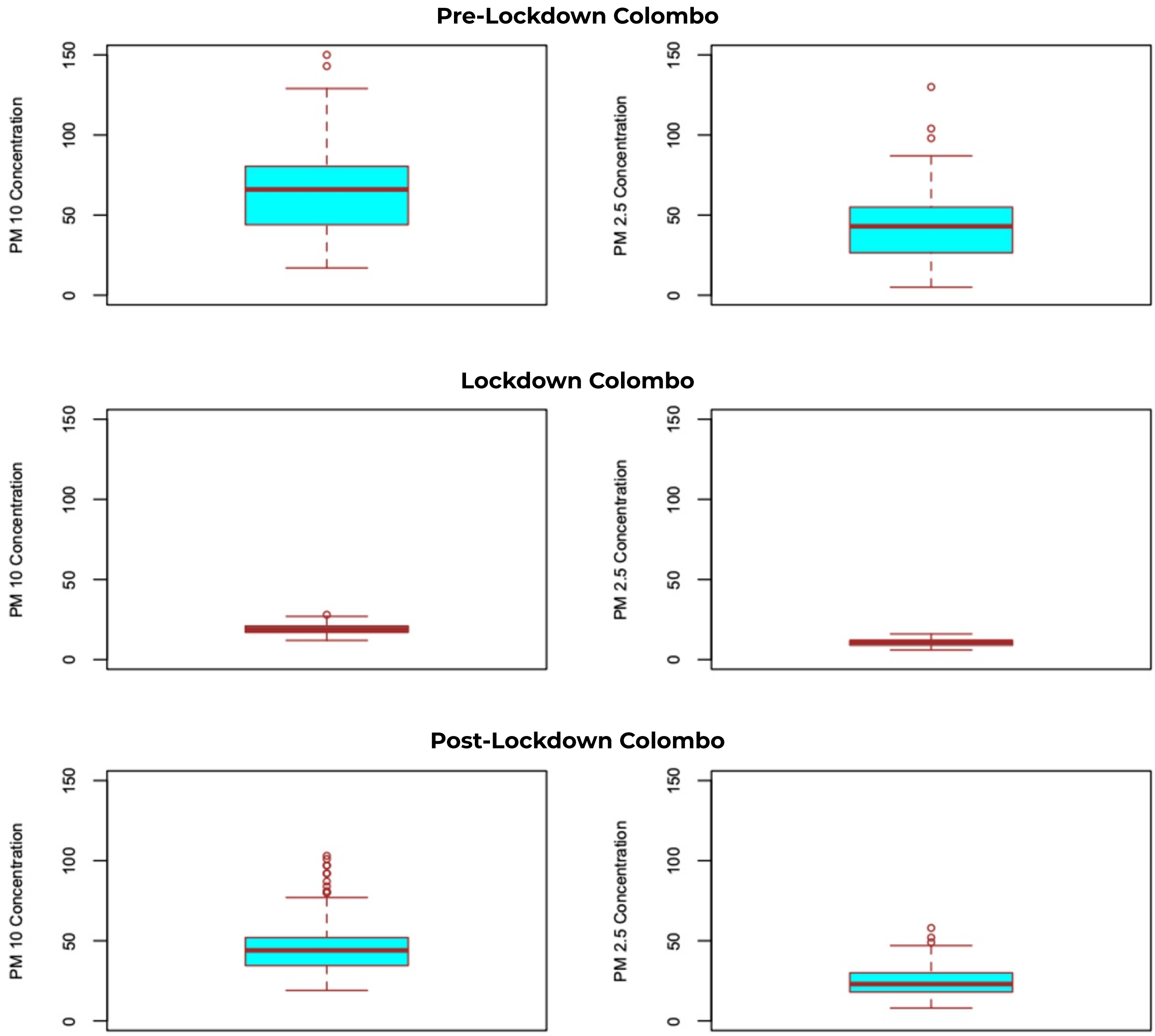

Figure 4-16.
$PM_{2.5}$ and PM_{10} Mean Concentration Changes during the Pre-Lockdown, Lockdown and Post-Lockdown Periods in 2020 at Monitoring Stations Located at the Department of Meteorology, Colombo

4.5 Estimation of Variation in 24-hour $PM_{2.5}$ Concentrations Based on Changes in Mobility

It was found that the highest impact of residential mobility on $PM_{2.5}$ concentration occurred at the lag of 0 days. Figure 4-17 shows the proportionate change in $PM_{2.5}$ concentrations or the relative risk (RR) at the lag of 0 estimated to the baseline "Residential" mobility of 0. The red line represents the RR estimate, and the shaded area represents the 95% ranging interval. The increase in "Residential" mobility or higher the proportion of people who stayed at their residence decreased the RR of $PM_{2.5}$ relative to the normality (or the baseline mobility pattern/pre-COVID pattern). The RR estimates become statistically significant starting with a threshold residential mobility of 15 and more (RR 0.78; 95% CI from 0.62 to 0.99).

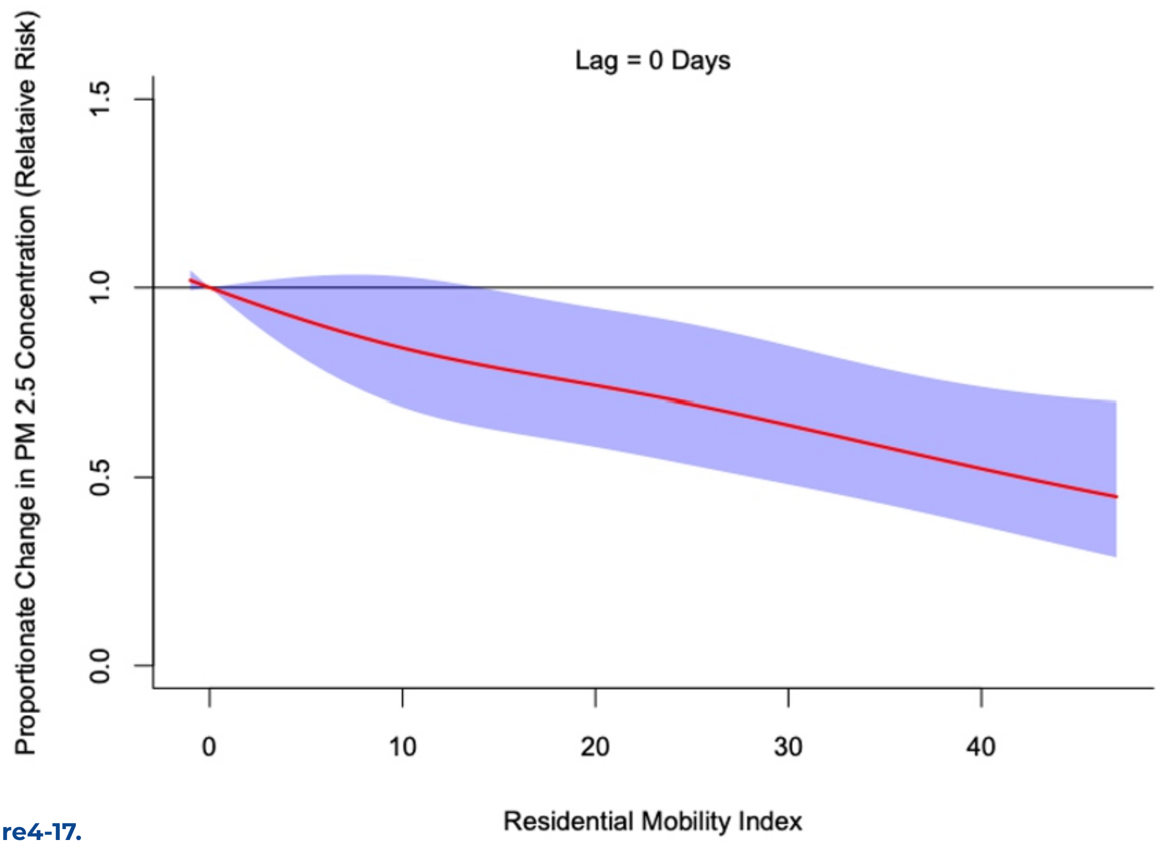

Figure4-17.
Proportionate Change in 24-hour $PM_{2.5}$ Concentrations Based on an Increase in Residential Mobility (Data from the Monitoring Station at the Meteorology Department, Colombo)

Percentage increase in residential mobility	Proportionate change in the PM 2.5 Concentration (95% confidence interval)	Percentage decrease in PM 2.5 Concentration(95% confidence interval)
10%	0.91 (0.80 to 1.02)	9 (-2 to20)%
25%	0.81 (0.65 to 1.01)	19 (-1 to 35)%
50%	0.71 (0.55 to 0.92)	29 (8 to 45)%
100%	0.44 (0.28 to 0.69)	56 (31 to 72)%

Table 4-6.
Percentage Change in 24-hour $PM_{2.5}$ Concentrations Based on Increases in Residential Mobility (Data from the Monitoring Station Located at Meteorology Department, Colombo)

Similarly, the chapter found that the greatest impact of “workplace” mobility on $PM_{2.5}$ concentration at the lag of 0 days. Figure 4-18 shows the proportionate change in $PM_{2.5}$ concentration or the relative risk at the lag of 0 estimated to the baseline “Workplace” mobility of 0. The red line represents the relative risk estimate, and the shaded area represents a 95% confident interval. The drop off in “workplace” mobility or a reduction in the proportion of people attending to workplaces decreased the relative risk of $PM_{2.5}$ relative to the normality (or the baseline mobility pattern/pre-COVID patterns). The relative risk estimates become statistically significant starting a threshold of residential mobility of -24 and more (RR 0.83; 95% CI from 0.69 to 0.99).

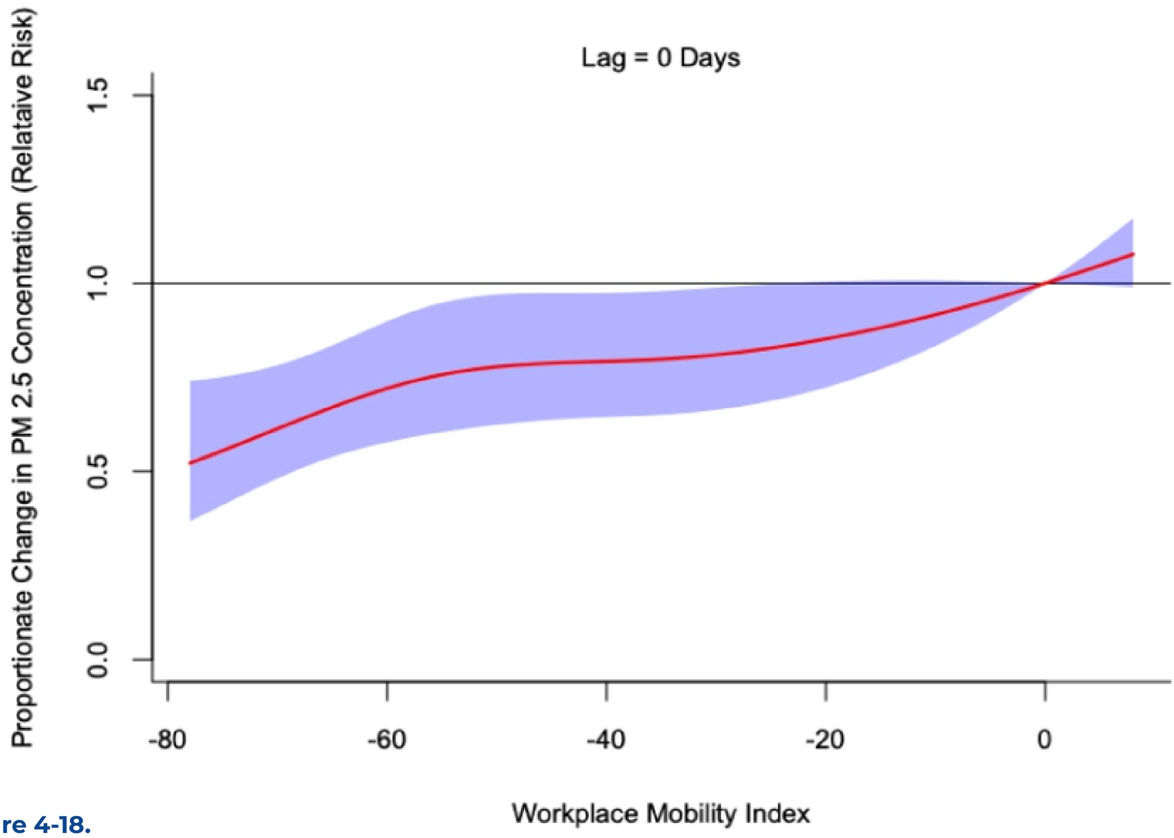

Figure 4-18.
Proportion Change in 24-Hour $PM_{2.5}$ Concentrations Based on an Increase in Workplace Mobility (Data from the Monitoring Station at the Meteorology Department, Colombo)

Percentage decrease in workplace mobility	Proportionate change in the PM 2.5 Concentration (95% confidence interval)	Percentage decrease in PM 2.5 Concentration (95% confidence interval)
10%	0.93 (0.83 to 1.00)	7 (0 to 17)%
25%	0.84(0.70 to 1.00)	16(0 to 30)%
50%	0.78 (0.63 to 0.96)	22 (4 to 37)%
100%	0.52 (0.36 to 0.74)	48 (26 to 64)%

Table 4-7.
Percentage Change in 24-Hour $PM_{2.5}$ Concentrations Based on an Increase in Residential Mobility (Data from the Monitoring Station at the Meteorology Department, Colombo)

4.6 Discussion

COVID-19 spread across the world following its initial discovery in China in 2019. By early 2020, the increasing number of COVID-19 cases led the World Health Organization (WHO) to declare a global pandemic. Like many countries, the pandemic had a significant effect on Sri Lanka.

The Sri Lankan government took many steps to limit those effects. Social mobility restrictions were one of the main interventions. These restrictions led to a reduction in traffic as well as drops in air pollution. This chapter used several sources of data to explore this phenomenon and inform policies to improve long term air quality in Sri Lanka ((WHO Regional Office for Europe n.d.).

Figure 4-19.
A Picture of Administrative Buildings at the Colombo Municipal Council During the Lockdown Period
Source: Public Internet Resources

One of the key data points in the chapter involved mobility patterns. The chapter assessed how these patterns were correlated with travel restrictions. The data helped show that daily concentration of $PM_{2.5}$ fell due to a decrease in mobility and fluctuated with changes in mobility.

It is important to quantify the reduction of $PM_{2.5}$ concentrations with different mobility patterns to inform policy. The data analysis revealed that an increase in mobility around residences by 10% from baseline led to reductions in $PM_{2.5}$ daily concentrations by about 9%. In other words, changes in transport around residential areas, could bring down $PM_{2.5}$ daily concentrations. On the other hand, an increase in workplace mobility—commuting to work—likely led to an increase in the percentage of $PM_{2.5}$ daily concentrations. In this case, the data suggests that 10% and 25% increase in travel to the workplace increased $PM_{2.5}$ daily concentrations by between 7% and 16%.

The annual financial reports of the Central Bank of Sri Lanka show that the sales quantities of Sri Lankan Petroleum Cooperation fell in 2020 compared to 2019 (Figure 4-20).

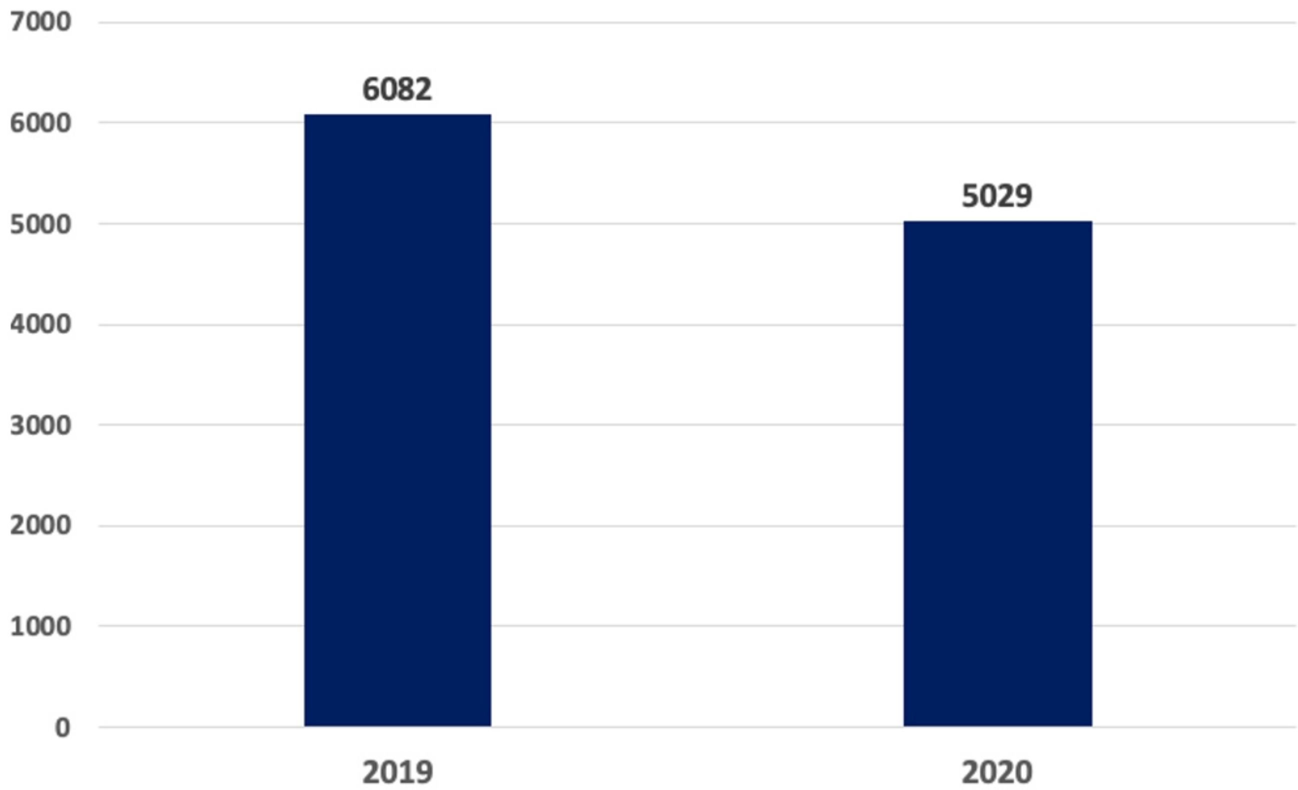

Figure 4-20.
Sales Volumes of the Sri Lankan Petroleum Cooperation

The use of fossil fuels and associated emissions fell in 2020 relative to 2019. Most petroleum products are imported from other countries. Sri Lanka spends a considerable amount of revenue on imported fuels. The reduction in mobility likely led to a decline in transportation and traffic as well as air pollution and imported fuel expenditures.

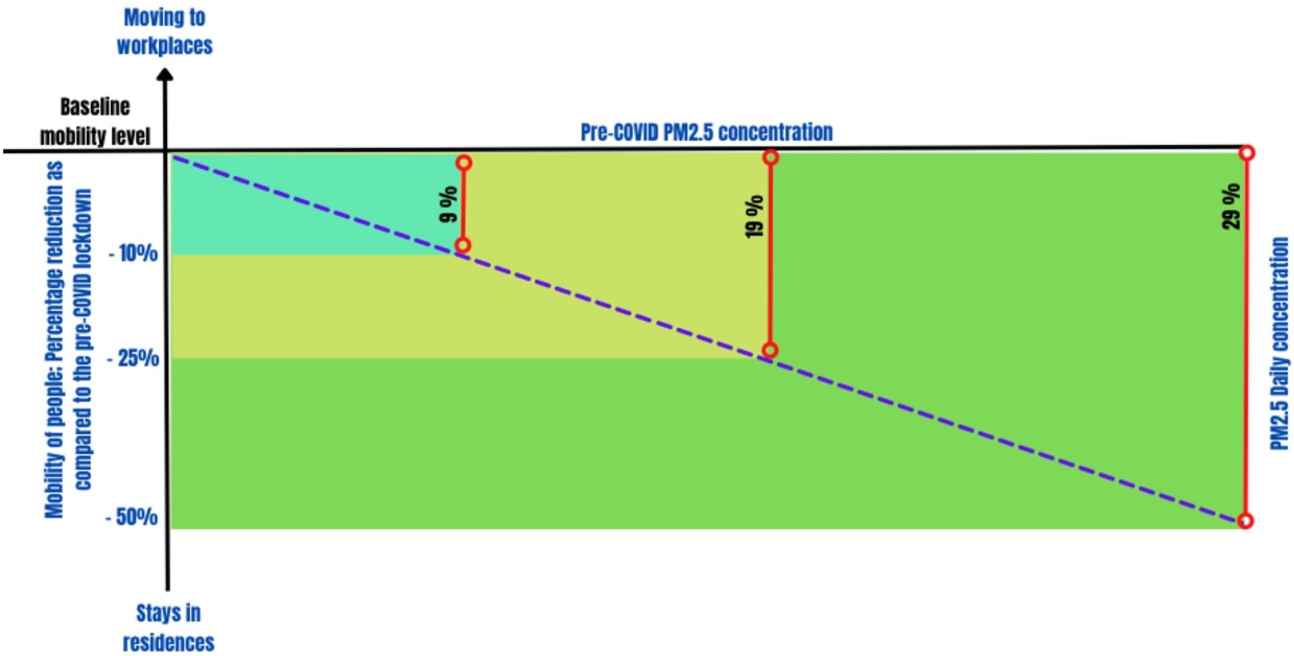

Figure 4-21.
Mobility and Daily $PM_{2.5}$ Concentrations

Several interventions were promoted to limit non-essential transport, including work from home programs as well as online platforms for banking, shopping and school. While important to sustain productivity, work from home needed to be implemented carefully as it could not impact work itself but the mental health and welfare of employees (A Study on Work Life Balance n.d.).

While limiting unnecessary mobility, offering improvements in transport, especially improving access and quality of public transport, required attention. About 25% of the population in Colombo use solid fuel and kerosene for cooking that contribute to household air pollution. Travel restrictions could increase the exposure to the household air pollution. Therefore, promoting clean cooking and heating and preventing of waste burning also required attention. However, it should be borne in mind that travel restrictions are likely to affect wealthier parts of population who also more on cleaner fuels for cooking (Nandasena, Wickremasinghe, and Sathiakumar n.d.).

Social restrictions and other COVID-related health interventions prevented the effects of air pollution exposure. The wearing masks, for instance, likely prevented the spread of respiratory diseases, exposure to air pollutants and then the health impacts from this exposure.

Figure 4-22.
Health Measures for School Children
Source: Public Internet Resources

Compulsory mask wearing helped to prevent air pollution exposure, especially for children, the elderly, people with poor health, and those working outdoor jobs (police managing traffic). Sustaining these practices could arguably continue to improve health.

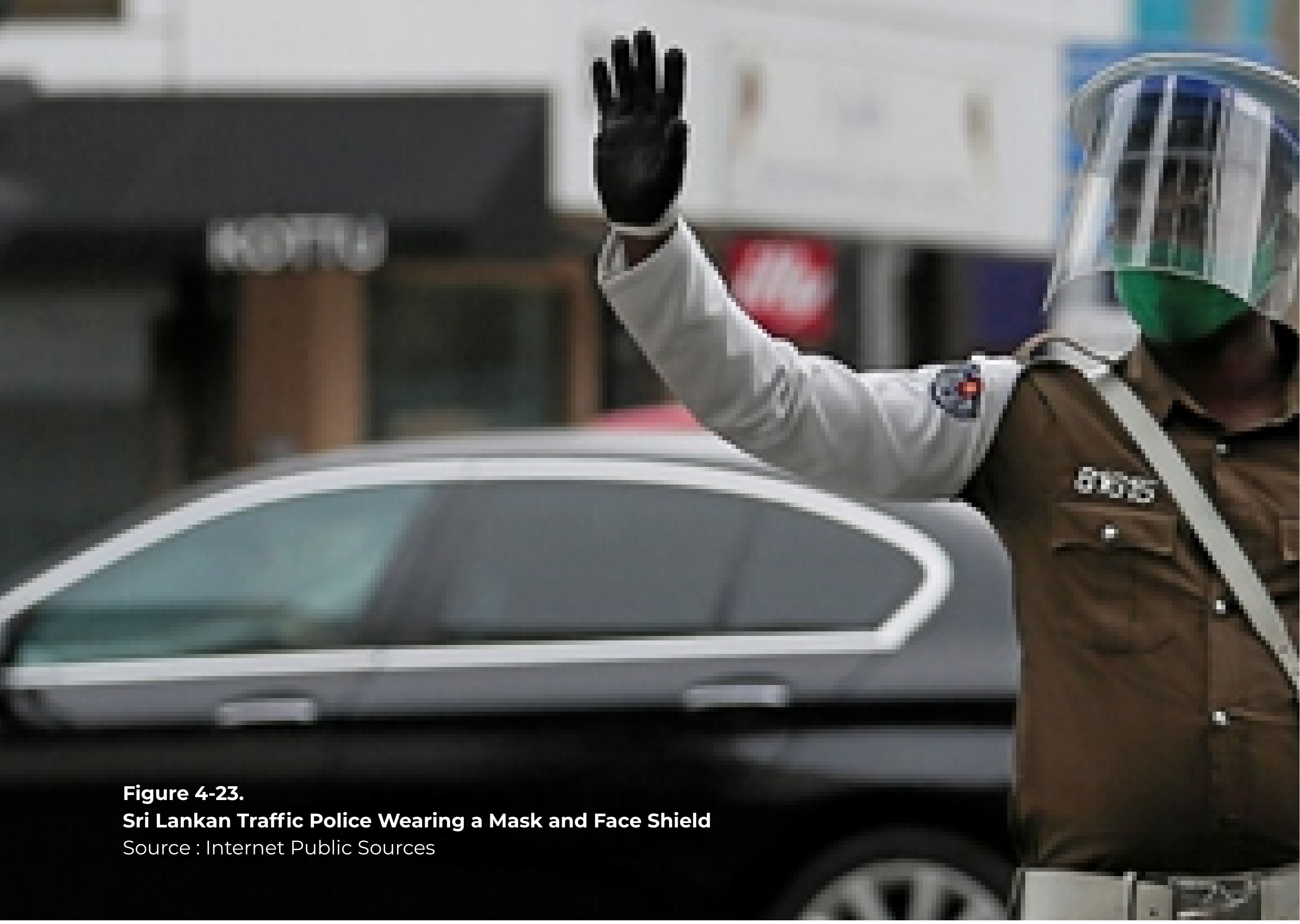

Figure 4-23.
Sri Lankan Traffic Police Wearing a Mask and Face Shield
Source : Internet Public Sources

The WHO recently updated the indoor and ambient air quality guidelines (see Table 4-8) (WHO 2021c).

Pollutant	Averaging time	Interim Targets				AQG level
		1	2	3	4	
$PM_{2.5}$	Annual	35	25	15	10	5
	24 hours	75	50	37.5	25	15
PM_{10}	Annual	70	50	30	20	15
	24 hours	150	100	75	50	45
O_3	Peak season	100	70	-	-	60
	8 hours	160	120	-	-	100
NO_2	Annual	40	30	20	-	10
	24 hours	120	50	-	-	25
SO_2	24 hours	125	50	-	-	40
CO	24 hours	7	-	-	-	4

Table 4-8.
Recommended Air Quality Guidelines (AQG) and for PM2.5 Interim Targets Daily and Annual Concentrations
Source: WHO 2021c

Table 4-9 presents permissible air quality levels in Sri Lanka based on the gazette no:1562/22 – Friday, August 15, 2008 (Sri Lanka 2008). The comparison of the AQG of WHO and the Sri Lankan gazette shows legally permissible levels are set at the WHO interim level 2 and above (i.e., interim level 1).

Pollutant	Averaging time	Maximum permissible level	Comments based on the WHO AQG level 2021
$PM_{2.5}$	Annual	25	AQG interim level 2
	24 hours	50	AQG interim level 2
PM_{10}	Annual	50	AQG interim level 2
	24 hours	100	AQG interim level 2
O_3	Peak season	-	
	8 hours	-	
	1 hour	200	Higher than peak season AQG interim level 1
NO_2	Annual	-	
	24 hours	100	Between interim level 1 and 2
	8 hours	150	No reference value
	1 hour	250	No reference value
SO_2	24 hours	80	Between interim level 1 and 2
	8 hours	120	No reference value
	1 hour	200	No reference value
CO	24 hours	-	No reference value
	8 hours	10,000	No reference value
	1 hour	30,000	No reference value
	Any time	58,000	No reference value

Table 4-9.
Air Quality Standards in Sri Lanka

The reported $PM_{2.5}$ daily concentrations in different periods (i.e., Pre-lockdown period – 01.01.2020 to 19.03.2020; Lockdown period – 20.03.202o to 11.05.2020; Post lockdown period – 12.05.2020 to 31.12.2020) were compared with WHO air quality guidelines and Sri Lanka's standards (Figure 4-24).

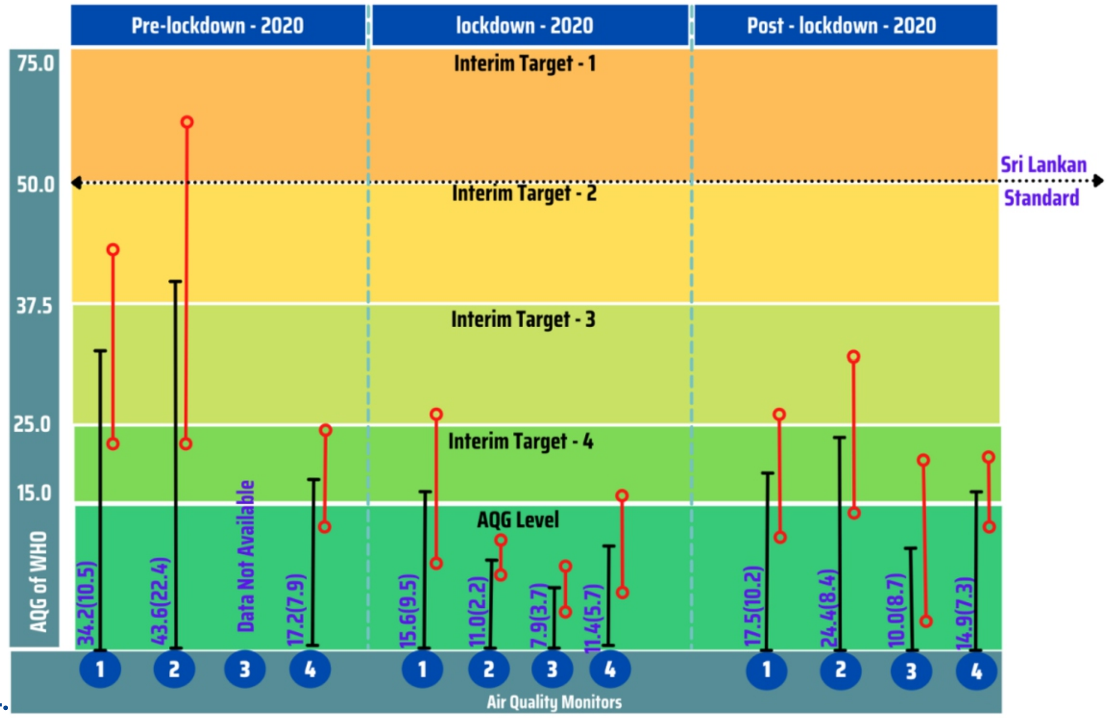

Figure 4-24.
Comparison of 24-Hourly Average for $PM_{2.5}$ Concentrations at Different Periods during 2020 Using the AQG of WHO and Sri Lankan Standards

Notes for above figure:
Data was taken from the following air quality monitoring stations:
1 - Central Environmental Authority Premises, Battaramulla, Colombo;
2 - Meteorology Department, Colombo;
3 - Municipal Council, Colombo; Kandy.
The Periods were as follows:
Pre-lockdown period – 01.01.2020 to 19.03.2020; Lockdown period – 20.03.2020 to 11.05.2020;
Post lockdown period – 12.05.2020 to 31.12.2020;
All concentrations are in μgm^{-3}.
Standard deviations of average $PM_{2.5}$ daily concentrations are represented with red lines.

In the early part of year 2020 (i.e., pre-lockdown), $PM_{2.5}$ daily concentrations typically exceeded the Sri Lankan air quality standards. However, $PM_{2.5}$ daily concentration from all monitoring stations during the post-lockdown period met WHO interim target 4 or below. The standard deviations of $PM_{2.5}$ daily concentration of two monitors were within WHO interim targets 4 and 2.

Most economic activities and the services picked back up during the post-lockdown period. However, social restrictions in small geographic areas were enforced during the post-lockdown period. Public gatherings were also limited, while schools and higher education institutions closed for select periods. At the same time, work from home, online payment systems and e-commerce continued during post-lockdown periods of 2020 in some communities. Collectively, the evidence suggests Sri Lanka could reach $PM_{2.5}$ the WHO interim target 3 for daily concentrations (i.e., 37.5 µgm^3) and policymakers should consider tightening national standards.

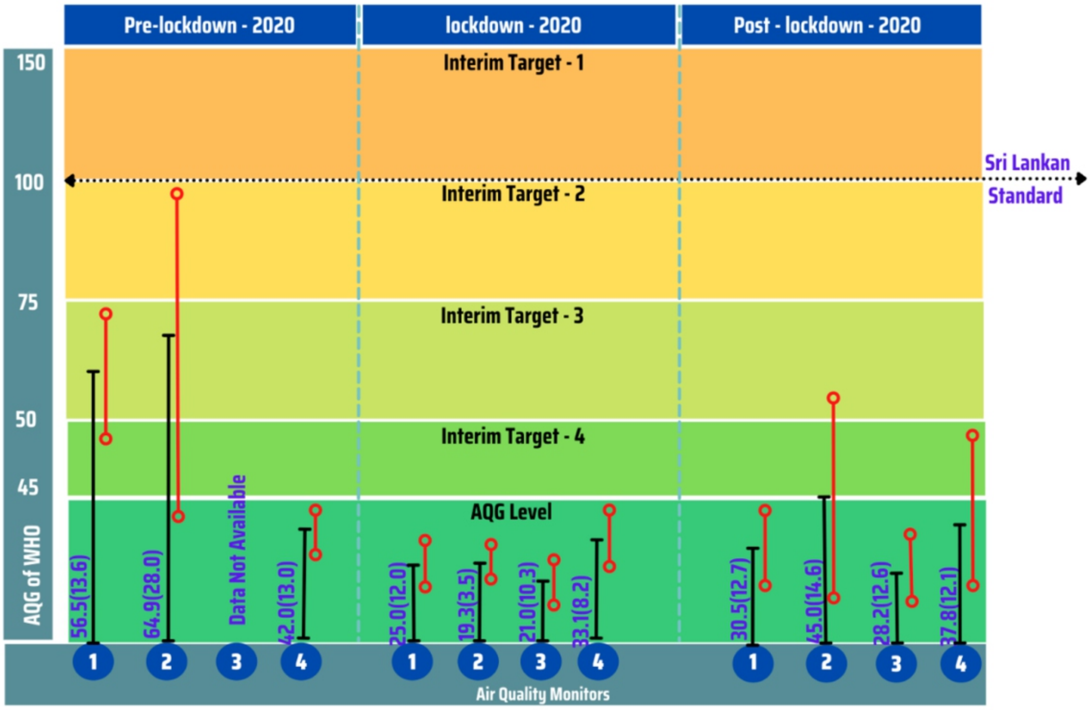

Figure 4-25.
Comparison of 24-Hour Average PM_{10} Concentrations during Different Periods in 2020 Using the AQG of WHO and Sri Lankan Standards

Notes for above figure:
Data was taken from the following air quality monitoring stations:
1 - Central Environmental Authority Premises, Battaramulla, Colombo;
2 - Meteorology Department, Colombo;
3 - Municipal Council, Colombo; Kandy.
The Periods were as follows:
Pre-lockdown period – 01.01.2020 to 19.03.2020; Lockdown period – 20.03.2020 to 11.05.2020;
Post lockdown period – 12.05.2020 to 31.12.2020;
All concentrations are in µgm^{-3}.
Standard deviations of average $PM_{2.5}$ daily concentrations are represented with red lines.

Similar to the $PM_{2.5}$, the daily concentration of PM_{10} is provided in the Figure 4-25. The balance of evidence suggests Sri Lanka could reach PM_{10} daily concentration less than 75.0 µgm^3, and policymakers should consider tightening the $PM_{2.5}$ standards daily concentration to WHO interim target 3 (i.e., 75.0 µg/m^3).

4.7 Conclusions and Recommendations

1. ***The strength of travel restrictions varied during COVID-19; the strongest restrictions were adopted from 20 March to 11 May 2020 in Sri Lanka.*** Transport to work and shopping (groceries and pharmacies) fell the most, while transport around residences increased the most over this period.

2. ***Travel restrictions and lockdowns led to air quality improvements.*** For instance, daily $PM_{2.5}$ concentrations in the pre-lockdown period, lockdown period and post-lock-down periods were 34.2 μg/m^3, 15.6 μg/m^3 and 17.5 μg/m^3 respectively at the monitoring stations at the Central Environmental Authority. Meanwhile, the monitoring stations at the Department of Meteorology showed that $PM_{2.5}$ daily concentrations in the pre-lockdown period, lockdown period, and post-lock-down periods were 43.6 μg/m^3, 11.0 μg/m^3 and 24.4 μg/m^3 respectively in 2020.

3. ***$PM_{2.5}$ and PM_{10} levels were within WHO guidelines during lockdowns.*** Moreover, levels of $PM_{2.5}$ and PM_{10} stayed within the WHO interim target 3 and 4 during post lockdown period. Importantly, compliance with these guidelines appeared to be associated with the strength of travel restrictions. This merits attention since average $PM_{2.5}$ concentrations were often above Sri Lankan standards prior to the lockdowns.

4. ***Increasing mobility around residential areas led to a reduction in $PM_{2.5}$, while increasing travel for work had the opposite effect.*** The analysis presented in this chapter suggested that 10% and 25% increase in travel for work led to an increase the $PM_{2.5}$ daily concentration between 7% and 16%.

5. ***COVID-19 health measures such as wearing masks, handwashing, and social distancing likely prevented exposure to air pollution.*** For example, respiratory infections admissions declined more than 50% in 2020 compared to 2019.

6. ***Efforts to limit nonessential motorized transport such as work from home can improve air quality and health.*** Although not be possible for everyone, work from home programs can help lower pollution levels. Efforts to limit unnecessary travel should be coupled with the improvements in public transportation, especially for those who need to commute.

7. ***Promoting mask wearing and comparable measures can also limit the adverse effects of air pollution on health.*** These practices should continue even in as the immediate threat of COVID-19 fades.

8. ***$PM_{2.5}$ daily concentration standards of Sri Lanka should be lowered 37.5 µg/m^3 (WHO Interim Target 3), while PM_{10} daily concentration standards should be lowered to 75.0 µg/m^3 (WHO Interim Target 3).*** The analysis in this chapter demonstrated the potential to comply with stronger standards.

9. ***Air quality monitoring in major cities should be strengthened.*** The assessment included data from three air quality monitoring stations in Colombo and one air quality monitoring station in Kandy for 2020. However, the data for 2021 was not available in most monitoring stations.

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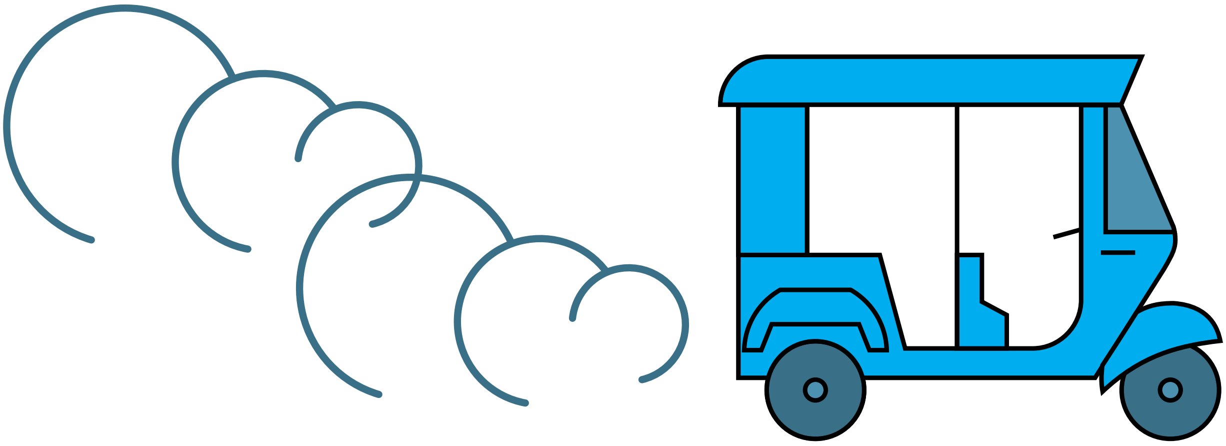

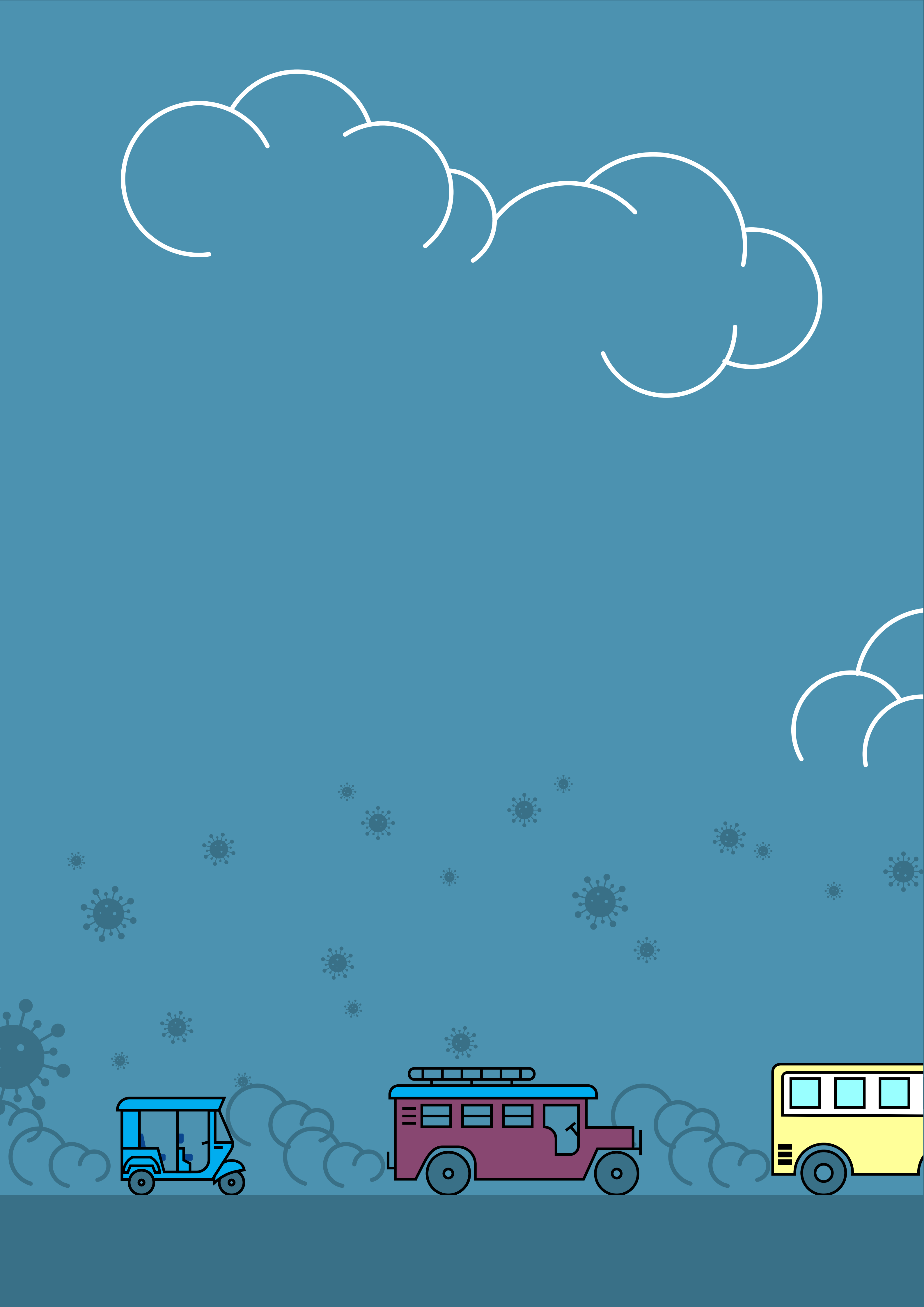

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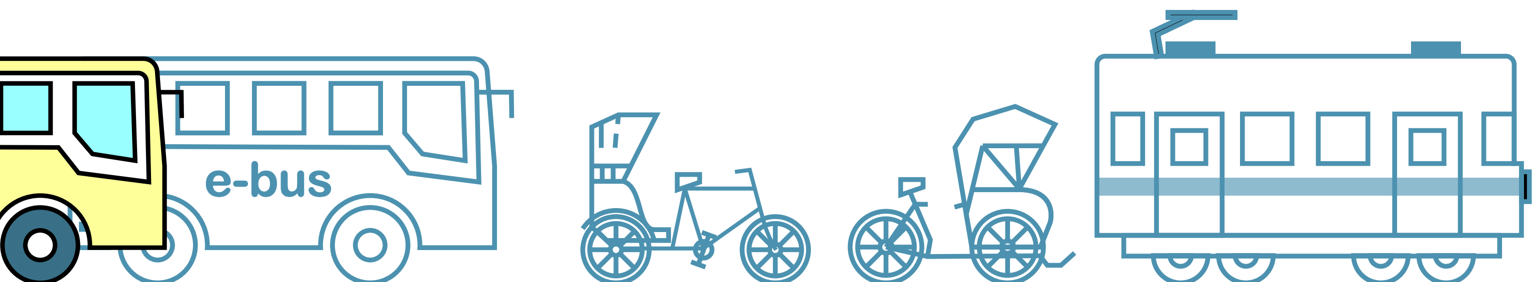

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