Asian and Pacific Centre for Transfer of Technology

Assessment Report

City Action Plans and Technology Adoption Strategies in Bangkok, Thailand

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FOREWORD

It is with great pleasure that I introduce this document: *City Action Plans and Technology Adoption Strategies in Bangkok, Thailand*.

The Asian and Pacific Centre for Transfer of Technology (APCTT) of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), has long been dedicated to fostering innovation and facilitating the transfer of technology across our diverse member countries. APCTT's key mandate is to strengthen the technology transfer capabilities in the Asia- Pacific region and to facilitate exchange of new, emerging and environmentally sound technologies between the member countries.

This document was produced under the project *"Enhanced capabilities to adopt innovative technologies for city air pollution control in select countries of the Asia Pacific"* supported by the Korea ESCAP Cooperation Fund. The project objective was to support three ESCAP member States (Bangladesh, India and Thailand) to strengthen policies and city level action plans to facilitate adoption of innovative technologies for controlling air pollution. The project aimed to improve the availability of technical knowledge regarding innovative technologies, and good practices and enabling policies for air pollution control in three cities (Bangkok, Dhaka and Gurugram).

This report, a collaborative effort involving experts and stakeholders, presents a detailed analysis of existing measures and proposes strategic approaches for technology adoption. The findings herein serve as a valuable resource for policymakers, city planners, and technologists in Bangkok and other cities, providing insights into the effectiveness of current initiatives and recommending future policy pathways for enhancing air quality. We hope that this report significantly advances our understanding of air quality dynamics and stimulates further discourse and evidence-based actions for a cleaner and more resilient urban environment in Asia Pacific.

Preeti Soni
Head
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This publication was prepared by Dr. Ekbordin Winijkul and Ms. Kanokwan Limsiriwong of the Environmental Engineering and Management Department of the Asian Institute of Technology, Bangkok under a consultancy assignment with ESCAP-APCTT. The contributions of the Thailand Institute of Scientific and Technological Research (TISTR), Pollution Control Department (PCD), Office of Transport and Traffic Policy and Planning (OTP), Bangkok Metropolitan Administration (BMA) and Thailand's Hub of Talents on Air Pollution and Climate (HTAPC) have been integral in enhancing the depth and relevance of the findings. The report benefited from comments and suggestions from Mr. Satyabrata Sahu and Mr. Pankaj Kumar Shrivastav from the ESCAP-APCTT.

We gratefully acknowledge all of the above.

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1. INTRODUCTION

Current air quality management in Bangkok

The air quality in Bangkok has gradually improved (Figure 1). The concentration of $PM_{2.5}$ continually decreased from 27 µg/m³ in 2018, followed by 26 µg/m³ in 2019, 23 µg/m³ in 2020, 23 µg/m³ in 2021, and 22.7 µg/m³ in 2022 (PCD, 2023). Figure 2 shows that the percentage of hours meeting the WHO $PM_{2.5}$ guideline (5 µg/m³) increased from 5% in 2019 to 17.8% in 2022 due to different policies and the involvement of various sectors and stakeholders (IQAir, 2022).

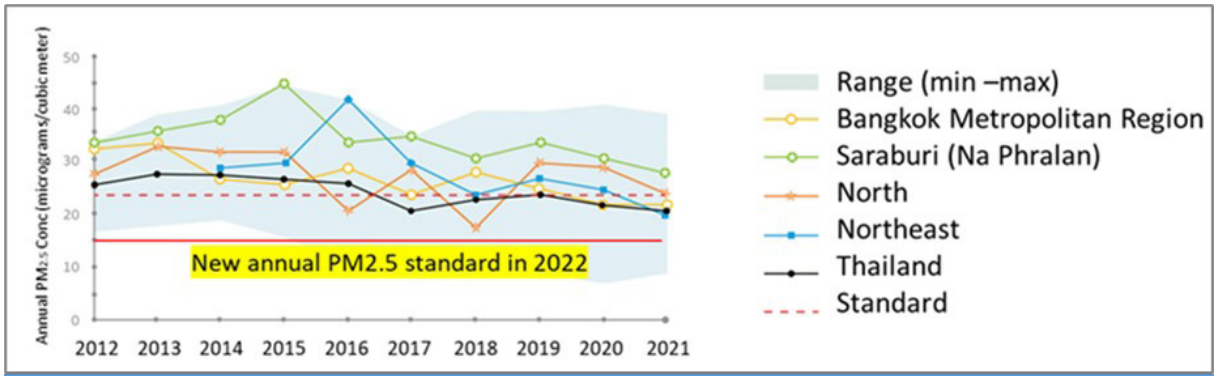

Figure 1: Annual $PM_{2.5}$ Concentration in Bangkok and Thailand *(PCD, 2022)*

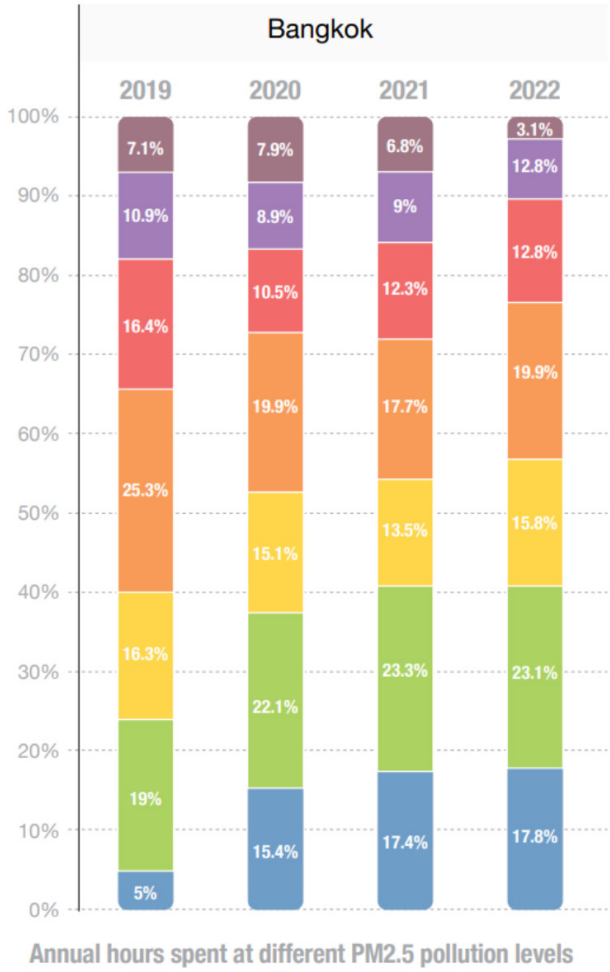

Figure 2: Annual hours spent at different $PM_{2.5}$ pollution levels *(IQAir, 2022)*

This achievement can be attributed to a collaborative endeavor involving all sectors and interested parties. Governmental bodies, private enterprises, educational institutions, and the public have joined forces to consistently address air pollution issues. Notably, their focus has been on tackling pollution at its source, which involves aspects such as raising emission standards for vehicles and enhancing fuel quality. Nevertheless, certain areas in Bangkok currently experience $PM_{2.5}$ air pollution that is five times higher than the WHO-prescribed standards. The prevailing meteorological conditions, characterized by stagnant air and light winds, have led to the entrapment of PM in the atmosphere. If proactive solutions for the future are not effectively planned, the situation could exacerbate in such hotspots across Bangkok city. All stakeholders must collaborate in resolving these issues. Consequently, the government has declared that combating the issue of $PM_{2.5}$ air pollution is a national priority, necessitating comprehensive and coordinated efforts from all parties to enhance the air quality for both Thai residents and visitors.

The Bangkok Metropolitan Administration (BMA) has introduced several policies aimed at monitoring $PM_{2.5}$ in real-time using regulatory monitoring stations. The collected data is accessible through various platforms, including www.bangkokairquality.com, www.prbangkok.com, the official Facebook page of the Air Quality and Noise Management Division within the Environment Department, the Public Relations Office of the BMA, as well as the website www.air4thai.com, operated by the Pollution Control Department (PCD). Additionally, the BMA has collaborated with other relevant organizations to execute measures targeted at tackling the $PM_{2.5}$ issue. These measures encompass (C40.org):

- Establishment of the BMA's $PM_{2.5}$ Air Pollution Prevention and Solution Committee under the leadership of the Governor of Bangkok. The committee's primary objectives encompass monitoring the situation of ambient $PM_{2.5}$ concentration, analyzing data to direct operational units, coordinating pertinent agencies, disseminating information about the $PM_{2.5}$ status, and furnishing guidelines through social media platforms to prevent and mitigate health-related impacts.

  The Committee's oversight of short-term actions include:

  - Providing regular road cleaning.
  - Increasing checkpoints and enforcing restrictions on vehicles emitting black smoke.
  - Collaborating to alleviate traffic congestion and promoting greater use of the public transportation systems.
  - Prohibiting waste and open burning.
  - Enforcing strict dust control measures for Skytrain construction.
  - Managing and resolving issues related to dust from building construction.
  - Augmenting green spaces.
  - Regulating pollution emissions from industrial facilities to meet the prescribed standards.
  - Distributing surgical masks and providing information on $PM_{2.5}$ prevention, especially for vulnerable groups like children, patients, and the elderly.

  For implementing long-term strategies, the Committee supervises the following:

  - Enhancing pollutant emission standards for vehicles and fuel quality.
  - Developing an expanded network for comprehensive public transportation systems.
  - Advocating increased utilization of public transportation.
  - Establishing "Park & Ride" facilities to promote public transportation use.
  - Expanding green areas.

- Establishing the BMA's Air Pollution Coordination and Resolution Center chaired by the Governor of Bangkok to monitor, report, and announce the situation on $PM_{2.5}$ air pollution, as well as to unite efforts to solve the problem promptly. In the case of $PM_{2.5}$ exceeding the Thailand ambient air quality standard, the Center will notify the district offices in the areas and relevant agencies to take all necessary actions on an immediate basis.
- Implementing the Nuisance Control Program abided by the Ministry of Public Health Act. These activities aim to use the existing act under the control of BMA to control diesel-engine vehicles that emit black smoke exceeding the standard, open burning, and construction activities that affect air pollution.
- The Governor of Bangkok, being the single Commander, is fully responsible for Bangkok. He had invited all relevant government stakeholders to define and recommend actions to pursue during periods of high $PM_{2.5}$ concentrations that exceed the prescribed standard, in order to ensure that all relevant agencies or authorities engaged in the implementation work can promptly take necessary actions.

2. ACTION PLAN ON AIR POLLUTION

Thailand National Action Plan on Fine Particulate Matter

Air pollution is one of the most significant problems in Thailand, affecting not only urban areas but the entire country. This issue intensifies during the dry season, also referred to as the 'burning season,' when agricultural fields are burned to clear biomass after harvesting. Additionally, pollution from the industrial and transport sectors poses a year-round challenge (Nikam J. et al., 2021; Enviliance ASIA, 2023). Consequently, $PM_{2.5}$ has gained significant attention in Thailand since 2018, particularly when the issue became severe in Bangkok and the metropolitan region. $PM_{2.5}$ pollution is now a national agenda. An action plan named 'Solving the Dust Pollution Problem' was established for 5 years from 2019 to 2024, comprising three main strategies as outlined below (Enviliance ASIA, 2023; PCD, 2019):

Measure 1: This measure enhances area-based management during crises categorized according to the following air quality levels:

- Level 1 ($PM_{2.5}$ below 50 µg/m^3): All agencies continue regular operations.
- Level 2 ($PM_{2.5}$ between 51-75 µg/m^3): All agencies intensify measures.
- Level 3 ($PM_{2.5}$ between 76-100 µg/m^3): Bangkok/provincial governors use a single command and control system to work with corresponding agencies.
- Level 4 ($PM_{2.5}$ exceeds 100 µg/m^3): Propose measures for the Prime Minister's consideration.

Measure 2: This measure focuses on preventing and reducing pollution at sources by controlling pollution from the transportation, agricultural, industrial, construction, and residential sectors. Several short-term actions are proposed for implementation to combat $PM_{2.5}$, including:

1. Inspecting black smoke emissions at sources.
2. Upgrading vehicles to Euro V/VI emission standards.
3. Promoting the use of electric vehicles in Bangkok.
4. Expanding road capacity to reduce traffic congestion.
5. Eliminating dust-generating activities.
6. Implementing a complete ban on open burning.

7. Installing Continuous Emission Monitoring Systems (CEMs) and inspecting factories.
8. Encouraging the use of clean fuels in households.
9. Promoting the use of public transportation.
10. Controlling dust from construction sites.

Measure 3: This measure aims to enhance the efficiency of initiatives to manage air pollution control and management. Examples include developing an air quality monitoring network, compiling air pollution inventory reports, and addressing transboundary hazard pollution issues.

Bangkok Air Quality Action Plan on fine particulate matter

According to data from the air quality monitoring system in Bangkok from December to February every year, $PM_{2.5}$ concentration exceeds the national ambient air quality standard in many areas (International Affairs Office, 2022). The $PM_{2.5}$ concentration exceeded the standard for 64 days in Bangkok in 2021. The emission inventory developed for Bangkok for the base year of 2019 (Figure 3) shows $PM_{2.5}$ emissions from various sources in Bangkok. Transportation (including road dust) contributes the highest emission of $PM_{2.5}$ in Bangkok (55%), followed by open burning (which accounts for 20%), and the industrial sector (accounting for 11% of $PM_{2.5}$ emissions in the city) (Winijkut et al., 2023).

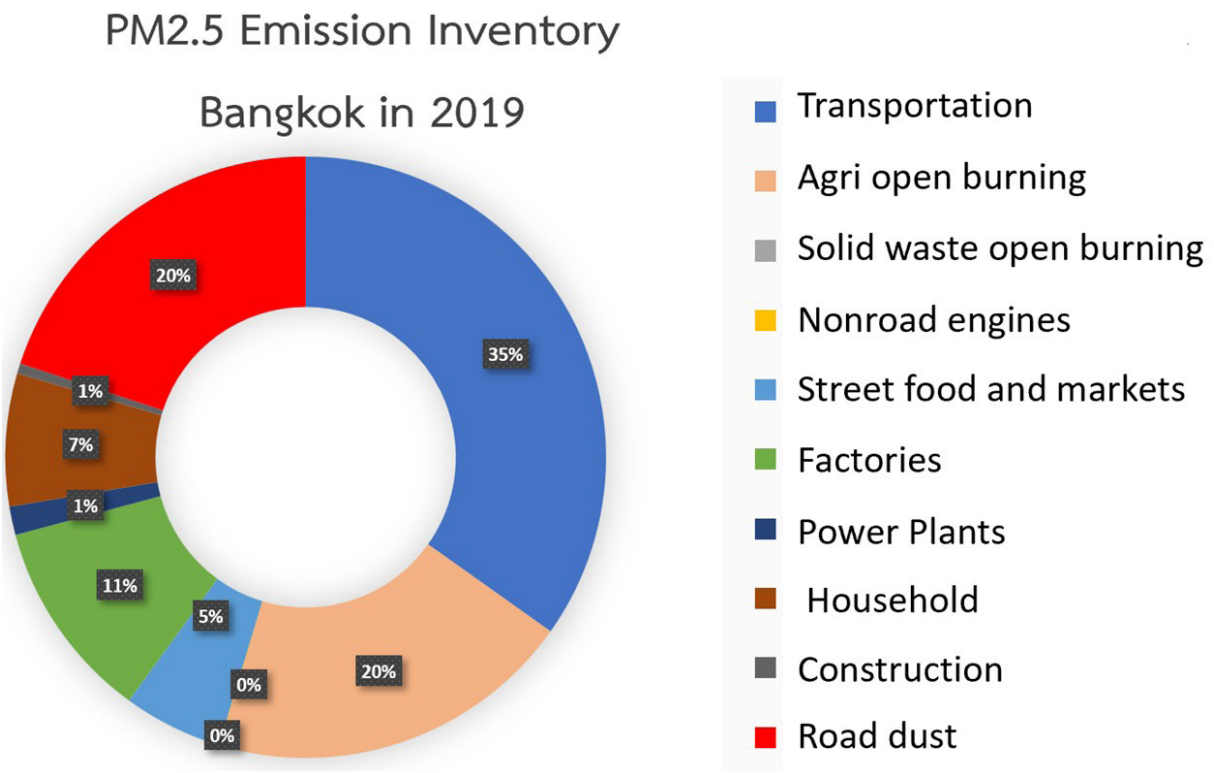

Figure 3: $PM_{2.5}$ Emission Inventory in Bangkok for the base year of 2019 *(Winijkut et al., 2023)*

Therefore, BMA has established and implemented an "Ad Hoc Plan on Solving Dust Pollution Problem in Bangkok 2023" to control the source of pollution by appointing a committee to direct the prevention and control of fine particulate matter problems in Bangkok, with the Governor of Bangkok as the Chairman (International Affairs Office, 2022). This BMA's ad-hoc action plan categorizes procedures according to air quality from levels 1-4 as follows: Level 1 ($PM_{2.5}$ below 37.5 µg/m^3), Level 2 ($PM_{2.5}$ between 37.6 - 50 µg/m^3), Level 3 ($PM_{2.5}$ between 51-75 µg/m^3), and Level 4 ($PM_{2.5}$ exceeds 75 µg/m^3). However, this action plan has no policy on emission control for the residential sector (BMA, 2022).

Moreover, in 2022, the newly instated Governor of Bangkok identified air pollution control as one of the work priorities to make Bangkok a welcoming and livable city for everyone. Hence, some of the schemes and policies introduced after he took office were aligned with the "Ad Hoc Plan on Solving Dust Pollution Problem in Bangkok 2023". For example, increasing air pollution monitoring, warning and prevention of $PM_{2.5}$, black smoke inspection, and reducing personal vehicle use in the Low Emission Zone (BMA, 2022; IQAir, 2022; Bangkok Open Policy, 2023)

3. RECAP ON THE POSSIBLE TECHNOLOGIES TO REDUCE AIR POLLUTION IN BANGKOK

There are existing technologies and management practices for air pollution control that can be adopted to help improve air quality in Bangkok, especially fine particulate matter. These technologies can be categorized into four main groups based on emission sectors as follows:

Transportation Sector:

1. Electric Vehicles (EVs) can completely reduce $PM_{2.5}$ and greenhouse gas (GHG) emissions because of their non-reliance on fossil fuel combustion.
2. Remote Sensing devices, which are monitoring devices that help screen high-emission vehicles on the road.
3. Low Emission Zone (LEZ) is a management practice from European countries and should be used in combination with other supplementary measures, such as 'Work from Home,' to reduce the use of private vehicles during high levels of $PM_{2.5}$.
4. Diesel Particulate Filter (DPF) is a device that reduces emissions from diesel engines by capturing soot particles and other pollutants before releasing exhaust gases through the tailpipe.
5. DPF can be retrofitted with in-use vehicles with an efficiency of more than 90% PM emissions reduction.

Waste Management Sector (open burning):

1. Burn check application can be used to manage agricultural waste.
2. The application does not directly reduce pollution, but it can help manage agricultural waste to avoid burning during high $PM_{2.5}$ concentration periods. Thus, additional in-situ and ex-situ waste management can be used to help manage the waste in the area.
3. Satellite detection can be used to inspect the open burning of agricultural wastes in collaboration with remote sensing technology that provides information to the public.

Industrial Sector:

1. Continuous Emission Monitoring System (CEMS) is a real-time online monitoring technology that helps control emissions emitted from the industrial sector. CEMS is the total equipment necessary for the determination of a gas or particulate matter concentration or emission rate using pollutant analyzer measurements and a conversion equation, graph, or computer program to produce results in units of the applicable emission limitation or standard. This technology can help the factory to detect and thus undertake mitigation, in case the pollution load exceeds the prescribed emission standards.
2. Baghouse, ESP, and other conventional emission control technologies have been widely used to control emissions in Bangkok and other areas in Thailand.

Residential Sector:

1. Cleaner cooking (cleaner fuel and cleaner stove) is the technology that helps control $PM_{2.5}$ emitted from the residential sector. It is evident that if people change to use modern stoves in households, it can reduce fuel use by 30%-60%. Moreover, clean stoves and clean fuels can reduce black carbon emissions by 50%-90% with significantly improved indoor air quality.

4. CONTRIBUTION OF EMISSION SOURCES OUTSIDE BANGKOK TO PM2.5 CONCENTRATION IN BANGKOK

The concentration of $PM_{2.5}$ in Bangkok is influenced by both local emission sources within the city and the long-range transport of pollutants. The amount of emissions entering Bangkok from outside its boundaries and thus contributing to its overall $PM_{2.5}$ concentration is crucial information. It helps in understanding the extent of air quality management needed in Bangkok to ensure that all local sources of $PM_{2.5}$ are reduced by the Bangkok Metropolitan Administration (BMA). For the remainder, the BMA can seek collaboration with other organizations, provinces, and even countries.

An air quality modeling study for Bangkok found that, during January, 16-32% of the $PM_{2.5}$ concentration was from sources within Bangkok. In contrast, during October, 17-57% of the $PM_{2.5}$ concentration in Bangkok was contributed from local sources. Thus, a large portion of the $PM_{2.5}$ concentration in Bangkok was transported by wind from other areas, both inside and outside Thailand. Consequently, managing only emission sources in Bangkok may not significantly reduce $PM_{2.5}$ concentration, especially during the January month. Information on the percent contribution of emission sources inside and outside Bangkok to $PM_{2.5}$ concentration in Bangkok is presented in Figure 4. (Winijkut et al., 2023).

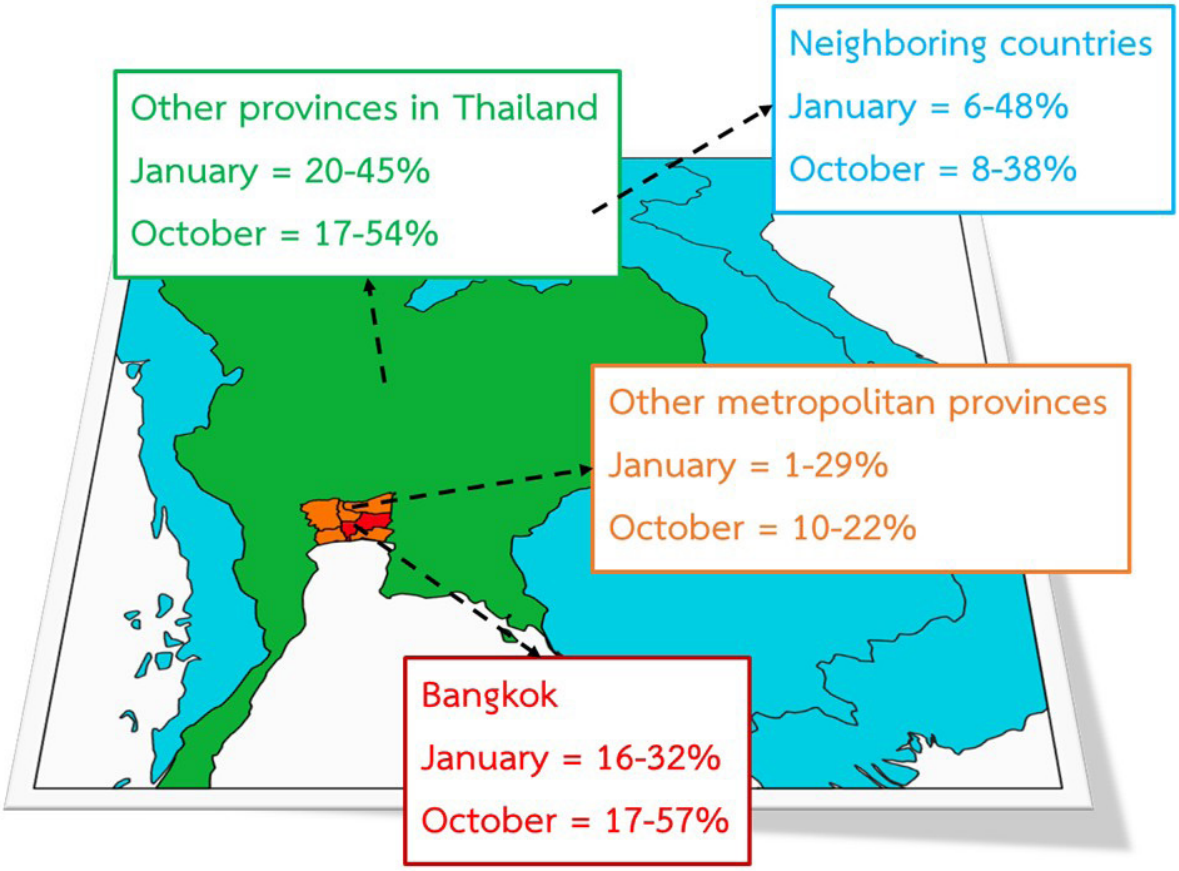

Figure 4: Percent contribution of emission sources inside and outside Bangkok to $PM_{2.5}$ concentration in Bangkok *(Winijkut et al., 2023)*

5. GAPS AND CHALLENGES OF CURRENT POLICIES/STRATEGIES FOR ADOPTING AIR POLLUTION CONTROL TECHNOLOGIES

This assessment is based on the Action plan to solve the $PM_{2.5}$ problem in Bangkok 2023 under the action plan to drive the National agenda 'problem-solving for dust pollution' (BMA, 2022), (BMA, 2022), announced in October 2022. However, on 1st June 2023, the Pollution Control Department of Thailand, with the approval of the National Pollution Control Board, revised the Thailand National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$ from 50 µg/m^3 to 37.5 µg/m^3 for a 24-hour average concentration and from 25 µg/m^3 to 15 µg/m^3 for an annual average concentration, following Interim Target 3 set by the World Health Organization (IT3-WHO). Thus, the level of $PM_{2.5}$ with the stage of the action plan may not be synced with the new NAAQS. The level of action in the action plan was separated into 4 stages as discussed in Section 2 of this report.

The evaluation of the policy implementation in this report utilized data from three main reports of the responsible agencies in Bangkok, i.e., Bangkok Open Policy (http://gov.bangkok.go.th/policy/web/index.php?r=site/budget) to provide information on financial status and the performance of each project (Bangkok Open Policy, 2023), the report of the Ad Hoc Plan on Solving Dust Pollution Problem in Bangkok 2023 to provide information on measures/schemes/activities to reduce $PM_{2.5}$ concentration according to the government action plan (BMA, 2022), and the report on the Implementation of the Bangkok Metropolitan Administration Operational Plan for the fiscal year 2021, providing information on the performance, obstacles, and recommendations of each project (Administrative Strategy Division, 2021).

As for the assessment of policy gaps and support needs for adopting technologies to control $PM_{2.5}$ emission in Bangkok, this part utilized data from different sources, including the review paper, "Regulating air quality in Thailand – a Review of policies" (Nikam J. et al., 2021), the report of implemented measures in Bangkok, and inquiries to the policymakers. The assessment is separated into 5 tables corresponding to the policy gap and needs for controlling $PM_{2.5}$ emissions from transportation (Table 1), open burning (Table 2), industry (Table 3), residential (Table 4), and monitoring (Table 5).

Table 1: Assessment of the policy gaps, challenges, and supports needed for adopting air pollution control technologies in the transportation sector

Technology Considered	$PM_{2.5}$ Level	Related measures, missions, and activities	Responsible agencies	Policy gaps	Challenges and supports needed for adopting air pollution control technologies
1.1 Electric vehicles	Level 1	- Supporting the use of electric vehicles (EVs) and buses in Bangkok by replacing diesel vehicles that have been in service for more than 20 years with EVs.	- Bangkok Mass Transit Authority (BMTA)	The tax on older vehicles is lower than on new vehicles, which promotes the usage of older, inefficient cars (Nikam J. et al., 2021)	Enforcing a policy on having a vehicular age limit; Providing economic incentives to encourage the purchase of newer and more efficient vehicles (Nikam J. et al., 2021), including electric vehicles (EVs).
	Long term	- Replacing government vehicles under the Bangkok Metropolitan Administration (BMA) that use diesel (e.g., garbage collectors, buses, and trucks) with electric vehicles. - Promoting the growth of electric vehicles in Bangkok by supporting charging station facilities and the EV manufacturing industry.	- Bangkok Metropolitan Administration (BMA), BMTA		
1.2 Remote Sensing for Vehicle Inspection	Level 1	- Inspecting black smoke at emission sources. - Using CCTV to identify vehicles emitting black smoke.	- BMA	The technology for CCTV to detect black smoke is unavailable, and black smoke inspection can only cover a small portion of the vehicle fleet population.	Technology transfer of remote sensing for vehicle inspection and data analysis is necessary since this capability is lacking in Thailand.

Table 1: *(Continued)*

Technology Considered	$PM_{2.5}$ Level	Related measures, missions, and activities	Responsible agencies	Policy gaps	Challenges and supports needed for adopting air pollution control technologies
1.3 Low Emission Zone	Level 3	- Reducing private car usage during rush hours in the Low Emission Zone. - Promoting remote work and urging public agencies to implement a 'Work from Home' policy, at 60%. - Implementing a discount promotion for sky train fare and parking fees at the MRT Parking Building to decrease private car usage in high traffic and polluted areas. - Requesting sky train service providers under BMA, and BRT buses/trains, to reduce fares to discourage private car usage in high-traffic and polluted areas. - Providing electric shuttle bus service on selected routes.	- Pollution Control Department (PCD), Mass Rapid Transit Authority of Thailand (MRT), BMA	Urban areas are inadequately planned to promote mass transit and active transport (Nikam J. et al., 2021).	Promoting mixed land use to reduce travel time, encouraging the use of less-polluting cars (e.g., electric cars), and advocating alternative forms of transportation (e.g., public transport, biking, and walking) (Nikam J. et al., 2021).

Table 1: *(Continued)*

Technology Considered	$PM_{2.5}$ Level	Related measures, missions, and activities	Responsible agencies	Policy gaps	Challenges and supports needed for adopting air pollution control technologies
1.3 Low Emission Zone	Level 4	- Reducing the number of private car usages during rush hours in the Low Emission Zone. - Promoting remote work and urging public agencies to implement a 'Work from Home' policy, at 100%. - Prohibiting parking along the main roads and secondary roads at all times to increase the smoother flow of traffic. - Limiting the time for large trucks to enter Bangkok, with exemptions for logistic, businesses, or electric vehicles (EVs). - Asking construction sites and logistic businesses to avoid using regular routes of trucks or highly polluted areas in Bangkok.	- PCD, BMA, Metropolitan Police Headquarters, Royal Thai Police, BMA	- It is a short-term policy (used on days with high $PM_{2.5}$). Thus, the approach is different from Europe. - Insufficient detail in the approach (e.g., fee, engine standard). - Lack of plans or alternative routes for heavy-duty vehicles. - People are not adequately informed in advance. - The previous pilot project in the Prathumwan area was unsuccessful due to a lack of regulations and insufficient enforcement. - The public transportation system does not sufficiently cover the Bangkok area.	- Regulations and enforcement are needed to establish a Low Emission Zone (LEZ) with clear details of vehicle information to be allowed in the area. Moreover, public transport needs to be available with adequate coverage.

Table 1: *(Continued)*

Technology Considered	$PM_{2.5}$ Level	Related measures, missions, and activities	Responsible agencies	Policy gaps	Challenges and supports needed for adopting air pollution control technologies
1.4 Diesel Particulate Filter for in-used vehicles	Long term	- Black smoke inspection at sources. - Enforcing emission standards for new cars to Euro V/VI. - Reducing sulfur contents in fuel to below 10 ppm, from 1 January 2024. - Encourage gas stations to sell Euro V diesel oil, from 1 January 2024.	- BMA, BMTA, Thai Industrial Standards Institute (TISI), Department of Energy Business	- Not applicable to vehicles older than Euro II. - High cost of Diesel Particulate Filter (DPF). - The process of implementing Euro V/VI standards is progressing slowly. For example, Euro V was originally scheduled for 2020 but has now been pushed back to 2024 (Nikam J. et al., 2021). (Table 6 and Table 7)	- Supporting the production of low sulfur fuel and NOx reduction technologies for the Euro VI standard in Thailand. - Providing financial and other incentives for Diesel Particulate Filter (DPF) installation. - Conducting a study on the possibility of using partial flow filters on in-used pre-Euro – Euro I vehicles.

Table 2: Assessment of the policy gaps, challenges, and supports needed for adopting air pollution control technologies in the agricultural sector

Technology Considered	$PM_{2.5}$ Level	Related measures, missions, and activities	Responsible agencies	Policy gaps	Challenges and supports needed for adopting air pollution control technologies
2.1 Burn check application for the management of agricultural wastes	Level 1	- Open burning control in agricultural areas in the Lat Krabang, Nong Chok, and Khlong Sam Wa districts. - Encouraging farmers not to burn rice stubbles and agricultural wastes by assisting them in removing rice straws from rice fields for free. - Ensuring 100% compliance with no burning in the Lat Krabang, Nong Chok, and Khlong Sam Wa districts.	BMA, Provincial Agriculture Metropolitan Provinces	- Lack of public awareness regarding the health impact of haze and open burning (Nikam J. et al., 2021). - The majority of farmlands are leased, leading to a lack of both incentives for investment in alternative farming practices and protection of farmers' rights on financial returns. This results in a lack of will and capacity to invest in alternative waste management practices (Nikam J. et al., 2021). - Burning is the quickest way to get rid of waste on the field since there is no support for agricultural waste management (e.g., using it for biofuel production) in Bangkok. - The pilot project has been implemented in the northern region of Thailand, and expanding to Bangkok is not currently available.	- Increase awareness and technical capacity of the locals (Nikam J. et al., 2021). - Introduce the application to the community and provide guidelines and rules for controlling open burning (Nikam J. et al., 2021). - Farming is dominated by the older generation; an increase in farmers' incomes would encourage the younger generation, who may have more innovative residue management practices, to be involved (Nikam J. et al., 2021).
	Level 2	- Strictly controlling open burning in Bangkok and its vicinity through enhanced enforcement of laws against offenders.	BMA		
	Level 3	- Supervising, controlling, and enforcing announcements and laws related to banning open burning of agricultural wastes, weeds, grass, and solid wastes.	Provincial government		
	Long term	- Achieving 100% no open burning in Bangkok within the next 3 years.	BMA		

Table 2: *(Continued)*

Technology Considered	$PM_{2.5}$ Level	Related measures, missions, and activities	Responsible agencies	Policy gaps	Challenges and supports needed for adopting air pollution control technologies
2.2 Satellite detection for agricultural open burning control	Level 2	- Monitoring hot spots in Bangkok and its vicinity on the GISTDA website. In case there are hot spots in Bangkok, the BMA Fire and Rescue Department should be called to take action at the scene. - Reporting hot spots caused by open burning and coordinating with the local government in the areas.	BMA	- Lacking a framework that enables multi-sectoral collaboration (Nikam J. et al., 2021) and a central database for air quality management. There are still some gaps in managing fires after detection. - Most fires happen outside Bangkok, but the cooperation among different provinces and organizations is not clear.	- Developing a database for $PM_{2.5}$ management that includes online data from different organizations, such as monitoring data from PCD and BMA, hotspots from GISTDA, and the name and contact number of the community by BMA and metropolitan provinces.

Table 3: Assessment of the policy gaps, challenges, and supports needed for adopting air pollution control technologies in the industrial sector

Technology Considered	$PM_{2.5}$ Level	Related measures, missions, and activities	Responsible agencies	Policy gaps	Challenges and supports needed for adopting air pollution control technologies
3.1 CEMS for industrial air pollution control	Level 1	- Planning for annual audits and on-site inspections of the factories in Bangkok, leading to an order to close the factory according to the Factory Act of 1992 if emissions do not comply with the standard. - Controlling all business sites that emit $PM_{2.5}$ exceeding the standard, including Cement mixing business sites, Forging business sites, Car painting business sites, Incense manufacturing business sites, and Stone fabrication business sites.	Department of Industries Works (DIW), BMA	- The measure is insufficient to inspect and control factories that are not under the Department of Industrial Works (small factories or community businesses). - Shortage of industrial emissions data collection or measurement due to a lack of adequate air quality planning (Nikam J. et al., 2021). - Lacking public participation in the inspection and monitoring of industrial air emissions due to a lack of awareness and available data (Nikam J. et al., 2021).	- Regularly updating and publishing information on air quality conditions on an open-sourced website, through a Pollutant Release and Transfer Register (PRTR) process; collect data from stakeholders, rather than local leaders, for more accurate and community-centric information (Nikam J. et al., 2021). - Enabling public access to information about emissions through a PRTR process (Nikam J. et al., 2021). - Working with the community to control emissions from small industries (possible to use some simple technologies for monitoring emissions, e.g., Ringelmann Smoke Chart).
	Level 2	- Supervising and monitoring industrial plants in Bangkok, especially 260 industrial plants with fuel combustion and high $PM_{2.5}$ emissions, leading to an order to close the factory according to the Factory Act of 1992 if emissions do not comply with the prescribed standards.	DIW		
	Level 4	- Cooperating with industrial factories to plan production and strictly control air pollution emissions caused by their operations. - Urging forging business sites or businesses that use steam boilers with fuels such as diesel, biomass, or coal in the areas to achieve a 100% reduction in fuel burning during their production.	- DIW, BMA		
	Long term	- Enhancing air pollution emission standards for industrial factories to meet international standards.	- DIW		

Table 4: Assessment of the policy gaps, challenges, and supports needed for adopting air pollution control technologies in the residential sector

Technology Considered	$PM_{2.5}$ Level	Related measures, missions, and activities	Responsible agencies	Policy gaps	Challenges and supports needed for adopting air pollution control technologies
4.1 Cleaner cooking and street food	NA	NA	NA	- Lack of control measures (cleaner stoves and fuels) for the residential sector and street food.	- Street food is highly linked with local practices and the income of the local people, making it difficult to regulate by policy.

Noted: NA represents Not available

Table 5: Assessment of the policy gaps, challenges, and supports needed for adopting air pollution control technologies to monitor $PM_{2.5}$ concentration

Technology Considered	$PM_{2.5}$ Level	Related measures, missions, and activities	Responsible agencies	Policy gaps	Challenges and supports needed for adopting air pollution control technologies
5.1 Low-cost Sensor	Level 1	- Expanding monitoring systems for $PM_{2.5}$ and warnings at the district level from 557 points to 1,000 points. - Discussing with private agencies the possibility of installing multiple air quality monitors and sensor systems to expand coverage to 1,000 monitoring points.	BMA, PCD	- Insufficient air quality monitoring (Nikam J. et al., 2021). - Official monitoring stations are costly. - Sensor quality varies widely. This may lead to panic in the community.	- Creating a website and reporting format to avoid confusion between measurement values obtained from low-cost sensors and official monitoring stations. - Providing guidelines for quality control and usage of low-cost sensors. - Implementing policies for the production of low-cost sensors. - Mandating the calibration of low-cost sensors.
	Level 2	- Monitoring, reporting air quality data, forecasting, and notifying $PM_{2.5}$ situations for seven days in advance, in formats that are easy to understand online.	BMA		
5.2 WRF-Chem model	Long term	- Developing an air pollution forecasting system. - Studying an air quality model for $PM_{2.5}$ dispersion.	Thai Meteorological Department	The Meteorological Department is responsible for this task. However, PCD will use meteorological data from TMD to run the WRF-Chem model, and PCD also has the responsibility to provide $PM_{2.5}$ forecasting data to the public.	- More meteorological monitoring stations (surface and upper air) are required for WRF model validation. - The emission inventory for Bangkok needs to be updated frequently for the accuracy of the air quality model.

Noted: NA represents Not available

6. SUMMARY OF GAPS IN CURRENT POLICIES FOR ADOPTING AIR POLLUTION CONTROL TECHNOLOGIES

The primary problem in policy regulation in Bangkok is that the BMA has little authority to implement any regulations in Bangkok. For example, roadside inspection for black smoke cars can be done by Thai police, and the control of emissions from large-scale industries is under the Department of Industrial Works.

1. $PM_{2.5}$ from Transportation Sector

Policy gaps in the transportation sector include slow progress in cleaner (Euro 5 and 6) and electric vehicles, no clear regulation to remove old vehicles from roads, and no clear regulation on the Low Emission Zone.

i. ***Slow progress in cleaner and electric vehicles***: The current plan for Euro 5 vehicle standard implementation was pushed back from 2020 to 2024 (updated in 2023) making it has no movement in emission standards in Thailand since 2013. Moreover, there is no incentive to use electric vehicles.

ii. ***No clear regulation to remove old vehicles from roads***: Tax on older vehicles is lower than on new vehicles, which promotes the usage of older, higher emission cars. Moreover, roadside inspection for black smoke cars is done manually which leads to inefficient use of resources (staff and budget), and black smoke inspection can only cover a small vehicle population in the fleet.

iii. ***No clear regulation on Low Emission Zone***: Current LEZ is a short-term policy (use on days with high $PM_{2.5}$). Thus, the approach is different from the successful LEZ in other countries. Moreover, there is no detail of the approach (ex. fee collection, engine standard) which is available to the public. There is no plan or alternative routes for heavy-duty vehicles if they are not allowed to be in the city. A previous pilot project in the Prathumwan area was based on voluntary which is less successful due to lack of regulations and insufficient enforcement. The current public transportation system does not sufficiently cover the Bangkok area.

2. $PM_{2.5}$ from the Agricultural Sector

The majority of the farmlands are leased, leading to a lack of incentives for investment in alternative farming practices and protection of farmers' rights on financial returns. This leads to a lack of will and capacity to invest in alternative waste management practices Thus, burning is the quickest way to get rid of wastes on the field. The major policy gap to prevent farmers not to burning is no support for agricultural waste management (ex. using agricultural wastes as biofuel, and other products) in Bangkok.

For inspection of the open burning, no framework enables multi-sectoral collaboration and a central database for air quality management. There are still some gaps in managing fire after detection. Moreover, most fires happen outside Bangkok, but the cooperation among different provinces and organizations is not identified in the current policy.

3. $PM_{2.5}$ from the Industrial Sector

There is an insufficient measure to inspect and control the factories that are not regulated under the Department of Industrial Works (small factory or community business). Moreover, there is a shortage of industrial emissions data collection or measurement due to a lack of adequate air quality planning and a lack of public participation in the inspection and monitoring of industrial air emissions due to a lack of awareness. Thus, emissions from these types of factories cannot be estimated and controlled.

4. $PM_{2.5}$ from Other Sector and Air Quality Monitoring

There is control of pollution from the residential sector and street food which is difficult to manage due to a direct relation between privacy (household cooking) and people's income (using solid fuel for street food).

For low-cost sensors, there is no regulation or standard to control the quality of the low-cost sensor which may lead to the panicking of the community.

7. RECOMMENDATIONS FOR BMA TO STRENGTHEN POLICIES FOR ADOPTING AIR POLLUTION CONTROL TECHNOLOGIES

As discussed earlier, the primary problem in policy implementation in Bangkok is that BMA has little authority in the implementation of any regulations. Thus, the main responsibility ministry for the corresponding issues in Bangkok is also provided in brackets for each recommendation provided in this section.

1. $PM_{2.5}$ from Transportation Sector

i. *Slow progress in cleaner and electric vehicles (Ministry of Environment)*:

- Providing economic incentive measures to promote buying newer, more efficient cars, including EV cars.

ii. *No clear regulation to remove old vehicles from roads (Ministry of Transport)*:

- Enforcing policy on vehicular age limit which may include higher tax on older vehicles and emission fees that increase with the age of the vehicles.
- Using automatic roadside inspection to detect black smoke cars that cover major roads that connect Bangkok with other provinces.
- Using partial flow filters for diesel vehicles where technologies are older than Euro 2. For Euro 2 and Euro 3, a Diesel Particulate Filter can be used. However, there should be incentives for vehicle owners to install these devices.

iii. *No clear regulation on Low Emission Zone (Ministry of Transport)*:

- Developing regulations and enforcement to set LEZ with clear details of the vehicle information to be allowed in the area, traffic management in this area and another area in Bangkok, and fee structure. Moreover, public transport (including last-mile feeders) needs to be available and covered.
- Setting up an alliance for clean air with private companies and government agencies in Bangkok to be ready for work-from-home when needed.

2. $PM_{2.5}$ from the Agricultural Sector

i. *(Bangkok Metropolitan Administration)* Increasing awareness and technical capacity of local BMA staff and communities. BMA should introduce tools, such as burn checks, to the community and provide guidelines and rules for controlling open burning. Innovative residue management practices should be studied and set up (processes to transport wastes from farms to power plants and other factories).

ii. *(Bangkok Metropolitan Administration)* Developing a database for $PM_{2.5}$ management which include online data from different organization, such as monitoring data from PCD and BMA, hotspots from GISTDA, and name and contact number of the community by BMA and metropolitan provinces. This will allow smooth management of fire after detection.

iii. *(Ministry of Environment)* Preparing collaboration with other provinces to manage agricultural wastes in the whole region to mitigate open burning of the whole of Thailand.

3. $PM_{2.5}$ from the Industrial Sector

i. *(Ministry of Industry)* Regularly updating and publishing information on air quality conditions on a website, through a Pollutant Release and Transfer Register (PRTR) process by collecting data from stakeholders, rather than local leaders, for more accurate and community-centric information. Moreover, the process to enable public access to information about emissions through a PRTR process is needed.

ii. *(Bangkok Metropolitan Administration)* Working with the community to control emissions from small industries (possible to use some simple technologies for monitoring emissions, ex. Ringelmann Smoke Chart) is needed.

4. Air Quality Monitoring

i. *(Ministry of Environment)* Creating a website and reporting format to avoid confusion between measurement values obtained from low-cost sensors and official monitoring stations. Moreover, guidelines, including mandatory calibration of the sensors, for quality control and usage of low-cost sensors should be developed.

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ANNEX

Table 6: Implementation Plan for the Air Pollutant Emission Standards from Euro 5 and Euro 6 Vehicles *(TISI, 2023)*

Vehicle types		2023	2024	2025	2026
Benzene	Light-duty vehicle	Euro 4		Euro 6 (1 January 2025)	
	Heavy-duty vehicle	Euro 3	Euro 5 (1 January 2024)		Euro 6 (1 January 2026)
Diesel	Light-duty vehicle	Euro 4	Euro 5 (1 January 2024)		Euro 6 (1 January 2026)
	Heavy-duty vehicle	Euro 3	Euro 5 (1 January 2024)		Euro 6 (1 January 2026)

Table 7: The standard of EURO 1 to Euro 6 for each type of vehicle *(PCD, 2020)*.

Diesel		Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
Sulfur ppm		2000	500	350	50	10	10
Passenger cars		0.14 (0.18)	0.08	0.05	0.025	0.005	0.005
Light Commercial vehicle	≤ 1305 kg	0.14	0.08	0.05	0.025	0.005	0.005
	1305-1760 kg	0.19	0.12	0.07	0.04	0.005	0.005
	> 1760 kg	0.25	0.17	0.1	0.06	0.005	0.005
HD Diesel Engines	g/kWh	0.36 0.612	0.15 0.25	0.1	0.02	0.02	0.01