Comparative Analysis of Air Pollution Control Technologies and Policies in Three Asian Cities - Bangkok, Dhaka and Gurugram

ESCAP
APCTT
Asian and Pacific Centre for Transfer of Technology

*The shaded areas of the map indicate ESCAP members and associate members.**

The Economic and Social Commission for Asia and the Pacific (ESCAP) is the most inclusive intergovernmental platform in the Asia-Pacific region. The Commission promotes cooperation among its 53 member States and 9 associate members in pursuit of solutions to sustainable development challenges. ESCAP is one of the five regional commissions of the United Nations.

The ESCAP secretariat supports inclusive, resilient and sustainable development in the region by generating action-oriented knowledge, and by providing technical assistance and capacity-building services in support of national development objectives, regional agreements and the implementation of the 2030 Agenda for Sustainable Development.

**The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries*

Comparative Analysis of Air Pollution Control Technologies and Policies in Three Asian Cities - Bangkok, Dhaka, and Gurugram

ESCAP
APCTT
Asian and Pacific Centre
for Transfer of Technology

The views expressed in this document are those of the authors and do not necessarily reflect the views of the Asian and Pacific Centre for Transfer of Technology (APCTT) of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). The designations employed and the presentation of the materials in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This publication follows the United Nations' practice in reference to countries. Where there are space constraints, some country names have been abbreviated. Mention of a commercial company or product in this publication does not imply endorsement by ESCAP-APCTT.

This publication is issued in English only.

Links contained in this publication are provided for the convenience of the reader and are correct at the time of issue. The United Nations takes no responsibility for the continued accuracy of that information or for the content of any external website.

United Nations publication

Printed in New Delhi
ESCAP/2-PB/47

This publication should be cited as: *United Nations, Asian and Pacific Centre for Transfer of Technology, United Nations Economic and Social Commission for Asia and the Pacific (2024). Comparative Analysis of Air Pollution Control Technologies and Policies in Three Asian Cities - Bangkok, Dhaka and Gurugram.*

This document has been issued without formal editing.

FOREWORD

It is with great pleasure that I introduce this document: *Comparative Analysis of Air Pollution Control Technologies and Policies in Three Asian Cities - Bangkok, Dhaka and Gurugram*.

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 technology cooperation and transfer across Asia Pacific. APCTT's mandate is to strengthen capabilities and facilitate development, adoption and diffusion of new and emerging in the region.

This document has been prepared 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 strengthen policies and city level action plans to facilitate adoption of innovative technologies for controlling air pollution in Asia-Pacific. 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).

The three Asian cities under study - Dhaka in Bangladesh, Gurugram in India, and Bangkok in Thailand - represent distinct urban landscapes facing common challenges associated with air pollution. Through a meticulous comparative analysis, this document delves into the technological and policy interventions implemented in each city, offering a nuanced understanding of their respective approaches.

As we confront the intricate interplay between urbanisation and environmental sustainability, this comparative analysis aims to guide future strategies and interventions. We hope this document stimulates further academic inquiry, policy discourse, and informed actions, ultimately contributing to the advancement of air quality management strategies across diverse urban landscapes in Asia Pacific.

Preeti Soni
Head
Asian and Pacific Centre for Transfer of Technology
Economic and Social Commission for Asia and the Pacific

ACKNOWLEDGEMENTS

This document: *Comparative Analysis of Air Pollution Control Technologies and Policies in Three Asian Cities - Bangkok, Dhaka and Gurugram* is part of a set of reports developed under the project "Enhanced Capabilities to Adopt Innovative Technologies for City Air Pollution Control in Select Countries of the Asia-Pacific" funded by the Korea ESCAP Cooperation Fund. It has been prepared under the overall guidance and direction of Dr. Preeti Soni, Head, Asian and Pacific Centre for Transfer of Technology (APCTT) of the Economic and Social Commission for Asia and the Pacific (ESCAP).

This publication was prepared by Mr. Digvijay Bisht under a consultancy assignment with ESCAP-APCTT. The report builds on the city assessments done in Bangkok, Dhaka, and Gurugram. The report benefited from comments and suggestions from Mr. Satyabrata Sahu, Mr. Soumya Bhattacharya and Mr. Pankaj Kumar Shrivastav from the ESCAP-APCTT.

We gratefully acknowledge all of the above.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ACRONYMS

APCTT	Asian and Pacific Centre for Transfer of Technology
AQI	Air Quality Index
AQLI	Air Quality Life Index
AQM	Air Quality Management
ASG	Anti-Smog Gun
BAQP	Bangkok Air Quality Plan
BMA	Bangkok Metropolitan Administration
BCSIR	Bangladesh Council of Scientific and Industrial Research
BDS	Bangladesh Standards
BPC	Bangladesh Petroleum Corporation
BRTA	Bangladesh Road Transport Authority
BUET	Bangladesh University of Engineering and Technology
CAAQMS	Continuous Automatic Ambient Air Quality Monitoring Station
CAMS	Continuous Air Monitoring Stations
CAQM	Commission of Air Quality Management for NCR
CAP/CAAP	City Action Plan/ City Air Action plan
CASE	Clean Air and Sustainable Environment
CEMS	Continuous Emission Monitoring System
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CPCB	Central Pollution Control Board
DEP	District Environmental Plan
DESA	Dhaka Electric Supply Authority
DESCO	Dhaka Electric Supply Company Limited
DoE	Department of Environment
DMRCL	Dhaka Metro Rail Corporation Limited
DMTCL	Dhaka Mass Transit Company Limited
DPF	Diesel Particulate Filter
DTCA	Dhaka Transport Coordination Authority

EE	Energy Efficiency
EI	Emission Inventory
EPCA	Environment Protection and Control Authority
EV	Electric Vehicle
ERL	Eastern Refinery Limited
FCK	Fixed Chimney Kiln
GDP	Gross Domestic Product
GISTDA	Geo-informatics and Space Technology Development Agency
GMC	Gurugram Municipal Corporation
GMDA	Gurugram Municipal Development Authority
GRAP	Graded Response Action Plan
HSPCB	Haryana State Pollution Control Board
IDCOL	Infrastructure Development Company Limited
ICT	Information and Communications technology
LCS	Low-cost Sensors
LGD	Local Government Division
MOC	Ministry of Commerce
MOEFCC	Ministry of Environment and Forest and Climate Change, Govt. of Bangladesh
MoEFCC	Ministry of Environment and Forest and Climate Change, Govt. of India
MOI	Ministry of Industries
MOST	Ministry of Science and Technology
MSMEs	Micro, Small and Medium
NCAP	National Clean Air Program
NCR	National Capital Region Territory of Delhi
NGO	Non-Government Organization
NO_2	Nitrogen Dioxide
O_3	Ozone
Pb	Lead
PCD	Pollution Control Department
PM2.5	Particulate matter less than 2.5-micron size
PM10	Particulate matter less than 10-micron size

PRTR	Pollutant Release and Transfer Register
RAJUK	Rajdhani Unnayan Kartripakkha
RTHD	Road transport and Highway Division
SA	Source Apportionment
SO_2	Sulphur Dioxide
SPCB	State Pollution Control Board
SREDA	Sustainable and Renewable Energy Development Authority
TNAAQS	Thailand's National Ambient Air Quality Standards
TSPM	Total Suspended Particulate Matter
ULB	Urban Local Body
UN ESCAP	United Nations Economic and Social Commission for Asia and the Pacific (ESCAP)
VOCs	Volatile Organic Compounds
WASA	Water Supply Authority
WHO	World Health Organization
WRF-Chem Model	Weather Research and Forecasting /Chemistry Model

1 INTRODUCTION

1.1 Background information

Air pollution continues to be one of the most complex environmental challenges of contemporary times impacting human health, environment, and the economy. In terms of its global health impact, poor air quality accounts for 6 million deaths each year and 93 billion days lived with illness.[1] Exposure to air pollution is causing and aggravating several health conditions which include, but are not limited to, asthma, cancer, lung illnesses, heart disease, and premature mortality. In addition to the health impacts, air pollution has also resulted in economic damages amounting to over 8 trillion dollars, which is more than 6.1 % of the global annual gross domestic product (GDP).[2]

The major burden of air pollution is seen in the urban areas, especially in the developing nations. City dwellers, especially the poor, often suffer the most from air pollution, which along with imperilling lives, feeds climate change.[3] More than 80 % of people living in urban areas that monitor air pollution are exposed to air quality levels that exceed guidelines set by the World Health Organization (WHO), with populations in low-income cities being the most at risk for respiratory diseases and other long-term health problems.[4] Since many cities are not being monitored, it points to the fact that this burden is most likely to be much higher than the current estimates.

In Asia and the Pacific, air pollution is one of the key environmental crises, with 92 % of those living in the region (or 4 billion people) exposed to unhealthy levels of air pollution.[5] It is also impacting the environment, food, and agriculture, and is contributing to climate change, resulting in significant economic costs of between 0.29 % and 1.22 % of GDP in the East Asia and Pacific and South Asia subregions.[6] The Asia-Pacific region accounts for about 70 % of deaths globally due to air pollution and has recorded some of the highest air pollution levels in recent times.[7] As per the historical data of IQ Air, 49 of the 50 most polluted cities are in the Asian region, and of those 44 cities are in the South Asian region.[8]

In the past few decades, understanding the urgency that this situation brings, many Asian countries like Seoul (South Korea), New Delhi (India), Beijing (China), Mumbai (India), and Kolkata (India), have taken measures to mitigate air pollution, especially at the city level, where the potential for impact mitigation is higher. To achieve this, many policies, regulations, schemes, and plans were developed and implemented by each government in their respective countries. The measures being brought in through these policies/ regulations/ schemes/ plans of a specific government cover different aspects. Some of these aspects include the development of acts and standards for air pollution and emissions reduction; improvement in current regulatory compliance; sectoral approaches to emissions reduction with a focus on sectors such as residential, transportation, waste management, agriculture, industry, and commercial; enhancing air quality monitoring by setting up new monitoring networks or strengthening the existing

1 https://www.iqair.com/world-air-quality-report

2 2022 World Air Quality Report, IQ Air 2022

3 https://www.unep.org/news-and-stories/story/five-cities-tackling-air-pollution

4 https://www.un.org/sustainabledevelopment/blog/2016/05/un-health-agency-warns-of-rise-in-urban-air-pollution-with-poorest-cities-most-at-risk/

5 https://www.ccacoalition.org/content/air-pollution-measures-asia-and-pacific#:~:text=Air%20pollution%20in%20the%20Asia,significant%20risk%20to%20their%20health

6 Executive Summary, Air Pollution Series Actions on Air Quality in Asia and the Pacific (https://wedocs.unep.org/bitstream/handle/20.500.11822/36698/AAQAP_ES.pdf)

7 Asia-Pacific Tech Monitor, Vol. 39 No.2, April - June 2022

8 https://www.iqair.com/in-en/world-most-polluted-cities?continent=&country=&state=&sort=-rank&page=1&perPage=50&cities= (As viewed on 27th July 2023)

networks, using technological interventions for air pollution mitigation, e.g., through emission control, emission reduction, energy efficiency, and use of alternative fuel and renewable energy sources; focusing on developing sustainable infrastructure and urban habitat; and promoting awareness and knowledge among specific stakeholders as well as general public.

Of the above-listed aspects for air pollution mitigation, this report focuses on technolog y-based interventions being used in cities. This aspect is important owing to the rapid advancements in the development of new and more accurate technologies for mitigating air pollution. This field, which has emerged as an important area in recent years, has been providing viable new solutions, as well as suitable alternatives for replacing conventional technological approaches for air pollution mitigation through multiple intervention pathways, including source reduction of pollutants, enabling policy measures, regulations, and incentives.[9]

Technological intervention is an integral part of the current air action plans across Asia and the Pacific region. Understanding the importance of city-specific studies, Asian and Pacific Centre for Transfer of Technology (APCTT) supported assessment in Bangkok, Dhaka, and Gurugram based on four important indicators, which are innovative technological approaches adopted by these cities for air pollution control, current gaps and requirements for air pollution control, alignment of the city action plan with the national action plan, and strengths and challenges of the current strategies for adopting air pollution control. These studies are part of the project titled '*Enhanced capabilities to adopt innovative technologies for city air pollution control in select countries of the Asia Pacific.*'

The development of such important city -specific studies which are highlighting technological interventions for air pollution mitigation provides an opportunity for documenting and assessing each of these technologies for enhanced understanding of the efficiency and efficacy of each technological intervention being used.

Keeping the above in mind, this document compares the assessment in Bangkok, Dhaka, and Gurugram. This comparative study would support in improving the availability of technical knowledge regarding air pollution mitigation technologies, innovations, and good practices from different cities across Asia and Pacific; and to better understand the technological needs and gaps for air pollution control in the three cities. This study is the first of its kind, and therefore will also provide a framework to undertake similar analysis in the future.

9 Asia-Pacific Tech Monitor, Vol. 39 No.2, April - June 2022

1.2 Brief profile of all three cities – Bangkok, Dhaka, and Gurugram

1.2.1 Status of air pollution in the three cities

Table 1 – Status of Air Pollution in Bangkok, Bangladesh, and Gurugram

City	Main pollutants of concern	24-hr avg. conc. of the pollutant (s) of concern (In µg/ m^3)	Nat. avg. conc. of the pollutant (s) of concern (In µg/ m^3)	Annual avg. conc. of the pollutant (s) of concern (In µg/ m^3)	Have the official Ambient Air Quality Standards been prescribed? If yes, when was the latest revision done?	Source of pollutants	Is the human exposure reaching harmful levels?	Consideration of the transboundary component	Does the city experience episodes of high pollution levels?	Does the existing level of pollutants meet the national ambient air quality standard?
Bangkok	PM_{10}/ $PM_{2.5}$	29 – 414	22	10 –40	Yes; 2023	Sources in Bangkok[1] 1. Vehicular 2. Residential 3. Industry 4. Waste 5. Agriculture 6. Construction 7. Transboundary pollution	Yes	Yes	Yes	Yes : PM_{10} No: $PM_{2.5}$
Dhaka	PM_{10}/ $PM_{2.5}$	--	--	96.71 –156.40		Sources in Dhaka 1. Vehicular 2. Residential 3. Brick kilns 4. Industry 5. Waste 6. Agriculture 7. Construction 8. Transboundary pollution 9. Road dust/ Sea Salt	Yes	Yes	Yes	No : PM_{10} No: $PM_{2.5}$

1 Regulating air quality in Thailand – a review of policies, Jaee Nikam, Diane Archer and Chirat Nopsert, Stockholm Environment Institute (2021)

City	Main pollutants of concern	24-hr avg. conc. of the pollutant (s) of concern (In µg/ m^3)	Nat. avg. conc. of the pollutant (s) of concern (In µg/ m^3)	Annual avg. conc. of the pollutant (s) of concern (In µg/ m^3)	Have the official Ambient Air Quality Standards been prescribed? If yes, when was the latest revision done?	Source of pollutants	Is the human exposure reaching harmful levels?	Consideration of the transboundary component	Does the city experience episodes of high pollution levels?	Does the existing level of pollutants meet the national ambient air quality standard?
Gurugram	PM_{10}/ $PM_{2.5}$	--	--	163.67 –101.2[2]	Yes; 2009	Sources in Gurugram[3] 1. Vehicular 2. Residential 3. Road dust 4. Construction 5. Industry 6. Biomass 7. Waste 8. Others 9. Agriculture 10. Brick Kilns 11. Transboundary pollution	Yes	Yes	Yes	Yes : PM_{10} No: $PM_{2.5}$

2 CPCB Dataset (2017 –2021)

3 Source Apportionment of $PM_{2.5}$ & PM_{10} of Delhi NCR for Identification of Major Sources

Based on the three-city assessment reports, it is evident that particulate matter (PM) mainly PM_{10} and $PM_{2.5}$ are the main pollutants of concern across all three cities. Although the annual averages in the case of all three cities differ from each other (with Gurugram being the highest and Bangkok being the lowest), in all three cases the annual averages are exceeding the stated national standards, with Bangkok being the only exception in case of PM_{10}. It is also interesting to note that the sectors contributing to air pollution in all three cities, also have some major overlaps. Air pollution across all three cities also impacts human health in a significant manner, especially during the months or time periods of high air pollution episodes across all three cities.

1.2.2 Important aspects of city -specific studies on air pollution

City-specific air quality management (AQM) studies are crucial for addressing and mitigating air pollution in urban areas of different types and/or categories. Since AQM studies focus on understanding the unique characteristics of each city's air quality and tailoring strategies and approaches to improve the same, they are a handy tool for the policy and decision-makers. For undertaking a particular city-specific study, following important aspects needs to be taken into consideration.

1. **Understanding the type of city and its requirements:** Megacities usually grapple with air pollution challenges arising from high population density, severe traffic congestion, and industrial emissions, whereas smaller cities face distinct issues such as residential heating practices or specific industrial pollutants. The unique attributes of a city determine the sources and dynamics of air pollution within it. Consequently, studies conducted on a city-specific basis should prioritize the identification of local pollution sources, comprehension of prevalent meteorological conditions, and consideration of socio economic factors that influence pollution patterns. Moreover, the level of technological advancement, existing infrastructure, and regulatory frameworks significantly shape strategies for managing air quality within that city's jurisdiction. City-specific studies should not only evaluate current pollution levels but also project future trends in urbani sation and economic growth. By tailoring air quality management to the specific requirements of each city, the effectiveness of interventions can be enhanced, and sustainable and context-specific solutions can be promoted.
2. **Source Identification and Inventorization:** These aspects of the study sheds light on all major sources of air pollutants in the city like industrial activities, vehicular emissions, construction, residential, waste burning, transboundary impacts, etc., and whether they are categorically identified and quantified. It would also highlight, whether an emission inventory (EI) has been prepared for the city that lists all the recognised emissions sources within the city's jurisdiction. The EI helps in the understanding the local emission sources as well as transboundary influences on the local air quality to design targeted interventions.
3. **Continuous Air Quality Monitoring :** Air quality monitoring is vital to continuously measure pollution levels in a city and setting up an extensive network of a stations is a prerequisite for that. These stations provide real-time data on pollutants, especially $PM_{2.5}$ and PM_{10}. The data help in assessing air quality trends, identifying hotspots, and determining the effectiveness of the control measures that are in place.
4. **Meteorology and Its Impact:** Often important factors with a significant impact on the local air quality are the meteorological factors like wind patterns, temperature inversions, and precipitation patterns. These factors are crucial as they influence the dispersion of pollutants and accumulation, and a careful analysis of the same would help in planning pollution control strategies effectively.
5. **Source Apportionment Studies :** Source apportionment (SA) studies use advanced techniques to attribute specific pollutants to their sources and to assess the approximate magnitude of their contribution to the pollution load in the city. This knowledge aids policymakers in designing targeted air pollution control measures to mitigate pollution from different sources.

6. **Health Impact Assessments :** Understanding the health impacts of air pollution on the city's population is essential due to air pollution's chronic and acute impact on human health. Such studies estimate the number of premature deaths, hospital admissions, and other health issues that can be attributed to poor air quality. This information creates awareness and strengthens the case for urgent and targeted action.
7. **Mobility Management :** The city's transportation system is an essential for the economic sustenance and development of the city. Mobility studies evaluate the impact of vehicular emissions from different grades of vehicles using different quality of fuels on air quality and suggest measures (e.g., promoting public transportation, encouraging electric vehicles, retrofitting old vehicles, transitioning to newer vehicle technology, and implementing congestion pricing).
8. **Industrial Emissions and Regulations :** Industrial emissions contribute significantly to the city's emissions, and therefore their identification and regulation plays an important role in improving the city's air quality. As an important aspect of a city-based study, industrial studies would highlight the status of compliance of industries on notified emission standards and recommend measures to reduce pollution.
9. **Urban Planning :** City-specific air quality management studies often propose changes in urban planning to reduce pollution exposure, especially targeting the emissions from the residential and the waste management sectors. This may involve improving building design, increasing green spaces, optimis ing land-use patterns, and promoting mixed-use developments to minimi se the distance between residential areas and sources of pollution.
10. **Other S ectoral Contribution :** Just as in the case of the major sectoral emissions impacting the air quality within the city, there are more specific sources including the Micro, Small, and Medium (MSMEs), local businesses, road dust, construction and demolition, transboundary sources, etc. that contribute to the city's air pollution. These may vary from city to city, and thus there is a variability in them featuring in a city -specific study.
11. **Public Awareness and Behaviour Change :** Raising public awareness about air quality issues and promoting behaviour change is critical. City studies highlight the communication strategies and educational campaigns that have been undertaken to encourage citizen participation in air quality management and its effectiveness.
12. **Policy Recommendations :** Based on comprehensive research and data analysis of the current situation in the city and the issues to be addressed, the city level studies evidence-based policy recommendations. These recommendations encompass short-, mid-, and long-term measures to control air pollution and improve overall urban air quality.

City-specific air quality management studies help local authorities and stakeholders make informed decisions to tackle air pollution effectively. Each city's unique characteristics and challenges require tailored solutions, making these studies indispensable for sustainable urban development and public health improvement.

1.3 Objectives of the report

As mentioned earlier, this report is a comparative study of Dhaka, Gurugram, and Bangkok, based on individual city-level assessments conducted by respective national consultants from Thailand, Bangladesh, and India, respectively. This analysis draws learnings from the three city reports, identifying opportunities and good practices for the adoption of innovative air pollution control technologies. In addition, it also analyses the alignment of the three city action plans with their respective national policy or strategy on technology adoption and implementation for air pollution control, and suggests recommendations for future work.

Thereby, this comparative analysis distils factors across these three cities as well as other cities facing similar challenges across Asia -Pacific region. Further, the analysis also shed light on relevant interventions for strengthening city-level policies for facilitating adoption of innovative technologies for air pollution control at city level. For these reasons, the report will be a relevant document for the policy and decision -makers across Asia specific.

APCTT works to assist the members and associate member states of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) by strengthening their capabilities to develop and manage national innovation systems; develop, transfer, adapt and apply technology; improve the terms of transfer of technology; and identify and promote the development and transfer of technologies relevant to the region. The findings of this comparative analysis would also be shared with policy and decision makers, and government stakeholders in the Asia and Pacific region for wider dissemination and adoption of best practices. Besides the policy and decision makers at the city level, the report would also be useful for pollution control authorities or departments, city municipal authorities, city administrations, urban local bodies (ULBs), instrument manufactures and suppliers, research and development organis ations and institutes, and the private sector. Additionally, this study would also identify the most viable technologies for scaling up across Asia Pacific.

To conduct a systematic comparison, an indicator framework approach has been developed to draw a detailed comparison of the three cities on various AQM indicators to provide a better understanding on the technological interventions, city action plans, and alignment of these plans with national strategies.

2 METHODOLOGY

The comparative analysis between the three cities of Bangkok, Dhaka, and Gurugram involves a structured approach based on second hand research and stakeholder interactions, in addition to the city -specific assessments. The methodology attempts to ensure robustness and use verified secondary data addition to vetting through multi-stakeholder interactions.

The methodology consisted of the following steps :

1. Review of city-based assessments for comparative analysis.
2. Design framework for the comparative analysis report consisting of:
   a. Analysis of the three city action plans, and
   b. Analysis of the technological interventions for air pollution mitigation in each of the three cities followed by suitable recommendations and learnings.
3. Internal consultation with the project team and city consultants to validate the draft analysis.
4. Consultation(s) with external experts and other partner organis ations to get their feedback and inputs on the analysis.
5. Report compiling inputs from above steps.

The research objectives were clearly outlined for undertaking the comparative analysis, including identifying best practices, assessing challenges, and understanding the effectiveness of air quality management strategies using technological interventions for air pollution mitigation. This was followed by the selection of the relevant key criteria that reflect air quality, pollution sources, management strategies, health impacts, and other important aspects. These criteria were used to compare the cities, with the focus being on the technological intervention for air pollution mitigation.

2.1 Criteria for comparative analysis

In the context of development and economic activities, and in the areas that impact air pollution, the cities of Bangkok, Dhaka, and Gurugram have commonalities. The three cities are major urban centres in their respective countries and their commonalities are as follows.

1. **Geographical Location :** The geographical diversity of the three cities includes aspects such as its climate condition, topography, and weather conditions, which play a pivotal role in the air quality.
2. **Urbanis ation and Population Density :** The total number of people living per sq. km in Bangkok, Dhaka, and Gurugram is crucial due to its influence on the number and type of pollution sources, transportation patterns, and overall AQM strategies within these three cities. All three cities are densely populated, and experience rapid urbani sation (mostly unplanned). These cities also attract a significant influx of people from the rural areas, neighbouring regions, and other parts of their respective country seeking better economic opportunities leading to population growth and increased urban sprawl.
3. **Economic Development :** Based on the levels of economic development within Bangkok, Dhaka, and Gurugram, these can be classified into either developing or developed cities, based on which, different approaches to AQM may be required to plan for resource availability and technological capabilities.
4. **Status of Air Quality :** The status of air quality prevalent in each of the three cities includes the pollutants of concern, their yearly averages, and the range within which the variations have been observed for each of the pollutants, are critical for analysis.
5. **Air Pollution Challenges :** Pollution sources prevalent in Bangkok, Dhaka, and Gurugram resulting in severe air pollution include vehicular emissions, industrial processes, agricultural activities, construction, waste burning, agricultural activities, commercial development, and residential sources . Unfavourable weather conditions as well as the transboundary impact need to be studied to capture a comprehensive understanding of pollution profiles. The elevated levels of particulate matter ($PM_{2.5}$ and PM_{10}) and other pollutants contribute to deteriorating air quality and pose severe health risks to residents.
6. **Heat and Humidity:** Being in tropical regions, Bangkok, Dhaka, and Gurugram experience hot and humid climates. Elevated temperatures, combined with urban heat island effects, exacerbate air pollution and impact overall living conditions.
7. **Cultural and Social Factors:** Aspects related to cultural norms and social behaviours influence pollution sources and their management.
8. **Availability of Data:** The extent of data availability, its reliability, and comparability for the three cities would also enable meaningful analysis.
9. **Diverse Environmental Challenges :** Consider other environmental challenges that cities might face, like traffic congestion, excessive use of diesel, waste management issues, etc., each of which adversely impacts the air quality of each of the three cities.
10. **Urban Governance :** The city administrations in Bangkok, Dhaka, and Gurugram play a crucial role in managing urban development, infrastructure, and environmental issues. Effective governance and policymaking are essential for addressing the shared challenges they face. However, there are gaps in implementing the city Master Plans and other schemes on air pollution control.
11. **Urban Mobility :** Mobility is an important criteri on for the analysis of AQM owing to varying transportation systems in Bangkok, Dhaka, and Gurugram. Aspects such as reliance on private vehicles, public transportation infrastructure, and degree of non-motorized modes of transport being used need to be considered. These cities suffer from heavy traffic congestion, resulting in increased vehicular emissions, longer commuting times, and reduced air quality.

12. **Challenges in Waste Management :** Proper waste management is a common challenge in these three cities. The large volume of waste generated requires efficient and sustainable waste management practices to prevent waste burning, and consequent air pollution. Although the status of waste management practices is slightly different across the three cities, the contribution to air pollution from the waste management sector is still significant.
13. **Rapid Development and Construction :** The three cities are witnessing rapid development and construction activities to accommodate their growing populations and expanding economies. Construction-related dust and emissions from heavy machinery are therefore important sources of air pollution.
14. **Economic Centres and Industrial Activities :** It is also important to consider the type and level of industrial activity to understand the distinct pollution sources and their management challenges. Bangkok, Dhaka, and Gurugram are major economic centres in their respective countries. They attract investments, host numerous multinational corporates and industries of all kinds, contributing significantly to their nations' economic growth and development.
15. **Cultural Diversity :** All three cities boast a rich cultural diversity due to historical influences and migration for better employment opportunities. They are home to people from various ethnicities, languages, and cultural backgrounds. Due to this, there are a mix of practices that in their own way also tend to contribute to the air pollution problem.
16. **Government Policies :** Highlighting the varying degrees of government commitment to air quality management in each of the three cities would include aspects of current city action plan, mitigation policies, technology being employed for mitigation, and the enforcement mechanisms for ensuring compliance monitoring, all of which can provide valuable lessons.

Despite the above similarities, each city also has its unique characteristics, culture, and specific challenges related to policies, plans, implementation, coordination, finance, and technology. Therefore, while it is possible to have a common approach for addressing the above aspect of air pollution mitigation in all three cities, certain aspects would need tailoring to address the distinct air pollution and urbani sation issues specific to the three cities.

2.1.1 Conceptual Framework for Comparative Analysis

The following criteria were used to conduct the comparative analysis.

1. **Status of Technological Intervention :** This criteri on addressed the status of progress for each of the technological intervention that has been presented across all three cities. The status is categorised into five categories.
2. **Applicability :** It defines the relevance and versatility of each of the assessed technological intervention in terms of its potential for mitigating air pollution across diverse urban landscapes. This helps in understanding how each of the technological interventions can be customis ed to address the specific sources and characteristics of air pollution across different cities through targeted and timely interventions.
3. **Feasibility :** This category analyses the degree of ease with which a technological solution can be used for air pollution mitigation in an urban area. Multiple factors need to be considered for feasibility including how advanced the technology is, its availability, its overall economic viability, government policies, public acceptance, and the specific environmental conditions of the urban area being considered for implementation, all of which play an important role in assessing the feasibility of a given technology. Further, for the final successful feasibility, the government organisations, businesses, and communities need to work together to find the best ways to reduce air pollution.

4. **Innovativeness :** Innovativeness refers to the capacity of a solution to allow fresh and imaginative approaches, methodologies, or technologies that surpass traditional methods. It implies the utilisation of state-of-the-art concepts and advancements to tackle the intricate challenges associated with air pollution. The significance of innovativeness in such interventions cannot be overstated, as it propels the development of more efficient, effective, and sustainable solutions. Cutting-edge technologies play a pivotal role in enhancing the precision and impact of efforts to mitigate air pollution. The continual pursuit of innovative solutions is indispensable for addressing the emerging pollution threats and ensuring the adaptability of interventions to evolving environmental conditions and technological landscapes.
5. **Affordability :** Refers to the economic viability and accessibility of implementing a specific technological solution for air pollution mitigation. It encompasses factors such as the initial investment costs, ongoing maintenance expenses, and the overall financial burden placed on stakeholders, including governments, industries, and communities. Affordability is crucial as it would directly influence the feasibility and widespread adoption of air pollution mitigation technologies. C ost-effective interventions are more likely to be embraced by a diverse range of stakeholders, thereby facilitating broader implementation and impact. Striking a balance between technological effectiveness and economic feasibility is imperative to ensure that air pollution mitigation strategies are not only environmentally beneficial but also economically sustainable. This balance allows for long-term commitment and support from stakeholders at various levels.
6. **Availability :** Availability, within the context of a technological intervention aimed at mitigating air pollution, pertains to the accessibility and preparedness of the solution for practical implementation and encompasses various factors like the widespread deployment of the technology, the ease of integrating it into existing infrastructure, and its ability to respond promptly to changing environmental conditions. The role of availability is of utmost importance as it directly affects the efficiency and effectiveness of efforts to mitigate air pollutio Readily available technologies can be swiftly deployed to address urgent pollution concerns, thereby making an immediate impact on the ongoing AQM work. Further, the availability of solutions ensures that they can be easily expanded and replicated across different regions, thereby contributing to a broader and more sustainable geographical impact to tackle air pollution more effectively.
7. **Scalability :** Scalability, within the realm of technological interventions aimed at mitigating air pollution, refers to the ability of a solution to be replicated in a wide range of environmental challenges. This entails designing interventions that can be implemented across different geographical locations, populations, and levels of pollution severity, and adaptation to diverse environments and varying degrees of scenarios of air pollution. Scalable interventions should therefore be customizable to the unique requirements and limitations of different urban settings. Scalable solutions are also more likely to receive support from policymakers, industries, and communities, thereby facilitating its integration into broader strategies for mitigating air pollution at regional, local, and hyperlocal levels.
8. **Resilience :** Resilience refers to the ability of the system to adapt, recover, and maintain its functionality despite disturbances or alterations in the surroundings, especially the environmental conditions. A resilient air pollution mitigation technology is one that can withstand unforeseen challenges, such as severe weather events, technological malfunctions, or changes in pollution patterns, without compromising its effectiveness. Resilience ensures long-term success of a technological intervention by providing continuous advantage across dynamic and unpredictable urban settings and ensuring to confront emerging challenges, thereby contributing to the sustained enhancement of air quality over time.
9. **Ease of Maintenance :** The ease of maintenance is another important aspect when it comes to air pollution mitigation technologies including the ease of service, repair, or upgrade this hardware. This factor directly impacts the long-term viability and sustainability of the solution. Technologies

that are easy to maintain require fewer resources, time, and expertise for upkeep, which in turn reduces operational costs and minimizes disruptions to service. This attribute is particularly crucial in ensuring the continuous functionality of pollution mitigation systems, as regular maintenance is necessary for optimal performance, providing a reliable and long-lasting solutions for addressing air quality concerns in urban environments.

10. **Emission Reduction Potential for PM_{10} and $PM_{2.5}$:** The emission reduction potential for PM_{10} and $PM_{2.5}$ pertains to the ability of a technological intervention to significantly decrease the emissions of particulate matter with diameters of 10 micrometres or less (PM_{10}) and 2.5 micrometres or less ($PM_{2.5}$). The role of emission reduction potential is pivotal as it directly affects the effectiveness of the intervention in enhancing air quality and such technologies contribute to creating a healthier urban environment, mitigating the negative impacts on public health and ecosystems. These technologies facilitate compliance with prescribed regulations, and air quality standards.
11. **Environmental Impact :** Another critical criterion to develop technologies for air pollution is the effect it has on the surrounding ecosystem, biodiversity, and overall environmental health, without causing any unintended harm to the environment. Technologies that have a positive environmental impact not only enhance air quality but also contribute to the preservation of ecosystems, soil quality, and water resources. On the other hand, an insufficient evaluation of the environmental impact may result in unintended ecological consequences. Therefore, it is essential that technological interventions for air pollution mitigation align with broader sustainability objectives, promoting a harmonious balance between urban development and environmental well-being.
12. **Health Benefits :** Human well-being is being severely affected due to continuous exposure to air pollutants. Technologies that effectively reduce the levels of harmful pollutants, such as particulate matter and hazardous gases, directly contribute to enhancements in respiratory and cardiovascular health and overall mortality. Thus, the health impact of the technology is a core criterion .
13. **Integration with Existing Systems :** Selection of a technology is also based on seamless integration into the existing urban infrastructure, regulatory frameworks, and societal practices. Such technologies are more likely to be adopted and maintained over time, minimi sing disruptions, and optimi sing resource utilis ation. A well-integrated technological solution enhances its compatibility with the social, economic, and regulatory aspects of a city, thereby promoting a comprehensive and coordinated approach to air pollution mitigation.
14. **Life Cycle Attributes :** Life cycle attributes pertain to the comprehensive evaluation of a technology's impact on the environment, its utilis ation of resources, and its overall sustainability throughout its entire life cycle, from production implementation, maintenance, to disposal. The significance of considering life cycle attributes cannot be overstated, as it ensures that the selected intervention minimis es its environmental impact and operates in a sustainable manner. By assessing factors such as energy consumption, material acquisition, and end-of-life disposal, decision-makers can opt for interventions that align with broader environmental conservation objectives without inadvertently exacerbating other environmental challenges.
15. **Regulatory Compliance :** Regulatory compliance relates to the adherence of the technological interventions under consideration, to the established laws, standards, and regulations that govern air quality and environmental protection. Compliance fosters accountability and trust among stakeholders, including government bodies, industries, and the public, and facilitates the successful implementation of strategies to improve air quality. Further, it helps prevent potential legal consequences and promotes a harmonious relationship between technological advancements and environmental governance, thereby reinforcing the ethical and responsible use of interventions for sustainable urban development.

16. **Social Acceptance :** Social acceptance is the willingness and endorsement of the community, encompassing residents and other relevant parties, to embrace and endorse the implementation of a specific technology. This favourable reception amplifies the efficacy of interventions by fostering community involvement, cooperation, and adherence to recommended practices, and cultivating a sense of shared responsibility, trust, and collaboration among diverse stakeholders.

2.2 Approach and research methodology used for data collection

The qualitative part of the analysis includes the development of a matrix in which criteria-based representations are given. Two main aspects that the report has captured in each of the three cities includes :

1. City action plans and its alignment with the national policy/ strategy, and
2. Technological interventions being undertaken for air pollution mitigation.

It is pertinent to note that the matrix has different qualitative criteria corresponding to the aspects of alphabetical as well as colour-based scoring criteria. This has been done to facilitate and maintain a healthy balance of the two qualitative aspects in the analysis, as well as address the complex nature of the matrix being developed. The criteria that have been used in the qualitative analysis have been bifurcated in a sector specific manner.

The analysis framework is based on the matrix approach presented in tables 15 and 19. Qualitative analysis was also included to highlight and capture the complexity of air quality management, using internal consultation, cross-verification from reliable data sources, and through multiple stakeholders working on ground.

The framework also provided the means to interpret the findings in the context of each city's unique characteristics, technological and policies interventions which allowed the framing of the outcome of the analysis, drawing the recommendations for each city to enhance its respective air quality management practices. These recommendations aimed to be focused, practical, actionable, and tailored to the specific needs of each city.

3 BRIEF ABOUT THE CITIES

Before the analysis, it is important to understand and highlight the pertinent aspects of each of the three cities that would be influencing the comparative analysis either directly or indirectly. This is being presented in the form of city briefs for all three cities, highlighting aspects such as city -specific overview, the current status of air quality in the city, the main pollution sources, city's current regulatory framework, the current status of monitoring and data collection, sectoral overview, health- related impacts, key initiatives and interventions being undertaken at the city level, current challenges and future plans, collaborations and partnerships being undertaken, and performance and trends being noticed.

3.1 Bangkok City

3.1.1 City brief – Programmes on air quality management in Bangkok

City Overview

Being a megacity, Bangkok (latitude 13° 44' 12.1812'' N, longitude 100° 31' 23.4696'' E)[10] with an area of 1,568.7 square kilometres is one of the major cities of Thailand. It shares boundaries with the districts of Nonthaburi and Pathum Thani in the North, Chachoengsao in the East, Samut Prakan in the South, Nakhon Pathom and Samut Sakhon in the West. The topology of Bangkok is that of a relatively flat land,

10 https://www.latlong.net/place/bangkok-thailand-778.html

with moderate climatic conditions throughout the year. In the year 2010, Bangkok had 50 districts and 169 sub districts. It has the highest population in Thailand (AQLI, 2022), which is estimated to be 10.72 million in 2022. Bangkok's average population density is 5,294.3 per sq. km.[11]

The main known factors of Bangkok's air pollution problem are diesel fumes from the city's dense traffic; agricultural burning, which occurs when thousands of farmers across the country ignite their fields to clear agricultural waste before the next harvest; and secondary aerosols which could be dust, among other things, from construction and cars.[12] Bangkok city has one of the largest car ownerships per capita in the world.[13]

Air Quality Status

Over the past 5 years (2018-2022), the air quality in Bangkok has gradually improved with the concentration of $PM_{2.5}$ continually reducing from 27 µg/m³ in 2018 to 22.7 µg/m³ in 2022 (PCD, 2023). Further, based on the statistical data compiled from air quality measurements reported by IQ Air, Bangkok has experienced an improvement in air quality over the past 4 years with the percentage of hours meeting the WHO's $PM_{2.5}$ guidelines increasing from 5% in 2019 to 17.8% in 2022 because of different policies and the involvement of different sectors and stakeholders (IQ Air, 2022).

The data from monitoring stations in Bangkok from pollution control department (PCD) in 2021 showed that the concentration of six criteria air pollutants in Bangkok are well under National Ambient Air Quality Standard, except ozone (O_3) and $PM_{2.5}$.

The $PM_{2.5}$ problem in Bangkok can be attributed to two primary factors—meteorology and the sources and human activities contribut ing to emission in the area. The meteorology (causing air stagnation and high air pressure during the dry season) contributes to a large accumulation of air pollution in the area. $PM_{2.5}$ concentration are also high on several consecutive days in the central region of Bangkok and the vicinity of Thailand in the month of February each year (PCD, 2018). The top three pollution sources and human activities which contribute to emission in the area in Bangkok are transportation, industrial and agricultural sectors (Nikam J. et al., 2021; PCD, 2018; Winijkut et al., 2020).

Ozone is another pollutant that should be a concern in Bangkok. The overall trend of ozone in Thailand shows a steady decline over the past 5 years. However, in 2021 the level of O_3 has exceeded the standard and increased by 3% on average from the previous year, especially in the Bangkok area and Central region of Thailand (PCD, 2022). However, O_3 is a secondary air pollutant and forms in the atmosphere in the presence of precursor pollutants and sunlight. Thus, the control of O_3 is not as simple as primary air pollutants.

Pollution Sources

As per the EI developed for Bangkok in 2019, the major sectors contributing to the air pollution in the Bangkok city are as follows :

Table 2 – Sectoral contribution based on the 2019's Emission Inventory (EI) of Bangkok

Transportation (35%)	Residential (7%)
Road dust (20%),	Commercial (Street food and markets) (5%)
Agriculture burning (20%)	Others (2%)
Industry/ Factories (11%)	

Regulatory Framework

In Thailand, there are both sector -specific legislations and plans, as well as overarching and multi sectoral plans.

11 https://worldpopulationreview.com/cities/bangkok-population#:~:text=Bangkok%20population%20in%202022%20is,is%20710%20people%20per%20sq.

12 https://www.ccacoalition.org/news/bangkoks-air-pollution-reaches-dangerous-levels-researchers-are-working-determine-how-boats-fit-emissions-puzzle

13 https://www.thai-german-cooperation.info/wp-content/uploads/2022/09/Bangkok-congestion-charging_Small.pdf

Table 3 – Sector -specific legislations and plans in Thailand

ENERGY **1. Legislations** a. Fuel Trade Act, 2000 b. Energy Conservation and Promotion Act, 2007 c. National Energy Policy Council Act, 2008 **2. Plans** a. Power Development Plan (2018 -2037) b. Alternative Energy Plan (2015-2036) c. Thailand Smart Grid Development Master Plan (2015-2036) d. Oil Development Plan (2015-2036) e. Energy Efficiency Development Plan/20-year Energy Efficiency Plan (2011-2030)	**ENVIRONMENTAL PROTECTION** **1. Legislations** a. Promotion & Conservation of Natural Environment Quality Act (2008- 2011) b. Notification of Ministry of Natural Resource and Environment, 2018 **2. Plans** a. Thailand Environment Quality Management Plan (2017-2021) b. National Strategy on Climate Change (2013-2017) c. Constitution of the Kingdom of Thailand, 2017
FORESTRY AND AGRICULTURE **1. Legislations** a. Factory Act, 2019 b. Land Transportation Act, 1979 **2. Plans** a. National Master Plan for Open Burning (2004- 2009) b. National Fire Haze Control Plan of Action, 1997 c. Northern Haze Prevention & Mitigation Plan, 2015	**INDUSTRY** **1. Legislations** a. Energy Industry Act, 2007 b. Industrial Estate Authority of Thailand Act, 1979 c. Order 3/2016 and Order 4/2016, 2016 d. Zero Burning Measure, 2007 **2. Plans** a. Burnt Sugarcane Solving Plan, 2019
TRANSPORT **1. Legislations** a. Passenger car Act/Vehicle Act, 1979 b. Land Transportation Act, 1979 **2. Plans** a. Environment Sustainable Transport Plan (2013)	**WASTE MANAGEMENT** **1. Plans** a. Waste Management Road Map (2016- 2021)

Monitoring and Data Collection

Of the 77 official monitoring stations of the Thai Pollution Control Department (PCD, 2022) in Thailand across 46 provinces, 12 are in Bangkok. 06 (six criteria of air pollutants are monitored under Thailand's

National Ambient Air Quality Standards (NAAQSs), namely Particulates (including Total Suspended Particulate Matter (TSP) and Particulate Matter (both PM_{10} and $PM_{2.5}$), Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Sulphur Dioxide (SO_2), Ozone (O_3), and Lead (Pb). Daily Air Quality Index (AQI) values are also calculated based on the available air quality data that refer to the situation of air pollution in terms of health impacts, and this daily AQI is presented on the official website. (PCD etc., 2018). The stations provide 24-hour average concentrations, annual averages concentrations, and national average concentrations.

Health Impacts

As per the AQLI, Bangkok is one of the three provinces with the highest health burden of air pollution. In April 2022, $PM_{2.5}$ concentration in Thailand's air was four times higher than the WHO annual air quality guideline value. This means the Thai population breaths in air that is too polluted and which will affect their health. In 2016, it was estimated that over 33,000 deaths in Thailand were attributable to ambient air pollution.[14]

Sectoral Overview

1. **Transportation Sector:** Since the transportation industry in Bangkok is one of the drivers for its development, it also ends up playing a significant role in the city's air pollution challenges, contributing around 35% to the city's total emission load. The extensive network of roads, combined with a high concentration of vehicles, particularly motorcycles and cars, leads to increased levels of particulate matter and emissions of gaseous pollutants.[15] Traffic congestion, that has grown in the last decade, has also remained a persistent problem, resulting in prolonged idling and higher fuel consumption.[16] It has been observed that Bangkok's ambient air is mainly influenced by pollution from land transport, where car engines are considered to be the primary source of $PM_{2.5}$.[17]

   Despite the presence of a well-established public transportation system, such as the BTS Skytrain and MRT subway, the heavy reliance on private vehicles and the limited use of eco-friendly alternatives contribute to the transportation sector's substantial impact on air quality.[18] Coupled with slow progress in the introduction of cleaner (Euro 5 and 6) vehicular standards and electric vehicles (EVs), and lack of new regulations to remove old vehicles from roads, and on establishing Low Emission Zone (LEZs)—the air pollution situation has become a major challenge for the city administration and the national government.

2. **Road Dust:** The road dust in Bangkok is a major source of the city's air pollution , contributing close to 20% of its total emissions. With the recent urban development and sprawl with Bangkok, combined with heavy traffic, construction work, and limited green spaces, the build-up of PM_{10} and $PM_{2.5}$ on and along the roads has worsened. Resuspended road dust is the dominant non exhaust emissions contributor, particularly to the total concentrations of PM_{10}, with its daily concentration measuring higher than 120 $\mu g/m^3$, surpassing the daily PM emission standards set by WHO.[19] Due to the continuous movement of vehicles along the city roads, especially during congested periods, the resuspended road dust remains in suspension for a much longer duration, leading to higher levels of PM_{10} and $PM_{2.5}$ for a prolonged period. Along with road dust, brake and tire particles and road surface wear also contribute to PM emission.[20] Furthermore, construction projects add to the release of dust, with four types of activities causing the highest risks from dust, namely demolition, earthworks,

14 https://www.who.int/thailand/news/detail/08-06-2022-the-cost-of-clean-air-in-thailand

15 https://www.sciencedirect.com/science/article/abs/pii/S1352231014002830

16 https://journals.librarypublishing.arizona.edu/jpe/article/2254/galley/2463/view/

17 https://www.sciencedirect.com/science/article/pii/S2405844023014688#bib5

18 https://www.researchgate.net/publication/355573620_Transportation_System_in_Bangkok_City

19 https://www.eeer.org/journal/view.php?number=1523

20 https://www.eeer.org/journal/view.php?number=1523

construction, and track out.[21] This challenge is further worsened due to climatic factors, especially the dry season, which allows fine particulates to stay suspended and spread in the atmosphere.[22]

3. **Agriculture Burning:** Thailand is an agricultur e-based country that produces a large amount of biomass residues that are frequently burned in the field to prepare for the next crop cycle and to remove weeds, insects, and animals. This open burning of the agricultural residue is a conventional method to easily eliminate residues on small farms in agricultural zones and is a traditionally widespread crop -management practice in Thailand. This results in considerable emissions of pollutants in the area, directly causing large amounts of PM emissions.[23]

   In Bangkok, most of the emissions from the burning of the agricultural residue are transboundary in nature. Almost every year during the dry season (November- February), high-pressure conditions are created across the central Thailand region includ ing Bangkok. Coupled with the phenomenon of temperature inversion and minimum to no wind speed, the local and transboundary particulates and gases accumulate in this area, especially the Bangkok city, resulting in higher dust concentrations than normal. [24]

   Since most farmlands are leased, this leads to a lack of incentives for investment in alternative farming practices and protection of farmers' rights on financial returns, which results in lack of will and capacity to invest in alternative waste management practices by the farmers, thus making burning the easiest and the quickest way to get rid of the agricultural residue on the field. Currently, there are no policy measures or incentivised best practices that would prevent farmers from not burning the agricultural residue. Additionally, no framework has been defined that would promote multi sectoral collaboration among different provinces and organi sations, especially for managing fire after detection since most fires happen outside Bangkok.

4. **Industrial Sector:** Bangkok's industrial sector plays a crucial role in its economic development, while also presenting a significant challenge in terms of air pollution. A wide range of manufacturing activities like combustion of fossil fuels and certain industrial processes contribute to the release of pollutants leading to higher levels of pollutants like PM_{10}, $PM_{2.5}$, SO_2, and volatile organic compounds (VOCs) , especially due to the scale and the types of chemicals and processes being used. Although the large industries are situated in the outskirts of the Bangkok city, the overall emissions from all industrial facilities, including factories and power plants, have a significant impact on the air quality of the city.[25] The database from the Department of Industrial Works in December 2022 found 5,639 factories in the Bangkok area. Additionally, 260 factories have the potential to emit high pollutants in the Bangkok area. It is estimated that the Industrial sector (Factories and Power plants) produces 12% of $PM_{2.5}$ emissions in Bangkok.[26] Although regulatory measures have been put in place to control industrial emissions, the continuous growth of the sector and the need for strict enforcement pose ongoing challenges.

5. **Residential Sector:** The urban landscape of Bangkok is complex urban environment constituting a mix of commercial, residential, and some industrial establishments. In many places, the city has a densely populated residential areas that contribute to the city's air pollution challenges. Aspects

21 Pusapukdepop, Jitrapun and Pengsa-ium, Vipa, Measures to Reduce the Impact of Dust From Construction in Bangkok (May 22, 2018). Available at SSRN: https://ssrn.com/abstract=3182991 or http://dx.doi.org/10.2139/ssrn.3182991

22 https://www.researchgate.net/publication/376378416_Comprehensive_review_of_the_annual_haze_episode_in_Northern_Thailand

23 https://www.sciencedirect.com/science/article/pii/S2405844023014688

24 https://www.sciencedirect.com/science/article/pii/S2405844023014688

25 https://www.researchgate.net/publication/5594532_Levels_and_major_sources_of_PM25_and_PM10_in_Bangkok_Metropolitan_Region

26 https://www.sciencedirect.com/science/article/abs/pii/S130910422300168X#:~:text=The%20results%20indicated%20that%20the,construction%20(36.0%25)%2C%20respectively

such as the use of solid fuels like wood and charcoal for household cooking, extensive reliance on motorized vehicles for personal transportation within residential areas, lack of proper air circulation and ventilation due to the presence of numerous buildings in proximity, and limited green spaces, all cause the pollutants, especially the $PM_{2.5}$ to become trapped, leading to localized air quality problems. While the residential sector is not a major contributor to Bangkok's air pollution, it is closely intertwined with other sectors, highlighting the necessity for comprehensive strategies that address not only household practices but also the broader urban context.

6. **Commercial Sector:** Since Bangkok city has wide range of businesses including retail, hospitality, and service industries, the commercial sector heavily relies on energy, transportation, and generates a substantial amount of waste. Street food eateries and markets are very prevalent and a major source of livelihood for many. There is a massive dependence on low-cost fuel sources, motorized vehicles for logistics and delivery services, and energy consumption of other commercial establishments, leading to the release of pollutants like NO_2, PM_{10}, and $PM_{2.5}$.

Key Initiatives and Interventions

1. Bangkok Air Quality Plan (BAQP)
2. Ad Hoc Plan on Solving Dust Pollution Problem in Bangkok 2023

Challenges and Future Plans

1. Enforcing policy on vehicular age limit.
2. Using economic incentive measures to promote buying newer and more efficient cars including EV cars.
3. Technology transfer of remote sensing for vehicle inspection and data analysis is necessary since this is lacking in Thailand.
4. Promoting mixed use of land to reduce traveling time.
5. Cars that cause less pollution (e.g., electric cars).
6. Using alternative forms of transportation (e.g., public transport, biking, and walking)
7. Need regulations and enforcement to set LEZ with clear details of vehicle information to be allowed in the area.
8. Public transport needs to be available and accessible.
9. Supporting the production of low-sulphur fuel and NOx reduction technologies for Euro VI standard in Thailand.
10. Providing financial and other incentives for DPF installation.
11. Proving study on possibility of using partial flow filter on in-used pre-Euro – Euro I vehicles.
12. Increase awareness and technical capacity of the locals (Nikam J. et al., 2021).
13. Introducing the application to the community and providing guidelines and rules for controlling open burning (Nikam J. et al., 2021).
14. Farming is dominated by the older generation.
15. Increasing farmers' incomes would encourage the younger generation, who may have more innovative residue management practices, to be involved.
16. Developing database for $PM_{2.5}$ management which includes online data from different organis ation, such as monitoring data from PCD and Bangkok Metropolitan Administration (BMA), hotspots from GISTDA, name and contact number of the community by BMA and metropolitan provinces.
17. Regularly updating and publishing information on air quality conditions on an open-sourced website, through a Pollutant Release and Transfer Register (PRTR) process.

18. Collect data from stakeholders, rather than local leaders, for more accurate and community centric information.
19. Enabling public access to information about emissions through a PRTR process.
20. Working with community to control emission from small industries (possible to use some simple technologies for monitoring emission, e.g., Ringelmann Smoke Chart)
21. Street food is highly linked with local practices, and the income of the local people which is difficult to regulate by policy.
22. Creating website and reporting format to avoid confusion between measurement values obtained from low-cost sensors and official monitoring stations.
23. Providing guidelines for quality control and usage of low-cost sensors.

The above challenges have dual purpose, that of highlighting the challenges for the Bangkok city as well as being the future action points to work on for enabling improved air quality and reducing pollution levels in the city.

Collaboration and Partnerships

Like many megacities, Bangkok is also facing challenges in coordinating among its different agencies/ bodies/ organis ations for managing its air pollution. Owing to the complex nature of the issue, especially the complexity of the air pollution sources, and the diverse sectors involved, it has been a difficult task for the BMA. While there were instances of inter-agency cooperation, such as joint action plans and task forces, the level of collaboration has been hindered by bureaucratic hurdles, differing priorities, and limited resources. Additionally, since there exists no concrete framework that would enable multi sectoral collaboration at different levels of governance, the collaborations are more ad hoc and on need basis.

Further, since the current list of initiatives ranges from promoting cleaner transportation options to enforcing emission standards for industries, these collaborations become even more important. The establishment of monitoring systems and data sharing is another area where collaboration is crucial to understanding pollution patterns and devising effective strategies; however, it stands missing as of now. Future efforts to combat air pollution would require strengthening of coordination since multiple agencies like transportation, environmental regulation, industrial management, agriculture management, urban planning, public health, and many others need to be roped in, and initiatives facilitated with greater ease.

Performance and Trends

As highlighted earlier, from 2018 until 2022, Bangkok's air quality has shown gradual improvement, especially for $PM_{2.5}$. Additionally, the percentage of hours meeting the WHO's $PM_{2.5}$ guidelines have increased from 5% in 2019 to 17.8% in 2022 due to policy action and wider stakeholder engagement. Most importantly, PCD's monitoring data from 2021 showed the concentrations for the 4 criteria air pollutants in Bangkok are well under the NAAQS, except O_3 and $PM_{2.5}$.

3.1.2 List of important technology interventions for air pollution mitigation for Bangkok from the Assessment study

Table 4 – Technological Interventions from the Bangkok City Assessment

Area/ Sector	Technological Interventions
Transport Sector 1. Use of Diesel Particulate Filter (DPF) for diesel vehicle emission control 2. Electric vehicle 3. Remote Sensing for vehicles exhaust emissions 4. Low Emission Zones	**Air Quality Monitoring and Forecasting** 1. Low-cost Sensor for ambient air quality monitoring 2. Weather Research and Forecasting /Chemistry Model (WRF-Chem model)
Industrial Sector 1. Use of Continuous Emission Monitoring Systems (CEMS) for industrial air pollution control	**Commercial Sector** 1. Cleaner cooking (cleaner fuel and cleaner stove)
Agriculture Sector 1. Web and mobile applications to manage agricultural wastes (not to burn) 2. Satellite detection for agricultural open burning control	**Residential Sector** 1. Cleaner cooking fuel 2. Cleaner cooking stove

3.1.3 City level action plans and strategies for air pollution control

Table 5 – City Level Action Plan and Strategies from the Bangkok City Assessment

S. No.	Strategies/ Plan/ Scheme	Purpose
1	**Thailand National Action Plan on Fine Particulate Matter**	$PM_{2.5}$ pollution has been considered as national agenda ad gained significant attention in Thailand since 2018, especially when the issue became severe in Bangkok and the metropolitan region. 'Solving the Dust Pollution Problem' was established for the period 2019 -2024, and it comprises three main strategies. **Measure 1** – To enhance area-based management during crises, categorized according to air quality levels as follows – **a. Level 1 ($PM_{2.5}$ below 50 µg/m³)** – All agencies continue regular operations. **b. Level 2 ($PM_{2.5}$ between 51-75 µg/m³)** – All agencies intensify measures. **c. Level 3 ($PM_{2.5}$ between 76-100 µg/m³)** – Bangkok/provincial governors use single command and control system to work with corresponding agencies. **d. Level 4 ($PM_{2.5}$ exceeds 100 µg/m³)** – Propose measures for the Prime Minister's consideration.

S. No.	Strategies/ Plan/ Scheme	Purpose
		Measure 2 – Prevent and reduce pollution at sources by controlling pollution from the transportation, agricultural, industrial, construction, and residential sectors using short-term actions to combat $PM_{2.5}$. a. Inspecting black smoke emissions at sources b. Upgrading vehicles to Euro V/VI emission standards c. Promoting the use of electric vehicles in Bangkok d. Expanding road capacity to reduce traffic congestion e. Eliminating dust-generating activities f. Implementing a complete ban on open burning g. Installing Continuous Emission Monitoring Systems (CEMS) and inspecting factories h. Encouraging the use of clean fuels in households i. Promoting the use of public transportation, and j. Controlling dust from construction sites **Measure 3** – Enhance the efficiency of air pollution control and management. a. Developing an air quality monitoring network b. Compiling air pollution inventory reports, and c. Addressing transboundary hazard pollution issues
2	**Bangkok Air Quality Plan (BAQP)**	The 20-year Development Plan for Bangkok Metropolis (BMA, 2013) is derived from people's vision regarding the development of Bangkok in the next 20 years and the translation of the plan into action. Bangkok residents divided measures into four 5-year phases based on their priorities to drive the strategy. The six strategies are – a. Bangkok as a safe city b. Bangkok as a green and convenient city c. Bangkok as a city for all d. Bangkok as a compact city e. Bangkok as a democratic city f. Bangkok as an economic and learning centre Of these, the first strategy is relevant as it focuses on developing better environment in Bangkok, free from pollution from wastewater, solid waste, and air pollution. BAQP aims that at least 80% of Bangkok residents living in inner-city areas have fresh air equivalent to at least 200 days per year, especially for $PM_{2.5}$ by 2032; which would be achieved by reducing concentration by 15% in 2032 compared with the base year.

S. No.	Strategies/ Plan/ Scheme	Purpose
3	**Ad Hoc Plan on Solving Dust Pollution Problem in Bangkok 2023**	Aimed to control the source of pollution by appointing a committee to direct the prevention and how to solve fine particulate matter problems in Bangkok, with the Governor of Bangkok as the Chairman (International Affairs Office, 2022) Under this, procedures are categorized according to air quality from levels 1 to 4 a. Level 1 ($PM_{2.5}$ below 37.5 µg/m³) b. Level 2 ($PM_{2.5}$ between 37.6 - 50 µg/m³ c. Level 3 ($PM_{2.5}$ between 51 – 75 µg/m³), and d. Level 4 ($PM_{2.5}$ exceeds 75 µg/m³) However, this action plan is not comprehensive to control emissions from the residential sector (BMA, 2022).

3.1.4 Alignment of city level action plans/strategies with national policy and strategy for air pollution control

Numerous legislations and plans have been prepared for tackling sector -specific issues, and their cross-cutting nature, as well as the commonalities between the Thailand National Action Plan on Fine Particulate Matter, BAQP, and Ad-Hoc Plan on Solving Dust Pollution Problem in Bangkok in 2023. Thus, the city of Bangkok has shown to have a seamless alignment of its local action plans and strategies with Thailand's national policy and strategy for air pollution control. This synchronized approach positions the city of Bangkok in a way to enable it to exemplify a harmonious synergy between regional and national authorities, and in fostering a united front in tackling the pressing issue of air pollution. By integrating the city's initiatives with the broader national framework, Bangkok has demonstrated its commitment towards addressing air quality challenges in a comprehensive and effective manner. This alignment also ensures that a consistent and coordinated implementation of measures such as implementation of technological solutions to mitigate air pollution; promoting cleaner transportation; enhancing green infrastructure; tackling and/or preventing emissions from area and point sources; enhancing regional and local coordination; and enforcing stricter emissions regulations across all the polluting industries, at both the local and national levels, is undertaken. Through this concerted effort, Bangkok is not only setting a pioneering example for other urban centres but also bolstering the nation's endeavours to safeguard public health and the environment from the adverse impacts of air pollution.

3.1.5 Discussion

1. Objectives, strategies, and specific technologies employed

Bangkok's comprehensive approach to air pollution mitigation thus far shows close alignment between its objectives, strategies, and the implementation of specific technologies for air pollution mitigation. The city has worked towards reducing pollution sources, promoting sustainable transportation, enhancing better agricultural practices, and enforcing stricter emissions regulations and controls on industries. These coordinated efforts have yielded tangible improvements in air quality and have laid the groundwork for a healthier urban environment. However, while substantial progress has been made, further endeavours are required to fully meet the stringent air quality standards set by the WHO. Additional measures might involve greater investment in the wider implementation of the stated activities including air pollution mitigation.

2. Evaluation of the effectiveness and impact of these interventions

Some of the interventions, like the low-c ost sensors (LCS) and introducing more EVs to the roads are being undertaken ; however, it has been concluded that the difficulties in implementing aspects such as LEZs and clean cooking and street food have been challenging, especially since it involves different organis ations that need to work closely together and most likely affects the income of the people (e.g., in the case of cleaner cooking for street food). The recommendations that were gathered through consultation also extend to suggest the fact that there is a need for technologies for ex-situ management of agricultural wastes like conversion to biofuel, pellets, and other mitigative technologies in Bangkok. In all, the stated nine technologies and approaches are only practical for a small-scale implementation as of now, but there is still shortage of the mechanism to expand these to a larger area including knowledge transfer and funding/ tax supports.

3.2 Dhaka City

3.2.1 City brief – Programmes on air quality management in Dhaka

City Overview

Dhaka (latitude 23° 48' 37.1916'' N, longitude 90° 24' 45.0756'' E)[27], the capital of Bangladesh, is ranked third[28] in terms of population density and is the fourth[29] largest city in the world. Greater Dhaka population is over 23.44[30] million as per 2022 census, making Dhaka a megacity with a total of 10.27[31] million people living within the main city. Dhaka city is situated in the central part of the country along the banks of the Buriganga River and has one of the most densely populated built-up urban area in the world.

Dhaka's topography is characteris ed by a relatively flat terrain, sitting at an average elevation of approximately 16[32] meters (52 feet) above sea level. The city's landscape is comprised of riverbanks, low-lying areas, and an intricate network of rivers and water bodies. Being part of the Ganges d elta, Dhaka's topography is heavily influenced by the riverine geography of the region. The city has undergone rapid urbanis ation, resulting in the expansion of built-up areas, the creation of numerous water bodies, and the emergence of challenges related to drainage and flood management, particularly during the monsoon season.[33]

The urban fabric of Dhaka showcases a blend of modern skyscrapers and traditional structures. In recent years, Dhaka's population has experienced significant growth, leading to challenges related to infrastructure, traffic congestion, and environmental sustainability. Coupled with its high population density; exponential growth of the industries and economic activities and unrestrained urban development, the city is experiencing high levels of ambient air pollution.

Air Quality Status

In the past decade, Dhaka has been grappling with persistent air quality issues, particularly during specific periods of the year due to rapid urbanis ation, and industrialis ation coupled with massive infrastructure development. The city frequently encounters elevated levels of particulate matter (PM_{10} and $PM_{2.5}$), which are the primary pollutants responsible for Dhaka's poor air quality during the dry

27 https://www.latlong.net/place/dhaka-bangladesh-5656.html

28 https://www.statista.com/statistics/1237290/cities-highest-population-density/

29 https://worldpopulationreview.com/world-cities

30 https://bbs.portal.gov.bd/sites/default/files/files/bbs.portal.gov.bd/page/b343a8b4_956b_45ca_872f_4cf9b2f1a6e0/2023-09-27-09-50-a3672cdf61961a45347ab8660a3109b6.pdf

31 https://bbs.portal.gov.bd/sites/default/files/files/bbs.portal.gov.bd/page/b343a8b4_956b_45ca_872f_4cf9b2f1a6e0/2023-09-27-09-50-a3672cdf61961a45347ab8660a3109b6.pdf

32 https://elevation.maplogs.com/poi/dhaka_bangladesh.168492.html

33 https://en.banglapedia.org/index.php/Dhaka,_Geology

season. The primary pollutant responsible for Dhaka's poor air quality during the dry season is PM, whereas, around the year, other gaseous pollutants (i.e., SO_2, CO, NO_x, and O_3) across Dhaka city satisfies the respective air quality standards with few exceptions. Accordingly, between 2018 and 2021, the rate of accurate daily averaged data for PM_{10} and $PM_{2.5}$ concentrations was 156.40 µg/m^3 and 96.71 µg/m^3, respectively; both values were thrice and six-fold the national limit (35 µg/m^3 and 50 µg/m^3 limit for $PM_{2.5}$ and PM_{10}, respectively). The concentrations of PM_{10} and $PM_{2.5}$ in Dhaka increased in 2021 compared to 2018 to 2020 (Department of Environment, DoE).

While particulate pollution decreased slightly (2.2%) from 2020 to 2021, it has increased over time. Since 1998, average annual particulate pollution has increased by 63%.[34] Dhaka city faces a complex array of pollution challenges including the high density of older vehicles running on low-quality fuels; open burning of waste; industrial emissions, especially the brick kiln emissions; fugitive emissions from the construction activities; road dust and its resuspension; burning of agricultural residue; and use of inefficient stoves and cooking fuel in the residential housing. Pollution levels are further aggravated by seasonal meteorological factors such as weather conditions and temperature inversions. However, during the monsoon season, the rainfall helps improve the air quality of the cities substantially.

To address this concern, the government and various organi sations have undertaken initiatives to monitor and enhance the air quality in Dhaka. These efforts include the establishment of air quality monitoring stations, implementation of regulatory measures, and conducting public awareness campaigns. To obtain the most up-to-date and accurate information regarding Dhaka's air quality, efforts are being undertaken for real-time air quality monitoring and develop indices that provide suitable representation of the pollutant concentration through an AQI with the help of local environmental agencies and other relevant organis ations.

Pollution Sources

Currently, since there is no source apportionment that has been done for Dhaka city, the reference is drawn for a World Bank report titled Striving for Clean Air – Air Pollution and Public Health in South Asia[35] published in 2022, where the total sectoral contribution of Dhaka has been given for $PM_{2.5}$. As per the report, the major sectors contributing to Dhaka's air pollution are cited in Table 6.

Table 6 – Sectoral contribution of $PM_{2.5}$ emission in Dhaka City based on World Bank's Report

Industrial (~35%)	Open waste burning (~7%)
Residential (~28%)	Soil dust (~5%)
Agriculture burning (~11%)	Others (~5%)
Transportation (~9%)	

An important point to note here is that a little over 10% of the $PM_{2.5}$ emissions originate in Dhaka. Most of the $PM_{2.5}$ in Dhaka is due to transboundary impacts .

Regulatory Framework

Some of the major legislations are :

1. Bangladesh Environment Conservation Act 1995 (and its Amendment in 2010)
2. Air Pollution Control Rules, 2022
3. Brick Manufacture and Brick Kiln Set-up (Control) Act, 2013 (and its Amendment in 2019)
4. Comprehensive guidelines/ directives for the control and reduction of air pollution from various sectors (including brick kilns, construction activities, vehicles, open biomass burning, industry,

34 https://aqli.epic.uchicago.edu/wp-content/uploads/2023/08/Bangladesh-FactSheet-2023_Final.pdf
35 https://openknowledge.worldbank.org/server/api/core/bitstreams/fa89a482-f616-4da0-914f-40dac1a88bdc/content

and others).

5. Environment Conservation Rules, 1997
6. Road Transport Act, 2018
7. Bangladesh National Ambient Air Quality Standards (BNAAQS)
8. Bangladesh Standards and Testing Institution (BSTI)
9. Local Government (City Corporation) Act, 2009
10. New Clean Dhaka Master Plan 2018-2030,
11. Sustainable and Renewable Energy Development Authority Act, 2012,
12. Energy Efficiency and Conservation Rules, 2016,
13. Renewable Energy Policy of Bangladesh,
14. Country Action Plan for Clean Cooking, 2013
15. Sustainable Finance Policy
16. Local Government (City Corporation) Act, 2009
17. Setting schedules narrating emission standards for different pollutants across different sectors
18. Energy Efficiency and Conservation Master Plan, 2030
19. Dhaka Air Pollution Control Guideline, 2020
20. Electric Vehicle Charging Guideline, 2022
21. Solid Waste Management Rules, 2021
22. Energy Audit Regulations, 2018
23. Energy Efficiency and Conservation Master Plan, 2030

Some initiatives undertaken across Dhaka :

1. Green banking initiative (under a Sustainable Finance Policy)
2. Subsidy on EVs
3. Learning and Innovation Loan (LIL) project
4. Removal of lead from gasoline in 1999
5. Phasing out of 2-Stroke 3-Wheeled baby taxis from Dhaka in early 20 s
6. Introduction of cleaner fuel like CNG in the transport sector in early 90 s
7. Enlargement of the chimney height of the fixed chimney kiln (FCK) for brick production
8. Phasing out of the FCK technology and pushing for the adoption of the zig-zag technology under the new Brick Manufacturing and Brick Kiln Establishment (Control) Law – 2013
9. Clean Air and Sustainable Environment (CASE) project

Government has brought in various policies and rolled out different initiatives to curtail air pollution, especially to mitigate emissions from the industrial sector including brick kilns, construction sector, vehicular sector, and solid waste and biomass burning.

Monitoring and Data Collection

The DoE, which is under the Ministry of Environment, Forest, and Climate Change (MoEFCC), Bangladesh has been consistently monitoring the ambient air quality of the country through its 16 (sixteen) Continuous Air Monitoring Stations (CAMS) across 8 major cities, and 15 (fifteen) Compact-CAMS installed across the country. 05 (five) criteria air pollutants are continuously monitored by these stations, namely particulate matter (PM_{10} and $PM_{2.5}$), c arbon monoxide (CO), oxides of nitrogen (NO_X), SO_2, and O_3. Daily Air Quality Index (AQI) values are also calculated based on the available air quality

data that refer to the situation of air pollution in terms of health impacts, and this daily AQI is presented on the DoE's website.

It is pertinent to note that according to Open AQ's Open Air Quality Data: The Global Landscape 2022 report, the country does not have fully accessible air quality data. Making these datasets more fully accessible on a more periodic basis would allow Bangladeshi citizens with a variety of skill sets to participate in addressing air pollution.[36]

Health Impacts

In case of Dhaka City, since the PM pollution is the second greatest threat to human health across Bangladesh (closely following cardiovascular diseases), when measured in terms of life expectancy, the PM pollution takes an estimated 6.8 years off the life of the average Bangladeshi citizens. Since 1998, average annual PM pollution has increased by 63 % further reducing life expectancy by 2.8 years. In some of the most polluted districts of the country, spread across the states of Dhaka and Chittagong, 74.7 million residents or 45.3% of Bangladesh's population are on track to lose 7.6 years of life expectancy on average relative to the WHO guideline, and 6.6 years relative to the national standard if the current pollution levels persist. If Bangladesh were to reduce particulate pollution to meet the WHO guideline, residents in Dhaka—the most populous district in Bangladesh—would gain 8.1 years of life expectancy.[37]

Sectoral Overview

Industrial Sector

Dhaka's industrial sector plays a crucial role in the city's economy but also poses the highest air pollution challenges, contributing around 35% of the total city's emissions. This sector, which includes brick kilns, textile, manufacturing, steel rerolling mills, cement industries, tanneries, and various other industries are collectively releasing a substantial quantum of pollutants into the city's airshed, which majorly includes PM_{10} and $PM_{2.5}$, and sometimes other gases—elevating the level of air pollution within Dhaka city. Industries located in and around the city contribute the most to the city's air pollution.

Since the Dhaka division is the core industrial zone with most industries operating perennially, this results in a surge in the critical levels of harmful emissions, especially PM, within the micro airshed of the city and the surrounding areas, which is further exacerbated by the region's rapidly growing industries.

Inadequate environmental regulations and lack of enforcement and compliance assurance are hindering the work towards tackling air pollution at the city and micro airshed level. However, efforts are being made to enforce stricter emission standards, promote cleaner technologies, and encourage sustainable practices. A major challenge for Dhaka's authorities is also the aspect of coordination and collaboration with other agencies and authorities to create a more pollution -free environment in Dhaka.

Residential Sector

The residential sector in Dhaka, which is known for its dense and rapidly growing population, contributes around 25% to 28% of the city's total air pollution. The use of conventional inefficient solid fuels for cooking, often due to limited access to clean energy sources, contributes to high levels of indoor and outdoor air pollution, especially with regard to $PM_{2.5}$. Furthermore, the extensive use of motorized vehicles for personal transportation within residential areas further adds to the overall burden of air pollution. The combination of high population density and limited green spaces worsens the pollution concerns by hindering air circulation. There are a lot of construction activities that are also contributing to the overall emissions. Although, the city authorities are undertaking the developed and/or

36 https://aqli.epic.uchicago.edu/wp-content/uploads/2023/08/Bangladesh-FactSheet-2023_Final.pdf

37 https://aqli.epic.uchicago.edu/wp-content/uploads/2023/08/Bangladesh-FactSheet-2023_Final.pdf

implementing, initiatives that promote cleaner cooking technologies, enhance public transportation, and raise awareness through campaigns to encourage environmentally friendly practices within households.

Agriculture Sector

Around 11% of the total city's emission can be attributed to the agricultural sector in Dhaka, posing a significant challenge to the city's air quality due to various practices—one of which is agricultural burning that involves clearing fields and disposing of crop residues through in-situ burning. This burning results in the release of a significant amount of PM (including black carbon) and other gaseous pollutants into the air. Another contributor to air pollution is the extensive use of pesticides in farming activities, as they emit VOCs during application. Additionally, certain fertilizers used in agriculture release NO_X into the atmosphere. To tackle this issue, efforts are being made to promote different sustainable farming practices, provide alternative methods to crop burning, and educating farmers about environment friendly approaches.

Transportation Sector

Dhaka's transportation sector's growth has contributed around 9% to the city's overall emissions. The cumulative impact of the vehicles, particularly privately owned cars and motorcycles, coupled with the buses, taxis and 3-wheelers has been higher in cases of PM, NO_X, and other pollutants. To add to this, the persistent issue of traffic congestion and prolonged idling time further increases the emissions. Moreover, the use of older and poorly maintained vehicles fuelled by low-quality fuels, further worsens the pollution levels. Despite the existence of a growing public transit system (buses and rickshaws), heavy reliance on personal vehicles obstructs efforts to combat air pollution in this sector. Large number of vehicles plying on an inadequate number of roads generate traffic congestion, resulting in excessive vehicular emissions and thus high air pollution in Dhaka city. Most city buses are old with inefficient engines, thus emitting black smokes and unburnt fuels particles, increasing emissions further. A collective of old and outdated vehicular fleet, improper traffic and parking management; overloading of roads; lack of maintenance of the mobility infrastructure; and nonstandard adulterated fuel has driven the vehicular sector's contribution to air pollution in the Dhaka city to levels that are much higher than the city's carrying capacity. Further, the emissions from the transportation sector in Dhaka is leading to an economic losses of 3.8 billion USD per year and manhour loss as per the Annual Report of Dhaka Metro Rail Corporation Limited (DMRCL), 2022.

To address this substantial contribution of the transportation sector to the city's air quality challenges, Dhaka's authorities are implementing initiatives that promote sustainable transportation modes, enhance traffic management, off-roads the older vehicles, and enforce stricter emission standards.

Waste Management Sector

Dhaka's waste management sector plays a crucial role in maintaining urban sanitation, but unfortunately, it also contributes significantly to the city's air pollution problems due to inadequate waste disposal practices. Open burning of solid waste, which is a common practice in areas where the collection is rarely undertaken and during winter months, results in the release of PM, CO, black carbon, and VOCs. Moreover, the absence of proper waste segregation and recycling infrastructure further exacerbates pollution concerns. The inefficiencies in waste collection and disposal systems, combined with the rapid population growth of the city, create significant challenges in ensuring a clean and sustainable urban environment. To address the issue of air pollution stemming from the waste management sector, the city administration is developing comprehensive waste management strategies that includes initiatives to reduce waste generation, proper disposal methods, and the promotion of recycling practices to minimis e the environmental impact of waste-related activities in Dhaka.

Road and Soil Dust

Dhaka city has recently witnessed an enormous construction work in the form of some mega-projects that include metro-rail, elevated expressway, and the third terminal of the Hajrat Shahjalal International airport. Dust is a significant byproduct of these ongoing construction activities. These PMs are particularly prevalent during excavation, earthmoving, and building construction. Unfortunately, the lack of adequate dust control measures results in the resuspension of dust particles from construction sites, leading to increased levels of PM_{10} and $PM_{2.5}$ in the air. This issue is further exacerbated by dry and windy conditions, which contribute to the dispersion of dust and ultimately contribute to poor air quality. On the contrary, each year, with the onset of winter, the air quality dips to its worst as $PM_{2.5}$ fill the air around the city roads, especially in areas where construction work is in progress. Unfortunately, currently there is no concrete safeguard to protect public health in such places.

Transboundary Pollution

The share of local sources in ambient $PM_{2.5}$ varies over South Asia, depending on topography, meteorology, the intensity and spatial patterns of emissions, and the size of the administrative regions. Figure 1 compares sources across the Indo-Gangetic Plain city of Patna, with Dhaka, Bangladesh; Kathmandu, Nepal; Rawalpindi, Pakistan; and Colombo, Sri Lanka. As can be seen, the sources vary significantly within and across the major cities in South Asia. In Dhaka city, the major air pollution sources are large industries, small industries (brick kilns), household and commercial sources, and m obile sources. Dhaka itself produces 10% of pollution and the rest of the pollution comes from outside of Dhaka. The inside pollution's major sources are small and big industries, residential, mobile sources, and municipality waste.

Table 7 – Key Initiatives and Interventions in Bangladesh

Control Transport Emissions – 1. Bangladesh Environment Conservation Act, 1995 2. Bangladesh Road Transport Act, 2018 3. Air Pollution Control Rules, 2022 4. Dhaka Air pollution Control Guideline, 2020 5. CNG and LPG conversion facilities are available.	**Brick kilns and other industries** 1. Manufacture and Brick Kiln Set-up (Control) Act, 2013 (and amended in 2019) 2. Air Pollution (Control) Rules, 2022 3. Use of non-fired bricks in all government development works by 2025
Shift freight transport from road to lower-emission modes including rail and water. 1. Establishment of Dhaka Mass Transit Company Limited (DMTCL) 2. Air pollution Control Guideline, 2020 3. Electric Vehicle Charging Guideline, 2022 (Targeting EV operability of 30% by 2030 and 100% by 2041)	**Municipality solid waste management** 1. New Clean Dhaka Master Plan 2018-2030 2. Solid Waste Management Rules, 2021 3. Air P ollution Control Rules, 2022 4. Dhaka Air pollution Control Guideline, 2020 5. Waste to Energy Projects in North and South Dhaka
Transportation management for construction works and construction materials 1. Air Pollution Control Guideline, 2021 2. Air Pollution Control Rules, 2022	**Switch to low sulphur fuel (50 ppm)** 1. Bangladesh Standards and Testing Institution (BSTI) Standards

Table 7 – *(Continued)*

Clean technologies (Solar) 1. Sustainable and Renewable Energy Development Authority Act, 2012 2. Country Action Plan Clean Cooking. 2013 3. Energy Audit Regulations, 2018 4. Energy Efficiency and Conservation Master Plan up to 2030 5. Solar Command Centre (SCC)	**Energy efficiency technology** 1. Sustainable and Renewable Energy Development Authority Act, 2012 2. Country Action Plan Clean Cooking , 2013 3. Energy Audit regulations, 2018, 4. Energy Efficiency and Conservation Master Plan up to 2030
Provide cleaner fuel (LPG, Electricity) and biomass stoves with an efficiency of 50% or more and with a forced draft fan for those who can afford LPG. 1. Country Action Plan Clean Cooking , 2013	**Ambient air quality and industrial emission monitoring** 1. Environmental Conservation Act, 1995 2. Air Pollution (Controls) Rules, 2022
Source apportionment study and Emission Inventory 1. Air Pollution (Controls) Rules, 2022	**Awareness** 1. Air Pollution Control Rules, 2022

Challenges and Future Plans

The following list represents the areas where different aspects are the immediate challenges for Dhaka's administration and their immediate future plan is to be addressed at the earliest.

1. Transport
    a. Clean fuel
    b. Electric mobility
    c. Mass transport
2. Municipal solid waste
3. Construction activities
4. Dust management
5. Industries
6. Residential
    a. Cleaner technologies
7. Multistakeholder and cross-sectoral coordination
8. Institutional strengthening, capacity, and technology development
9. Regulatory and compliance
    a. Air quality monitoring and forecasting
    b. Source apportionment study and emission inventory
    c. Compliance enforcement
10. Skill enhancement and awareness generation

Collaboration and Partnerships

Efforts to address AQM and promote collaboration and partnerships in Bangladesh have been ongoing at both the city and national levels.

Focusing on Dhaka, the city authorities have been working with various stakeholders, including environmental organis ations, research institutions, and international agencies, to implement measures aimed at improving city's air quality. These measures have included the establishment of air quality monitoring stations, public awareness campaigns, and the development of action plans to mitigate pollution. However, there is no concrete plan in place on how the city administration would be going about it, and what would be the format and structure of such collaborations and partnerships.

At the national level, the government of Bangladesh has recognized the significance of tackling air pollution and has put in place policies and regulations to control emissions from different sectors. However, just as in case of Dhaka's city administration, the DOE, Bangladesh, which is the main regulatory body supporting the MOEFCC, Bangladesh, does not have concrete plan in place on how they would be undertaking collaborations and partnerships for their AQM work.

Furthermore, since the success of collaborations and partnerships involves the use and sharing of expertise, data, and best practices to develop effective strategies for pollution control, which is limited at this given point in time, it becomes difficult to strategize and plan such collaborations to move things ahead even when there is extensive active support from international organis ations, non governmental organis ations (NGOs), and research institutions.

It is equally important for the government agencies to keep themselves updated with all the latest developments and progress, especially with regard to data monitoring and other official regulatory information. This will help them in keeping pace with the evolving nature of collaboration and partnerships, since all stakeholders who are engaged with the government on any of their AQM initiatives, would seek government support to access all such official information. Since government agencies are the best sources for obtaining the most current information, it would be helpful in further strengthening such collaborative efforts, thus boosting the success rate of the AQM initiatives being undertaken.

Performance and Trends

Being one of the most polluted cities globally, Dhaka has been experiencing major challenges in addressing its air pollution problem in recent years. Industrial (~35%), residential (~28%), agriculture residue burning (~11%), transportation (~9%), open waste burning (~7%), and fugitive dust (~5%) remain the mains sources with about 90% of the city's pollution originating from outside the city's boundaries. Garment manufacturers (RMG), chemical industries, brick kilns, pharmaceutical industries, and other industrial emission from the industries located in and immediately outside Dhaka contribute to its air pollution[38]. PM_{10} and $PM_{2.5}$ are the most prevalent pollutants of concern for Dhaka . The annual average concentration of $PM_{2.5}$ in Dhaka from 2017 to 2022, has ranged 79.7 μg/m³, 97.1 μg/m³, 83.3 μg/m³, 77.1 μg/m³, 78.1 μg/m³, and 65.8.7 μg/m³, respectively[39]. Despite the average value exceeding 10 times the WHO guidelines for ambient air quality, a decreasing trend can be observed. This can be attributed to the multiple policy measures and initiatives that have been taken by the city administration to mitigate air pollution and prevent its further increase.

38 https://pubs.aip.org/aip/acp/article-abstract/2713/1/060013/2887353/Estimation-of-air-pollutants-from-different?redirectedFrom=fulltext

39 https://www.iqair.com/in-en/world-most-polluted-cities?continent=59af92b13e70001c1bd78e53&country=C6qfKtSfvq5FAxdC8&state=&sort=-rank&page=1&perPage=50&cities=

It is, however, important to note that according to some recent studies and research, air pollution-related fatalities and diseases have been on the rise in recent years in Dhaka, exerting significant health burden on the city dwellers. Besides the PM_{10} and $PM_{2.5}$, some research also points towards an increasing trend of CO, NOx, and SO_2 from the industrial sector. Whereas, in case of the transportation sector, only CO and NOx emissions are on the rise, but SO_2 emission is on the decrease. Moreover, CO and NOx emission from the residential, commercial, and other combustion sectors is on the rise, while on the contrary, SO_2 emission follows the same trends as is the case of the transportation sector.[40]

3.2.2 Description of the air pollution mitigation technology interventions implemented in Dhaka

Table 8 – Technological Interventions from the Dhaka City Assessment

Area/ Sector	Technological Interventions
Transport Sector	1. Diesel particulate filter (DPF) 2. Electric v ehicles (EVs) 3. Remote sensing for vehicle exhaust emissions 4. Enhancement of inspection and maintenance (I&M) systems, and 5. Fleet modernization Inspection and Maintenance Systems 6. Cleaner fuel compressed natural gas (CNG) and lead-free diesel to the transport sector in the early 90s
Industrial Sector	1. Filters and dust collectors 2. Continuous Emission Monitoring Systems (CEMS) for industrial air pollution monitoring
Residential Sector	1. Use of improved Cook Stove (ICS) 2. Use of LPG or natural gas for cooking
Waste Management Sector	1. Waste-to-energy production project
Construction Sector	1. Alternative building materials including construction blocks
Dust Management	1. Dust Control Measures
Air Quality Monitoring	1. Low-cost Sensor (LCS)

3.2.3 City level action plans and strategies for air pollution control

At present there is no specific action plan for the city of Dhaka , but the city administration is currently in the process of developing a city-specific action plan. However, some of the major regulations that have been notified by the MOEFCC, Bangladesh including Air Pollution Control Guidelines, 2020; Air pollution Control Rules, 2022; New Clean Dhaka Master Plan 2018-2032; and Solid Waste Management Rules, 2021 are being used for undertaking targeted actions in Dhaka to mitigate sectoral emissions.

One of the initial actions that was taken to mitigate the air pollution in Dhaka city was following the High Court order of 26th November 2019, in compliance of which, the MOEFCC prepared the Air Pollution Control Guidelines (2022) to take necessary steps to find the causes of air pollution and take required measures to prevent and reduce air pollution in Dhaka. In addition to this, the New Clean Dhaka Master Plan 2018-2032 was another official document to be notified by the Dhaka North City Corporation

40 https://pubs.aip.org/aip/acp/article-abstract/2713/1/060013/2887353/Estimation-of-air-pollutants-from-different?redirectedFrom=fulltext

(DNCC) with an aim to undertake SWM in Dhaka. By using Air Pollution Control Rules, 2022, the MOEFCC, Bangladesh issued comprehensive guidelines/ directives to relevant government and non government entities to control and reduce air pollution from their respective activities, particularly pollution from brick kilns, construction activities, vehicles, waste/biomass burning, waste handling, and others.

Air Pollution Control Rules, 2022; the Air Pollution Control Guideline, 2020; Solid Waste Management Rules, 2021; and the New Clean Dhaka Master Plan 2018-2032 for solid waste management were also used collectively to define the City Corporation's duties and responsibilities for taking actions on some pressing aspects such as open burning; waste management; construction activities; and construction materials transportation; and road and soil dust control. In addition to this, work has also started for operationalis ing waste-to-energy (WtE) plants in the Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC).

The following table summarizes the current actions/activities/policy measures being undertaken to improve Dhaka's air quality.

Table 9 – Summary of the policy actions being undertaken across Dhaka to mitigate the city's air pollution

Action	Lead and Co-lead ministry/ Department/ Institute/ Agency	Relevant Policies
Control Transport Emissions	RTHD, BRTA, Bangladesh Police	Bangladesh Environment Conservation Act, 1995; Bangladesh Road Transport Act, 2018; Air pollution Control Rules, 2022 ; Dhaka Air pollution Control Guideline, 2020.
Switch to low sulphur fuel (50 ppm) and implement like Euro-V)	EMRD, BPC, RTHD, BRTA, BSTI and development partners	BSTI Standards
Shift freight transport from road to lower-emission modes such as rail, electric vehicles, public transport development	MORTB, Bridges Division, RTHD, LGD, City Corporation BRTA, MRTA and development partners	DMTCL target; Air pollution Control Guideline, 2020; Electric vehicle charging guideline, 2022
Municipality solid waste management	Local Government Division North and South City Corporation	New Clean Dhaka Master Plan 2018-2030, Solid waste management Rules, 2021 ; Air pollution Control Rules, 2022 ; Dhaka Air pollution Control Guideline, 2020
Construction works and Construction materials transportation management	LGD, North and South City Corporation, RAJUK, WASA, DESA, DESCO, ICT division	Dhaka Air pollution Control, Guideline, 2020 ; Air pollution control Rules, 2022

Table 7 – *(Continued)*

Action	Lead and Co-lead ministry/ Department/ Institute/ Agency	Relevant Policies
Launching a national Clean Air Mission of Dhaka for multi- scale and cross-sectoral coordination	All concern ministry/division/ institute/Authority	Relevant Plan and Policies
Phase out most polluting brick kilns from surrounding of Dhaka and Implement emission standards and to control gaseous pollutants (NO, SO) and fine particulate (black carbon and fly ash) emissions from big industries.	MOEFCC, DoE, DC offices	Brick production and Kilns Establishment (Control) Act, 2013 (amended 2019), Air pollution (control) Rules, 2022
Clean technologies (Solar)	Power Division SREDA, MOI, MOST, MOC, IDCOL, NGOs and development partners	Sustainable and Renewable Energy Development Authority Act, 2012; Country Action Plan Clean Cooking , 2013; Energy Audit regulations, 2018; Energy Efficiency and Conservation master plan up to 2030
Energy efficiency technology	Power division, PDB, SREDA, MOST, Energy Regulatory Authority and development partners	Sustainable and Renewable Energy Development Authority Act, 2012; Country Action Plan Clean Cooking , 2013; Energy Audit regulations, 2018 ; Energy Efficiency and Conservation master plan up to 2030
Provide cleaner fuel (LPG, Electricity) and biomass stoves with an efficiency of 50% or more and with a forced draft fan for those who can afford LPG.	Local Government division, City Corporation, IDCOL, NGOs, and development partners	Country Action Plan Clean Cooking, 2013
Institutional strengthening, capacity, and technology development	All concern ministry/division/ institute/Authority	Relevant Acts, Rules and policies
Source apportionment study and emission inventory	DoE and Academia	Air pollution (Controls) Rules, 2022

Action	Lead and Co-lead ministry/ Department/ Institute/ Agency	Relevant Policies
Ambient air quality and industrial emission monitoring	MOEFCC, DoE, industries, and Academia	Environmental Conservation Act, 1995; Air pollution (Controls) Rules, 2022
Enforcement activities	All concern ministry/division/ institute/Authority	Relevant Acts Rules and policies
Awareness	All concern ministry/division/ institute/Authority	Air pollution Control Rules, 2022

3.2.4 Alignment of city level action plans/strategies with national policy and strategy for air pollution control

To understand the alignment of the city level action plan/ strategies with the national policies and strategies, it is important to understand the jurisdiction of the main regulations and initiatives that are relevant in the case of Dhaka. First , the Government of Bangladesh promulgated Air Pollution Control Rules 2022 and Solid Waste Management Rules 2022, which are applicable for the entire nation including Dhaka city. Second , the MOEFCC, Bangladesh also notified the Air Pollution Control Guidelines (2022) following the direction given by the High Court on 26th November 2019, with an objective to take necessary steps to find the causes of air pollution and take required measures to prevent and reduce air pollution in Dhaka City and its surrounding area—providing a regulatory framework and policy guidelines for controlling air pollution of the city of Dhaka. However, these policies are sector/ aspect specific, and it doesn't correspond to a city-level action plan. Since a city-level action plan for AQM in Dhaka city is yet to be prepared, these guidelines would be used for taking the necessary action until the city-specific action plan is developed. The city-specific action plan for Dhaka would be a city-specific document containing a time bounded and targeted roadmap of implementing various air pollution mitigation and prevention measures, that would have to be achieved as per the defined timeline and targets, in a phased manner. And all the policies pertaining to the control of air pollution in the city of Dhaka, that have been notified at the national level as well as the city level, would be applied through Dhaka's city-specific action plan that is currently being developed.

3.2.5 Discussion

1. Objectives, strategies, and specific technologies employed

Dhaka city has undertaken a multifaceted approach to mitigate its escalating air pollution, driven by clear objectives, strategic interventions, and the implementation of specific technologies. However, most of the aspects are still existing only on paper, especially their city air action plan, and need to see ground-level implementation. Dhaka city's main mitigation approaches encompass curbing emissions from the major pollution sectors to enhance public health and improve overall quality of life. Strategies include promoting sustainable transportation options; improvement in the current waste management system; better monitoring network and data; adoption of more effective mitigation technologies; switching to cleaner energy sources; stringent enforcement of emissions norms industries, especially the brick kiln; undertaking emission inventory and source apportionment studies for the city; and enhancing public support and generating awareness have been the main highlights. Dhaka has also emphasis ed modifying city infrastructure to develop more green spaces and creating pedestrian-friendly zones to reduce vehicle emissions and enhance urban greenery. Technological solutions, such as introducing compressed natural gas (CNG) buses, installing air quality monitoring networks, and advancing waste

management practices, have been deployed to partially mitigate the high pollution levels and address sources at their roots. Despite these efforts, the challenge of air pollution remains significant due to rapid urbanis ation, industrial activities, and population growth. Continued dedication to these strategies and the exploration of innovative technologies will be vital to ensure a healthier and more sustainable future for Dhaka's residents.

2. Evaluation of the effectiveness and impact of these interventions

The effectiveness and impact of air pollution interventions in Dhaka have yielded mixed results. While efforts to implement stricter emission standards for vehicles and industries, improve public transportation, and regulate industrial emissions have been initiated and have also been successful in controlling the increase in the annual average concentration of PM (especially $PM_{2.5}$), challenges arising due to lack of proper enforcement, rapid urbanis ation, and traffic congestion continue to hinder their full potential. Consequently, Dhaka still faces significant air quality issues, especially during the winter months when factors like crop residue burning and adverse meteorological conditions further exacerbate the air pollution levels within the city. While these interventions have shown promise, the city needs sustained commitment and a holistic, multi pronged approach to make more substantial and lasting improvements in air quality, underscoring the complex nature of addressing air pollution in densely populated urban environments like Dhaka. Another important intervention that needs to be considered in case of Dhaka is the aspect of coordination and collaboration, at the regional as well as international level since more than 90% of the pollution of Dhaka comes from outside the city.

3.3 Gurugram City

3.3.1 City brief – Programmes on air quality management in Gurugram

City Overview

Gurugram city (latitude 28° 27' 27.0828'' N, longitude 77° 1' 34.8384'' E) is located 30 km south of India's national capital New Delhi. Over the past 25 years, the city has undergone rapid development and construction, particularly in industry and urbanis ation. Gurugram is one of Delhi's major satellite cities and is part of the National Capital Region (NCR). It is within commuting distance of Delhi via an expressway and Delhi Metro.

The city is the second largest in the Indian State of Haryana and is the industrial and financial centre of Haryana. It has the 3rd highest per capita income in India after Chandigarh and Mumbai. It is also the only Indian city to have successfully distributed electricity connections to all its households. It is also the IT hub & centre of various BPO companies.

It has a total area of 1253 sq. km , with a population density of 1241 people/ sq. km. As of 2011 census, Gurugram city has a population of 1,514,085; however, the current estimated population as of 2023 is 1,209,000, while that of Gurgaon metro population is estimated at 1,243,000.

Gurugram faces an overwhelming challenge in the sheer urban explosion – along with aspirational pressures – that it is witnessing. This is triggering immense environmental and sustainability concerns, one of which is air pollution. Gurugram is among the worst affected cities by air pollution. In 2018, it ranked number 1 as the most polluted city in IQAir AirVisual's 2018 World Air Quality Report. In March 2019, Gurugram was again named the 7th most polluted city in the world by the IQ Air's World Air Quality Report.

Air Quality Status

The primary pollutant responsible for Gurugram's poor air quality, especially during the autumn and winter season is the PM. The PM_{10} and $PM_{2.5}$ annual average concentrations were 163.67 µg/m^3 and 101.2 µg/m^3 respectively; both values were more than twice the national limit (60 µg/m^3 and 40 µg/m^3) [41] for both PM_{10} and $PM_{2.5}$ respectively. The concentrations of PM_{10} and $PM_{2.5}$ in Gurugram have been increasing.

Over the last decade, the rapid urbanis ation and industriali sation together with massive infrastructure development have caused increased air pollution in the city. Furthermore, since Gurugram is in the NCR's airshed, the air quality deteriorates even further. There is only a limited number of real-time air quality monitoring stations in the city which are not a suitable representative of the city's air quality. The air pollution level in Gurugram is very severe, especially during the winter season when the wind speed is low in a region that is land-locked, and therefore it becomes extremely vulnerable to trapping of toxic air.[42]

In recent years the air quality in Gurugram has been one of the worst in the country. As per the official data published by the CPCB, the air quality index (AQI) this February in Gurugram was the worst in the past 3 years, with the average daily AQI being around 228 when compared to 212 and 224 in 2022 and 2021, respectively.[43]

Pollution Sources

There is no official pollution inventory or source apportionment study for the NCR or Gurugram to indicate the relative contribution of different pollution sources to overall pollution load and air quality. Assessment shows that the key pollution sources are vehicles, industrial areas, construction activities, high use of diesel generator sets, waste burning, road dust, and biomass chulhas, among other things. Explosive growth in motorisation and extensive use of diesel generator sets are serious sources of direct toxic exposure.[44]

There is no previous official source apportionment study that has been undertaken, however, as per the Delhi-NCR source apportionment of $PM_{2.5}$ & PM_{10} undertaken by TERI, that highlights the PM_{10} concentrations in Gurgaon has a contribution of dust (road dust, construction, and other sources) between 32% and 52% in summers and 23% to 30% in winters; vehicular emissions is between 14% and 19% in summers and 16% to 23% in winters; industrial contributions (mainly from sources outside of Gurgaon) are between 13% and 26% across both seasons; and the biomass contributes is between 13% and 19% during summer and 14% to 20% during winters. All other sources (including residential, DG sets, Refuse burning, crematoria, restaurants, airports, waste incinerators, and landfill fires) contribute 6% to 8% across both seasons. [45]

In terms of $PM_{2.5}$, Gurugram shows significant contribution across both summer and winter seasons across all major sectors. For the vehicular sector, the contribution of $PM_{2.5}$ ranges between 16% and 26%; contribution of dust (road dust, construction, and other sources) is between 29% and 49%; contribution of the industrial sector ranges between 13% and 19%; in case of biomass it is between 14% and 16%, and the contribution from all other sources (including residential, DG sets, Refuse burning, crematoria, restaurant, airports, waste incinerators, and landfill fires) ranges between 8% and 10% across both seasons.[46]

Regulatory Framework

41 https://cpcbenvis.nic.in/airpollution/standard.htm

42 http://cdn.cseindia.org/attachments/0.89397800_1525342802_gurugram-a-framework-for-sustainable-development-update.pdf

43 https://timesofindia.indiatimes.com/city/gurgaon/february-air-worst-in-3-years-in-gurgaon-lack-of-rain-severe-cold-main-factors/articleshow/98321216.cms?from=mdr

44 http://cdn.cseindia.org/attachments/0.89397800_1525342802_gurugram-a-framework-for-sustainable-development-update.pdf

45 https://www.teriin.org/sites/default/files/2018-08/Report_SA_AQM-Delhi-NCR_0.pdf

46 https://www.teriin.org/sites/default/files/2018-08/Report_SA_AQM-Delhi-NCR_0.pdf

The Constitution of India included provisions for the protection of the environment—it was inserted after the Forty-Second Constitutional Amendment on 28th August 1976[47] under Article 48A and 51A(g). The stated preamble of Article 48A[48] made environmental protection the responsibility of the Government. Whereas under Article 51A(g)[49], environment protection was made part of the Fundamental Duties.[50] The major thrust for these Articles under the 42nd Amendments came from the United Nations Conference on Human Environment, 1972 that took place in Stockholm (Stockholm Conference), which India was a part of.

1. Air (Prevention & Control of Pollution) Act 1981 (Air Act)
2. Environment (Protection) Act 1986 (EP Act)
   a. Environment (Protection) Amendment Rules, 2015[51]
   b. Construction & Demolition (C&D) Waste Management Rules, 2016
   c. Dust Mitigation Notification, 2018
   d. Guidelines of Dust Mitigation measures for construction & demolition activities, 2017[52]
   e. Solid Waste Management Rules, 2016
3. The Commission for Air Quality Management in National Capital Region and Adjoining Areas Act, 2021

Monitoring and Data Collection

The CPCB has been consistently monitoring the ambient air quality of the country using two of its networks—National Air Quality Monitoring Programme (NAMP) with a series of manual monitoring stations across India, and the real-time Continuous Ambient Air Quality Monitoring (CAAQM) stations. Whereas the NAMP monitors 4 pollutants, i.e., SO_2, NO_2, $PM_{2.5}$, & PM_{10} regularly, the CAAQMS monitors 8 parameters ($PM_{2.5}$, PM_{10}, CO, SO_2, NO_2, NH_3, O_3, and C_6H_6). Daily Air Quality Index (AQI) values are also calculated based on the available air quality data that refers to the situation of air pollution in terms of health impacts, and this daily AQI is presented on the official CPCB website and many other official and information relevant websites.[53]

As of October 2023, 931 NAMP stations and 498 CAAQMS stations are operational across India. Both these networks are currently being expanded to ensure more spatial as well as temporal coverage in the coming months.

Health Impacts

The Ministry of Health and Family Welfare (MoHFW), Government of India, constituted an inter-agency steering committee on air pollution and health in January 2014 with two important goals—collating and critically appraising evidence available both at Indian and global levels linking air pollution exposure to adverse health effects, and for providing recommendations for policy and programmatic responses across sectors which can both enable mitigation of exposure and adaptation for harm reduction. This was undertaken

47 https://legislative.gov.in/constitution-forty-second-amendment-act-1976 (Viewed on 11th November 2021)

48 Article 48A mentions that, "*The State shall endeavour to protect and improve the environment and to safeguard the forests and wildlife of the country.*"

49 Article 51A(g) mentions that, "*It shall be the duty of every citizen of India to protect and improve the natural environment including forests, lakes, rivers and wildlife, and to have compassion for living creatures*;"

50 https://legislative.gov.in/constitution-forty-second-amendment-act-1976 (Viewed on 11th November 2021)

51 Environment (Protection) Amendment Rules, 2015, S.O. 3305(E), 7th December 2015 (https://egazette.nic.in/WriteReadData/2015/167141.pdf) (Viewed on 11th November 2021)

52 Guidelines on DUST mitigation measures in handling Construction material & C&D wastes (Control of Urban Pollution Series CUPS/89/2017-18) https://cpcb.nic.in/openpdffile.php?id=UmVwb3J0RmlsZXMvNTYxXzE1MTE5MzMzNzJfbWVkaWFwaG90bzEyNjcxLnBkZg== (Viewed on 11th November 2021)

53 National Ambient Air Quality Status & Trends 2019 (National Ambient Air Quality Monitoring; NAAQMS/45/2019-2020), CPCB, September 2020

based on studies that have shown that exposure to air pollution, be it ambient or household, is part of a continuum, and reinforces the need for an integrated approach towards mitigation and harm reduction. [54]

As recent as last year, there was an observed rise in asthma and chronic obstructive pulmonary disease (COPD) patients as soon as the winter approaches, which is where the air pollution is at its worst. Many residents experience breathlessness, coughing, watering of eyes, and irritation of nose. When combined with the rise in the viral respiratory symptoms, the increase in air pollution during winter months is forcing patients with respiratory issues to increase their doses of inhalers and nebulization, and in some cases even hospitalisation of elderly patients and children to support them in managing their breathlessness.[55]

Overview Of Sectoral Challenges

Overburdened due to economic and commercial boom in Gurugram coupled with the population boom and the unplanned development along the outskirts of the city, and the multiple SEZs and industries of all sizes, have been collectively putting pressure on the city's air quality.

Transportation Sector

About 450,000 vehicles ply on Gurugram roads daily. About 50,000 are added every year, while 900 trucks cross the city every day. Diesel use is also very high because of the huge numbers of diesel cars and SUVs, as well as the 10-to-14-seater diesel autos that are used for shuttle services.[56]

The limited public transport options in Gurugram result in high vehicle ownership and pollution. The city has one of the highest vehicle ownership rates in the country – i.e., 323 cars per 1,000 people, which is higher than in Delhi (88 cars per 1000 people). In Gurugram, 43 % of the households' own two-wheelers and 33 % own cars. Bus numbers have not increased appreciably in the city and are 50 % less than the service level benchmark of 60 buses per lakh population (it was 31 per lakh in 2014-15).

Although the implementation of stringent fuel and vehicular emission standards is being undertaken gradually nationally, starting April 1, 2020, the volume of the number of vehicles per household is only going up—adding to the already traffic jam causing vehicular fleets in the city. Therefore, despite the introduction of improved vehicular emission standards and low Sulphur fuel standards which are geared to reduce emissions from all new vehicles, the emissions from the transport sector are not seeing a decreasing trend. In addition to this, the public transportation, including the last mile connectivity in Gurugram is not as per the growth and development that the city is witnessing, which is pushing the citizens to go for private ownership of a vehicle, be it two-wheelers or three -wheelers.

Agricultural Sector

The stubble burning problem that exists in the IGP region is highlighted globally on an annual basis. The deliberate ignition of crop residues after harvest across the fields of Punjab, Haryana, and Uttar Pradesh has emerged as a grave concern for air quality in Gurugram city. As the harvest season unfolds, farmers across the agriculture district of these three states resort to this method to clear their fields quickly and prepare them for the next planting cycle. However, the repercussions of stubble burning on air quality have been found to be substantial and distressing. The prevailing winds during this period carry the smoke and pollutants produced by these fires directly into low-lying areas which includes Gurugram city as well, causing a significant deterioration in air quality. The resultant smoke comprises a hazardous mixture of particulate matter ($PM_{2.5}$ and PM_{10}), CO, VOCs, and other noxious gases. These pollutants inflict severe health consequences, exacerbating respiratory ailments, triggering irritation in the eyes

54 https://main.mohfw.gov.in/sites/default/files/5412023661450432724_0.pdf

55 https://www.hindustantimes.com/cities/gurugram-news/gurugram-hospitals-see-increase-in-patients-with-respiratory-issues-101667327443433.html

56 http://cdn.cseindia.org/attachments/0.89397800_1525342802_gurugram-a-framework-for-sustainable-development-update.pdf

and throat, and elevating the risk of cardiovascular diseases among the city's residents. Furthermore, the dense smog generated by stubble burning severely reduces visibility, disrupts transportation, and impairs the overall living conditions in Gurugram. The agencies and government of all three states have been working year after year on tackling this issue, that is demanding a multifaceted approach involving policy measures, educational initiatives for farmers on alternative residue management techniques, and technological innovations to curtail the detrimental impact of stubble burning on Gurugram's air quality, but the results have been relatively sluggish.

Residential Sector

Residential sector is contributing to a cumulative net positive impact on the air pollution of the Gurugram city. The population of the city has been booming since the onset of economic and infrastructure in the city—leading to more energy utilis ation for livelihood, commuting, recreation, etc. Although the residential fuel that is being utilised are the efficient in nature like electricity, LPG, etc., the per capita consumption is increasing at a rate that is negating any positive development that may have taken place due to government policies and/or plans.

To make matters worse, the areas surrounding the city are dominated by low-income families that do not have access to the same facilities as the city dwellers and thus are using conventional energy sources, which are inefficient and contribute much more to the air pollution—which in turn is putting more burden on an already polluted city-level micro-airshed.

Furthermore, the Haryana government authorities estimate that, at present, more than 14,000 diesel generator sets are running in Gurugram (2019). Besides shopping malls, markets and offices, thousands of residential apartments run on diesel generators as well. A study by Centre for Science and Environment (CSE) in 2018 reported that the use of diesel generator sets increases the level of $PM_{2.5}$ and PM_{10} in Gurugram by 30 %.

Industrial Sector

The industrial belt stretching from the south-west of Gurugram, i.e., starting from Alwar, and making its way to Gurugram through Bhiwandi is a region that contributes a significant amount of pollution to the NCR region. There is a total of 21[57] industrial areas in Alwar that include large, medium, and small-scale industries. Some of the major mines and mineral processing is also done in different parts of the Alwar district.

Then comes the Bhiwandi district that is majorly an industrial area for all three types of industries, i.e., large, medium, and small-scale industries, with a total of 2250 registered industrial units. As the district is famous for its mineral resources especially kankar, saltpeter, and road metal. There are about 110 queries of kankar and building stone in the district. In addition to that, about 270 stone crushing units are also functional, mostly in the Kalyana and Tosham areas of the district. These stone crushers units are important as they meet the building material demand of the major area.[58] Other small and medium types of industries include brick kilns, textile, steel, and rerolling metal, cement, tannery, electroplating, are also part of these industrial clusters.

Then there are special economic zones in Gurugram itself. A total 28 SEZs have been notified in Gurgaon district, which are bifurcated into 20 SEZs for Information Technology (IT) and Information Technology Enabled Services (ITeS); 2 SEZs each for multi-service, biotechnology, and electronics and hardware; and 1 each for textiles, and engineering. [59]

Brick kilns that are spread across the region and are operational across 6 to 7 months a year, have a

57 https://dcmsme.gov.in/old/dips/DIPR_Alwar.pdf

58 https://dcmsme.gov.in/old/dips/har_bhiwani.pdf

59 https://www.india-briefing.com/news/special-economic-zones-warehousing-clusters-delhi-ncr-18871.html/

significant contribution to the Delhi-NCR airshed. Since most of the brick kilns that were using Fixed Chimney Bull's Trench Kiln (FCBTK) technology have now transitioned to the Zig-Zag technology, the emissions from the kilns have reduced. However, as per CPCB, the number of operational brick kilns are estimated to be more than the carrying capacity of the airshed. Near Gurugram, there are over 390 operational brick kilns, that are running on the zig-zag technology.[60]

Multiple industries and SEZs in and around Gurugram have an adverse impact on its air quality. Since most of the industries, which are closer to the city area have shifted to clearer fuels like the CNG, LPG, etc. or alternative fuels like the agro-residue biomass pellets have replaced the traditional coal and wood, the impact due to the operations of these industries have come down. However, that is not the case with other industries that are operating outside the city limits.

Brick kilns, mining, steel and rerolling meal, cement, tire-burning, stone querying, crushing, etc., and other big and small industries both independent and in the SEZs are contributing to the air pollution in Gurugram.

Waste And Construction

Due to the rapid development of Gurugram city and its surrounding areas, the construction has been one of the major causes of concern for the city authorities and the residents. In the source apportionment study undertaken by TERI, the dust emanating from the road and the construction sites account for the lion's share across both seasons, pointing towards its impact. In the case of waste management, open waste burning has been curtailed significantly in recent years, but it's not been eliminated completely.

Transboundary Pollution

Most of the studies that have been undertaken in recent years have only pointed towards significant contribution to Gurugram from the surrounding areas. This is mainly due to the topography, meteorology, and the intensity and spatial patterns of emissions in the Delhi-NCR airshed.

Residential Sector

Although the development of the Gurugram is done to ensure that the residential emissions are kept lowest, the sheer number of residences in the city has a much higher cumulative impact. To add to the vows, the outskirts of the city are mainly comprised of underdeveloped low-income households where cheaper and widely available solid fuel (biomass) is used for their daily cooking, and heating (only during winter months).

Another aspect is the extensive use of DG sets across different housing societies in Gurugram due to the intermittent nature of the electricity supply. Although the supply has improved significantly in recent years, it goes from time to time, which is when the residents need to turn to the large DG sets to meet their daily electricity requirements.

Waste Management Sector

The waste management in the city is much better in recent years than it used to be, with improvements in each of the areas starting from segregation to collection, to transportation, and its proper management. However, the major challenge lies in the waste that remains uncollected. These include both wet and dry faction, where the latter is of concern since that is used for open burning.

In addition to this, despite the Extended Producers Responsibility (EPR) being mandated for different categories of waste streams, many important wastes, especially the e-waste, rubber, plastics are not taken up to ensure more circular approach to waste management. To make it worse, there are some areas where these wastes are burning as fuel to for extracting important components that have commercial viability.

Dust Sector

60 http://www.indiaenvironmentportal.org.in/files/file/brick-kilns-zig-zag-technology-NGT-order-Feb17-2021.pdf

The infrastructure boon that Gurugram has experienced, especially owing to its location near the country capital has been nothing less than a fairytale. However, it has also brought in the associated problems with it, especially that of construction related fugitive emissions. The road dusts add to the problem making it even worse for the city dwellers. Measures are being imposed only when the situation is dire, and the impact are becoming more evident. Lack of oversight, stringent construction protocols, and planning and preparation to deal with such situations of violations among the concern authorities are some of the important factors contributing to this issue.

The uncovered and loose soil patches across the city and transboundary influences are two other reasons that have increased the dust related air pollution with the Gurugram.

Sporadic Public Action

This has gained traction in recent years due to the major coverage in different media platforms, the discussions in the national and the state legislatures, court orders, and the outreach campaign. Although all this has made considerable difference, public participation remains limited to only the times when there is a situation the people at large, otherwise, the participation is only by those who are suffering.

Table 10 – Key Initiatives and Interventions

Air Quality and Emissions Monitoring	**Transportation Sector**
1. National Ambient Air Quality Standards (NAAQS)	**1.** Bharatmala Pariyojana
2. National Clean Air Programme (NCAP)	**2.** Green National Highways Corridor Project (GNHCP)
3. National Air Monitoring Programme (NAMP)	**3.** National Electronic Toll Collection (NETC)
4. Continuous Ambient Air Quality Monitoring (CAAQM)	**4.** CNG as an alternative fuel
5. Satellite-based Monitoring	**5.** Improvement in Fuel Quality
6. Sensor-based monitoring	**6.** National Policy on Biofuel, 2018
7. Certification Scheme for Ambient Air Quality and Emissions Monitoring Instruments	**7.** Green Corridor Project
8. NAMP Network Data	**8.** Green Energy Corridor Project
9. All India CAAQM Portal (Central Control Room for Air Quality Management - All India)	**9.** National Hydrogen Energy Mission (NHEM)
10. Air Quality Index (AQI)	**10.** Hydrogen Corpus Fund
11. SAMEER Mobile Application	**11.** Implementation of BS VI Standards (fuel and vehicles)
12. Portal for Regulation of Air Pollution in Non-Attainment Cities (PRANA)	**12.** National Electric Mobility Mission Plan (NEMMP), 2020
13. Air Quality Early Warning System (AQ-EWS)	**13.** Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME India)
14. System of Air Quality and Weather Forecasting and Research (SAFAR)	**14.** Voluntary Vehicle-Fleet Modernization Programme (VVFMP)
15. Decision Support System (DSS)	**15.** Metro Rail Policy
	16. National Urban Transport Policy (NUTP), 2014
	17. Sustainable Alternative Towards Affordable Transportation (SATAT)

	18. Linking of Pollution Under Control (PUC) data with the VAHAN database **19.** 18 % blend of Hydrogen with CNG (HCNG) **20.** Improving last mile connectivity to public transport and incentivise non-motorised transport
Residential Sector **1.** City Air Action Plan **2.** City Gas Distribution (CGD) **3.** Graded Response Action Plan (GRAP)	**Industrial Sector** **1.** Comprehensive Environmental Pollution Index (CEPI) **2.** Stricter emission norms for thermal power plants (TPPs)
Waste Management Sector **1.** Swachh Bharat Mission (SBM) **2.** Swachh Bharat Mission-Urban (SBM-U/ SBM2.0) **3.** Lakshya Zero Dumpsite **4.** Extended Producer's Responsibility (EPR)	**Agricultural Sector** **1.** National Policy for the Management of Crop Residues (NPMCR) **2.** Pradhan Mantri Kisan Urja Suraksha Evam Utthan Mahabhiyan (PM-KUSUM) **3.** Scheme on the 'Promotion of Agricultural Mechanisation for In-Situ Management of Crop Residue in the States of Punjab, Haryana, Uttar Pradesh and NCT of Delhi' **4.** Sub-Mission on Agricultural Mechanisation (SMAM)
Construction Sector **1.** Smart City Mission (SCM) **2.** Guidelines on the Management of Construction and Demolition (C&D) Waste **3.** Atal Mission for Rejuvenation and Urban Transformation (AMRUT)	**Energy Efficiency Programmes** **1.** National Mission on Sustainable Habitat (NMSH) **2.** National Building Code of India (NBC), 2016 **3.** Energy Conservation Building Code (ECBC), 2007 **4.** National Initiative to Promote Habitat Energy Efficiency (I-PHEE) **5.** Eco Niwas Samhita (ENS), 2018 and 2021 **6.** National Solar Mission (NSM) **7.** 'Shunya' Labelling Programme Promoting Net Zero Energy Buildings **8.** Bureau of Energy Efficiency's (BEE) Star rating programme for Office buildings

Collaboration and Partnerships

Under the NCAP, all the above-mentioned initiatives are being looked at as a mechanism for reducing air pollution. 6 central Line Ministries of the Government of India are undertaking one or more of these initiatives. These ministries are Ministry of Agriculture Cooperation and Farmers' Welfare (MoAFW), Ministry of Heavy Industries (MoHI), Ministry of Housing and Urban Affairs (MoHUA), Ministry

of Power (MoP), Ministry of Petroleum and Natural Gas (MoPNG), Ministry of Road, Transport and Highway (MoRTH), Ministry of New and Renewable Energy (MNRE), which is being spearheaded under the leadership of the MoEFCC to ensure a collective action.

Performance and Trends

As per the recent data by the MoEFCC, 82 NACs cities under NCAP have shown improvement in their PM_{10} level, when compared to its level during the base year of 2017-18. This improvement in air quality across various areas has been attributed to many interventions that have been undertaken by different line ministries to reduce PM_{10}.

Despite not being covered under NCAP, the implementation of many of the policies and plans mentioned above have happened in varying degree throughout Gurugram city, and across varying timelines. Furthermore, there is no qualitative measurement criteria that has been development by the government agencies for measuring the impact of the each of the policy /plan in reducing the PM_{10} at the city level. Due to these limitations, it is difficult to attribute the degree of increase or decrease in the PM_{10} of Gurugram city to the measures being taken and their effectiveness.

However, MoEFCC has developed guidelines on 'Swachh Vayu Sarvekshan- Ranking of Cities' released as part of the National Clean Air Programme (NCAP) under which it would be promoting the ranks of 131 NACs in the country for implementing City Action Plans prepared as part of NCAP for reducing PM_{10} levels up to 40% by 2025-26.[61]

And even though Gurugram is not being a NAC, and the guidelines are not applicable to it, the guidelines can still be used for quantitatively assess the impact of all the city-level measures that are being undertaken, along with their efficacy and efficiency.

The practice-related interventions that have been proposed through various plans, court judgements and directions are as follows.

Table 11 – Interventions proposed for Gurugram through various plans, court judgements and directions

Reduction of emissions in industry	**Industrial Emission Controls**
• Setting priorities by focusing on emissions from the major emission sources; • Emphasizing on the requirements for use of cleaner fuels; • Highlighting the requirement for the use of – and providing an action plan for • Implementation of – best available technology for specific industrial processes. • Compulsory notification of accidents; • Strict licensing of specified polluting processes; • To follow the norms of compulsory emission standards, as well as an enforcement strategy for such; and • Imposing strict fines for exceeding emission standards	• Land use planning and zoning • Location of new industries should be assigned keeping in mind the planning regulations. • Along with this, suitable industrial areas/ zones should also be established as part of city planning. • All new industries, especially specific major industries should compulsorily undergo environmental impact assessment to ascertain their potential to contribute to the air pollution. • This should be followed by recommendations to improve location, processes, fuels, industry technology and emission limits; and • Relocation of existing industries away from residential and other sensitive land uses

61 https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1861932

Industrial Emissions • Improved emissions standards and technologies; • Cleaner fuels; • Improved fuel efficiency; • Improved inspection and maintenance; • Improved transport planning and traffic demand management; • Shift to public transport, promotion of non-motorized/active transport (i.e., cycling, walking)	**Measures to Reduce Emissions from Area Sources** • Enforcement of bans on burning of materials or waste; • Water fogging and spray at construction and demolition sites and roads • Promotion of alternative solutions to burning waste. • Better waste management and monitoring; and • Proper strategies for paving roads, revegetation programs in dust control areas, and • Use of street sweeping equipment for road cleaning
Promotion of cleaner production • Increase the efficiency of industrial processes; • Promote energy and materials saving by adopting good manufacturing practices; • Use of improved quality fuels (e.g., with lower sulphur content) or switch to cleaner fuels such as natural gas; and • Adoption of new technologies.	**Transportation Sector** • Improved emissions standards and technologies; • Cleaner fuels; • Improved fuel efficiency; • Improved inspection and maintenance; • Improved transport planning and traffic demand management; • Shift to public transport, promotion of non-motorized/active transport (i.e., cycling, walking)
Agriculture Sector • In-situation management of the crop residue • Ex-situ management of crop residue • Utilis ation of the crop residue as • An alternative fuel source • Resource material for manufacturing furniture • For bio methanation and ethanol production	

3.3.2 Description and analysis of the air pollution mitigation technology interventions implemented in Gurugram

Table 12 – Technological Interventions from the Gurugram City Assessment

Transportation Sector • Bharat Stage-VI (BS-VI) technology which uses Diesel Particulate Filters (DPF) and Selective Catalyst Reduction (SCR) systems for emission reduction; • Retrofitting to attach and/or convert • Emission control devices diesel particulate filters (DPFs) and diesel oxidation catalysts (DOCs); • Old cars to CNG or electric vehicles • Improved fuel quality to meet BS-VI norms; • Pollution Under Control Certification (PUCC) Scheme; • Promoting e-Mobility under the FAME Scheme; • Use of mechanical road sweepers	**Infrastructure Sector** • Use of on-site site and peripheral dust Suppression Systems like Smog Gun • Special Storage Units for construction materials • Use of tarpaulins during transportation of debris • Wheel wash facility • Construction Site Barriers • Air Filters with a small Low-Powered Fan • Wayu (Filtration-based air cleaning technology) • Use of wet cutting techniques • Employing low-dust equipment, such as electric-powered tools and dust extractors
Industrial Emissions • Flue Gas Desulfurization (FDGs) • Electrostatic precipitators (ESPs) • Filters and dust collectors (baghouses) • Wet scrubbers • Low-NOx burners • Zig-Zag technology (Brick manufacturing) • Plantation in and around the industrial area/ complex	**Waste Management** • Biogas recovery system • Anaerobic digestion unit • Waste-to-energy plants • Catalytic Pyrolysis and Gasification • Composting
Reduction of emissions in residential • Use of LPG • DG Set retrofitting • Smog Towers • Smog Free Tower	

3.3.3 City level action plans and strategies for air pollution control

Gurugram being the city that is not included so far in NCAP, is not having a detailed work plan in the format that is prescribed for the non-attainment cities (NACs). However, the Haryana State Pollution Control Board (HSPCB) has prepared and submitted the city action plan for Gurugram with the CPCB, wherein they have identified the major hot spots/ areas of concern with the city and spread across different sectors.

Table 13 – City Level Action Plan and Strategies from the Gurugram City Assessment

Sector	Action Points
Transport	a. Plying of electric vehicles for public transport and establishment of charging stations for all vehicles b. Construction of expressways/ bypasses/ peripheral roads c. Arrangement of multi-level parking facilities d. Development of cycle zone e. Retrofitting of particulate filters in diesel vehicles f. Use of bioethanol g. Widening of Roads h. Remote sensor-based PUC system
Industry	a. Adoption of zig zag technology in brick kilns b. Monitoring of Industrial emissions through Online Continuous Emission Monitoring System (OCEMS) c. Shifting of air pollution industries to conforming zones d. Installation of web cameras and OCEMS in gross polluting industries e. Undertaking compliance assurance through proper enforcement
Waste burning	a. Extensive drive against open burning b. Proper collection of horticultural waste burning c. Door to door collection of segregated waste d. Establishment of compost pits
Construction	a. Control measure for fugitive emissions b. All construction areas must be covered to avoid dispersion of particulate matter c. Ensure carriage of construction material in closed/covered vessels.
Dust	a. Maintaining 33% forest cover b. Creation of green buffers c. Maintain potholes free roads d. Introduce water fountains e. Wall to Wall pavement f. Blacktopping of metallic roads

3.3.4 Alignment of city level action plans/strategies with national policy and strategy for air pollution control

Since there is no concrete city level action plan for Gurugram as per the NCAP format, the reference is being drawn collectively from the city action plans that have been prepared for other cities in the NCR region and the specific action plan for that has been prepared by the HSPCB for addressing the air pollution issues across various hotspots in Gurugram. Furthermore, it has been evident with the work that is being undertaken by the city administration with support from the state and the district administration, is on similar lines that is being undertaken in a NAC that is under the ambit of the NCAP. By looking at the current hotspot action plan is that has been prepared by HSPCB and comparing it with the action plans for the NACs, especially in the NCR regions, it can be inferred that there is a high degree of alignment between the two, and that is further reinforced by the work that is being undertaken on the ground for mitigating air pollution.

3.3.5 Discussion

1. Objectives, strategies, and specific technologies employed

Gurugram's air pollution mitigation efforts encompass a comprehensive approach involving regulatory measures, both prevention and mitigation strategies, and the adoption of some generic as well as specific technologies for air quality management. By working towards aligning these objectives, strategies, and technologies, the city administration of Gurugram is aiming to create healthier air for its residents by targeting the pollutants of concern, especially the PM_{10} and $PM_{2.5}$.

2. Evaluation of the effectiveness and impact of these interventions

Although the city has no defined city action plan, most of the work being undertaken at the city level is on the same lines as that being undertaken in a NAC, which has been brought under the purview of the NCAP. This impacts the city in terms of seeking performance-based grants that are being allocated under NCAP.

In recent years, there has been some improvement in the air quality of Gurugram city due to the measures being enforced based on the directions of NGT and the EPCA. However, there are certain periods where the air quality of the city has recorded poorer air quality compared to previous years. Furthermore, as has been mentioned earlier that since there is no specified framework to quantify the effectiveness of the impacts of the measures being undertaken, the improvements are being gauged solely based on daily and annual averages of the pollutants being measure d, the AQI levels and the number of good and bad days the city is experiencing in a specified time period.

3.3.6 Relevant air quality management challenges

Table 14 – Sector-wise Air Quality Management Challenges across the three cities

Sector-wise	Bangkok	Dhaka	Gurugram
Transport Sector	• Plying of Pre-Euro and Euro I vehicles, especially the diesel-based vehicles. • Majority of the heavy-duty transports (HDTs) and buses are using Euro II and Euro III, • The percentage share of all Euro III vehicles is highest among all the vehicle standards, as well as across each of the categories. • Technology is not available for the CCTV to detect black smoke and black smoke inspection. • Increasing traffic congestion and underutilis ation of the public transportation systems • No policy on having vehicular age limit. • No economic incentive to encourage purchase of newer and more efficient vehicles. • Urban areas are inadequately planned to promote mass transit and active transport	• Use of old vehicle across the city • Lack of enforcement of latest emission standards • Lack of inspection and maintenance (I&M) systems • Limited vehicle emission testing and its irregularity • Lack of tailpipe controls like diesel particulate filters (DPF) for PM and selective catalytic reduction (SCR) for NOx. • Incomplete mobility-related infrastructure work like the MRT. • Extensive presence of road dust	• Ineffective pollution-under-control (PUC) testing • Majority of the vehicles are still BS-IV complaint. • EV infrastructure still sparce. • Prominent issue of road dust • Congestion and traffic idling is a major source

Sector-wise	Bangkok	Dhaka	Gurugram
Waste Sector	• Open burning of waste • Lack of will and capacity to invest in alternative waste management practices	• Lack of collection, segregation, and sanitary landfilling of waste • No waste-to-energy (WTE) (incineration) project • Widespread open burning o biomass and household waste • Municipality drainage and roadside are not well-managed • Lack of compliance monitoring and enforcement	• Source segregation is still an issue • Open burning of waste, majorly in winter season • No Waste-to-energy plant as of now • Circularity is still not mainstreamed
Agriculture Sector	• Lack of stringent control over the burning of agricultural residue • No prescribed methods for in-situ and ex-situ management of agricultural residue • Open burning control in agricultural areas in around the Bangkok city • Gaps to manage fire after its detection.		• Autumn harvest season sees the highest spike • Majority impact is transboundary from the north and north-west direction. • Residents exposure to high pollutant levels for a period of 10 to 15 days.
Residential Sector	• Dust control measures not being enforced at different construction sites across the city. • Lack of promoting clean fuels in households • No control measures (cleaner stoves and fuels) for the residential sector and street food.	• Lack of access to clean fuels (such as LPG; Electricity) • Continued reliance of households on solid fuels • Yet to switch to induction stoves (powered by solar or gas) • Subsidy mechanisms and resource availability is lacking	• Exponential increase in residential emissions • Unabated residential development projects • Use of solid biomass fuel in the city's urban slums

Sector-wise	Bangkok	Dhaka	Gurugram
Energy Sector		• Adequate space for setting solar system required • Transition from diesel genset to solar power is yet to take place • National standards related to the energy efficiency labelling program and energy efficiency tests are yet to be developed.	• Diesel generators are a major source. • Use of coal in commercial eateries • Electricity supply not around the clock
Industrial Sector	• Lack of enforcement of emissions standards for the industrial facilities • Enabling public access to information about emissions • Lacking public participation in the inspection and monitoring of industrial air emissions due to lack of awareness and available data	• Renovation of Eastern Refinery Limited (ERL) and develop capacity to produce 10 ppm sulphur contents diesel. • Development of a robust continuous emission monitoring system (CEMS) programme for major industrial sources is yet to be made mandatory	• Most industries are in the upwind direction. • Not all industries have switched to the clean fuels like PNG and LNG • Industries and industrial zones located within the city
Regulatory	• Pollutant emission standards for vehicles and fuel quality are yet to be updated. • Insufficient air quality monitoring since official monitoring stations are costly. • Lack of air pollution forecasting system	• Yet to develop enough trained manpower and logistics within the bodies	

Sector-wise	Bangkok	Dhaka	Gurugram
Coordination & Planning	• Lack of public awareness regarding health impacts of haze and open burning • Lacking framework that enables multi-sectoral collaboration.	• Lack of coordination among the concern implementation authorities • Lack of planning among the concern authorities • Unplanned development of the city • A multi-Scale and cross-sectoral coordination action against the air pollution sources • Support from the people is missing due to lack of awareness	• Lack of consultation and coordination still exists among the various departments. • Approach to city-based planning is ad hoc and undertaken in silos • Component of sustainability and its benefits are considered as secondary in the planning process • Inadequate trained manpower, logistic support, and resource availability
Financial Support	• Lack of financial and other incentives for enhancement of the technological solutions across different sectors • Majority of the farmlands are leased, leading to a lack of both incentives for investment in alternative farming practices and protection of farmers' rights on financial returns	• No robust incentives and/or subsidies for undertaken pollution control • Financial support such as loan and incentive not provided for any sector • Insufficient resource allocation for the regulatory authorities • Lacking access to the available resource • No clear implementation mechanism • Market access lacking • High initial cost is a barrier in most cases	• City not covered under the NCAP so the allocation of funds is limited • National level programmes are being implemented but their exact benefits are still unclear • Support is only being extended after judiciary interventions and directions

4 COMPARATIVE ANALYSIS

The analysis of the City Air Action Plan (CAAP) for the Bangkok, Dhaka, and Gurugram reveals a comprehensive and multifaceted approach to addressing air quality challenges by each of the three cities in their own specific manner—taking into consideration various city, national, and location specific facets like the historical trends in air pollution; geographical and meteorological conditions; policies at the national, state/regional, city/county-level, monitoring mechanism and networks, citizen awareness, etc. Even though the CAAPs vary across all three cities, the plans have certain commonalities and present a qualitatively comprehensive view of the important facets. The indicators are presented in the table.

4.1 Analysis of the City Action Plans

In Bangkok, the action plans have been designed to emphasize the activities geared towards reducing from the transportation sector, which when considered with the road dust, contributes to approximately 55% of the city's $PM_{2.5}$ emissions. The next is the agricultural sector where the open burning of crop residue emissions pitches in about 20% of Bangkok $PM_{2.5}$ emission. This is followed by the industrial sector (factories and power plants) emits 12% of Bangkok $PM_{2.5}$ emission. This is followed by the residential sector (street food and markets and household) which cumulatively emits 12% of Bangkok $PM_{2.5}$ emission.

In Dhaka, the action plan has being designed as well as being updated to include measures to tackle emissions from the industries (especially from the brick kilns), vehicular sector, residential sector, construction activities, road dust and its resuspension, transboundary air pollution and open solid waste/ biomass burning have been identified as the main sources with the maximum share of 58% coming from the brick kiln sector, and of fine particles in Dhaka city to brick kilns, followed by 25% from the residential and commercial sector, 15.3% from the road dust and its resuspension, and 10.4% from the mobility sector.

In case of Gurugram, the designated action plan focuses on transportation sector, industrial sector (including power plants and medium and small-scale industries), construction industry, waste management sector, and residential sector (especially the diesel generator (DG) sets), and transboundary emissions.

The analysis for the CAAP, given in the table, presents a comprehensive outline of the three cities in terms of their policy level action.

Table 15 – Comparative of the CAAP/ Regulatory or Policy Mechanism of the three cities

S. No.	Components of the City Air Action Plan (CAAP/ Regulatory OR Policy Mechanism)	Bangkok	Dhaka	Gurugram
1	Has any CAAP/ city's regulatory or policy mechanism been approved for spearheading the city's AQM work?	YES	YES	YES
2	If No, is there one that is in the process of being developed/ finalised/ approved?	NA	NA	NA
3	If No, which official mandate (including court orders/ is driving the work for the city?	NA	NA	NA
4	Has the CAAP/ city's regulatory or policy mechanism been checked for its technical, financial, legal, and implementation feasibility?	YES	NA	IN PROCESS

S. No.	Components of the City Air Action Plan (CAAP/ Regulatory OR Policy Mechanism)	Bangkok	Dhaka	Gurugram
5	Is the CAAP/ city's regulatory or policy mechanism backed by a suitable regulatory framework/ legislation?	YES	YES	YES
6	Is the CAAP/ city's regulatory or policy mechanism based on suitable ground-level findings?	YES	YES	IN PROCESS
7	Has the city administration considered the baseline information for formulating the CAAP/ city's regulatory or policy mechanism?	YES	YES	IN PROCESS
8	Have the historical trends for air pollution been considered in its formulation	YES	YES	YES
9	Is the CAAP/ regulatory or policy mechanism plan resilient?	YES	YES	YES
10	Is the CAAP/ regulatory or policy mechanism plan target based?	YES	NA	YES
11	Is there a timeline for the implementation of the CAAP/ regulatory or policy mechanism plan?	YES	NA	IN PROCESS
12	Is the CAAP/ regulatory or policy mechanism plan backed by suitable financial and institutional resources?	YES	YES	IN PROCESS
13	Does the CAAP/ regulatory or policy mechanism plan provide for long-terms emission reduction through targeted actions?	YES	NA	YES
14	Has the CAAP/ regulatory or policy mechanism plan been designed in the format that is acceptable to the regulatory authorities and the policy makers?	YES	YES	YES
15	Is the existing CAAP/ regulatory or policy mechanism plan scalable?	IN PROCESS	YES	YES
16	Does the CAAP/ regulatory or policy mechanism plan also consider the short and long-term health benefits of the proposed measures?	YES	NA	YES
17	Is the CAAP/ regulatory or policy mechanism plan aligned with the National strategy for AQM in the country?	YES	NA	YES
18	Does the CAAP/ regulatory or policy mechanism include component on technological interventions for air pollution mitigation?	YES	YES	IN PROCESS
19	Does the CAAP/ regulatory or policy mechanism include component on IEC activities?	YES		YES

S. No.	Components of the City Air Action Plan (CAAP/ Regulatory OR Policy Mechanism)	Bangkok	Dhaka	Gurugram
20	Can the CAAP/ regulatory or policy mechanism be integrated into the existing system of AQM (if any)?	YES	YES	YES
21	Does the CAAP/ regulatory or policy mechanism list the actions based on the priority set forth by the policymaker and the regulators?	YES	YES	YES
22	Is the CAAP/ regulatory or policy mechanism performance linked?	YES	YES	YES
23	Has an evaluation criterion been designed for the CAAP/ regulatory or policy mechanism?	YES	NO	IN PROCESS
24	Does the CAAP/ regulatory or policy mechanism specify sector-specific measures?	YES	YES	YES
25	Does the CAAP/ regulatory or policy mechanism take transboundary impacts into consideration for AQM interventions?	YES	NO	IN PROCESS
26	Have all potential risks associated with the implementation plan of the CAAP/ regulatory or policy mechanism been highlighted in the CAAP/ regulatory or policy mechanism document?	NA	NA	IN PROCESS

Table 16 – Nomenclature referring to the status of CAAP/ Regulatory or Policy Mechanism for each of the three cities

YES	When the response is YES for the question
IN PROCESS	When the city is the process of a YES or NO.
NO	When the response is NO for the question
NA	When the information is not available

Looking at the three cities, it is evident that Bangkok has made significant strides towards addressing the city-level air pollution through holistic and well-rounded policy landscape with most of the policy related aspects being addressed in or through its CAAP and other regulatory and/or policy mechanisms.

Next is Gurugram, which too is following suit through various actions and implementation work being undertaken at the ground-level. However, it still has many aspects that are still under process before these can become a part of the current CAAP and other regulatory and/or policy mechanisms.

Dhaka has the most potential for growth among the three cities since it is yet to address about 46% of the components of CAAP and other regulatory and/or policy mechanisms. However, it is pertinent to note that Dhaka's policy landscape for on mitigating its air pollution started only in towards the end of last decade, making it the most recent among the three cities, and at the current rate, it's expected to catch up to match the progress made by Bangkok and Gurugram in the years to come.

4.2 Analysis of the Air Pollution Mitigation Technological Interventions

4.2.1 Comparative analysis – Air pollution mitigation technology interventions across Bangkok, Dhaka and Gurugram

The following framework has been developed based on various aspects that would make a technology viable for use across different regions.

The representation has been assigned from 'A' to 'E' as well as from 'High' to 'Low' in the following assessment matrix to ensure a structured approach for evaluating each criterion for a given air pollution mitigation technology. The representation for the technology matrix has the following interpretation.

Table 17 – Nomenclature referring to the suitability of the technological intervention in the comparative matrix

High	The trait for the technology is highly suitable for the city
Moderate	The trait for the technology is moderately suitable for the city
Low	The trait for the technology is minimally suitable for the city
No Solution	The technology is considered a 'No Solution' for the city

Table 18 – Nomenclature defining the extent of the status of implementation of the technological intervention in the comparative matrix

A	The technological intervention is now implemented by the city for mitigating air pollution
B	The technological intervention has been sanctioned and will be implemented soon/ is in the process of being implemented
C	The technological intervention has been recommended for implementation and is currently awaiting official government clearance.
D	The technological intervention has been identified as a potential measure to be implemented for air pollution mitigation in the city
E	The technological intervention has not been identified as a potential measure for mitigating air pollution

For each criterion, careful assessment has been undertaken to gauge how well the technology meets the specified criteria, and then a suitable representation has been assigned based on its overall performance. Consistency and objectivity have been given due consideration while assigning representation to ensure that the assessment is fair and unbiased. However, it is important to note that these representations are subjective and may vary based on the opinion of an individual. Additionally, the relative importance of each criterion may vary based on the specific context and objectives of the assessment being undertaken.

Table 19 – Comparative Matrix for assessing all relevant technological interventions across the three cities

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
Transportation and Mobility Infrastructure Sector																		
1	BS VI/ Euro 6	Bangkok	B	High	High	Moderate	High	High	High	High	High	High	Low	High	High	Low	High	High
		Dhaka	D	High	High	High	Low	Low	Low	High	Low	High	Low	High	Low	High	High	Moderate
		Gurugram	A	High	High	High	Moderate	High	High	High	High	Moderate	Moderate	Moderate	High	Moderate	High	High
2	Diesel Particulate Filters (DPF)	Bangkok	D	High	Moderate	Low	Moderate	Low	Low	Low	Moderate	High	Low	High	High	Low	Low	Low
		Dhaka	D	High	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate	High	Moderate	Moderate	Low	Moderate
		Gurugram	A	Low	Low	Moderate	Moderate	Moderate	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	High	Moderate
3	Selective Catalyst Reduction (SCR) systems	Bangkok	A	High	High	Low	High	High	High	High	Low	Low	Low	Moderate	High	Low	High	High
		Dhaka	D	High	Moderate	Moderate	Low	Low	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Low
		Gurugram	B	Low	Moderate	High	Low	Moderate	High	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	High	Moderate

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
4	Diesel oxidation catalysts (DOCs)	Bangkok	A	High	High	Low	High	High	High	High	Low	Moderate	Low	Moderate	High	Low	High	High
		Dhaka	D	High	Moderate	Moderate	Low	Low	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Low
		Gurugram	A	Moderate	Moderate	Moderate	Moderate	High	High	High	Moderate	Moderate	Moderate	Moderate	High	Moderate	High	Moderate
5	CNG Retrofitting	Bangkok	A	High	High	Low	Moderate	High	Moderate	High	Moderate	High	Low	High	High	Low	High	Moderate
		Dhaka	A	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High
		Gurugram	A	Moderate	Moderate	Moderate	Moderate	High	High	High	High	High	Moderate	Moderate	High	High	High	High
6	EV Retrofitting	Bangkok	D	High	Moderate	High	Moderate	Low	Moderate	Moderate	Moderate	High	Moderate	High	High	Moderate	High	Moderate
		Dhaka	D	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	High	Low	Low	Low	Low
		Gurugram	E	Moderate	Low	Moderate	Low	Low	Low	Low	Low	Moderate	Moderate	Moderate	Low	Low	High	Low

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
7	EV	Bangkok	A	High	High	Moderate	High	Moderate	High	Moderate	Moderate	High	Moderate	High	High	Moderate	High	High
		Dhaka	D	High	High	High	High	Low	High	High	Moderate	High	High	High	High	High	High	High
		Gurugram	A	High	High	High	Moderate	High	High	High	High	High	Moderate	High	High	Moderate	High	High
8	Pollution Under Control Certification (PUCC) Scheme	Bangkok	A	High	Moderate	Low	Low	Low	Low	Low		High	Low	High	High	Low	Low	Low
		Dhaka	D	High	Moderate	High	High	Low	High	High	Moderate	High	High	High	High	High	Moderate	Moderate
		Gurugram	A	Moderate	High	Low	High	High	High	High	High	Low	Low	Moderate	High	High	High	High
9	Improved fuel quality	Bangkok	A	High	High	Low	High	High	High	High		Low	Low	Low	High	Low	High	High
		Dhaka	D	High	High	High	Moderate	Low	High	Moderate	Moderate	High	High	High	High	High	Moderate	High
		Gurugram	A	High	High	High	Moderate	High	High	High	High	High	High	High	High	Moderate	High	High

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
10	Mechanical road sweepers	Bangkok	E															
		Dhaka	D	Moderate	High	High	High	Low	High	Moderate	Low	High	High	High	Moderate	Moderate	High	Moderate
		Gurugram	B	High	High	Moderate	Moderate	High	High	High	Moderate	High	High	High	High	Moderate	High	High
11	Remote sensing device for detecting vehicle exhaust	Bangkok	D	High	Moderate	Low	Low	No Solution	Low	High		No Solution	Low		High	Low	Low	Low
		Dhaka	E	Moderate	Moderate	Moderate	Low	Low	Moderate	Moderate	Low	High	High	High	Moderate	Low	Moderate	Moderate
		Gurugram	E	Moderate	Moderate	High	Low	Low	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate	Moderate	Low	
12	Alternative fuel (CNG, Ethanol blended fuel, H_2)	Bangkok	A	High	High	Low	High	High	High	High		Low	Low	Low	High	Low	High	High
		Dhaka	A	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High
		Gurugram	A	High	High	Moderate	High	High	High	High	Moderate	High	High	High	High	High	High	High
13	Enhanced Public Transport	Bangkok	A	High	High	Low	High	High	High	High		Low	Low	Low	High	Low	High	High
		Dhaka	B	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High
		Gurugram	A	High	High	Moderate	Moderate	Moderate	Moderate	High	Moderate	High	High	High	High	High	High	High

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
14	Intelligent traffic management system	Bangkok	B	High	Moderate	High	Moderate	Moderate	Moderate	Moderate	Moderate	High	High	High	High	High	High	High
		Dhaka	D	Moderate	Moderate	High	Moderate	Low	Moderate	Moderate	Low	Moderate	High	High	Moderate	Moderate	Moderate	Moderate
		Gurugram	D	High	High	High	Low	High	High	High	Low	High	High	High	Moderate	Moderate	Moderate	High
15	Parking policy: congestion charges, no parking zones	Bangkok	B	High	Low	Moderate	Moderate	Low	Moderate	Moderate	Moderate	High	Moderate	High	High	Moderate	High	Moderate
		Dhaka	D	High	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate	High	High	Moderate	Moderate	Moderate
		Gurugram	D	High	Low	High	Low	Low	High	Low	Moderate	Moderate	Moderate	Moderate	High	Moderate	Low	Low
16	Vehicle scrapping policy and scrapped vehicle collection mechanism	Bangkok	D	High	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate	High	High	High	High	High	High	Low
		Dhaka	D	High	Low	Low	Moderate	Low	Moderate	Moderate	Moderate	High	High	High	Moderate	Moderate	Low	Moderate
		Gurugram	D	High	High	High	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	High	Moderate	Moderate	High	Low

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
17	Road dust cleaning using mechanical sweeping machines	Bangkok	A	Mod-erate	High	Low	High	High	High	High	Mod-erate	Moder-ate	Mod-erate	Mod-erate	High	High	High	High
		Dhaka	A	High	Mod-erate	Mod-erate	Mod-erate	Low	High	High	Mod-erate	High	High	High	Mod-erate	High	Mod-erate	High
		Gurugram	A	High	Mod-erate	Low	Low	Low	High	High	Mod-erate	High	High	High	High	High	Mod-erate	High
18	Wall-to-Wall Carpeting	Bangkok	E															
		Dhaka	B	Mod-erate	Mod-erate	Low	Mod-erate	Mod-erate	High	High	Mod-erate	High	High	High	High	Mod-erate	High	High
		Gurugram	C	Mod-erate	Mod-erate	Low	Low	Low	High	High	Low	High	High	Mod-erate	Mod-erate	Mod-erate	High	Mod-erate
19	Roadside Plantation	Bangkok	A	Mod-erate	High	Low	High	Mod-erate	High	High	Mod-erate	Low	Mod-erate	Low	High	High	High	High
		Dhaka	A	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Moder-ate	High	High	Mod-erate	Mod-erate	High	High
		Gurugram	B	Low	Low	High	Low	Low	Mod-erate	High	Mod-erate	Moder-ate	Mod-erate	Mod-erate	Mod-erate	Low	Low	High

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
20	Curb Design for Pedestrians	Bangkok	A	Moderate	High	Low	High	Low	High	High	Moderate	Low	Moderate	Low	High	High	High	High
		Dhaka	B	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	High	High	High	High	Moderate	Moderate	Moderate	High
		Gurugram	B	High	Moderate	Moderate	Moderate	Low	Moderate	Moderate	High	High	Moderate	High	Moderate	Moderate	Moderate	High
21	Efficient road design for smooth traffic flow including intelligent traffic management	Bangkok	E															
		Dhaka	D	High	High	High	Moderate	Low	High	Moderate	Moderate	High	High	High	High	Moderate	Moderate	High
		Gurugram	D	High	High	High	Moderate	Moderate	High	High	High	High	High	High	High	High	High	High

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
Infrastructure Sector																		
1	On-site site and peripheral dust Suppression Systems	Bangkok	E															
		Dhaka	A	High	High	Moderate	High	High	High	Moderate	High	High	High	High	High	High	Moderate	High
		Gurugram	B	High	High	Moderate	Moderate	High	High	High	Moderate	Moderate	Moderate	High	Moderate	Moderate	High	High
2	Special Storage Units	Bangkok	A	High	High	Low	High	High	High	High	High	Low	Low	Low	High	Low	High	High
		Dhaka	D	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Moderate
		Gurugram	B	Moderate	High	Moderate	Moderate	Moderate	High	High	High	Moderate	Moderate	Moderate	Moderate	Moderate	High	Moderate
3	Tarpaulins covered trucks	Bangkok	A	High	High	Low	High	High	High	High	High	Low	Low	Low	High	Low	High	High
		Dhaka	A	High	High	Moderate	High	High	High	High	High	High	High	High	High	High	High	High
		Gurugram	B	Moderate	High	Moderate	High	High	High	High	High	Moderate	Moderate	Moderate	High	High	High	Low

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
4	Wheel wash facility	Bangkok	A	High	High	Low	High	High	High	High	High	Low	Low	Low	High	Low	High	High
		Dhaka	B	Moderate	Moderate	Moderate	Moderate	Low	Moderate	Moderate	High	High	High	High	Moderate	High	Moderate	Moderate
		Gurugram	C	Moderate	High	Moderate	High	High	High	High	High	Moderate	Moderate	Moderate	High	Moderate	High	Low
5	Construction Site Barriers	Bangkok	A	High	High	Low	High	High	High	High	High	Low	Low	Low	High	Low	High	High
		Dhaka	A	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High
		Gurugram	A	Moderate	High	Moderate	High	High	High	High	High	High	Moderate	Moderate	High	Moderate	High	High
6	Air Filters with a small Low-Powered Fan	Bangkok	E															
		Dhaka	E	High	High	High	High	Low	High	High	High	High	High	High	High	Moderate	Moderate	High
		Gurugram	C	Low	Low	Moderate	Moderate	High	Low	Low	Low	Low	Moderate	Moderate	High	Moderate	Low	High
7	Wayu (Filtration-based air cleaning technology)	Bangkok	E															
		Dhaka	E	High	High	High	High	Low	High	High	High	High	High	High	High	Moderate	Moderate	High
		Gurugram	C	Low	Moderate	Moderate	Moderate	High	Low	Low	Low	Low	Low	Moderate	High	Low	Low	High

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
8	Wet cutting techniques	Bangkok	E															
		Dhaka	B	High	Moderate	Moderate	High	High	High	High	High	High	High	High	High	High	High	High
		Gurugram	B	Moderate	Moderate	High	Moderate	Low	High	High	Moderate	High	Moderate	Moderate	High	Moderate	High	High
9	Low-dust equipment, (Electric-powered tools and dust extractors)	Bangkok	E															
		Dhaka	B	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
		Gurugram	E	Moderate	Moderate	High	Low	Moderate	High	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Low	Moderate	Moderate
10	On-site utilis ation of the C&D derbies	Bangkok	A	Low	High	Low	High	High	High	Low	High	Moderate	Low	Low	High	Low	High	High
		Dhaka	A	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High
		Gurugram	D	Moderate	Moderate	High	Moderate	Moderate	High	Moderate	Moderate	Moderate	Moderate	Moderate	High	Moderate	High	Moderate
11	Use of the BAT for the mixing of Asphalt	Bangkok	E															
		Dhaka	B	Moderate	Moderate	Moderate	Low	Low	Moderate	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
		Gurugram	B	Moderate	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	High	High

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
12	Use of zig-zag tech-nology for brick manu-facturing	Bangkok	E															
		Dhaka	A	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High
		Gurugram	B	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate	High	High	High	Moder-ate	Mod-erate	Mod-erate	High	Mod-erate	High	Mod-erate
13	Envt sound construction technology: Precast, Ready-mix concrete, 3D printing	Bangkok	E															
		Dhaka	D	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate	High	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate
		Gurugram	E	Mod-erate	High	High	Mod-erate	Low	High	High	High	High	Mod-erate	High	Mod-erate	Mod-erate	Mod-erate	Mod-erate
14	Road laying technology, particularly mattock layer laying	Bangkok	E															
		Dhaka	D	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate	High	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate	Mod-erate
		Gurugram	D	Mod-erate	High	High	Mod-erate	Mod-erate	High	High	Mod-erate	High	Mod-erate	High	Mod-erate	Mod-erate	High	High

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
Industrial Sector																		
1	Flue Gas Desulfurization (FDGs)	Bangkok	A	Low	High	Low	High	High	High	High	High	No Solution	Low	Moderate	High	Low	High	High
		Dhaka	D	Low	Low	Low	Moderate	Low	High	Moderate	Moderate	Moderate	Moderate	High	Moderate	Moderate	Moderate	
		Gurugram	B	Low	Low	High	Low	Moderate	Low	Moderate	Low	Moderate	Moderate	Moderate	Low	Low	Moderate	Low
2	Electrostatic precipitators (ESPs)	Bangkok	A	Low	High	Low	High	High	High	High	High	High	Low	Moderate	High	Low	High	High
		Dhaka	D	High	Moderate	Moderate	Low	Low	Low	Low	Low	Moderate	Moderate	High	Moderate	Moderate	Moderate	Low
		Gurugram	B	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Moderate	High	Moderate
3	Filters and dust collectors (baghouses)	Bangkok	A	Low	High	Low	High	High	High	High	High	High	Low	Moderate	High	Low	High	High
		Dhaka	D	High	Moderate	Moderate	Low	Low	Low	Low	Low	Moderate	Moderate	High	Moderate	Moderate	Moderate	Low
		Gurugram	A	High	High	Moderate	Moderate	High	High	High	High	Moderate	Moderate	Moderate	High	High	High	High

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
4	Wet scrubbers	Bangkok	A	Low	High	Low	High	High	High	High	High	Moderate	Low	Low	High	Low	High	High
		Dhaka	D	High	Moderate	Moderate	Low	Low	Low	Low	Low	Moderate	Moderate	High	Moderate	Moderate	Moderate	Low
		Gurugram	A	High	High	Moderate	Moderate	High	High	High	High	Moderate	Moderate	Moderate	High	High	High	High
5	Low-NO_x burners	Bangkok	A	Low	High	Low	High	High	High	High	High	No Solution	Low	Low	High	Low	High	High
		Dhaka	B	High	Moderate	Moderate	Low	Low	Low	Low	Low	Moderate	Moderate	High	Moderate	Moderate	Moderate	Low
		Gurugram	A	High	Moderate	High	Low	Moderate	High	High	Moderate	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate
6	Zig-Zag technology (Brick manufacturing)	Bangkok	E															
		Dhaka	A	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High
		Gurugram	A	High	High	High	Moderate	High	High	High	Moderate	High	High	Moderate	Moderate	Moderate	High	High

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
7	Plantation/ Landscaping in and around the industrial area/complex	Bangkok	A	Low	High	Low	High	Moderate	High	High		Low	Low	Low	High	Low	High	High
		Dhaka	A	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High
		Gurugram	A	High	High	Moderate	Moderate	Moderate	High	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	High	Moderate
8	Modification of smaller furnaces and ovens used by small scale industries	Bangkok	B	Moderate	Low	Low	Low	Low	Low	Moderate	Low	High	High	High	Low	High	Low	Moderate
		Dhaka	E	Moderate	Moderate	Low	Moderate	Low	Moderate	Low	Low	Moderate	Moderate	High				
		Gurugram	A	High	High	High	Moderate	Moderate	High	High	Moderate	High	Moderate	Moderate	Moderate	Moderate	High	Moderate
9	Point sources like Bakeries and restaurants/ tandoors	Bangkok	B	Moderate	Low	Low	Low	Low	Low	Moderate	Low	High	High	Moderate	Low	High	Low	Moderate
		Dhaka	E	Moderate	Moderate	Low	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Moderate
		Gurugram	C	High	High	Moderate	Low	Low	High	Low	Low	High	Moderate	High	Moderate	Moderate	High	High

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
10	Common heat/power/ steam supply	Bangkok	E															
		Dhaka	E	Moderate	Moderate	High	Low	Low	Moderate	High	Moderate	High	Moderate	High	Moderate	Moderate	Moderate	Moderate
		Gurugram	D	Moderate	Moderate	High	High	Moderate	Moderate	High	High	High	High	High	High	High	High	Moderate
11	Continuous emission monitoring system with messaging and reporting systems	Bangkok	A	Moderate	High	High	Moderate	Moderate	Moderate	High	Moderate	Moderate	Moderate	Moderate	High	High	Moderate	Moderate
		Dhaka	A	High	Moderate	High	Moderate	Low	Moderate	Moderate	Low	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate
		Gurugram	A	High	Moderate	Moderate	Low	High	High	Moderate	Low	Low	Low	Low	Low	Low	High	Low
12	Cleaner Fuel: CNG/ LPG/ ammonia for industry	Bangkok	A	High	High	Low	High	High	High	High	No Solution	Moderate	Moderate	Moderate	High	High	Moderate	Moderate
		Dhaka	B	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	High	High	High	Moderate	High	Moderate	Moderate
		Gurugram	A	High	Low	Moderate	Moderate	Moderate	Moderate	Moderate	High	High	High	High	High	High	High	Moderate

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
Waste Management Sector																		
1	Biogas recovery system	Bangkok	E															
		Dhaka	A	High	High	High	High	Moderate	Moderate	Moderate	Moderate	Moderate	High	High	High	High	High	Moderate
		Gurugram	B	High	High	Moderate	High	High	High	High	High	High	Moderate	Moderate	High	Moderate	Moderate	High
2	Anaerobic digestion unit	Bangkok	E															
		Dhaka	D	High	Moderate	Moderate	Moderate	Low	High	Moderate	Low	Moderate	Moderate	High	Moderate	Moderate	Moderate	Moderate
		Gurugram	B	Moderate	High	Moderate	Moderate	Moderate	Moderate	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
3	Waste-to-energy plants	Bangkok	A	Moderate	High	Low	Moderate	Low	Moderate	High		High	Low	High	High	Low	High	High
		Dhaka	B	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
		Gurugram	C	Low	Low	High	Low	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
4	Catalytic Pyrolysis and Gasification	Bangkok	E															
		Dhaka	D	Low	Low	Moderate	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	High
		Gurugram	D	Low	Low	High	Low	Moderate	Low	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low
5	Composting	Bangkok	A	High	High	Low	High	High	High	High		High	Moderate	Moderate	High	Low	Low	High
		Dhaka	A	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
		Gurugram	B	High	High	Moderate	High	High	High	High	High	Moderate	Moderate	Moderate	High	Moderate	Moderate	Low
6	Circular economy-based business models	Bangkok	A	High	High	Moderate	Moderate	High	High	High	High	Moderate	Moderate	Moderate	High	Moderate	Moderate	High
		Dhaka	D	High	High	High	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
		Gurugram	D	High	Moderate	High	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	High	Moderate	High	Moderate

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
Residential Sector																		
1	Use of LPG	Bangkok	A	High	High	Low	High	High	High	High		Moderate	Low	High	High	Low	Moderate	Moderate
		Dhaka	A	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High
		Gurugram	A	Moderate	High	High	Moderate	High	High	High	Moderate	Moderate	High	High	High	High	Moderate	High
2	DG Set retrofitting	Bangkok	E															
		Dhaka	C	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
		Gurugram	A	Moderate	High	High	Low	Moderate	Moderate	Moderate	Moderate	Low	Low	Moderate	Moderate	High	High	Moderate
3	Smog Towers	Bangkok	E															
		Dhaka	D	No Solution	No Solution	Low	Low	Low	Low	No Solution	Low	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution
		Gurugram	E	No Solution	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
4	Smog Free Tower	Bangkok	E															
		Dhaka	D	No Solution	No Solution	Low	Low	Low	Moderate	No Solution	Low	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution
		Gurugram	E	No Solution	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
5	Cleaner Fuel	Bangkok	A	High	Low	Low	Moderate	High	Moderate	High		Moderate	Low	High	Low	Low	Moderate	Moderate
		Dhaka	C	High	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate	High	High	High	Moderate	Moderate	Moderate	Moderate
		Gurugram	A	High	High	High	High	High	High	High	High	High	High	High	Moderate	Moderate	High	High
6	Cleaner Stoves	Bangkok	A	High	Low	Low	Moderate	High	Moderate	High	High	Moderate	Low	High	Low	Low	Moderate	Moderate
		Dhaka	A	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
		Gurugram	B	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Low	High	Low	Moderate	Low	High

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
7	Use of energy efficient appliances	Bangkok	A	High	High	Low	High	High	High	High	High	Moderate	Low	Low	High	Low	High	High
		Dhaka	A	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
		Gurugram	A	Moderate	High	High	Moderate	High	High	High	High	Low	Moderate	Moderate	High	Moderate	Moderate	High
8	Use of mechanical air blower	Bangkok	E															
		Dhaka	A	Low	Moderate	Moderate	Low	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
		Gurugram	E	No Solution	Low	Low	Low	Moderate	Low	High	Low	Moderate	Low	Low	Low	Low	Low	Low
Agricultural Sector																		
1	Satellite monitoring for agricultural burning	Bangkok	A	Moderate	High	Low	High	High	High	High	High	No Solution			High		High	High
		Dhaka	B	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
		Gurugram	B	High	High	High	Moderate	Moderate	High	High	High	High	High	High	High	High	High	High

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
2	Use of Bio Enzyme-PUSA for in-situ management of the crop residue	Bangkok	E															
		Dhaka	E	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution
		Gurugram	B	High	High	High	Moderate	High	Moderate	High	Moderate	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Low
3	Use of happy seeder machine	Bangkok	D	Moderate	High	Moderate	Moderate	Low	Moderate	Moderate	High	Moderate	Low	Moderate	High	Low	Low	Low
		Dhaka	E	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution	No Solution
		Gurugram	B	High	High	Moderate	Low	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
4	Promotion of biomass-based products using circular economy principles	Bangkok	A	High	High	High	High	Low	Moderate	High	High	High	High	High	High	High	High	High
		Dhaka																
		Gurugram	B	High	Moderate	High	High	Low	Moderate	High	High	Moderate	Moderate	Moderate	High	High	Moderate	Moderate

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
Monitoring of Air Quality																		
1	Manual monitoring stations	Bangkok	A	High	Moderate	Low	Moderate	Low	Low	Low	Moderate	Low	Moderate	Moderate	Moderate	Low	High	Moderate
		Dhaka	E	Low	Low	Low	Moderate	Low	Low	Low	Low	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate
		Gurugram																
2	Real-time monitoring stations	Bangkok	A	High	High	Moderate	Moderate	High	High	High	Moderate	Low	High	Moderate	High	High	High	High
		Dhaka	A	High	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
		Gurugram																
3	Low-cost Sensors for monitoring	Bangkok	A	High	High	Moderate	High	Moderate	High	Low	Low	Low	Moderate	Moderate	High	Moderate	Low	High
		Dhaka	E	High	High	High	High	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
		Gurugram																

S. No.	Type of Technology	Cities being used in	Status of Technological Intervention	Applicability	Feasibility	Innovativeness	Affordability	Availability	Scalability	Resilience	Ease of Maintenance	Emission Reduction Potential for PM10 and PM2.5	Environmental Impact	Health Benefits	Integration with existing systems	Life Cycle Attributes	Regulatory compliance	Social Acceptance
4	Satellite-based monitoring for air quality	Bangkok	A	High	High	High	High	Moderate	High	High	No Solution	Low	Moderate	Moderate	High	Moderate	Low	Moderate
		Dhaka	E	High	Moderate	High	Low	Low	Low	Low	Low	Low	Low	Moderate	Low	Low	Low	Moderate
		Gurugram																
5	Data management systems	Bangkok	A	High	High	High	Moderate	High	High	Moderate	Moderate	Low	Moderate	Moderate	High	High	High	High
		Dhaka	B	High	High	High	Moderate	Moderate	Moderate	Moderate	Low	Moderate	Moderate	High	Moderate	Moderate	Moderate	Moderate
		Gurugram																

Looking at the technological implementation across all three cities in a sector-specific manner, Gurugram and Bangkok have made a significant stride towards technological implementation. In case of Gurugram, the adoption of Bharat Stage VI (which is Euro VI equivalent standards in India) has brought in the DPF into all the new car models. The corresponding improvement of the fuel quality to match the vehicular transition to BS VI standard has been one of the most recent milestone, and a case of BAT implementation in the transport sector. For Bangkok, the use of Selective Catalyst Reduction (SCR) systems, development of intelligent traffic management system, having a parking policy to ease through congestion charges and designating no parking zones, ensuring extensive roadside plantation, and ensured accessible curb design for the pedestrians are some of the aspects that have been significant in combating air pollution at the city-level. Even though Dhaka is not far behind in addressing all the sectoral aspects in the transportation and mobility sector, some of the aspects that have been addressed at the city-level in Dhaka involve roadside plantation, manual road dust cleaning using, and the retrofitting of cars with CNG kits. However, Dhaka has the maximum scope of further mitigating the pollution from the transportation sector.

With regards to the infrastructure sector, Dhaka has made significant stride in air pollution mitigation technologies especially in aspects such as on-site and peripheral dust suppression systems, tarpaulins -covered trucks, wet cutting techniques, low-dust equipment (electric-powered tools and dust extractors), on-site utilis ation of the C&D derbies, and in the use of zig-zag technology for brick manufacturing. In the case of Gurugram and Bangkok, although the focus for minimizing the emissions from the infrastructure sector is comprehensive, many aspects are either under consideration or yet to be addressed.

The industrial sector remains the most well covered sectors, with Bangkok and Gurugram leading the way in aspects such as installations of FGDs, ESPs, bag houses, wet scrubbers, and low-NOx burners. In the case of Dhaka, most mitigation technological aspects are in the early stages of being assessed for their feasibility w.r.t to their applicability for various industries located in and around Dhaka. Some common aspects such as point sources like bakeries and restaurants/ tandoors, and common heat/ power/ steam supply systems.

Although waste management sector has limited aspects, its contribution has been found to be significant to the overall city emissions, especially in some seasons and instances. All three cities are making strides in different aspects of technological mitigation within the waste management sector. In case of Bangkok, the waste-to-energy (WtE) plants, composting, and circular economy-based business models are implemented and running ; however, aspects of Biogas recovery system, anaerobic digestion unit, and catalytic pyrolysis and gasification are yet to be considered within the preview of the possible technological measures for emissions reduction from the waste management sector. Dhaka, on the other hand, has made strides in implementing biogas recovery system, WtE plants, and composting. However, it is still working towards the implementation of anaerobic digestion unit, catalytic pyrolysis and gasification, and circular economy-based business models. And finally, in Gurugram, most aspects excluding catalytic pyrolysis and gasification, and circular economy-based business models have been either implemented or are in the process of being implemented.

In case of residential sector, aspects such as LPG usage, cleaner stoves, and use of energy- efficient appliances have been implemented across all three cities, however, smog tower and smog-free tower aspects are either to be considered or is in its very early stages of being considered in each of the three cities. Most of the aspects for the residential sector have been covered by Dhaka and Gurugram, while Bangkok is yet to pick up on some of the more recent technological advances like DG set retrofitting and use of mechanical blowers.

One of the major sectors contributing to the city's emissions load through transboundary emissions is the agriculture sector. It is one of the major sources in the case of all three cities. Of the three Gurugram has had undertaken the implementation of many aspects for curbing emissions through the agricultural sector with measures like satellite monitoring for detecting and addressing agricultural burning, use of

bio-enzyme for in-situ management of the crop residue, use of happy seeder machine, and promotion of biomass-based products using circular economy principles. Bangkok and Dhaka are following suit and in the process of strengthening the detection, reporting and addressing some of the aforementioned sectoral aspects.

4.2.2 Comparison of the outcomes and impacts of the interventions

It is important to understand how the comparative of all the technological interventions across all three cities measures up to the mitigation from the listed high emission sectors in each of the cities. This is important since it would help in developing an understanding about how impactful technological interventions have been and what more is warranted to make further headway in strengthening the aspect of technological mitigations.

Sectoral Outlook for Bangkok's Technological Interventions

Looking at the technological intervention for Bangkok, the emphasis on reducing vehicular and mobility related emissions has been strong, with only aspects like DPF, EV retrofitting, vehicle scrappage policy, remote sensing device for detecting vehicle exhaust, wall-to-wall carpeting and road design for effective traffic management needing further consideration/ formal implementation. Additionally, mechanical road sweepers on a wider scale are needed to mitigate $PM_{2.5}$ emissions the road dust and its resuspension.

Despite not having construction sector as one of the major emission contributors to the overall city emissions, Bangkok has suitable interventions in place for emission abatement. However, some facets such as on-site and peripheral dust suppression systems, air filters with a small low-powered fan, Filtration-based air cleaning technology, wet-cutting techniques, low-dust equipment, (electric-powered tools and dust extractors), use of the BAT for the mixing of asphalt, environmentally sound construction technologies (like precast, ready-to-use mix concrete, 3D printing, etc.), road laying technology, particularly mashteck layer laying, etc., which would drastically improve its arsenal of technological interventions for any necessary future intervention that would arise in this sector.

The city of Bangkok presents a strong front with regard to its technological interventions for the industrial sector, as it's the third highest contributing sector towards its overall emissions. If aspects of common heat/power/steam supply, and emissions from the point sources like bakeries and restaurants/ tandoors can be addressed, it would be a major milestone for the city administration.

Since open burning of waste is not a major issue in Bangkok owing to the circular economy-based business model being followed, many of the measures are not relevant to the city's intervention. However, the WtE and composting are being practiced widely as part of the circularity model existing in the city.

The PM levels in Bangkok are much less when compared to Dhaka and Gurugram, yet they are still higher than the latest ambient air quality guidelines prescribed by WHO. Therefore, aspects such as smog towers, and smog-free towers are not applicable for Bangkok. Even the use of DG sets and mechanical air blowers isn't much across Bangkok, which is why these aspects too aren't relevant to this city. However, aspects of LPG usage, cleaner fuel and stoves, and use of energy -efficient appliances are applicable and thus well addressed at the city level.

Sectoral Outlook for Dhaka's Technological Interventions

Despite being an important sector needing mitigation, most of the technological interventions are still under consideration by the government to understand its feasibility and other related nuances before they are sanctioned for implementation.

Considering the importance of the construction sector's contribution to the overall city-specific emissions, Dhaka's action plan has either addressed or is on its path to addressing most of the mitigation aspects. However, there is potential scope to further strengthen the technological interventions within the sector to further minimize its impact on the city's emission profile.

Dhaka's interventions are yet to be at par considering that industrial sector tops the list of the sector-specific emissions contribution towards Dhaka's air pollution. Some important and prompt measures like the installation of FGDs, ESPs, bag houses, wet scrubbers, and low-NOx burners are missing, before the action plan can address more advanced measures including modification of smaller furnaces and ovens used by small -scale industries, emissions from the point sources like bakeries and restaurants/ tandoors, and common heat/power/steam supply can be investigated. One major positive is how effectively Dhaka has been successful in reducing the emissions from the brick manufacturing sector through the implementation of the zig-zag technology.

The contribution of waste burning in Dhaka has risen in recent years due to economic development and thus has higher degree of presence in it s overall emission profile. Despite achieving implementation status in aspects of biogas recovery and composting, aspects such as anaerobic digestion, WtE plants, catalytic pyrolysis and gasification, circular economy-based waste management model are yet to be formalized and sanctioned.

Dhaka still needs to address the emissions from biomass based cooking in its residential sector, in addition to DG set retrofitting, smog towers, and smog-free tower—with each of the three very much in the pipeline for being sanctioned soon and thus will become part of the mitigation technology in the near future for Dhaka.

Sectoral Outlook for Gurugram's Technological Interventions

Being the leading sector contributing to the city-level emissions, Gurugram has made major efforts for addressing its emissions from the transportation sector, with most of the interventions either implemented or in the pipeline to be addressed and/or implemented—barring two aspects of remote sensing device for detecting vehicle exhaust and EV retrofitting; which can potentially be brought in the purview of the technological interventions in the future version of the city-level action plan.

Considering the pace and expanse of infrastructure development that Gurugram has seen in the last decade, the measures have the scope for further enhancement and that too with immediate effect. Although, aspects such as on-site site and peripheral dust suppression systems, specific storage units, tarpaulins- covered trucks, wheel wash facilities, wet cutting techniques, and on-site utilization of the C&D derbies could have been part of the interventions at least half a decade back, these measures must be brought in a prompt manner, which can lead to significant reduction of the construction sector-related emissions.

With industry being the second most important sector for Gurugram, the sectoral interventions have been at par with the demands of the mitigation requirements, especially with regard to the TPPs, brick kilns and other small-scale industries. However, the technological interventions of FGDs, ESPs, and emissions from the point sources like bakeries and restaurants/ tandoors are in the pipeline and would need to be addressed in coming years.

With the kind of resources and a national-level programme like the Swachh Bharat Mission being implemented on a mission mode, the mitigation of emissions due to open burning of waste is not as required it should be, which is why emissions from waste burning is one of the significant contributors to the overall emission profile of the city. Aspects such as biogas recovery, anaerobic digestion, composting, and WtE are yet to be implemented, which highlights some of the underlying reasons for the open burning of waste, besides the aspect of not collecting 100% of the city's waste.

Gurugram has many aspects covered except the smog towers, which in case of this city is considered a 'No Solution' due to the extremely high level of PM concentrations and its non-localized city-wide presence—rendering Smog towers a suitable solution only in case of indoor air pollution mitigation. Since there are limited number of urban slums and many peri-rural and rural areas around the city have

access to LPG, the aspects of cleaner stoves too are limited. And finally, just like the case with Bangkok, Gurugram too has no requirement of mechanical air blowers since that would lead to significant dust resuspension, something which would be counterproductive, and thus can be considered a 'No Solution' in this case.

4.3 Summary – Comparative Analysis

Comparing the three cities, the outcomes and impacts of air pollution interventions in Bangkok, Dhaka, and Gurugram reveal a host of commonalities and variations in the efforts undertaken by all three cities. They have made progress in implementing stricter emission standards, improving public transportation, raising public awareness, investing in addressing/ improving air quality monitoring, and improving mitigation actions using better policies, practices, and technologies when compared in a sector-specific manner—although to varying degrees. Consequently, these efforts have led to some degree of emission reduction and thus a consequent improvement in the city's air quality. However, the extent of impact varies due to the unique challenges faced by each city with regard to the limitation associated with the policies and the consequent implementation measures that have been undertaken thus far. Bangkok, with its extensive public transit system and green initiatives, has seen notable improvements in air quality, and is aiming to achieve the WHO's recommended ambient air quality guidelines. Dhaka, while making strides, still grapples with significant seasonal variations in pollution, and needs to further strengthen its city-level policies and consequently, its technological interventions for air pollution mitigation. Gurugram faces challenges related to rapid urbanization, location disadvantage, and limited public transport options, making its progress more gradual than other cities around it. Even though many measures have been put in place, with many more in the pipeline, it not being classified as a NAC further limits it from tapping its full potential in combating its local air pollution sources.

5 CURRENT GAPS AND CHALLENGES AS PART OF THE EXISTING INTERVENTIONS

Table 20 – A comparative of the gaps and challenges being faced across the three cities

S. NO.	BANGKOK	DHAKA	GURUGRAM
1	Tax on older vehicles is lower than new vehicles, which promotes the usage of older, inefficient cars	Insufficient monitoring stations and data accuracy issues hindered the ability to gather real-time air quality data, making it challenging to understand the extent of the problem and track progress accurately	Lack of adequate regulatory monitoring stations
2	Technology is not available for the CCTV to detect black smoke and black smoke inspection can only cover small vehicle fleet population	Enforcement of air quality regulations is often lacking, and industries or vehicles violating emission standards face minimal consequences, allowing them to continue polluting	Insufficient availability of timely and accurate air quality data to policymakers for allowing them informed decision-making

S. NO.	BANGKOK	DHAKA	GURUGRAM
3	Urban areas are inadequately planned to promote mass transit and active transport	Many industries in Dhaka lack adequate pollution control measures, leading to the release of pollutants into the air	Inefficient pollution control requires stringent emissions standards, regular monitoring, and incentives for industries to adopt cleaner technologies and practices
4	Reducing the number of cars is a short-term policy (use on days with high PM2.5).	A significant portion of industrial activities are categorized under the informal sector and thus avoided regulation	Lack of incentive to facilitate the adoption of cleaner transportation options, such as electric vehicles and public transit.
5	The public transportation system does not sufficiently cover the Bangkok area	Insufficient green spaces and urban planning for parks and tree planting has been limiting Dhaka's ability to absorb pollutants and improve air quality	Lack of infrastructure like charging stations and efficient public transport networks.
6	Diesel Particulate Filter for in-used vehicles Not effective for vehicles older than Euro II and has a high cost.	Dhaka is facing challenges in providing efficient, affordable, and widespread public transportation, leading to an overreliance on private vehicles.	Inadequate resources, limited capacity, and laicity in enforcement mechanisms hindering enforcement of the air quality regulations
7	The process of implementing Euro V/VI standard is moving slower than the intended timeline.	High traffic congestion is resulting in prolonged idling and increased emissions from vehicles.	Strengthening regulatory frameworks and ensuring consistent enforcement are needed to drive compliance with emission standards and pollution control measures
8	Lack of public awareness regarding health impacts of haze and open burning.	Open burning of waste was a common practice, releasing harmful pollutants into the air	Lack of technologies that are both easily available and can be used on a wide scale
9	Majority of the 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 leads to a lack of will and capacity to invest in alternative waste management practices	Dhaka city lacks proper waste management facilities, leading to rampant open dumping and burning	Challenges related to implementing and scaling up technological solutions for air pollution control (such as air purifiers) and pollution monitoring systems, requires overcoming challenges related to affordability, maintenance, and their long-term impact on air quality

S. NO.	BANGKOK	DHAKA	GURUGRAM
10	Burning is the quickest way to get rid of wastes on the field since there is no support for agricultural waste management	Many residents are unaware of the sources and health impacts of air pollution, making it difficult to mobilize public support for bringing change at the ground-level.	Improper waste management practices, including open burning and inadequate waste disposal, non-segregation of wastes
11	Lacking framework that enables multi-sectoral collaboration and central database for air quality management.	Limited financial resources and competing priorities made it challenging to allocate funds to air quality improvement projects	Increasing presence of plastics in waste and inconsistent quality of solid waste
12	Most fires happen outside Bangkok, but the cooperation among different provinces and organizations is not clear.	Political will to enforce stringent regulations and make tough decisions on issues like vehicle restrictions is at times lacking	Involvement of a large number of informal workers in the entire waste management chain
13	No control of pollution from the residential sector and street food.	Dhaka experienced significant seasonal variations in air quality, with severe pollution during the winter months due to factors like crop residue burning	Financial model for running the WTE plants and the lack of stringent regulatory requirements for it
14	Lacking public participation in the inspection and monitoring of industrial air emissions due to lack of awareness and available data	Transboundary pollution has a significant impact on the local air quality.	Since Gurugram is part of the National Capital Region (NCR), coordinating air pollution interventions across these regions requires harmonizing policies, regulations, and strategies among different local governments and state authorities, which is not always the case
15	Shortage of industrial emissions data collection or measurement due to lack of adequate air quality planning	Collaboration with neighbouring regions and countries to address transboundary pollution issues is limited, despite the impact of cross-border pollution sources.	Coordination among various government agencies, departments, and private entities is not effective, which results in gaps in the stated mandate for collaboration and communication between these stakeholders.

S. NO.	BANGKOK	DHAKA	GURUGRAM
16	The measure is insufficient to inspect and control the factories that are not under the Department of Industrial Works	The healthcare system is faced with challenges in dealing with the health impacts of air pollution, including respiratory diseases and related health issues.	Due to the differing priorities, mandates, and levels of authority of the stakeholders— their coordination efforts are not as effective as they have the potential to be.
17	Transboundary pollution has a significant impact on the local air quality.	Limited public access to air quality data and information, on top of their lack of understanding of the situation on the city's AQM plans makes it even more challenging for residents to actively engage in addressing the issue.	Transboundary pollution has a significant impact on the local air quality.

5.1 Challenges arising due to limitation of information and analysis

An important aspect to highlight pertains to the availability of information for all three cities in varying degrees. First , in most cases, there is no official website or portal that gives information which would facilitate all relevant information for the comparative analysis. Second , in cases where there is a portal highlighting information, it's not complete and therefore data needs to be sourced from other sources. Third , most sources are government or official websites, reliability of the information being accessed was always an issue. Although efforts were made to cite using government sources, from a peer-reviewed published scientific journal, or an international agency report, chances of inherent discrepancies in the results can't be ruled out. Fourthly, it is difficult to find a well-researched source that has given proper and logical reasoning, backed by historical data and trends citing official government sources. All of this has had a direct bearing on the analysis, thereby leaving scope for polishing and strengthening this analysis further, contingent on the availability of more relevant and targeted information for all three cities.

Further information to be considered for the comparative analysis would include real-time concentration data on the annual average of the pollutant(s) of concern; major sources contributing to pollution in each of the cities; status of regulatory compliance; aspect relating to public health, awareness, and involvement of another stakeholder; existing technological application and the potential gaps; status of implementation of the city-level action plan and the challenges in the same; existing policies and practices at the city level and its alignment with the national policies; and status of collaboration and coordination, to name a few.

6 LESSONS LEARNT

6.1 City Action Plans

There is also a clear scope of cross-city exchange of practices, through which the three cities can learn from each other, as well as further scope of promulgating those practices to other cities in the region based on the effectiveness of the overall success of each of the intervention. Adopting the innovative

and effective technologies would be beneficial to the city's administration, implementing organizations/ agencies, individual experts/ assessors, and society at large. Therefore, highlighting tried and tested good practices that have shown success through ground-level implementation across different landscapes also becomes an important aspect.

The lessons learned from the interventions for air pollution mitigation based on the city action plan in each of the three cities have many similarities. The current set of actions being undertaken provides valuable insights into addressing air quality issues in all three densely populated urban centres.

A. **Context-Specific Strategies** – One of the most crucial learning is the importance of developing context-specific strategies, since each city has its own unique and dynamic urban environment with its own specific sources of pollution; climatic and geographical conditions; city-specific economic and development activities; existing policy landscape and norms; availability of resources at the city-level; and specific social outlook and behaviour, among other things. Hence, city-level air pollution management demands context -specific strategies which entails and encapsulates a nuanced understanding of all these unique characteristics and challenges of the city's urban environment. Tailoring strategies to the specific conditions of a city greatly enhances the likelihood of attaining success during implementation, thus resulting in sustained improvements in air quality.

B. **Targeting long-term air quality improvements** – The need for sustained commitment to long-term air quality improvements is something that has come to fore long back, but only in the last decade has it gained traction. It targets aspects that would make lasting change in the city's air quality through mitigation as well as preventive approaches.

C. **Development of a robust and dynamic city action plan** – This is the need of the hour since just one of the three has an approved city action plan even though the work is being undertaken across all three cities in an almost similar manner. Having an action plan that covers all aspects of air quality management and can be revised from time to time is an essential and invaluable tool for the policymakers and the implementing authorities.

D. **Enforcing stricter emission standards** – The enforcement of stringent emission standards for vehicles and industries is essential. All three cities' experience highlights the need for continuous monitoring and regular updates to these standards across all sectors, to keep pace with technological advancements, and vice versa.

E. **Strengthening multi-stakeholder collaboration** – Successful air quality improvement initiatives in these three cities have often involved collaboration among government agencies, local authorities, industry stakeholders, and the public. Therefore, going ahead, engaging with all relevant stakeholders must be kept paramount to ensure effective policy implementation.

F. **Developing policies to strengthen public mobility** – Expanding and improving modes of public mobility systems, such as the metro rails, buses, and non-fossil fuel transport, along with facilitating last mile connectivity by promoting walkability and bicycle lanes and small EV vehicles connectivity can help reduce the number of private vehicles on the road, easing traffic congestion and reducing emissions across all three cities.

G. **Fiscal Policy to support the AQM work** – Development of a suitable policy that would provide yearly allocation work to enhance the AQM work within the city and link it with the city action plan and the performance of the city administration in achieving the intended targets, could greatly support the AQM mandate. This can also include the component of incentives and subsidies for activities contributing towards transitioning towards net zero.

H. **Developing policy to make green infrastructure mandatory** – Introducing policies that would set a minimum criterion for the development of green spaces while undertaking any planning in urban areas would greatly help in improving urban air quality. Integrating green infrastructure into city planning is a long-term investment in public health and air pollution mitigation.

I. **Promoting stringent policy measures to ensure industrial compliance** – Since all three cities have industries in and around their boundaries, policies that would ensure strict enforcement of emissions regulations, while allowing self-regulation in the industries would be critical. Monitoring, providing necessary support and guidance, and in case of repeated offenders, penalizing non-compliance can be a suitable approach towards ensuring significant reductions in industrial emissions.

J. **Public Awareness and Education** – Educating the public about the sources and health impacts of air pollution is essential. The experience that all three cities have had in the past underscores the importance of running year-round public awareness campaigns to encourage behaviour changes.

K. **Air Quality Monitoring** – Establishing and maintaining a comprehensive air quality monitoring network is essential for tracking pollution levels and making informed decisions. Real-time data accessibility helps both policymakers and the public stay informed. All three cities would need to invest in increasing their real-time monitoring stations.

L. **Renewable and Alternative Energy Transition** – Promoting the use of renewable energy sources and clean technologies in power generation across various sectors through suitable time-bound and targeted policy measures can significantly reduce air pollution from energy production and also set a long-term roadmap for transitioning to net zero. Sectors such as transport, residential, and industries can be the biggest beneficiaries.

M. **Policy Flexibility** – Due to the changing nature of the challenge and the rapid advancement in technology, the experience in case of all three cities suggests that policies need to be flexible and adaptable to changing circumstances and emerging challenges, such as seasonal variations in air quality, newer sources of pollution, and duration of exposure.

N. **Regional Collaboration** – Collaborating with neighbouring cities, districts, states, regions, and countries to address transboundary pollution issues is crucial, as air quality problems often extend beyond city boundaries as is the case with all three of these cities.

O. **Healthcare Preparedness** – Preparing the city's healthcare systems to deal with the health impacts of air pollution is important, especially at the time or period of high exposure, which is a yearly phenomenon in all three cities. Investments in healthcare infrastructure and public health awareness have become essential components of air quality management in each of these three cities.

6.2 Technological interventions

Lessons learned from the current set of technological interventions, which are also integrated with the existing action plans of all three cities to some degree, presents an important aspect that highlights how many of these technological interventions are common across all three cities, although in varying degrees. It further highlights how the city administration would need to deploy technological measures in a context-specific way as per the national strategy and the city action plan—based on the city's requirement and needing a multi-pronged approach to address air quality challenges at the city level. Each of these cities faces unique circumstances and has implemented various technologies to combat air pollution, with varying degrees of efficacy. Some of the aspects that have been highlighted using the technological interventions,

City-Specific Technological Interventions – Technological interventions must be tailored to the specific context of each city. What works in one urban environment may not be directly applicable to another. Bangkok, Dhaka, and Gurugram have distinct challenges and sources of pollution, thus requiring customized and context-specific technological interventions.

Comprehensive Monitoring Systems – Effective technological interventions necessitate robust air quality monitoring systems. Regular and accurate data collection is vital for identifying pollution sources, measuring the impact of interventions, and thus making informed policy decisions, including what technological solutions would be needed.

Transportation Upgrades and Regulations – Transportation is a major contributor to air pollution in urban areas. Implementing and enforcing stringent emission standards, introducing cleaner fuels, and investing in public transport are effective measures. Bangkok's SkyTrain, Dhaka's introduction of CNG-powered vehicles, and Gurugram's focus on sustainable mobility highlight these efforts.

Green Infrastructure and Urban Planning – Interventions involving green infrastructure, such as parks, green roofs, and tree planting, contribute significantly to air quality improvement. Integrating these solutions into urban planning is crucial, as seen in Bangkok's green spaces and Gurugram's emphasis on landscaping and mobility infrastructure.

Waste Management Innovations – Efficient waste management technologies reduce air pollution from open burning and uncontrolled landfill emissions. Dhaka's waste-to-energy projects and Gurugram's emphasis on waste segregation and recycling showcase the importance of tackling this pollution source.

Community Engagement and Education – Successful technological interventions involve the active participation of the community. Educating the public about the sources and impacts of air pollution fosters a sense of responsibility. Bangkok's community-based air quality monitoring initiatives and Gurugram's awareness campaigns demonstrate this approach.

Collaboration and Policy Alignment – Effective air pollution management requires collaboration across sectors and levels of government. Policies must align with technological solutions. Gurugram's collaboration with the private sector for electric vehicle infrastructure and Bangkok's multi-stakeholder approach highlights the importance of such partnerships.

Integration of Smart Technologies – The integration of smart technologies, such as IoT-enabled air quality sensors and data analytics, enhances the effectiveness of interventions. The use of air quality monitoring and information apps like SAMEER App in Gurugram, and Bangkok's use of technology for traffic management showcase the potential of integrated smart solutions.

Strategic Urban Development – Urban development strategies should prioritize sustainability. This includes mixed-use zoning, energy-efficient buildings, and green construction practices. Bangkok's focus on eco-friendly urban planning exemplifies this aspect.

Long-Term Vision and Adaptability – Technological interventions for air pollution mitigation require a long-term vision and adaptability. Continuous assessment and adjustment of strategies based on changing urban dynamics and emerging technologies are essential for sustained success.

These lessons underscore the importance of a holistic and adaptable approach, considering the unique characteristics and challenges of each city. Technological interventions, when integrated with supportive policies and community engagement, contribute significantly to long-term air pollution mitigation.

7 CONCLUSION

Despite the differences across all three cities, the overall progress in each of the cities has been commendable, given the constraints across various areas encompassed in the domain of both policy and practices—including governance, resources, infrastructure, technology and its application, skill-level, and knowledge, inter and intra agency/ organization collaborations, and awareness. This brings in the aspect of future work planning with the potential to grow in each of the specified areas. It involves enhancing the national, regional, and city-level policy landscape further to include newer aspects based on the city report and the comparative analysis, as per the needs of the city. This may strengthen implementation work that is currently being undertaken across the city—and therefore, can further strengthen the city-level action plan and its various facets originating and/or being influenced by the well-informed ground- level implementation. The strengthening of the city-level action plan is only possible if the plan is made to be dynamic in nature.

Furthermore, the comparative analysis along with the city- specific information would provide valuable insight into the practices that work, and those that don't. This has the scope of being translated into a potential BAT document for cities with similar landscapes in terms of AQM.

Last but most importantly, this analysis is an important cross -learning tool for not just the three cities, but the entire Asia Pacific region, and potentially all regions across the world, while considering the fact that the uniqueness of each city would be a critical aspect that would majorly be influencing its city level action plans and technological interventions, while also maintaining its alignment with the respective national policies that are in use at the time.

8 RECOMMENDATIONS PROPOSED ACROSS ALL THREE CITIES

8.1 Bangkok

TRANSPORTATION SECTOR

1. Providing economic incentive measures to promote buying newer, more efficient cars, including EV cars.
2. 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.
3. Using automatic roadside inspection to detect black smoke cars that cover major roads that connect Bangkok with other provinces.
4. Using partial flow filters for diesel vehicles which 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.
5. 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.
6. Setting up an alliance for clean air with private companies and government agencies in Bangkok to be ready for work-from-home when needed.

AGRICULTURAL SECTOR

7. 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).
8. Developing a database for $PM_{2.5}$ management which includes online data from different organis ations, 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 the fire after detection.
9. Preparing collaboration with other provinces to manage agricultural wastes in the whole region to mitigate open burning of the whole of Thailand.

INDUSTRIAL SECTOR

10. 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.
11. 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.

AIR QUALITY MONITORING

12. 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.

8.2 Dhaka

TECHNOLOGICAL RECOMMENDATIONS

1. Mitigation of emissions in several sectors like transportation, residential cooking by biomass, industry and construction activities, and biomass burning to curb Dhaka PM pollution

2. Old economic life expired vehicles must not be allowed to ply Dhaka city roads

3. Automated modern vehicle emission testing centre must be installed, and vehicles should be tested before issuing fitness certificates

4. Remote sensing vehicle pollution monitoring centres can be established

5. Refining capacity and technology must be upgraded to produce high -quality fuels compatible with Euro 5/6 engines.

6. High-capacity energy efficient clean fuel transportation systems should be introduced in urban areas

7. The introduction of metro rail services, electric vehicles (cars and buses), express-ways, automated traffic signal systems, and high-volume mass transport facilities must be undertaken.

8. There is ample scope to improve solid waste management, reduce and stop open biomass burning, and segregate solid waste at source.

9. Ensuring proper collection, segregation, and sanitary land filling management system,

10. Adopting the Reduce, Reuse, and Recycle (3R) policy

11. Introducing Waste-to-Energy (WtE) (incineration) projects, and control of open waste burning are required to reduce its contribution to air pollution.

12. Increase penetration of LPG, preferably through an LPG subsidy with direct transfer schemes and electric stoves for cooking to greatly reduce air pollution caused from residential cooking.

13. Construction-related good practices such as proper debris handling, transporting construction materials in covered condition, keeping the construction area wet, minimizing dust generation, etc. must be followed.

14. Establishing protocol for using cleaner fuels and technology for asphalt mixing and minimizing the number of hot-mix plants.

15. Mechanical/vacuum street sweeping trucks and wet/mechanized vacuum sweeping trucks for road cleaning.

16. Green areas or open spaces, gardens, and community places to be increased.

17. Wall-to-wall paving, repair of broken roads and pavement, and water fountains to be put in place and kept in good running conditions.

18. Continuous Emission Monitoring Systems must be installed in large -scale highly polluting industries and mandate must be given to transmit their CEMS data to the central data facility.

19. Data centres should be established at the Department of Environment (DOE).

20. Compliance assurance and enforcement must be undertaken with utmost diligence.

21. The current and future projections of emission inventories need to be developed in consultation with academic institutions specializing in air pollution science.

22. Detailed source apportionment study and emission inventory in Dhaka City must be conducted.

23. Air quality modelling tools should be used to predict current and future air quality to enable informed policy decisions.
24. Public awareness needs to be enhanced through the display of air quality indices and spatial air quality maps using electronic media and message boards.

POLICY RECOMMENDATIONS

1. The national- level clean air plan and the city level action plan must be prepared and approved by the relevant authorities at the earliest.
2. Gradually improve the public practices and behaviour to encourage source segregation by using at least 3 bins for in-house waste storage and following the collection system.
3. All concerned authorities including the Ministry of Power, Energy and Mineral Resources, Bangladesh Petroleum Corporation (BPC), and SREDA should take initiatives regarding the promotion of improved cook-stoves and the use of clean alternative Fuels such as LPG, biogas, and NG.
4. All relevant departments and agencies (e.g. City Corporation, WASA, DESA, DPDC, TITAS) in the case of digging roads and footpaths for construction or repair activities related to ongoing development projects and various utility services in cities such as water, telephone, electricity, internet, gas, Directorate of Information and Communication Technology, etc.) should take effective measures to control air pollution including dust control.
5. A common Utility Duct should be laid for all mutual coordination.
6. Ensure prompt repair of the broken road, footpath, and divider, and monitor the contractors to ensure environmentally friendly operation of their activities.
7. Imposing a complete ban on open waste burning with strong monitoring and enforcement activities.
8. Ensure strict control on roadside waste production and open litter and/or storage.
9. Strictly monitor and control the polluting brick kilns in the periphery of Dhaka City and ensure the compliance with the emission standards by all industries.
10. Strengthen the monitoring and enforcement protocols.
11. Develop training/awareness among all stakeholders and public to combat air pollution.

8.3 Gurugram

1. There is a need for source inventory and source apportionment studies to identify major sources and source -wise contribution to ambient air quality for effective interventions in the city actions.
2. Improved monitoring for identification of hot spots within city limits would enable the local authorities to take immediate and effective action. The use of LCS and remote sensing could be potential options, though operation of LCS could be comparatively easy.
3. Promotion for Innovations and start-ups in the field of air pollution control and mitigation through policy interventions, mainly for areas of green construction, air pollution hot spot identification, circular economy in urban environment
4. Technological interventions provide an opportunity to mitigate the air pollution mainly at the receptor level, though significant efforts are required for control of air pollution at the sources.
5. Transport, industry, construction, road dust, and solid waste management have been reported to be the main contributors to city air pollution. They shall be given priority in the implementation of city action plans. The point sources like gensets, bakeries, and tandoors are also important.
6. Though there are several technologies for abatement, mitigation, and control of air pollution, their performance to achieve ambient air quality has not been tested sufficiently, hence there is a need to include performance evaluation of such technology intervention in its adoption in city action plans.

7. The area of influence of air pollution control technologies is an area of research and evaluation. Considering the capacity of urban local bodies, the environmental regulators including SPCB and CPCB need to play a critical role for technology appraisal and validation for uniform and consistent adoption of city action plans.
8. There is an urgent need to develop infrastructure and capacity at the urban local bodies and SPCB to deal with technical and scientific aspects of air pollution including technology adoption, evaluation, and operation for effective implementation of city action plans.
9. The airshed approach needs to be adopted for holistic air quality management as significant contributions have been reported from sources located outside city limits.
10. Studies are required to assess the adverse impacts of air pollution on human health, more particularly focusing on poor and marginalized communities, women and children, and aged persons.
11. Studies are required to assess the adverse impacts of air pollution on flora and fauna (including urban and rural areas and agriculture)
12. Effective cost -benefit analysis of air pollution mitigation action plan and preparation of detailed comprehensive action plan would attract investments in this sector as already evident from various countries including China and the Philippines.
13. Adoption of new principles and governance tools such as circular economy, carbon and green credits, and innovations need to be integrated in city action plans.
14. Economic instruments like green credits need to be explored for adoption of new technology and practices such as conversion of transport fleet to electrical/CNG, bakeries, tandoors, small boilers etc. There are opportunities to get institutional funding if such a project is planned.
15. The City action plan needs to be supplemented through various city specific policies like parking policy, scrapping policy, mobility action plan, development plan, among others.
16. There is a need to develop a city- specific action plan for Gurugram based on source inventory and source apportionment studies, which is dynamic but aimed to achieve the desired air quality in a time bound manner using various technologies discussed in this report.
17. There is need to increase meaningful public participation in city action plan through continuous engagement throughout the life cycle of city action plan, and city specific portal giving all relevant information on city air quality action plan including grievance redressal mechanism.

9 WAY FORWARD

The analysis of the action plans and technological interventions for the three cities emphasis es the significance of a customized and context-specific approach to urban development. It is imperative for cities to utilize the insights gained from this analysis to create tailored strategies that align with their unique challenges and opportunities. Collaboration among city officials, regulators, urban planners, implementers, and technology experts is crucial to co-create relevant sustainable solutions that address specific needs that enhance urban resilience and promote inclusive economic growth.

This analysis can also serve to plan tasks and activities in the future that may include one or more of the following.

I. Identify Shared Challenges and Opportunities:
   a. Conduct a thorough analysis of the comparative findings to identify common challenges and opportunities that are shared among the three cities.
   b. Prioritize key issues that require immediate attention, considering the unique circumstances of each city.

II. Establish a Platform for Knowledge-Sharing:
   a. Create an online platform or forum where urban planners, policymakers, and technology experts from different cities can share their experiences and insights.
   b. Encourage cross-city collaboration and the exchange of best practices by organizing regular webinars, conferences, or workshops.

III. Develop Customized Urban Development Strategies:
   a. Collaborate closely with city officials and urban planners to develop customized strategies based on the lessons learned from the comparative analysis.
   b. Tailor solutions to address specific challenges identified in each city, considering factors such as demographics, infrastructure, and economic conditions.

IV. Implement Pilot Projects:
   a. Identify feasible pilot projects that incorporate innovative technological interventions based on successful practices in Bangkok, Dhaka, and Gurugram.
   b. Work with local stakeholders to implement these pilot projects, closely monitoring and evaluating their impact on urban development.

V. Integrate Sustainable Practices:
   a. Highlight the importance of integrating sustainable practices in urban planning and technological interventions.
   b. Explore eco-friendly solutions for transportation, waste management, and energy consumption based on successful initiatives observed in the comparative analysis.

VI. Develop Capacity-Building Initiatives:
   a. Design and implement capacity-building programs for city officials, urban planners, and technology professionals to enhance their skills in adopting and managing technological interventions.
   b. Encourage a culture of continuous learning and adaptation to ensure cities remain at the forefront of urban development practices.

VII. Promote Public Engagement:
   a. Launch awareness campaigns to educate and involve the public.
   b. Design specific programme to promote citizen science with an aim to promulgate science-based learning.

Moreover, the results of this comparative analysis can serve as a foundation for knowledge-sharing and cross-city learning. Establishing a platform for cities to exchange best practices, success stories, and lessons learned can foster a global network of urban innovation.

This collaborative approach can expedite the development and implementation of effective solutions, enabling cities worldwide to navigate the complexities of urbanization more efficiently. Looking ahead, a comprehensive and adaptable approach, coupled with continuous dialogue and information exchange, will be pivotal in creating cities that are not only technologically advanced but also sustainable, resilient, and responsive to the evolving needs of their diverse populations.

9.1 Dissemination of the Report Findings Across Asia Pacific

A strategically important and crucial endeavour, which also happens to be one of the core mandates of APCTT, is the dissemination of methodology and findings of the comparative analysis along with the city-specific assessments across the entire Asia Pacific region, as it is likely to have far-reaching implications.

First , to begin with, this comparative analysis offers key insights into the unique challenges faced by these cities in terms of air quality and allied environmental management disseminating these findings widely will help policymakers, regulators, city planners, city administration, environmental organizations, researchers, and urban planners across the region to gain a comprehensive understanding of the similarities and differences among these cities. Secondly, this exchange of knowledge can serve as a basis for developing tailored strategies, policies, and interventions that draw on the collective wisdom derived from the comparative analysis.

Third , this comparative analysis further highlights the need for promotion of regional collaboration and the sharing of knowledge networks. It encourages cities facing similar environmental issues to collaborate across borders, facilitating the exchange of best practices, successful interventions, and lessons learned. Given that air quality problems often transcend political boundaries, such collaborative efforts are crucial for addressing transboundary pollution challenges. By establishing a platform for communication and collaboration, the Asia Pacific region can collectively work towards sustainable and effective solutions, leveraging the experiences of cities that have effectively tackled environmental issues.

Finally, increased awareness can drive public engagement, advocacy, and support for policy changes. Ultimately, the dissemination of findings serves as a catalyst for positive change, fostering a greater understanding of the importance of addressing air quality and environmental challenges in the entire Asia Pacific region.

10 REFERENCES

1. https://www.iqair.com/world-air-quality-report
2. 2022 World Air Quality Report, IQ Air 2022
3. https://www.unep.org/news-and-stories/story/five-cities-tackling-air-pollution
4. https://www.un.org/sustainabledevelopment/blog/2016/05/un-health-agency-warns-of-rise-in-urban-air-pollution-with-poorest-cities-most-at-risk/
5. https://www.ccacoalition.org/content/air-pollution-measures-asia-and-pacific#:~:text=Air%20pollution%20in%20the%20Asia,significant%20risk%20to%20their%20health
6. Executive Summary, Air Pollution Series Actions on Air Quality in Asia and the Pacific (https://wedocs.unep.org/bitstream/handle/20.500.11822/36698/AAQAP_ES.pdf)
7. Asia-Pacific Tech Monitor, Vol. 39 No.2, April-June 2022
8. https://www.iqair.com/in-en/world-most-polluted-cities?continent=&country=&state=&sort=-rank&page=1&perPage=50&cities= (July 27, 2023)
9. Asia-Pacific Tech Monitor, Vol. 39 No.2, April-June 2022
10. Regulating air quality in Thailand – a review of policies, Jaee Nikam, Diane Archer and Chirat Nopsert, Stockholm Environment Institute (2021)
11. CPCB Dataset (2017-2021)
12. Source Apportionment of PM 2.5 & amp; PM 10 of Delhi NCR for Identification of Major Sources
13. https://www.latlong.net/place/bangkok-thailand-778.html
14. https://www.populationu.com/cities/bangkok-population#:~:text=Bangkok%20population%20in%202022%20is,is%20710%20people%20per%20sq
15. https://www.ccacoalition.org/news/bangkoks-air-pollution-reaches-dangerous-levels-researchers-are-working-determine-how-boats-fit-emissions-puzzle
16. https://www.thai-german-cooperation.info/wp-content/uploads/2022/09/Bangkok-congestion-charging_Small.pdf
17. https://www.who.int/thailand/news/detail/08-06-2022-the-cost-of-clean-air-in-thailand
18. https://www.sciencedirect.com/science/article/abs/pii/S1352231014002830
19. https://journals.librarypublishing.arizona.edu/jpe/article/2254/galley/2463/view/
20. https://www.sciencedirect.com/science/article/pii/S2405844023014688#bib5
21. https://www.researchgate.net/publication/355573620_Transportation_System_in_Bangkok_City
22. https://www.eeer.org/journal/view.php?number=1523
23. https://www.eeer.org/journal/view.php?number=1523
24. Pusapukdepop, Jitrapun and Pengsa-ium, Vipa, Measures to Reduce the Impact of Dust From Construction in Bangkok (May 22, 2018). Available at SSRN: https://ssrn.com/abstract=3182991 or http://dx.doi.org/10.2139/ssrn.3182991
25. https://www.researchgate.net/publication/376378416_Comprehensive_review_of_the_annual_haze_episode_in_Northern_Thailand
26. https://www.sciencedirect.com/science/article/pii/S2405844023014688
27. https://www.sciencedirect.com/science/article/pii/S2405844023014688
28. https://www.researchgate.net/publication/5594532_Levels_and_major_sources_of_PM25_and_PM10_in_Bangkok_Metropolitan_Region

29. https://www.sciencedirect.com/science/article/abs/pii/S130910422300168X#:~:text=The%20results%20indicated%20that%20the,construction%20(36.0%25)%2C%20respectively.

30. https://www.latlong.net/place/dhaka-bangladesh-5656.html

31. https://www.statista.com/statistics/1237290/cities-highest-population-density/

32. https://worldpopulationreview.com/world-cities

33. https://bbs.portal.gov.bd/sites/default/files/files/bbs.portal.gov.bd/page/b343a8b4_956b_45ca_872f_4cf9b2f1a6e0/2023-09-27-09-50-a3672cdf61961a45347ab8660a3109b6.pdf

34. https://bbs.portal.gov.bd/sites/default/files/files/bbs.portal.gov.bd/page/b343a8b4_956b_45ca_872f_4cf9b2f1a6e0/2023-09-27-09-50-a3672cdf61961a45347ab8660a3109b6.pdf

35. https://elevation.maplogs.com/poi/dhaka_bangladesh.168492.html

36. https://en.banglapedia.org/index.php/Dhaka,_Geology

37. https://aqli.epic.uchicago.edu/wp-content/uploads/2023/08/Bangladesh-FactSheet-2023_Final.pdf

38. https://openknowledge.worldbank.org/server/api/core/bitstreams/fa89a482-f616-4da0-914f-40dac1a88bdc/content

39. https://aqli.epic.uchicago.edu/wp-content/uploads/2023/08/Bangladesh-FactSheet-2023_Final.pdf

40. https://aqli.epic.uchicago.edu/wp-content/uploads/2023/08/Bangladesh-FactSheet-2023_Final.pdf

41. https://pubs.aip.org/aip/acp/article-abstract/2713/1/060013/2887353/Estimation-of-air-pollutants-from-different?redirectedFrom=fulltext

42. https://www.iqair.com/in-en/world-most-polluted-cities?continent=59af92b13e70001c1bd78e53&country=C6qfKtSfvq5FAxdC8&state=&sort=-rank&page=1&perPage=50&cities=

43. https://pubs.aip.org/aip/acp/article-abstract/2713/1/060013/2887353/Estimation-of-air-pollutants-from-different?redirectedFrom=fulltext

44. https://cpcbenvis.nic.in/airpollution/standard.htm

45. http://cdn.cseindia.org/attachments/0.89397800_1525342802_gurugram-a-framework-for-sustainable-development-update.pdf

46. https://timesofindia.indiatimes.com/city/gurgaon/february-air-worst-in-3-years-in-gurgaon-lack-of-rain-severe-cold-main-factors/articleshow/98321216.cms?from=mdr

47. http://cdn.cseindia.org/attachments/0.89397800_1525342802_gurugram-a-framework-for-sustainable-development-update.pdf

48. https://www.teriin.org/sites/default/files/2018-08/Report_SA_AQM-Delhi-NCR_0.pdf

49. https://www.teriin.org/sites/default/files/2018-08/Report_SA_AQM-Delhi-NCR_0.pdf

50. https://legislative.gov.in/constitution-forty-second-amendment-act-1976 (November 11, 2021)

51. Article 48A mentions that, “The State shall endeavour to protect and improve the environment and to safeguard the forests and wildlife of the country."

52. Article 51A(g) mentions that, “It shall be the duty of every citizen of India to protect and improve the natural environment including forests, lakes, rivers and wildlife, and to have compassion for living creatures;”

53. https://legislative.gov.in/constitution-forty-second-amendment-act-1976 (November 11, 2021)

54. Environment (Protection) Amendment Rules, 2015, S.O. 3305(E), December 7, 2015 (https://egazette.nic.in/WriteReadData/2015/167141.pdf) (November 11, 2021)

55. Guidelines on DUST mitigation measures in handling Construction material & C&D wastes (Control of Urban Pollution Series CUPS/89/2017-18)

https://cpcb.nic.in/openpdffile.php?id=UmVwb3J0RmlsZXMvNTYxXzE1MTE5MzMzNzJfb-WVkaWFwaG90bzEyNjcxLnBkZg== (November 11, 2021)

56. National Ambient Air Quality Status & Trends 2019 (National Ambient Air Quality Monitoring; NAAQMS/45/2019-2020), CPCB, September 2020

57. https://main.mohfw.gov.in/sites/default/files/5412023661450432724_0.pdf

58. https://www.hindustantimes.com/cities/gurugram-news/gurugram-hospitals-see-increase-in-patients-with-respiratory-issues-101667327443433.html

59. http://cdn.cseindia.org/attachments/0.89397800_1525342802_gurugram-a-framework-for-sustainable-development-update.pdf

60. https://dcmsme.gov.in/old/dips/DIPR_Alwar.pdf

61. https://dcmsme.gov.in/old/dips/har_bhiwani.pdf

62. https://www.india-briefing.com/news/special-economic-zones-warehousing-clusters-delhi-ncr-18871.html/

63. http://www.indiaenvironmentportal.org.in/files/file/brick-kilns-zig-zag-technology-NGT-order-Feb17-2021.pdf

64. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1861932