DRIVING CLEAN AIR ACTION UNDER NCAP

AN ASSESSMENT AND INTERPRETATION OF GOOD PRACTICES IN INDIAN CITIES

- Transport and Mobility
- Industry
- Solid Waste
- Construction and Demolition Waste

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INTERPRETING GOOD PRACTICES TO DRIVE CLEAN AIR ACTION

NCAP has helped establish the national air quality management framework in the country. For the first time, non-attainment cities have been identified, given clean air targets, and made accountable for meeting them; and India has adopted performance-linked funding strategy for air quality management.

It is important to understand how this framework has catalysed good practices in key sectors of pollution. This review is not a report card on what all cities have done, but an assessment of selected case studies from the key sectors of transport, industry and waste steams with the aim of presenting a learning curve. The review is an effort to understand how NCAP can be made more purposeful to drive implementation.

Currently, the benchmarking of air quality improvement under NCAP primarily relies on the trends in PM10 levels. Therefore, a sizeable share of the funding has gone for dust control and is not equitably spread to address measures in combustion sectors of transport, industry, waste, etc. The NCAP framework needs to be strengthened to address these gaps.

However, NCAP has created opportunities for alignment with other schemes and funding to unlock more resources. This is already evident in the way programmes like Swachh Bharat Mission 2.0 (urban) have become part of the NCAP reporting on progress in cities.

This review builds optimism about the direction of change. Cities and regions are beginning to integrate the good practice principles, requisite systemic design, infrastructure development, monitoring and compliance strategies to implement a portfolio of solutions needed to make a difference and go beyond the common minimum requirements.

THE NATIONAL CLEAN AIR PROGRAMME (NCAP)

Ever since the launch of the National Clean Air Programme (NCAP) by the Union Ministry of Environment, Forest and Climate Change (MoEFCC) in January 2019, there has been heightened curiosity about its effectiveness in driving clean air action at scale and with speed to meet the clean air benchmark.

This expectation stems from the fact that for the first time, a national air quality management framework has been put in place with clean air targets, implementation plans and a fiscal strategy. Therefore, after five years of its implementation, it becomes imperative to understand the effectiveness of this framework in driving on-ground implementation of strategies in the key sectors of pollution — with the aim of making a difference to the air quality and addressing the public health crisis.

Therefore, Centre for Science and Environment (CSE) has undertaken this assessment of clean air action in cities and in different sectors to understand the direction of change, what is needed to drive action, and what enables adoption of good practices in different sectors that are sustainable, scalable and replicable.

Yet, this review is not a report card on what all cities have done and how they have progressed under the NCAP programme. Instead, the objective is to understand the nature and the scope of some selected good practices that have taken shape in different sectors and cities — get a grasp of their drivers, the combined role of forces and convergence to catalyse the change, and the key elements of the interventions that have improved the effectiveness and sustainability of the interventions.

Capturing this learning curve from the emerging sectoral good practices is an opportunity for cross-learning among cities. This shared understanding is necessary to maximise air quality gains from the diverse set of investments in cities and sectors under different national- and state government-supported programmes and schemes.

This focus on good practices is also driven by the fact that the cities that are recipients of growing amounts of funding under NCAP as well as other sectoral funds, need deeper understanding of the scope, scale, system design and infrastructure requirements in priority areas of interventions for the action to be effective. Otherwise, the investments will remain sub-optimal without delivering on the clean air objectives.

While looking at the ways the NCAP programme has influenced on-ground action, this review has considered synergistic role of other sectoral programmes as well. This helps identify the areas of further reforms needed in the NCAP programme itself to expand impacts across all sectors and further strengthen its catalytic role in mainstreaming clean air indicators in divergent sectoral programmes to upscale sectoral good practices.

It is also recognised that the clean air action in different sectors is not driven by any one programme. In most cases, it is a synergistic effect of several strands of programmatic support for implementation, as well as the strategic interventions by the judiciary including the Supreme Court of India, the High Courts in states and the National Green Tribunal

(NGT). Yet, within this ambit, it is necessary to understand the role of the NCAP and its reforms to drive sectoral good practices.

This review begins with the caveat that there is virtually no city or a region that has demonstrated the impact of implementation of the full scale of solutions across all sectors to achieve clean air. Only some have done more than the others and that too, in widely varying scale and scope. It is not even possible to compare all of them on a same scale. Yet any good initiative — of whatever scale and scope — needs to be recognised in order to draw lessons on how to make the investments more purposeful.

The good practices have been selected based on a simple logic: they must contribute towards ambitious sectoral targets defined by the new generation policy principles, to be able to meet the clean air goals. It is now well established that clean air requires massive clean energy transition across all combustion sectors including industry, vehicles and households, mobility transition to control growing congestion and automobility, and massive circularity of all waste streams to close the loop around waste. Some of these sectors also have serious challenges of fugitive emissions while dust remains a bane, especially in the Indo Gangetic Plains.

The action is largely driven by the local imperatives as well as the national regulations that are also the common minimum programme for all.

From this perspective, this review has selected a few case studies from the key sectors of transport, industry and municipal solid waste management. All of these combustion sectors together make up the biggest pie in the pollution charts generated from the emissions inventory and source apportionment studies in a large number of cities. They also contribute hugely to the toxic gases that make up the secondary particulates formed from gases in the air.

This review has also considered dust sources. Sometimes, the single largest contributor to air pollution can be the combined dust sources of road dust and construction and demolition (C&D) waste especially, in the states of northern India. C&D waste not only requires dust curbs, but the recycling of this waste can also reduce material and energy intensity of built structures in cities and regions. The case studies have also shown that the focus in most cities needs to go beyond road sweeping and pot-hole repairs — it must be co-joined with urban renewal and redevelopment.

Good practices are evolving continuously in scope and in stages: they are not an absolute idea. But it is important to understand the direction of change that can enable us to meet our targets: of energy transition and zero emission; service-level benchmarks; increase in modal share of sustainable transport modes; and complete circularity of waste streams to enable zero-landfill status.

However, the key caveat is that while several good practices display promising and positive trends, there are still gaps in action; there is a need for further reform for scale and impact. Our analysis of case studies have also highlighted that.

UNDERSTANDING THE GOOD PRACTICES WITHIN THE NCAP FRAMEWORK

To begin with, it is necessary to understand the operative conditions under the NCAP programme that have the potential to drive and upscale action, but may require further refinements for stronger impacts.

Clean air targets: As is now well known, NCAP has set overall regulatory clean air targets for cities that have been identified as non-attainment. These include reduction in particulate concentration by 20-30 per cent by 2024 from the base year of 2017, and further by up to 40 per cent by 2025-26 with respect to the base year of 2019-20. In addition to these overall targets for pollution reduction, individual targets have also been set for each city based on their unique air quality situation. About 130 cities have been identified as non-attainment cities so far. This is expected to establish a degree of accountability.

Performance-linked funding: For the first time, India has adopted a performance-linked funding strategy for air quality management that requires cities to demonstrate improvement in air quality to access the earmarked funds. There are three streams of fund flow:

- A smaller fund allocated by MoEFCC to 82 non-attainment cities under the NCAP programme
- Direct funding from the 15th Finance Commission as a grant to 42 cities and six urban agglomerations with more than a million population. This is also called the Million-Plus Cities Challenge Fund
- Accounting of the convergence funding — alignment of separate funding streams available for sectoral schemes that can also deliver on clean air objectives

The bigger share of the funding has been routed through the 15th Finance Commission to cities with more than a million population and urban agglomerations. The purpose is to augment measures to improve air quality. This grant to the ULBs is based on agreed outcomes, city-wise details of sources of pollution and proposed measures, and achievement of performance indicators. As much as Rs 19,711.00 crore has been earmarked for 130 cities for the period of FY 2019-20 to 2025-26, as stated in the 2023-24 MoEFCC report.

The involvement of ULBs in air quality management through this grant has happened primarily because the Central Finance Commission is responsible for making grants to ULBs to augment financial resources for helping them meet their mandated functions and maintain the service levels. The Central Finance Commission also has a system of performance-linked grants to improve financial management and service delivery of the ULBs. In this specific case, this has been leveraged for the purpose of air quality management. This has also shifted the fulcrum of authority from SPCBs to the ULBs with respect to clean air plan implementation.

The cities are given scores based on their ability to reduce particulate pollution or particulate matter less than 10 micron in size (PM10). This is used to decide if the cities will get the full grant or lose it partially or all of it. Thus, a carrot and stick approach is in place to drive action.

Competitive ranking of cities based on sectoral action: A parallel programme has also been launched in 2022 called the 'Swachh Vayu Survekshan' (SVS) to rank cities based on the level of policy measures implemented. These cities (classified based on population — above 10 lakh-plus, above 3-10 lakh, and under 3 lakh population) are ranked based on policy measures implemented in multiple sectors including biomass, municipal solid waste, road dust, dust from construction and demolition waste, vehicular and industrial emissions, other emissions, public awareness, and improvement in lowering the PM10 concentration. All NCAP cities are assessed under the SVS as well as based on a scoring framework and information provided by the cities/ULBs on the Portal for Regulation of Air-pollution in Non-Attainment Cities (PRANA) every financial year. Weightages are attributed and quantitative performance targets are set for each sector.

Supporting science for air quality monitoring and management to inform action and progress: NCAP has created an opportunity to expand the air quality monitoring network and build upon the science of pollution source assessment in cities. Cities have been supported to prepare clean air action plans to identify multi-sector action. They are obligated to carry out source apportionment and emissions inventory studies to assess air pollution sources and their relative contribution to the air quality — the aim is to inform and direct the clean air planning process and prepare sectoral roadmaps.

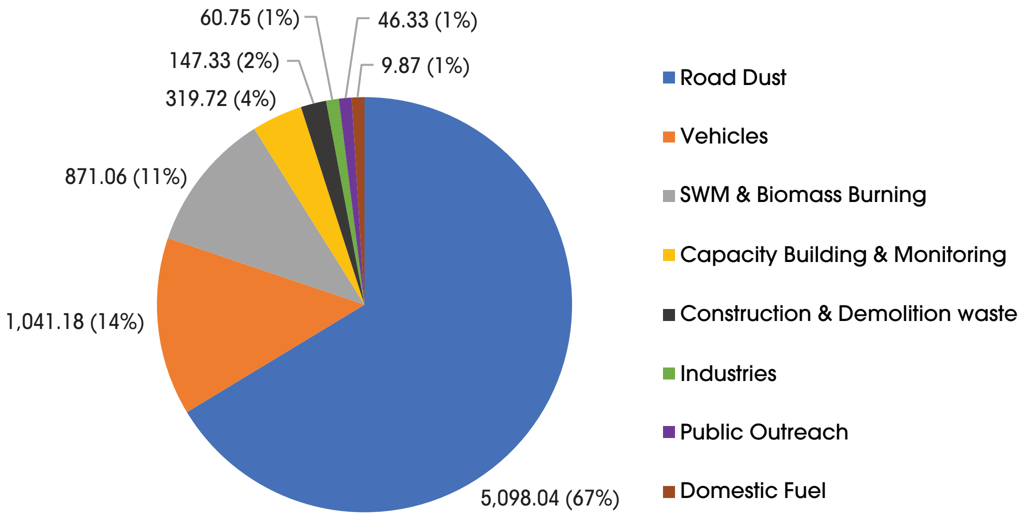
NCAP has also set up systems for monitoring and compliance that require cities to report progress every quarter on the centralised PRANA portal created by the Central Pollution Control Board (CPCB). For this purpose, the CPCB has provided detailed indicators for each sector that require cities to define the scope of the action accordingly, set targets for action, and indicate funding for implementation.

Thus, the overall performance-linked NCAP framework has helped lay down the foundations of national air quality management. One must remember that this is an evolving programme that has changed in response to new challenges and policy questions.

ACTION AND DIRECTION OF CHANGE WITHIN THE NCAP FRAMEWORK

How the NCAP programme has enabled action in cities is largely indicated by the nature of spending of the 15th Finance Commission funds in the 48 cities and urban agglomerations. Illustratively, out of the total grant of about Rs 19,711.00 crore for the 48 cities, 68 per cent has been utilised. The individual cities have received from a low range of Rs 80 crore and more to a high of Rs 300-400 crore. The remaining 81 NCAP cities — outside the ambit of the 15th Finance Commission funding — have received a much smaller grant of Rs 1,401.81 crore: the lower range is Rs 1-10 crore each for some cities and the higher is Rs 20-40 crore for a few others. This segment shows utilisation of about 72.48 per cent (*see Annexure : City-wise status of fund utilisation under XV-FC, FY 2020-21 to 2024-25, till May 7, 2025*).

Graph 1: NCAP: Sector-wise fund utilisation, FY 2019-20 to 2023-24



Note: The total funds released amount to Rs 11,211.13 crore and the total expenditure reported is Rs.7594.28 crore (68%) for FY 2019-20 to 2023-24 (as on September 7, 2024). The amounts in the pie chart are in Rs crore, with the corresponding sectoral share (in per cent) out of the total utilisation

Source: PRANA portal, as on September 7, 2024

This shows that the maximum share — 67 per cent — has been spent on road dust control which includes mechanical sweeping, water sprinkling, road repair and road redevelopment. The transport sector has hogged about 14 per cent for purchase of electric buses in a few cities of Maharashtra, construction of multi-level car parks, traffic management, and small-scale street development for walking, among other things. About 11 per cent has been spent on solid waste management followed by 2 per cent on managing C&D waste. Industry has got only 1 per cent (*see Graph 1: NCAP: Sector-wise fund utilisation*).

Even though the clean air action plans that were conditional to accessing NCAP and 15th Finance Commission funding have outlined a spectrum of multi-sector action, and the CPCB had originally given a wide set of indicators for each sector for the purpose of defining the scope of action and reporting progress in implementation, it has not led to implementation of priority measures in every sector. The actual spending is not equitably spread to address the priority measures in each sector.

It is now well understood that this disproportionate focus on road dust has been largely determined by the nature of the performance benchmark for cities, which considers the annual trends in ambient concentration of coarse dust or particulate matter less than 10 micron in size (PM10). This is getting further nudged by the results of the source apportionment and emission inventory studies in most states, especially those in the Indo-Gangetic Plain, that show dominant influence of dust on air quality. Moreover, urban local bodies that are primarily responsible for spending the 15th Finance Commission money, take road dust control as a 'low hanging fruit'.

The least funded sector is industry. The reason is the confined focus of implementation of the clean air action plans — only within the municipal limits; this leads to exclusion of most industries as they are located outside this orbit. Yet, the CPCB had originally provided detailed indicators for industrial pollution control, which included a wide spectrum of industrial sectors as well as strategies for them. Cities are largely reporting on adaption of approved fuel lists and regular inspection and challans, but not the real world transition in industry.

During the later stages of the NCAP programme, the CPCB has short-listed a few more standardised measures for all cities to implement.

The current design of NCAP implementation has limited the scope of multi-sector funding, especially in the combustion sectors. This is also evident from the limited information available in the PRANA portal for reporting of progress in cities under NCAP.

Multi-sector spending gets enhanced when state-level priorities are established: It is evident from the direct engagement with state pollution control boards (SPCBs) and urban local bodies (ULBs) that leveraging of the 15^{th} Finance Commission funding for multi-sector action in cities becomes possible when the state governments set explicit policy priorities in the sector.

The cities where NCAP funding has been spent more meaningfully are those that have drawn up state-level policy priorities. For instance, in the cities of Maharashtra, the advent of the 15^{th} Finance Commission funds had coincided with the emerging state government priority of expanding electric mobility and the electric bus fleet. Thus, nearly 80 per cent of the 15^{th} Finance Commission fund has been linked with procurement of electric buses for its non-attainment cities, including Mumbai. But this has also been possible because in Maharashtra ULBs are responsible for running city bus systems.

Similarly, Chennai had already adopted a non-motorised transport policy seeking at least 60 per cent of its infrastructure funding for street development for walking and cycling; implementation was already underway. Therefore, it created the opportunity to divert some amount of its NCAP money in that direction. In some cases, the state government could prioritise some specific measures for targeted pollution control and earmarked the clean air fund for that purpose. Such examples include replacement of solid fuel-based cookstoves with LPG stoves in open eateries of Kolkata.

This essentially shows that spending the national funds becomes more purposeful if state-level policy priorities are well established. It minimises *ad hoc* decisions and makes spending more purposeful. NCAP needs to become a more reform-based funding strategy to demand essential policy priorities at the state level to direct the nature of spending. In fact, several other performance-linked funding in different sectors qualify as reform-based funding.

NCAP — A CATALYSING CONVERGENCE FRAMEWORK FOR A MULTIPLIER EFFECT

It is clear that the scale of transition and ambition that is needed to drive action for clean air in key sectors of pollution control cannot be fully met by the NCAP and 15th Finance Commission funds. Clean air action and indicators need to be mainstreamed into the larger development process itself.

Even though direct funding under the NCAP framework has not been the key mover of multi-sector action — especially combustion sources — the NCAP strategy has helped formalise the convergence framework to combine reporting on multiple sectoral programmes and on funding in the sector. This aligns all other programmatic interventions to report on clean air indicators. This is something that needs to be taken forward.

NCAP has mandated the states to report on all sectoral action: not only under NCAP or the 15th Finance Commission funding, but also under the other funding schemes in the sector. This alignment is critical for maximising clean air benefits from the full range of investments in the sector.

Nearly all million-plus cities as well as several smaller cities have received large funds under other Central government schemes related to urban development, waste management and electric mobility, among others. These have a bearing on urban air quality. These parallel funds come from urban development and waste management programmes of the Ministry of Housing and Urban Affairs (MoHUA), including Smart City Mission, AMRUT (Atal Mission for Rejuvenation and Urban Transformation), CITIES 2.0 and Swachh Bharat Mission 2.0 (urban), and Swachh Sarvekshan.

Similarly, FAME II (Faster Adoption and Manufacturing of (Hybrid) and Electric Vehicles), PM e-Drive and PM e-Bus Sewa under the Ministry of Heavy Industry and MoHUA are driving electric mobility for zero emissions transition. All of these sectoral programmes have a strong bearing on air quality.

This brings out the importance of the convergence model in which dedicated funding for clean air action — if well designed — can play a catalytic role in mainstreaming the requirement of clean air plans in all sectoral funding. Cities are reporting a much larger number of measures under these aligned programmes.

Effectiveness of the convergence framework in pushing multi-sector action

Notably, several of parallel sectoral schemes have clear targets and sustainability criteria — if implemented well, these can have a strong bearing on the environmental performance of cities. At this stage, the detailed break-up of how much of each of these funds are received by individual cities is not available. But all the million-plus cities as well as several smaller cities are a part of these mega funding strategies.

A comparative assessment of the information available on PRANA and direct engagement with SPCBs and ULBs has shown that among the on-ground measures reported, the highest number of measures are related to road dust control followed by waste management (both municipal solid waste and C&D waste). There is also information on electric bus procurement and charging programmes. The rest are largely routine information on industrial inspection, implementation of the pollution under control certification programme, traffic management, installation of parking structures, etc.

The relatively more extensive reportage on waste management reflects the importance of target-driven performance funding of the SBM 2.0 programme. This has set clear sectoral and universal goals, mandates and timelines to drive performance on waste management in cities. It is co-joined with Swachh Sarvekshan ranking of cities based on actual action taken. Accordingly, the cities are required to collect and segregate 100 per cent municipal solid waste, process it for material recovery, divert at least 80 per cent of fresh waste from dumping in landfills, and remediate legacy waste by 2026. This system has also provided greater weightage to C&D waste as well. A lot more traction has been possible at the city level due to this — this is showing up in the reporting being done by cities.

Similarly, several cities have shown progress in urban systems, urban transport infrastructure and electric mobility because of the Smart city, FAME and electric bus programmes. But these developments have not been well captured in the reporting systems on PRANA. This shows that programmes with firm sectoral targets, mandates and funding are more effective in driving change on ground.

Even though the NCAP programme is also a performance-linked funding programme and the Swachh Vayu Sarvekshan ranking of NCAP cities is based on action taken in eight sectors, these are not as effective in driving change independently because these are not driven by binding sectoral targets for action.

Moreover, the city-level focus under NCAP has largely remained on short-term enforcement measures instead of systemic and infrastructure-level approaches. The scope of the strategies is not well defined as per the policies in the sectors for capturing the full portfolio of complex solutions. All the critical dots are not joined to decide on the scope and scale of implementation. As a result, implementation remains partial, micro and incapable of accelerating infrastructure and system-level development for upscaled and durable change.

To be catalytic NCAP programme requires ambitious sectoral targets in combination with clean air targets: The NCAP framework and the supportive funding is critical to create the conditions, opportunities and mandate for state governments to mainstream clean air requirements in their respective state budgets as well as sectoral implementation strategies. A similar approach is needed to align Central government programmes, fiscal instruments and pricing strategies of the concerned Union ministries.

NCAP has to create a higher level of ambition and sectoral targets to build scale and speed of change and align sectoral policies accordingly. Only this can upscale energy transition in industry, transport and household sectors; accelerate mobility transition for zero emissions mobility and reduced dependence on personal vehicles; and effect significantly upscaled circularity in waste streams to close the waste loops for material recovery and remediation of legacy waste. Otherwise, sectoral action will remain incremental even if it is in the right direction. The industry sector, particularly, may not even get adequate attention if specific sectoral programmes and funding are not in place.

NCAP requires reform-based funding with legal and fiscal strategies: The NCAP programme and related funding need to be catalytic and reform-based. Even though the CPCB provides the broad indicators for clean air action, these are recommendatory in nature and do not create the mandates and targets for reforms and priority strategies for a scalable change in each sector or for the concerned departments.

The NCAP programme can strategically outline the conditional reforms and priority strategies with targets for both national- and state-level programmes. For example, the SBM 2.0 (urban) that already has binding targets, needs to become more enforceable across cities for all waste streams under NCAP. The national- and state-level electric vehicle programmes need upscaled regulatory targets and mandates (for procurement, sales and registration) for accelerated zero emission transition in cities to fulfil the requirements of NCAP. There can be strategic support for targeted fleet renewal for heavy duty and commercial vehicles and scrappage and fleet electrification of targeted use cases like aggregators, deliveries, government-owned fleets etc; and significant nudging for upscaling of the public transport strategy and vehicle restraint measures. The national programmes on clean fuels can be leveraged to improve clean fuel access in households.

Similarly, NCAP funding can provide catalytic support for early adoption of targeted scalable technologies with strong emissions reduction potential in the MSME sector — such as common boilers, clean furnaces, clean kiln technologies and clean fuel infrastructure, among others — to influence and attract private investment and blended finance.

NCAP, therefore, needs to champion strategic priority measures in the key sectors for ambitious scalability and a larger solution portfolio for cities.

To enable this process, the Programme needs stronger legal backing — this would be possible if the NCAP policy along with the clean air action plans are mandated and notified under the Environment Protection Act, 1986 at the national level; besides this, specific directives based on the priority measures of the plans need to be further notified under the Air Act 1982 or under the relevant sectoral acts like the Central Motor Vehicle Act, Town and Country Planning Act, Municipal Act etc at the state level.

SELECTION OF SECTORAL GOOD PRACTICES AND THE LESSONS LEARNED

This review has primarily focussed on key critical intervention areas that can provide the maximum co-benefits:

- Energy and technology transition in industry and transport
- Mobility transition
- Circularity — management of municipal solid waste
- Control of dust from construction and demolition waste while reducing material and energy intensity of construction through recycling.

It has also been demonstrated how dust control needs a systemic approach through an urban redevelopment process.

Specific case studies have been identified from each of these sectors to indicate what is needed and the direction of change. The sectoral good practices display the ability to take a systems approach in strategy design (instead of focusing primarily on periodic enforcement measures) and build regulatory, institutional and fiscal enablers and community support systems — as the case may be — to drive action.

This assessment is not an exhaustive review of all known and reported action on ground. This has selected very specific cases in transport, industry and waste management sectors to demonstrate the elements of change that are steps in the right direction and with scale, can be impactful, sustainable and replicable.

This review recognises that interventions across cities and sectors are extremely uneven in scope, scale, approach and design. Therefore, the logic behind selection of the case studies follows multiple reasoning.

The methodology for application of criteria for selection has primarily relied on the policy principles of national policies, guidelines, regulations and standards, service-level benchmarks, targets and mandates — as applicable and available in different sectors. A good practice needs to integrate and implement all of these in entirety and go beyond the common minimum that all cities and regions are required to implement but have lagged behind in. The existing policies and associated guidelines and regulations provide adequate guidance to inform planning, design, targets and mandates in states; this linkage will have to be strengthened. However, it will be critical to bridge the gaps in current polices and regulations through further reforms. There are also voids and inconsistencies in the good practices which limit the scope of their impact; these have also been highlighted.

The methodology recognises innovation in approaches, technology adoption, institutional reform, fiscal strategy, process changes and system development, among others. Good practices are not treated as absolute and complete — but as ones that are evolving in stages.

Despite the enormous diversity and variability in approaches and scale, the case studies have been grouped as

- those that have demonstrated a more composite multi-sector approach
- those which show a more sector-specific composite approach
- those that have adopted specific process, system and technology approaches within the sector

Cities taking more comprehensive multi-sector action

Overall air quality in a city can improve if deep multi-sector interventions are implemented across all the key sectors of pollution over a period of time — vehicles, industry, power plants, waste burning, construction, roads, use of solid fuels in households and eateries, incinerators, captive power generation through diesel generator sets and widely dispersed sources of fugitive emissions.

However, the CSE review has shown that no city has implemented comprehensive multi-sector strategies with all the priority measures together, with the primary objective of cleaning up the air. There are very few instances where relatively more composite action has been implemented.

Delhi: Even though Delhi is still battling air pollution crisis, it has demonstrated the importance of regulatory mandate and targets in achieving upscaled implementation of multi-sector solutions to bend the pollution curve. Delhi's clean air action precedes NCAP programme and the interventions from the Supreme Court and its monitoring body Environment Pollution (Prevention and Control) Authority have catalysed substitution of diesel fuel with compressed natural gas in public transport and local commercial transport; restrictions on truck entry; imposition of pollution tax on daily truck entry, diesel fuel sold, and diesel car sold with 2000 cc engine; phase out of 10 year old diesel and 15 year old petrol vehicles. Polluting industrial fuels including coal, furnace oil and pet coke are banned and only legally defined clean fuels are permitted. All coal power plants have been closed.

Post-2020, the Commission for Air Quality Management has further restricted entry of pre Bharat Stage IV inter-state buses and diesel generator sets and initiated hot spot action on dispersed sources. Delhi government's electric vehicle (EV) policy has attained fleet electrification level of 12 per cent.

The cumulative impact of restrictions on diesel and industrial coal is evident in the massive reduction in their consumption with commensurate emission reduction benefits. But Delhi still requires yet another 60 per cent cut in PM2.5 levels to meet the national clean air standards. This can be met with more aggressive upscaling of mobility strategies, zero emission vehicles, robust waste management, action on unregulated industry and use of solid fuels in households and regional airshed level interventions.

Varanasi: Like several other non-attainment cities, the National Clean Air Programme has played a catalytic role in seeded the comprehensive air quality management programme in Varanasi leading to expansion of air quality monitoring network and emissions source assessment aiding in development of clean air action plan to initiate multi-sector action. Yet the notable aspect of the Varanasi experience is the convergence of the NCAP initiative with the urban redevelopment and renewal programme targeting the core city area and the river bank re-development that have contributed towards drastic reduction in air pollution and dust levels. In a city where the contribution of dust to particulate pollution is close to 84 per cent, only a system and urban infrastructure based development project can control this problem. This is also a lesson for other cities that are battling dust pollution by resorting largely to mechanical sweeping, water sprinkling and road repair. But dust control is a much bigger agenda requiring — as Varanasi has demonstrated — an eco-system approach through urban redevelopment and greening agenda while combining other multi-sector action.

PROGRESSIVE SECTORAL ACTION IN CITIES

Sector-specific action has been identified in transport, industry, municipal solid waste and C&D waste. The case studies are further classified as those cities that have taken relatively more composite approach towards sectoral action, and those that have taken stronger action on a few aspects of the larger solution. The purpose of the selection is not to present a comprehensive list from all cities but demonstrate, based on a few case studies, the qualitative and quantitative action that have been taken for impact and scale.

Vehicular pollution control

There is no one silver bullet to control vehicular emissions. It requires a diverse set of actions including advancement in emissions standards to drive the vehicle technology roadmap (these are national standards and common to all regions); state-level policy action and targets for advancing on-road emissions monitoring; fleet renewal and scrappage of end-of-life vehicles; accelerated electrification of vehicle fleet; integrated public transport system and transit-oriented development; walking and cycling infrastructure; low emissions zones; and vehicle restraint measures.

No city has done all of these together. Even those that have taken action, it has been sporadic in nature and limited in scope and scale. However, a few cities — despite the limitations — have adopted more integrated and cohesive approach towards transport and mobility interventions to address different aspects of transportation systems, integration and mobility requirements; a few more have shown strategy-specific progress in the areas of public transport, walking and cycling infrastructure and vehicle restraint measures. It is important to learn from both.

Composite approach to transport and mobility interventions:

Kochi: In Kochi, it is unique the way the Kochi Metro Rail Ltd (KMRL) — as a single specialpurpose vehicle — has developed different transportation systems including the land-based metro, allelectric water metro ferry network and a growing fleet of electric feeder buses and erickshaws; it is also working towards multi-modal integration. It is cleaning up its energy systems to run the transport infrastructure on renewable solar energy from *in-situ* generation. The water metro is on track to meet 100 per cent of its electricity demand from a dedicated solar farm and the land metro already sources about 40 per cent of its electricity from solar energy. The daily ridership on the combined railandferry system has rebounded beyond prepandemic levels while operating at a cash surplus. This has progressed far beyond the increase in public transport ridership in a situation where the baseline for modal share of public transport had plummeted drastically over the last decades.

Srinagar: Srinagar is among those cities that have initiated air quality management programme with the help of NCAP funding. But under the convergence framework, it has leveraged its Smart City programme funding to catapult from decades of piecemeal changes to leapfrog to significant upgradation and upscaling of its transport and mobility systems. At the early stages, this has simultaneously developed extensive city-wide pedestrian infrastructure, regenerated public spaces, restored the Jhelum river front, initiated electric boat services, and launched a new public bus division with 100 battery buses on 16 routes with improved service levels. The combined impact has been an increase in public transport ridership, greater share of zero emission commuting and an increase in pedestrian footfalls.

Reinvention of public transport

Public transport improvement is not only about increasing the bus numbers, but about augmenting bus services to improve access and affordability for the city population. This requires investments in buses and bus electrification at a scale, as also development of the infrastructure of depots and bus stations, use of information technology for passenger information and improved bus operations, and a fiscal strategy at the state/city level to keep the system sustainable. This also requires massive innovation in the organisation of the bus services to reach out to all segments of the population.

Bhubaneswar: Bhubaneswar is a unique example among the growing metropolitan cities that has demonstrated how a city can develop a new city bus system from a poor baseline for public transport system and usage, and how it can transform the system significantly to expand, modernise, electrify and improve service levels within a short time frame. Its Mo Bus service launched in 2018 has seen substantial increase in bus numbers including electric buses; women and transgender-run Mo ERide erickshaws provide lastmile connectivity; and IT systems are applied for ensuring better passengerinformation processes. This has led to a dramatic increase in bus ridership in the city within a short period of time.

Bengaluru: Bengaluru shows how a legacy operator can modernise its systems internally and evolve with the times. The Bangalore Metropolitan Transport Corporation (BMTC) has augmented its bus fleet including electric buses, installed GPS and farebox data systems, and enabled real time tracking of passenger information. Despite the severe congestion challenges in Bengaluru, its traffic revenue has grown by 11.5 per cent yearonyear; safety audits and driver retraining have reduced accidents; and the first 19km bus priority lane on the Outer Ring Road has trebled corridor ridership.

Surat: Surat demonstrates how investment in advanced information technology for bus operations can be leveraged to improve service levels and ridership. Surat's Sitilink SPV shows what happens when every operating decision is routed through data. An Intelligent TransportManagement System (ITMS), Automatic Fare Collection (AFC) and the Surat Money Card knit 891 buses (316 BRT, 575 city) into a single dashboard. Ridership has climbed from 28,000 to 2.7 lakh; 80 per cent of those riders previously used autos, twowheelers or walked. The network has the potential to subsume more private vehicle miles. Dynamic scheduling alone saves the operator Rs 2.7 crore a year.

State-level fiscal strategy to support bus transport: Even though Central government schemes have provided funding support to city bus services from time to time, primarily to meet the capital cost of bus procurement, there are very few instances where state governments have designed fiscal support for bus operations for longer term sustainability. Gujarat has stepped in with the Mukhyamantri Shaheri Bus Parivahan Yojana with a viability gap funding of up to Rs 22 per km (and 75 per cent of operating cost) for electric and CNG buses across 30 cities, including Ahmedabad. Early results in Ahmedabad show AMTS ridership stabilising after years of decline and municipalities once again ordering modern, lowfloor fleets.

Thiruvananthapuram and the urban-rural connect: Thiruvananthapuram's hop-on buses have expanded reliable services in the city. The city also has the community-led Gramavandi rural services run by the Kerala State Transport Corporation in partnership with local self-governments and panchayats. The local bodies are required to cover the fuel expenses of the buses. The routes are decided based on community demand. The local self-governments, panchayats and private entities contribute towards the cost of operations. This has halved the operating costs and pushed KSRTC's revenues to Rs 243 crore. Local sponsorships are encouraged for the service's financial sustainability.

Non-motorised transport

For public transport systems to be successful, safe and accessible, robust walking and cycling infrastructure are necessary. Though several cities have begun constructing pedestrian corridors and cycling lanes and even pedestrianising small corridors, these measures are fragmented and small in scale. They are not yet adding up to make a difference to the overall mobility in cites. More importantly, even the initiatives that have been implemented with substantial investments and efforts could not be maintained and sustained: an example is the Ajmal Khan pedestrianisation project in Delhi. Some of the selected case studies show stress and pressures in maintaining and sustaining the initiatives. But despite the limited efforts and challenges, there are cities that have demonstrated different approaches to street development that provide a good learning curve.

Chennai: The Greater Chennai Corporation (GCC) has demonstrated the importance of walking and cycling infrastructure with a Non-Motorised Transport (NMT) Policy to increase the use of this modes of movement. It has also earmarked a part of the budget to fund the initiative. About 100 km-long city streets have been transformed with pedestrian footpaths. This is being upscaled with committed funds from the Mega Streets Programme for seamless neighbourhood street networks integrated with utilities for equitable access for all road users. The Programme is adopting a 'complete streets' approach.

Gurugram: Gurugram has leveraged corporate social responsibility funding to transform a fivekm Janpath corridor into a treelined, floodproof street with protected cycle tracks and kiosks. Vacancy rates along the stretch have fallen from 30 per cent to under five per cent, and no traffic fatalities have been recorded since the redesign. This leveraging of private sector funding is an important lesson in view of the fact that most urban development projects are expected to rely substantially on private sector investment.

Vehicle restraint measures

There are barely any instances of vehicle restraint measures, despite the growing pressure of congestion. Even though national policies including the National Urban Transport Policy, National Habitat Standard for Transport, and the Transit-Oriented Development Policy have recommended parking strategies as a restraint measure, this has remained a non-starter in most cities.

Hill towns: Only the land-constrained hill cities and states of Shimla, Gangtok and Mizoram have implemented Proof of Parking Policy to ensure that prospective car owners provide legal proof of access to legal parking areas before purchasing a vehicle.

Delhi: Delhi is the only big city to have notified the Parking and Maintenance Rules under the Central Vehicles Act, 1986: this requires implementation of parking management plans which need inventories and demarcation of legal parking areas on-street; prohibition of parking in green areas, on footpaths, near intersections, on emergency vehicle lanes etc; penalty on illegal parking; variable parking pricing; and proof of parking for transport vehicles. This essentially operates on the principle that parking management plans will organise and also delimit parking availability while disciplining parking management. Delhi has implemented pilot projects on parking area management plans based on the Rules, but these have not been taken forward.

On-road emissions management

Even though all cities and regions have graduated to more advanced mass emission standards — directly from Bharat Stage 4 to Bharat Stage 6 — on-road emissions inspection and monitoring has remained archaic and dependent on a basic system of idling emissions testing: the pollution under control (PUC) programme. Cities have not moved to remote sensing monitoring, though this has been proposed in a number of city clean air action plans. Similarly, even though there are Central rules with respect to fleet renewal and scrappage of end-of-life vehicles with a special focus on heavy duty vehicles, there is not enough upscaled action except where phasing out of older vehicles is driven by court orders (as has been the case in Delhi and Kolkata etc). The NCAP programme needs to prioritise scalable fleet renewal, especially in the heavy duty and commercial vehicle segments, and enable advancement in on-road emissions monitoring and widespread upgradation of automated vehicle testing centres to identify end-of-life vehicles for scrappage.

Kolkata: Kolkata is the only city to have implemented remote sensing measurements for on-road emissions monitoring about a decade ago following a directive from the Calcutta High Court. This system monitors emissions even as the vehicles are moving on the roads. This does not require a physical testing and allows large-scale screening of the worst polluters on road. Kolkata has innovated to use this for enforcement aligned with the PUC programme. This initiative has also been recognised by the Supreme Court while looking at the potential of its application in Delhi-NCR. The Pollution Control Board of West Bengal has considered its further expansion in six other nonattainment cities.

But the state-led initiative and its expansion is slowing down because the Central rules to provide the framework and standards for its implementation have been delayed. The Automotive Indian Standards (AIS) 170 Rules for remote sensing, that were directed by the Supreme Court, need to be notified urgently. In fact, nation-level pilots planned for data generation can leverage the Kolkata programme to refine the strategies.

Cities progressing towards vehicle fleet electrification: The five years of NCAP implementation has also coincided with the steady expansion of the electric vehicle programme supported by national demand and incentives — the programme has the potential to contribute to zero emissions transition in polluted cities. While national-level fleet electrification is currently only 6.5 per cent, a few cities have achieved close to 10 per cent electrification — dominated by two- and three-wheelers. Delhi has achieved about 12 per cent. NCAP needs to play a very effective role in setting up and supporting an ambitious battery-operated electric vehicle programme to rapidly accelerate zero emissions transition and address toxic vehicular emissions.

Industrial air pollution control

It has been a challenge to address the problem of industrial air pollution within the ambit of NCAP, as most industrial areas are located outside the municipal boundaries of cities. Industrial pollution control is driven by national emission regulations and standards; state-level proactive actions by SPCBs to set guidelines and support specific technology transition in targeted industry segments; and industry-led initiatives to adopt improved technologies and emissions control systems, innovate on processes, switch to cleaner fuels, control fugitive emissions, and adopt circularity to address the issue of waste.

City- and region-specific large-scale composite action for industrial emissions control is evident in Delhi and to some extent, the NCR. There has been a massive shift from coal to natural gas in the legal industrial areas in this region — all coal-based power plants have been shut down. This has led to near-zero consumption of coal in these sectors.

Besides this, emerging good practices have been understood and identified in specific industry segments of micro-small and medium enterprises (MSME) that are highly polluting and are difficult to regulate and monitor.

The case studies have, therefore, focussed on regulatory and industry good practices in key technology approaches, including common boiler technology, clean furnaces for the foundry sector and brick kilns, and fugitive emissions in stone crushers. A common pattern emerges across these four technologies among MSMEs: cleaner combustion or all-electric processes up-front; robust capture and reuse in the middle; and renewable power plus digital monitoring at the tail-end.

Embedding that full-cycle logic — rather than chasing piecemeal controls — turns air quality compliance from a cost centre into a productivity and energy-saving dividend, offering SMEs a pragmatic route to stay competitive while meeting ever-stricter pollution norms. If these common technologies for MSMEs can be made scalable through the NCAP programme with strategic support and enablers, significant improvement is possible.

Centralised cluster boiler technology: This technology can replace large numbers of polluting tiny boilers that are stand-alone units in textile, pharma and chemical zones and are highly polluting. By centralising steam generation and ensuring cleaner fuel use and advanced pollution control systems, the Gujarat Pollution Control Board (GPCB) has successfully reduced emissions and improved compliance across the board. In fact, Gujarat has taken the lead in implementation of the common boiler policy in Surat, Vapi and Ankleshwar. The potential of replication is also increasing as is evident from the initiatives of Maharashtra Industrial Development Corporation (MIDC)-Patalganga, Haldia in West Bengal, and Sonipat in Haryana.

The GPCB did not wait for a Central mandate to promote development and implementation of common boiler facilities in industrial estates. In fact, the CPCB issued the guidance framework for community boiler for clusters of small-scale industries in 2023. The framework now asks for community boilers to be included in development plans of new or upcoming industrial clusters.

This assessment captures a specific case study from Surat which shows that this can supply steam through an insulated pipeline grid to 30-60 factories, improving thermal efficiency from 65 per cent to 83 per cent and cutting coal use — and therefore SO2 and PM emissions — by a quarter. This reduces the need for command and control measures. With new CPCB guidelines making such hubs mandatory in greenfield estates, feasibility studies are under way from Vapi to Haldia. If this can be made scalable with strategic support and enablers, a significant share of emissions can be addressed which otherwise will be challenging in stand-alone baby boilers.

Innovations in the foundry sector: The foundry sector is dominated by the highly polluting outdated furnace technologies like single blast cupola furnace. Although electric furnaces for melting cast iron are more advanced and clean, cupolas have remained important in the MSME sector as they are affordable and easy to operate. There are traces of regulatory interventions at the state level. The Rajasthan State Pollution Control Board (RSPCB) has taken important steps in controlling pollution from the foundry sector and directed foundry units to shift from single blast cupola furnaces to divided blast cupola (DBC) furnaces. The DBC technology is a significant improvement as it enables better combustion efficiency and reduces particulate matter emissions. The RSPCB's order is linked to technical guidelines to enable the transition.

There are also instances where enterprises in the foundry industry are pivoting away from coke-fired single blast cupolas — among the worst industrial emitters — to a tiered menu of cleaner melting options. Case studies have been presented that show divided blast cupolas, which simply split the combustion air feed, truncate 18-20 per cent off coke use and trim CO emissions by 30 per cent. PNG cupolas, proven in Agra, eliminate slag formation and keep specific melting costs below Rs 6 per kg of casting while meeting stack norms with only a spray-nozzle quench at the chimney top.

The case study presented here shows that the gold standard is the IGBT-based induction furnace: it runs on electricity, achieves less than 550 kWh per tonne specific energy, and when paired with hooded fume-extraction, bag filters and sand-reclamation loops, virtually erases both stack and fugitive dust. Foundries that have coupled these furnaces with sensors, real time energy dashboards and weekly APCD maintenance now recycle 60-80 per cent of moulding sand and sell recovered metals from filter dust, turning compliance into revenue.

NCAP can help increase the adoption of cleaner furnace technologies and switch to clean fuels. As demonstrated in Agra and Gurugram, PNG adoption is possible. Low-interest loans, subsidies for technology upgrades, and policy reforms can accelerate this.

Brick kiln industry: Once India's single biggest industrial source of black carbon, the switch from fixed chimney bull's trench designs to induced-draft zig-zag kilns has been slashing particulate emissions by up to 70 per cent and coal use by 30 per cent. Regulatory action that is driving good practices include the Ministry of Environment, Forest, and Climate Change (MoEFCC) notification that allows new kilns to be only zig-zag technology, vertical shaft kilns, or kilns that run on piped natural gas (PNG). Delhi-NCR allows zig-zag technology and use of agricultural waste (instead of coal), firewood, agricultural residues and PNG for heating; hazardous waste and plastics are banned.

Although a lot of brick kilns have been converted to zig-zag technology, the conversion often does not fully address the issues present in traditional FCBTKs (fixed chimney bull trench kiln). Stack emissions are still high due to poor conversion quality.

However, the case study presented shows that a model kiln in Jhajjar now records less than 0.8 MJ kg^{-1} specific energy and just 10 kg per day^{-1} of SPM, after adding a metal stack, flue-gas expansion joints, solar-powered ID fans and a three-ring green belt that doubles as a dust filter. Lifecycle extends beyond the firing zone — fly-ash is blended into the clay mix; wastewater from domestic use is gravity-settled and reused for moulding; and rooftop solar offsets grid power for fans and lighting. Several such innovations need to be shared and supported to accelerate the technology transition.

Leveraging convergence funding to build common infrastructure for industry clusters: In a progressive step, the Government of Uttar Pradesh has leveraged the Smart City Mission funds to create a common furnace facility centre in Moradabad. This is a PNG-based common furnace facility that was set up in Lakri Fazalpur Industrial Estate. This provides artisans an alternative to the coal-based furnaces in household units within the city. Proper air pollution control devices are installed in the facility to control emissions from furnaces. This is a very important instance of leveraging of urban infrastructure funding for upgradation of industrial infrastructure.

Controlling fugitive emissions from stone-crushing: To address this highly polluting activity, states including Maharashtra, Haryana, Madhya Pradesh and Jharkhand, among others, have begun to take action. While there are several NGT orders on controlling pollution from this industry, there are also proactive initiatives by SPCBs to improve implementation and monitoring. This is creating an important learning curve. The case study on Tamil Nadu Pollution Control Board (TNPCB) shows how it has regulated operation and management of stone crushing units in the state and enabled the siting and functioning of these units within designated zones with environmental safeguards.

The industry case study demonstrates how enclosure, atomisation and circular power can coexist. The best-in-class units roof every jaw-crusher and screen with GI sheets, sheath conveyor belts in semi-circular domes, fit telescopic chutes at transfer points and couple bag-filter extraction to water-mist curtains, bringing ambient PM levels inside the yard below regulatory limits. The case study from Pune shows how they layer the controls with metalled roads, 33 per cent tree cover, and two 1-MW solar farms that export surplus electricity to the state grid; PCS Industries in Tamil Nadu adds real time AAQ monitors and a closed-loop water system that recycles 50 m✣ a day for sprinklers.

Smart monitoring with continuous emissions surveillance: For good governance, smart and transparent monitoring of real time emissions from industrial stacks is necessary. This can enable preventive action, improve emissions performance, create a feedback loop on technology performance, push for stronger compliance strategies, and encourage adoption of market-based mechanisms like emissions trading. All this can become possible with widespread adoption of Continuous Emission Monitoring Systems (CEMS). The CPCB's mandate on installation of CEMS 2014 in the 17 categories of highly polluting industries and its Technical Guidelines of 2017 are the primary drivers.

Regulatory good practices are also emerging in a few states. The Odisha State Pollution Control Board, for instance, has leveraged CEMS data for strengthening monitoring and inspection. It has mandated CEMS in 205 industries: the state has 797 CEMS installations across 169 highly polluting industries (17 categories). With all the technology reforms as detailed out in the case study, the Odisha SPCB can effectively monitor industrial compliance, cross-verifying reported data with real time observations. This improves transparency, accountability and enforcement, ensuring that industries adhere to environmental regulations and accurately report their emissions.

Industrial economy around circularity: It is notable how new generation industrial enterprises are growing to recover material and energy from diverse waste streams in a circular economy. This not only helps close the waste loop, but also builds new economic opportunities, earnings and jobs while reducing both local air pollution and greenhouse gase emissions from open burning of biomass. There is notable growth in the compressed biogas (CBG) enterprises. By converting biodegradable waste into energy (CBG) and organic fertilizer (digestate), it can close the loop in the waste-to-energy cycle, support sustainable livelihoods, enhance energy security, foster integrated waste management systems and reduce emissions.

State-level initiatives are gaining momentum. The Madhya Pradesh government's Renewable Energy Policy 2025 supports biofuel (including CBG) plants in every development block. Similar bioenergy promotion frameworks in Bihar and Gujarat offer capital grants, tax breaks and interest subsidies to support project development. This is encouraging investments and innovation and strengthening the ecosystem for CBG solutions derived from waste.

The industry case studies presented from Indore indicate the scope and nature of this development. These CBG initiatives have led to strategic convergence of economic, environmental, energy and waste management goals, and provide localised solutions for waste management while building a new industrial economy.

Municipal solid waste management

Under the convergence framework, cities have begun taking an ecosystem approach to achieve zero landfill status. Some cities have taken this approach to address collection, segregation, processing and material recovery and remediation of legacy waste in a more composite way, while others have focussed on specific progressive strategies that contribute towards good management practices.

Indore: Indore has closed the entire waste and material loop that includes door-to-door collection covering all households, 100 per cent source segregation and bio-remediation of legacy waste in its 100-acre Devguradia site; in addition, all fresh wet waste (about 1,150-1,200 tonne per day) is channelled to treatment plants rather than to landfills. The city's GOBAR-dhan facility converts mixed organic waste into transport-fuel-grade bio-CNG and compost, turning what was once a liability into a revenue stream for the municipal corporation. The city has also attained scale. Bio-remediation and its green-waste pellet plant have created a substantial value chain around waste.

Pune: Pune has demonstrated an explicit equitable model that integrates informal workforce with the service delivery. Through the SWaCH cooperative, more than 3,900 self-employed waste-pickers service about 9.8 lakh households, and recover over 82,000 tonne of recyclables, saving the Pune Municipal Corporation (PMC) over Rs 100 crore in avoided collection and transport. Even though the scale is yet to be achieved, a foundation has been laid to build on a wholesome system. A share of the segregated dry fraction is channelled to material recovery, briquetting and refuse-derived-fuel pathways; the corporation has also tendered a waste-to-energy plant to deal with the residuals.

Bhopal: Bhopal is consolidating gains won through rigorous source segregation by-laws. About 850-900 tonne per day (TPD) of municipal solid waste is fully collected and 95 per cent of it is segregated; 11 transfer-station-cum-MRF hubs shorten haulage and integrate informal sorters; and 412 TPD of organics is composted or digested, while a 400 TPD bio-CNG plant and a torrefied-charcoal facility have been added to the infrastructure. The once notorious Bhanpur dump has been capped and partly landscaped, signalling a decisive break with the past.

Bengaluru: Bengaluru has leveraged its tech DNA to tame a daunting 5,500 TPD waste stream. Since 2020, the Bruhat Bengaluru Mahanagara Palike has rolled out RFID-based attendance, GPS-tracked routes for 4,665 vehicles, app-linked transfer stations and real time public dashboards. The result is 97 per cent door-to-door coverage, 99 per cent segregation and 81 per cent processing, with payments to concessionaires tied directly to digital proof of service. A parallel push is tackling almost 10 million tonne of legacy waste, half of which is already remediated, while new bio-CNG and waste-to-energy projects aim to close the 800 TPD processing gap.

Surat: After the plague outbreak in 1994, the city has rebuilt its entire public health apparatus. Today, 2,485 TPD of waste is 100 per cent segregated, collected by 623 GPS-enabled (and increasingly electric) vehicles and funnelled through eight semi-mechanised MRFs, 80 decentralised composting units and a 1,500-TPD windrow plant. Twenty-five lakh tonne of legacy waste at Khajod has been bio-remediated, and the city now enjoys a 'Seven-star Garbage-free' rating. It also has a thriving plastic-to-pellet and RDF markets that feed local industries.

Vengurla: The tiny coastal town of Vengurla illustrates that scale is no barrier to advancing waste management. Its three-TPD waste stream is collected twice daily, RFID-tagged and sorted into 27 categories — the town has achieved over 95 per cent segregation and a 'zero landfill' status. A 1.5-TPD biogas plant generates about 100 m✣ of gas and 50-60 kWh of electricity each day, while compost, briquettes and recyclables earn the municipal council more than Rs 2 lakh a month — enough to cover all operating costs and reinvest in further community IEC drives. Vengurla illustrates how micro-municipalities can run self-financing, zero-dump systems.

Ambikapur: Ambikapur has adopted a systemic framework for its waste management. It has Solid and Liquid Resource Management (SLRM) centres that are supported by public and private investments. The model is built on achieving 100 per cent collection and processing of waste, eliminating the need for landfill disposal. Households segregate waste at source into wet and dry categories — this is a result of a behavioural shift facilitated by sustained community-led awareness initiatives. The initiative has involved self-help groups (SHGs) and has embedded social equity by giving wastepickers and SHGs the pride of place.

CONSTRUCTION AND DEMOLITION WASTE

As urban areas are experiencing prolific growth in construction of buildings and infrastructure, the construction and demolition (C&D) sector is beginning to gain attention within the ambit of clean air planning. Like any other waste stream, this also requires an end-to-end ecosystem in an ideal scenario — spanning on-site dust control practices, reuse of material, and city-wide logistics for collection, segregation, transport, recycling and market uptake of recycled outputs. Only this can help prevent wasteful disposal of this resource in drains, green lungs, eco-sensitive areas and landfills.
While action has begun in many cities, only a few have been able to demonstrate substantive systemic changes to make a difference.

Delhi: Delhi has stitched together the country's relatively more complete loop on C&D waste. This includes a city-wide collection system with a web of 132 geo-tagged depots, most located close to generators, that funnel the debris into colour-coded skip-hauler bins that keep roads clean and help inspectors spot rogue dumpers. The New Delhi Municipal Council's red skips are craned on to covered lorries; elsewhere, the Municipal Corporation's ward stores double up as *malba* depots, and smartphone apps (MCD 311, NDMC Citizen) show residents the nearest drop-off point and even summon a pick-up truck. Shorter cartage distances hold Delhi's tipping fee to just Rs 210 per tonne, well below other metros; it also helps in slashing diesel consumption, congestion and road dust.

This city has also expanded its recycling capacity substantially: with five plants, the processing capacity is 5,150 TPD, the highest in India. This also ensures uptake of the processed material as the Delhi government has mandated all public agencies to use minimum shares of recycled aggregates — two per cent in new buildings and 10 per cent in roads. Private buyers have now jumped into the fray, and they take two-thirds of the city's annual output. However, more efforts are needed to improve the collection efficiency for maximum utilisation of the processing plants.

Even Delhi's linear megaproject agencies — the DMRC and NCRTC — are beginning to adopt dust control practices including enclosed batching yards, washing truck wheels, mist-elevated viaducts with anti-smog guns etc; they also feed their rubble into Mundka's dedicated 150-TPD plant.

Chandigarh: Chandigarh is yet another city that has taken an eco-system approach to waste management. It has not only modernised the C&D transportation system with ITS-enabled vehicles, but also expanded recycling capacity to 150 TPD, run entirely by the municipal corporation. It has adopted a strategy for uptake of recycled material — with a diverse product portfolio — by the municipal body and other agencies. This is supported by an intensive awareness campaign.

An inventive *non-availability certificate* locks demand — developers may lift recycled products free of charge up to half the processing fee they paid when pulling a building permit and must present a plant-issued certificate if they claim supplies aren't available. As a result, stock seldom sits on site; bricks and pavers move straight back into city works or the flagship Waste-to-Wonder Park.

Hyderabad: Hyderabad has adopted a unique model of decentralised waste management. Four plants (Jeedimetla, Fathullaguda, Shamshabad and Thumakunta) under a public-private partnership model ring fence the urban agglomeration with 2,250 TPD of capacity. This keeps average haul distances and the combined transport-plus-processing fee down to about Rs 450 per tonne, or a quarter of that if a generator self-delivers to the plant. Door-to-door collection is run by informal workers integrated into the formal fleet; QR-tagged trucks scanned at collection points deter illegal dumping and let police check authorisations in seconds.

Pimpri-Chinchwad: Where most cities struggle with enforcement, Pimpri-Chinchwad has outsourced the job. A third-party agency fields 39 patrolling staff, mobile cameras and GPS-tagged vehicles, pockets 60 per cent of every on-the-spot fine (Rs 4,000 per tonne for dumping, Rs 5,000 for uncovered loads) and registers each challan on a public portal — thus aligning private profit with public compliance and freeing the cash-strapped municipal corporation to focus on service quality.

Noida: This city demonstrates that a recycling plant itself can be a dust-free industrial site. Seven-metre steel wind barriers, a double ring of vegetation and an 80 m × 25 m enclosed processing shed cut fugitive PM by more than 90 per cent compared with open crushing; incoming trucks arrive net-covered, wet-suppressed and routed over paved, sprinkler-cooled roads, while quarterly stack tests track heavy metals and fine dust.

What these examples show is that each city picks the lever that fits its context, yet all treat C&D debris not as waste but as a circulating resource and a frontline defence against dust-driven air pollution. The lesson is clear: close the loop quickly, keep the dust down locally, and the construction boom can build rather than bury urban liveability.

UNDERSTANDING AIR QUALITY BENEFITS OF CLEAN AIR ACTION UNDER NCAP

There is a deep interest to assess the air quality benefits of the good practices. It is possible to attempt such an analysis for those case studies that have taken a relatively more comprehensive and ecosystem-based approach either at a city scale or at a sector scale. Delhi, Srinagar, Kochi and Indore have shown substantial reduction in their emissions loads. Delhi has demonstrated verifiable reduction in coal and high speed diesel consumption in the city and the attendant emissions — both toxic particulate emissions as well as heat-trapping carbon dioxide emissions. As the case of Indore demonstrates, a substantial reduction in the quantum of short-lived climate pollutants like methane is also possible.

However, attributing the interventions of varying scope and scale to changes in the ambient air quality trends is a tougher challenge. Accounting for air quality change requires longer term, sustained and deeper systemic action. Impact on air quality cannot be instantaneous unless it is a drastic temporary emergency measure initiated for a few days. Air quality benefits show up only after sustained efforts overtime, when stringent action is combined with curbs on proliferation of newer sources of pollution and consistent improvement in on-going emissions. There has to be scalable local multi-sector action for substantial reduction in ambient concentration and exposures.

Academically, some efforts have been made to assess the effects of short-term and local-level interventions on air quality. For example, after the implementation of the compressed natural gas programme in Delhi during the early stages, the US-based Resources for the Future had estimated the impact of the programme on the reduction in ambient particulate and nitrogen oxide concentrations. Several agencies have also tried to assess the impact of short-term interventions like the odd and even number plate-based restrictions on vehicle usage during the winter emergency action. Globally as well, the impact of stringent air pollution measures during the Olympic Games (such as in Atlanta Olympics) has demonstrated linkages between air quality trends and actions.

However, this has not yet been translated into effective policy tools in India for regulatory impact assessment. The NCAP has not yet taken on board the modelling tools to assess the impact of action on ambient air quality. Linking action with air quality trends requires robust data generation on all aspects of action — which is currently a missing link.

From this perspective, NCAP needs to revisit the method of setting clean air targets in cities that currently depend on annual changes in their PM10 levels. Short-term annual trends can be highly variable and can also be influenced by meteorology, climate, dust storms and heat waves. This may not adequately mirror the annual impact of action, especially in combustion sectors, unless something drastic like the lockdown phase of the covid

19 pandemic happens. There is a risk of attributing air quality success inadvertently to meteorological and atmospheric changes as well as transboundary movement of pollutants.

Between 2019 and 2024, a large number of NCAP cities have shown improvement in PM10 as well as PM2.5 levels (though there is a variation in the list of cities regarding the reach of these pollutants); nearly an equally substantial number of cities have shown a worsening of these trends (*see Graph 2: Air quality trends in non-attainment cities under the NCAP programme*). The information on action taken in these cities is too inadequate to explain these trends.

The air quality benefits from interventions emerge cumulatively over a longer time frame and across the airshed. Even globally, clean air target setting is done for a larger region. For instance, in the US, air quality targets are set for the entire state for the purpose of implementation of state-wide plans. In China, the initial five-year target for pollution reduction in Beijing was upscaled for 26 provinces around the city.

THE WAY FORWARD

Air pollution is a public health crisis in India and requires urgent upscaling of action to meet the clean air benchmark across all regions. The air quality management framework has to catalyse sectoral action and create conditions, opportunities and a mandate for scalability. As noted earlier, the NCAP framework has to enable massive energy transition in industry, transport and households, mobility transition, and circularity to close the waste loop.

Despite the challenges, the review of emerging good practices in several sectors build optimism and hope about the direction of change. Cities and regions are beginning to integrate the key elements, the essential systemic design, infrastructure, monitoring and compliance systems to implement a portfolio of solutions needed to make a difference. Several forces are coming together — national-level regulations and performance-linked funding, state-level policy innovations, judicial intervention, proactive participation of the industry, and community action — to catalyse change on ground.

The emerging good practices need scale and speed for a time-bound clean-up to protect public health and reduce the enormous disease burden — according to the *State of Global Air*, air pollution contributes to about 2.1 million deaths in India.

The fact that several plans, programmes and funding strategies are emerging in different sectors does not diminish the role of NCAP as an umbrella programme. On the contrary, the urgency of air pollution mitigation enhances its role further. As has already been demonstrated, NCAP, despite its current gaps, is helping mainstream the clean air indicators across sectors. It is creating opportunities to integrate these indicators with the standard operating procedures and management information systems of diverse departments in cities and states to define the scope of interventions.

Though this role is still nascent and unstructured in several cities, this is the way forward to ensure upscaling of sectoral interventions. Currently, it is only the NCAP programme that is demanding clean air action across the regions: this offers an opportunity to build ambition for action in the key sectors of pollution control. There are several sectors including industry, transport and energy use in households that, if not driven by the ambition of clean air targets, will remain incremental in approach and not leapfrog to tame the pollution curve.

From this perspective, several steps are needed to reform the NCAP programme and enable it to become the channel for upscaling good practices across sectors.

Reform the clean air target setting process while combining this with sectoral targets to drive good practices

The current NCAP framework can be strengthened by addressing existing gaps in its architecture. For the programme to become more catalytic and purposeful, a change is needed in the performance matrices, as well as the compliance, monitoring and

The clean air target setting process needs to be reformed. For NCAP to become more catalytic and purposeful, a change will be needed in the performance matrices and in compliance, monitoring and funding strategies funding strategies. Shift the benchmark for performance from PM10 to PM2.5. In addition to the city-based targets, set state-level targets to address the larger airshed and for upscaling action.

In addition to clean air targets, support the states to set sectoral targets to plan for the scale of change; accordingly, align all funding and programmes to deliver on these targets and identify the catalytic role for NCAP funds. It may be noted that several sectoral funding schemes such as those in SBM 2.0 (urban) in the waste sector are already being crafted to set actionable targets that can be monitored for all aspects of waste management. The NCAP will also have to align with these goals where they exist and also ask for similar targets in all the eight sectors that do not have them but are considered for ranking cities under the Swachh Vayu Survekshan.

NCAP-related funding needs to be the catalytic champion fund to upscale priority good practices in key sectors

This is needed to prioritise scalable interventions in each sector that require catalytic funding to upscale the portfolio of solutions across the airsheds, while addressing the local imperatives. For instance, in the industry sector, it can provide strategic support to initial adoption of key technology approaches in MSMEs including common boilers, clean furnaces, advanced brick kilns and technology processes, and common infrastructure for clean fuel grid; it can also help develop central-level policies to enable more competitively priced natural gas. This initial support can catalyse private sector investments in emerging good practices.

Similarly, in the transport sector, it can support state policies and common infrastructure and incentives to ensure fleet renewal of heavy-duty trucks and buses at a scale and enable scrappage of end-of-life vehicles. It can align with central policies on electric vehicles and support targeted fleet electrification and common infrastructure to meet ambitious zero emissions targets. NCAP requires a reform-based approach to upscale and fast track mobility management and public transport infrastructure development, and use the funding to act as a catalyst — for instance, the way metro funding currently requires development of non-motorised transport infrastructure within a certain radius.

In the waste sector, all it needs to do is to align with the SBM 2.0 targets and provide catalytic support to innovative practices or infrastructure as needed; at the same time, along with the Central government policy on LPG subsidy programme, find innovative pricing policies to upscale reliable access to clean fuels for poor households.

NCAP can develop an explicit mandate for all urban and road development and redevelopment projects to ensure that the massive investments in these integrate the requirements of dust control and creation of green and blue infrastructure adequately. It also needs to exercise its authority through environment impact assessment of urban projects to enable this process. The NCAP fund is not needed for road development, but the Programme needs to leverage the available funding to ensure proper infrastructure guidelines are being met to deliver the clean air objectives.

NCAP needs to unlock more resources at the national and state levels by leveraging other funding strategies to deliver on clean air objectives

NCAP requires a more efficient alignment with sectoral policies and programmes as well as with the spending priorities of multilateral and development banks, and blended finance to ensure that existing and augmented financial resources are tied with reforms and objectives of clean air. This is needed to establish priority for investments in infrastructure development and programmatic interventions in sectors and regions. The guidelines for spending need to adopt good practice approaches.

NCAP funding needs to become reform-based and conditional to substantially upscale good practices

State-level funding strategies need to become more reform-based to ensure that spending is linked with the requisite reforms in systems and infrastructure and is not at cross purposes with the clean air objectives. This need to be done in consultation with the state governments, keeping local imperatives and priorities in mind. The clean air fund must require state governments to develop a state-level policy mandate and targets for implementation in each sector, and to direct the funding accordingly. In fact, some of the good practices that have been documented as part of this review have demonstrated that wherever the NCAP funding has been well utilised purposefully, state-level policy priorities for decision making have been established.

Funding of urban local bodies under the 15th Finance Commission needs to be more purposeful

The funding from the 15th Finance Commission — by its own design and mandate — is meant for ULBs. After the 73rd and 74th Amendments of Constitution, the Finance Commissions have the mandate for offering direct funding to ULBs. The air quality grant has been channelised through this process.

As ULBs are the main recipients and custodians of this funding, they themselves need to strengthen their own role under the Finance Commission funding to address a diverse set of interventions that are part of their functions. These include management of waste streams (solid waste and C&D waste), improvement of local streets that can help upscale walking and cycling infrastructure, development of low emissions zones, parking management area plans to restrain congestion and reduce demand for parking, etc. A few states like Maharashtra where ULBs are responsible for public bus transport have the opportunity to leverage the clean air fund for expanding their electric bus programme, service levels and last mile connectivity. All of these functions will have to be strengthened considerably.

Otherwise, as noted in several states, while ULBs address waste management largely under the parallel SBM 2.0 (urban) with well-defined targets, the clean air fund is tied — barring a few instances — partly with waste management, but mostly with enforcement measures and mechanical road sweeping. The fund is not helping adequately to create assets and infrastructure to address the problem of air pollution more sustainably and durably. This will require reform-based funding. In fact, Finance Commission funding requires improvement in service levels in municipalities, but the service level needs to be defined in full scope for each sub-sector for interventions.

Clean air fund needs to be well distributed across sectors to promote good practices
Currently, the bulk of the 15th Finance Commission funding is linked with what the ULBs can do. However, at the state level, there are some variations in the decision making system with respect to the apportionment of the grant to other departments. The 15th Finance Commission has permitted some allocation to state pollution control boards for expanding air quality monitoring and supporting source assessment etc. Otherwise, state governments, based on the proposals received from different departments, apportion some amount of funds for specific purposes to other departments. This needs to be strengthened further to ensure there is more equitable funding of priority measures in other sectors. If there are limitations to the extent to which the Finance Commission funding can be diverted, the NCAP's own allocation needs to be augmented to combine with the Finance Commission-led funding.

Upscaling good practices requires legal back up and technical capacity
Even though more sweeping powers are available to the SPCBs under the Air (Prevention and Control of Pollution) Act, 1981 (amended in 1987), these are not exercised adequately and effectively for issuing appropriate instructions to the concerned departments — as needed under the clean air action plans. Thus, an SPCB's own role remains confined to its specific functions like industrial pollution, check list of dust control, and some aspects of waste management etc. Overlapping roles and ambiguous jurisdictions among departments create delays. As a result, the scale of infrastructure and systems that are needed for implementation of priority strategies in key sectors of pollution control, are not adequately planned at the department level.

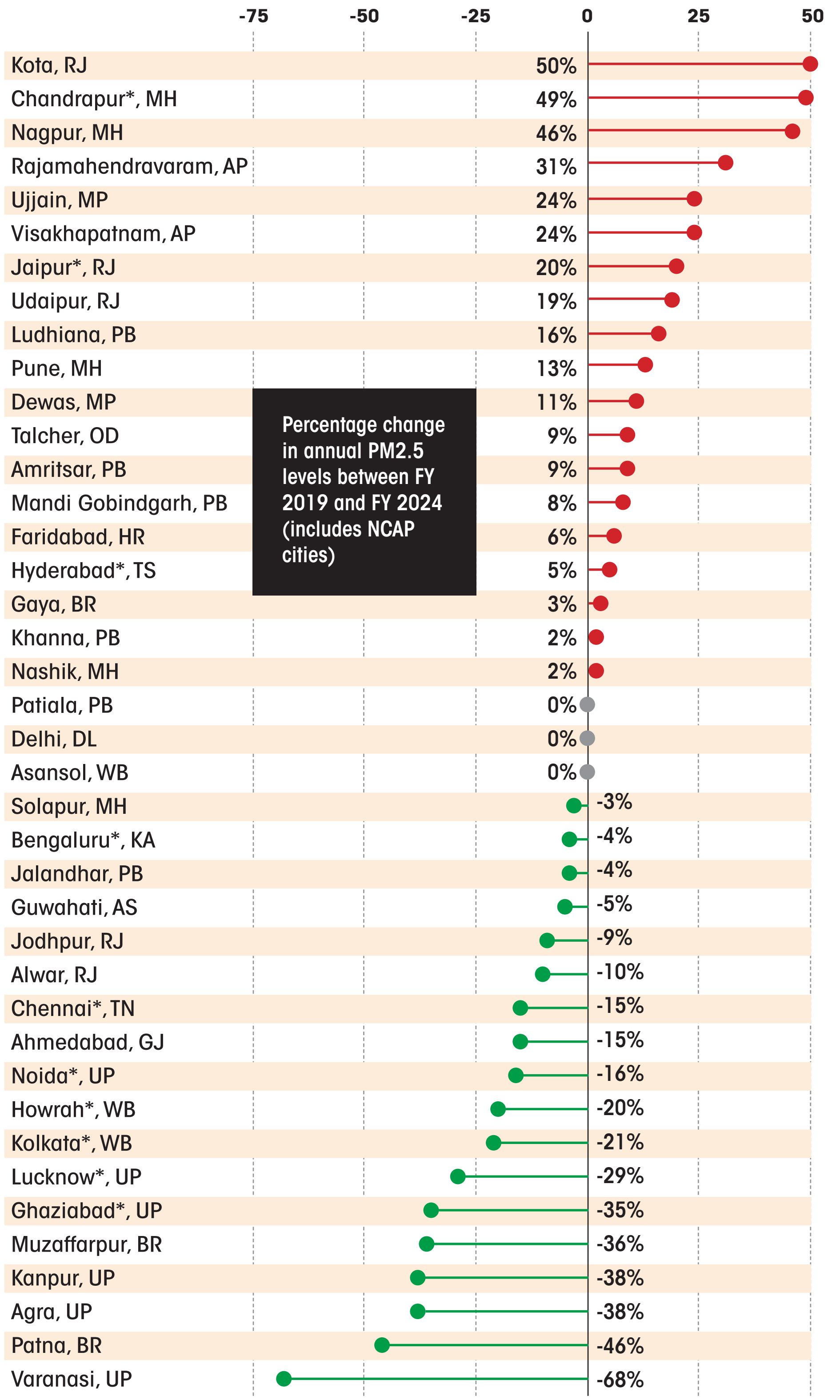
Moreover, other departments largely operate under different legislations (like the Central Motor Vehicles Act for transport action, or the Municipal Act for municipal functions etc). The SPCBs need to give specific instructions under the Air Act to the departments, in line with the clean air action plans.

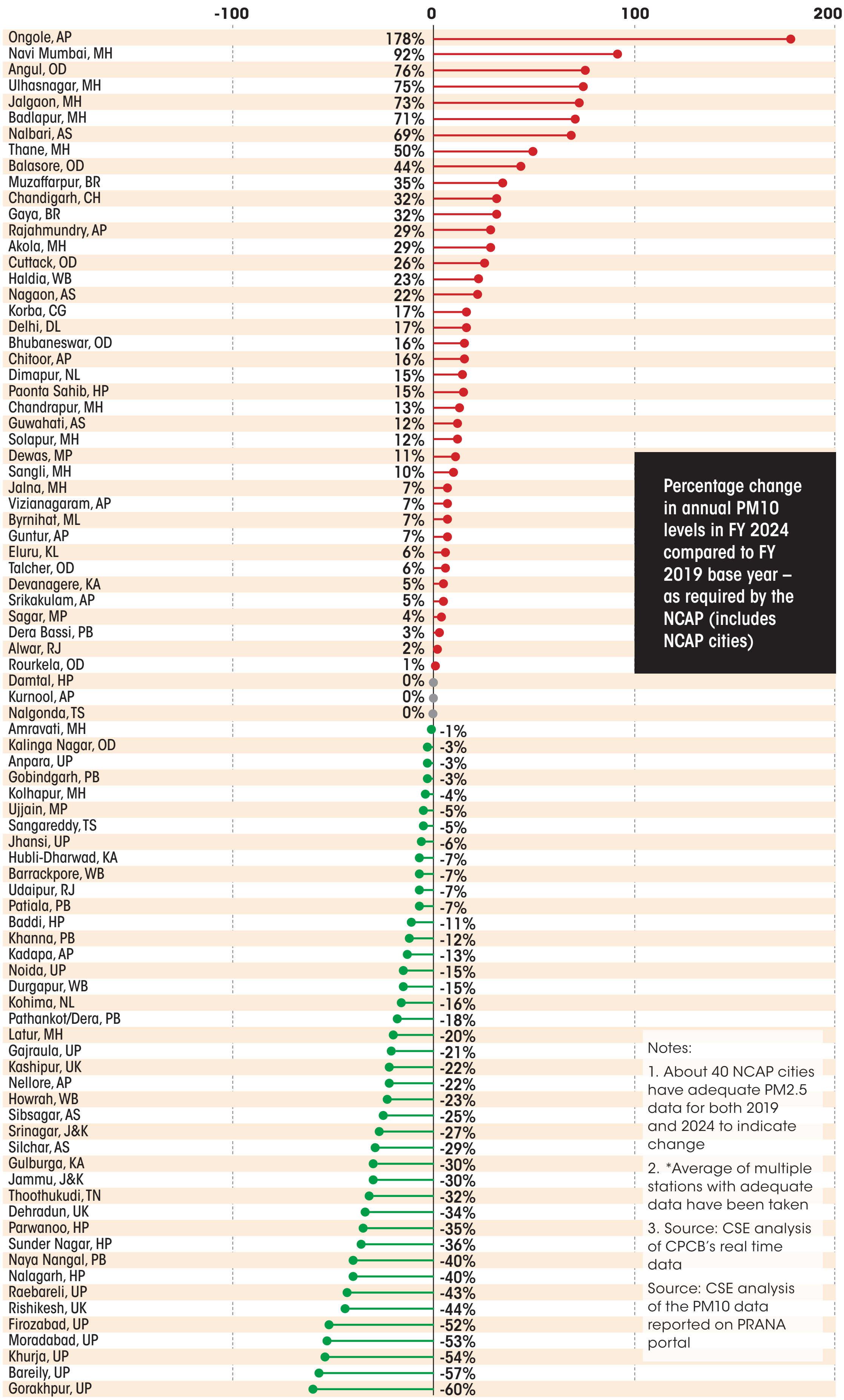
Upscaling of good practices will also require massive capacity building not only in the SPCBs, but also in ULBs and various departments (transport, urban development etc) to design implementation strategies and requisite infrastructure and systems for robust compliance and monitoring.

NCAP needs to adopt a good practice model to upscale action
The NCAP programme needs to develop a guidance framework for sectoral good practices in each sector — outlining the sectoral target setting process, systemic approaches, infrastructure requirements, design and planning details for different interventions, guiding policy principles and the scope of good practice approach — to inform and mandate qualitative and quantitative improvements needed on the ground.

For NCAP to be effective, implementation strategies need to go beyond short-term enforcement measures and common minimum requirements to more system-oriented upscaling.

Graph 2: Air quality trends in non-attainment cities under the NCAP programme





Percentage change in annual PM10 levels in FY 2024 compared to FY 2019 base year – as required by the NCAP (includes NCAP cities)

Notes:

1. About 40 NCAP cities have adequate PM2.5 data for both 2019 and 2024 to indicate change

2. *Average of multiple stations with adequate data have been taken

3. Source: CSE analysis of CPCB's real time data

Source: CSE analysis of the PM10 data reported on PRANA portal

DELHI

MULTI-SECTOR ACTION FOR CLEAN AIR

Although Delhi is still battling an air pollution crisis, it has demonstrated the importance of regulatory mandates and targets in achieving upscaled implementation of multi-sector solutions to bend the pollution curve.

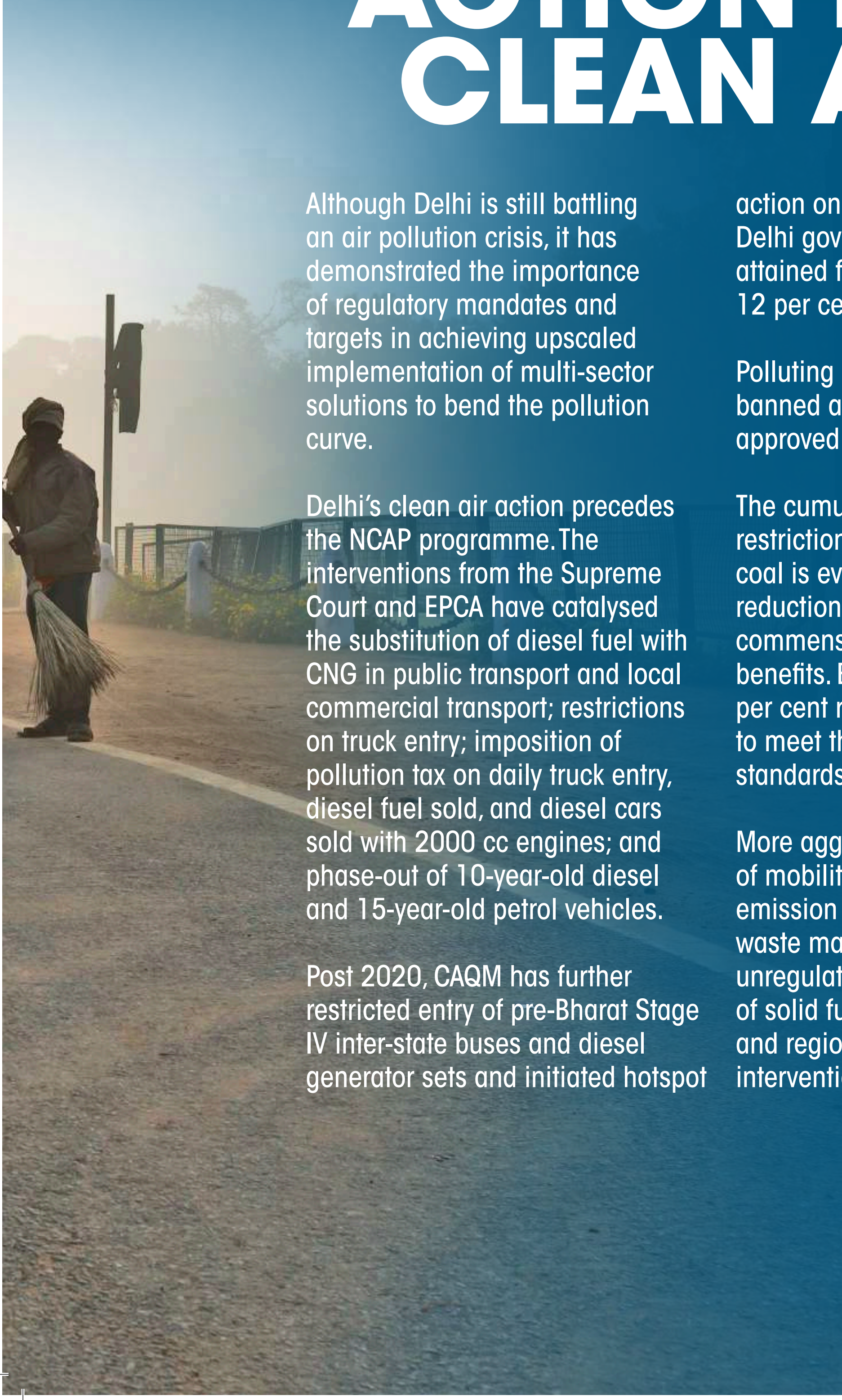
Delhi's clean air action precedes the NCAP programme. The interventions from the Supreme Court and EPCA have catalysed the substitution of diesel fuel with CNG in public transport and local commercial transport; restrictions on truck entry; imposition of pollution tax on daily truck entry, diesel fuel sold, and diesel cars sold with 2000 cc engines; and phase-out of 10-year-old diesel and 15-year-old petrol vehicles.

Post 2020, CAQM has further restricted entry of pre-Bharat Stage IV inter-state buses and diesel generator sets and initiated hotspot action on dispersed sources. Delhi government's EV policy has attained fleet electrification level of 12 per cent.

Polluting industrial fuels are banned and only legally defined approved fuels are permitted.

The cumulative impact of restrictions on diesel and industrial coal is evident in the massive reduction in their consumption with commensurate emission-reduction benefits. But Delhi still requires 60 per cent reduction in $PM_{2.5}$ levels to meet the national clean air standards.

More aggressive upscaling of mobility strategies, zero-emission vehicles, robust waste management, action on unregulated industry and use of solid fuels in households, and regional airshed-level interventions are needed.



Delhi is designated as a non-attainment city under the National Clean Air Programme (NCAP). But Delhi is not a recipient of the fund from the 15th Finance Commission meant for cities with more than a million population. However, between FY 2019–20 and 2024–25, Delhi received Rs 42.69 crore under the NCAP programme of the Ministry of Environment and Forests and Climate Change (MoEFCC) out of which Rs 13.94 crore or 32.64 per cent has been spent.

Clearly, the nominal action that Delhi may have taken with this small amount of funding cannot capture the magnitude of the multi-sector action that Delhi has implemented over time impacting the long term air quality trend. But it is important to capture the cumulative and evolving nature of Delhi's action in different sectors to understand and demonstrate what it takes to make a difference to the air quality.

Delhi is the only city that has undergone long and successive phases of clean air action to combat one of the toughest and the longest air pollution battles in this country. In the early 1990s, Delhi started experiencing the choking haze of pollution. Since then a lot has happened to improve the air quality. But despite the improvement the challenge remains. Other cities need to recognize the scale of multi-sector action in Delhi to understand the magnitude of change needed for sustained improvement in air quality.

Delhi is a unique case study because it has a strong legacy foundation of clean air action that has preceded the NCAP period. In most other non-attainment cities (barring a few mega and capital cities), the NCAP programme has been the prime driver for seeding and starting a clean air programme.

Currently, Delhi is required to report progress in action on the CPCB's PRANA portal. Delhi is also evaluated for controlling the annual average PM_{10} levels under NCAP and is ranked for taking sectoral action under the Swachh Vayu Sarvekshan. But this reveals a curious paradox – while Delhi is among the top ten cities for taking sectoral action, it is at the bottom for not improving the PM_{10} levels. It is therefore more important to understand the full spectrum of systemic changes that have over time contributed to the current long-term air quality trends.

Delhi is also unique because nearly all clean-air-related interventions have been driven primarily by air pollution concerns stemming from the directives of the Supreme Court in the onging public interest litigation. These are further complemented by the directives from the National Green Tribunal and Delhi High Court from time to time. The executive measures under the convergence framework have also contributed to the trend. This city has also witnessed some of the sharpest public and media campaigns to empower change.

Multiple forces have come into play to catalyse the clean air action in Delhi. The Supreme Court of India had first intervened in response to the ongoing public interest litigation that had started during the late 1980s (the M.C. Mehta case). This case has built further momentum from late 1990s onwards when more strident public campaign and voices began to demand clean air. After that, for more than two decades and until 2020, the Supreme Court has monitored and directed this process. The Environment

Pollution (Prevention and Control) Authority (EPCA) was appointed under the direction of the Supreme Court and set up under Section 5 of the Environment Protection Act 1986, in 1998, to advise the Supreme Court on the pollution matter and also monitor implementation of the Court directives.

Subsequently, in the second phase, post 2021, the Government of India created the unified executive authority called the Commission for Air Quality Management (CAQM) for the NCR and adjoining areas and beyond in 2020 under the Commission for Air Quality Management in National Capital Region and Adjoining Areas Act, 2021, as an empowered executive body with Central government oversight. However, parallelly, the PIL in the Supreme Court has also continued.

Delhi helps to answer a few critical questions around the scale and scope of multisector action to make a difference to the air quality, and the new action agenda needed to address the current gaps in action to meet the clean air benchmark. A substantial number of measures have been initiated targeting the technology and energy transition in transport and industry (primarily targeting coal and diesel). However, major gaps remain with respect to the mobility transition, waste management for circularity, unregulated industries in non-conforming areas, and energy poverty in households. This is an important learning curve for all the other cities embarking on air quality management.
Delhi has demonstrated how the problem of pollution cannot be won with incremental action but needs a leapfrog agenda that is cross-sectoral with a stringent compliance framework. Delhi has witnessed stabilisation and reduction in particulate pollution levels over time even while experiencing urban growth, motorisation, prolific construction, mushrooming of enterprises and piling up of waste dumps. Yet much stronger action is needed to stay ahead of the growth curve for clean air.

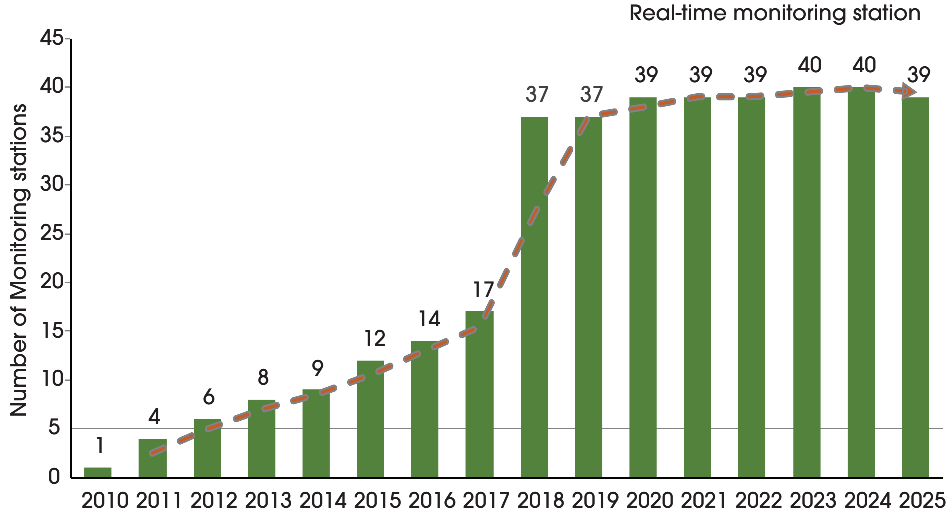
EXPANSION OF AIR-QUALITY MONITORING

Expansion of air-quality monitoring network: During the last decade Delhi witnesed massive expansion of air quality monitoring to provide real-time data to inform policy action. Until 2010, Delhi had very few monitoring stations and that too manual monitors capable of monitoring only coarse dust – the total suspended particulate matter or at best the larger-sized particulate matter less than 10 micron (PM_{10}).

From one real-time monitoring station in 2010, the numbers of real-time monitoring stations capable of monitoring finer $PM_{2.5}$ and other toxic gases increased rapidly to 37 real-time monitoring stations by 2018. Thereafter, three more stations were added to become 40 stations (see *Graph 1: Progress in expansion of real-time air-quality monitoring in Delhi*).

As of 2025, Delhi has 39 continuous air quality monitoring stations spread across an area of approximately 1,500 sq. km. Delhi does not require more monitoring stations but the exising ones can be better distibuted for an improved population coverage. Most stations are concentrated in the central areas while southern, northwest and peripheral regions remain inadequately-monitored (see *Map 1: Spatial spread of air-quality monitors in Delhi*). An additional six stations have been proposed in green campuss of Jawaharlal

Graph 1: Progress in expansion of real-time air-quality monitoring in Delhi



Note: New Moti Bagh station is not operational since Sept 2024.

Source: CSE analysis

Nehru University (JNU), Indira Gandhi National Open University (IGNOU), Delhi Cantonment, Netaji Subhash University (Waste Campus, Jaffarpur) and Commonwealth Games Village.

Availability of improved data helps to assess longer-term year-on-year changes in air quality and also pollution hotspots in the city. This also allows dynamic estimation for implementatation of the Graded Response Action Plan to respond to pollution emergency situations.

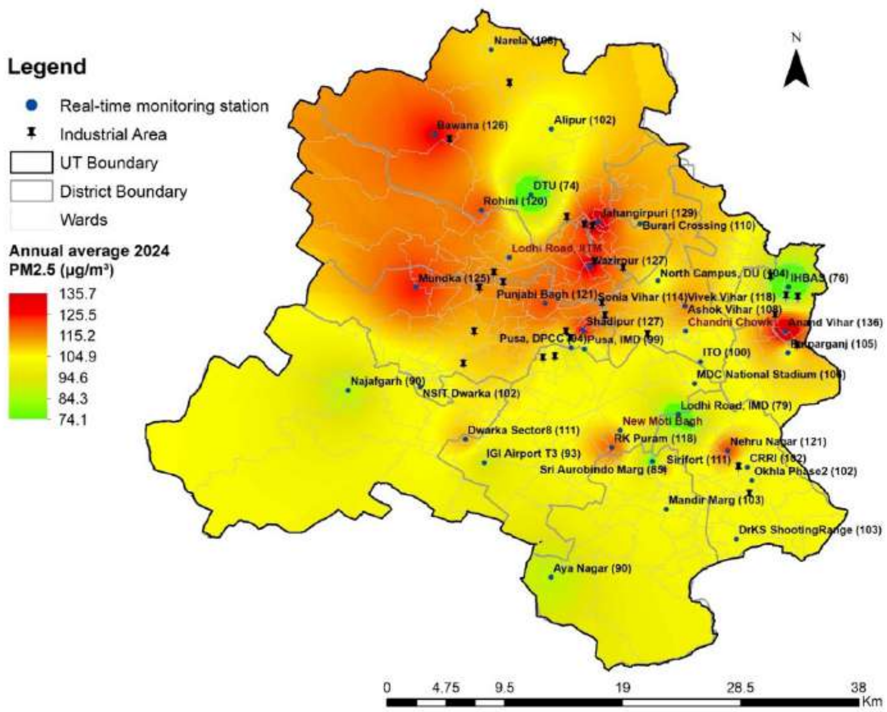
Need further rationalisation of the monitoring network: Further rationalisation of the monitoring network is needed for optimum coverage of population and land-uses. Despite such large number of monitors, these are not well distributed to cover population in all land uses and there are still some "shadow zones" with low station density. Currently, the monitoring stations in Delhi are mainly centred in and around the southern and central part of Delhi (see *Table 1: District-wise distribution of 39 monitoring stations*).

The southwest and northwest peripheries have minimal monitoring stations, leading to gaps in air quality monitoring. The stretch between Mundka, Bawana and Narela should have more number of monitoring stations as these are the areas that record some of the highest PM2.5 levels (see *Map 1: Spatial spread of air-quality monitors in Delhi*). Moreover, with a fully established monitoring network the focus now has to be on the auditing of the monitoring system to improve quality of the data and rationalisation of siting of monitors.

Table 1: District-wise distribution of 39 monitoring stations

City	District	No. of monitoring stations
Delhi	Central	7
	East	1
	New Delhi	5
	North	6
	North-east	0
	North-west	2
	Shahadra	2
	South	4
	South-west	1
	West	5
	South-east	6

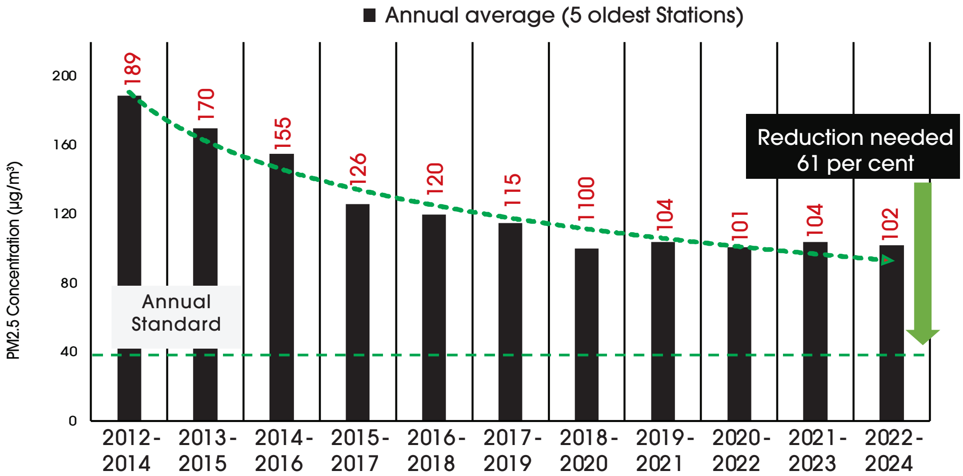
Map 1: Spatial spread of air-quality monitors in Delhi



Note: Average PM2.5 concentration is based on mean of daily values recorded at the 37 CAAQM stations given it has adequate data. Chandni Chowk and Lodhi Road IITM do not have adequate data for the year. New Moti Bagh station has not been operational since Sept 2024.

Source: CSE analysis

Graph 2: Three-year rolling average of $PM_{2.5}$ concentration based on the five oldest stations since 2012



Note: i. The five stations are ITO, IHBAS, Mandir Marg, Punjabi Bagh and RK Puram

ii. The tree-year average provides better view of the longer-term change and addresses high annual variation.

Source: CSE analysis of CPCB's real-time air-quality data

DATA ENABLES TRACKING OF AIR-QUALITY TRENDS

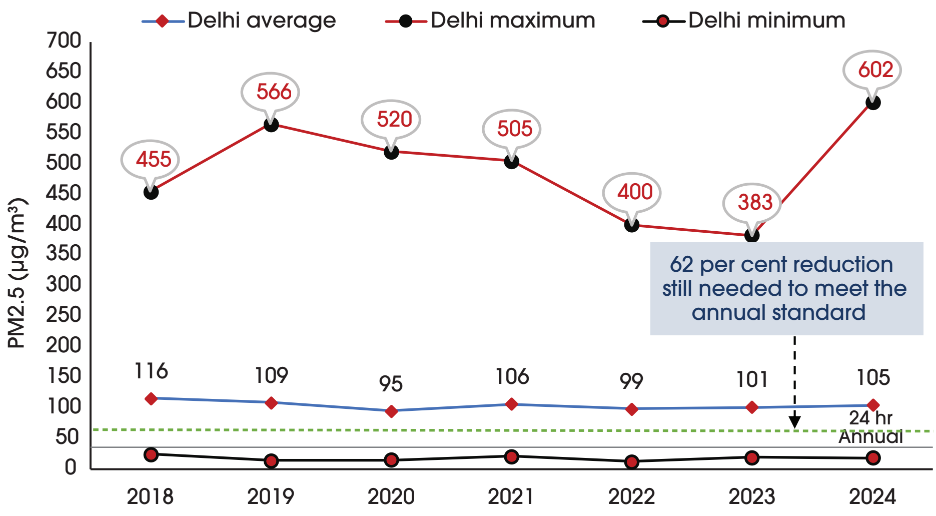
Long-term trend is downward: Even though most of the monitoring stations were set up between 2016 and 2019, five stations had come up around 2012–13. The rolling three-year average trends (more suitable to build long-term trend) in these stations show the change in the long term. There is a notable decline and the concentration level has dropped by 46 per cent over a span of 11 years (see *Graph 2: Three-year rolling average of $PM_{2.5}$ concentration based on the five oldest stations since 2012*). A series of multi-sector action spread over the two decades has contributed towards this trend.

More recent year-on-year air-quality trend since 2018, when most of the air quality monitoring stations were set up show that the average annual $PM_{2.5}$ levels (based on 38 stations) show a 10 per cent improvement since 2018 overall.

However, after the pandemic year of 2020–21, the levels have increased, stayed elevated and the curve turned upward in during 2023–24. The maximum values in 2024 has been the highest in the past few years (see *Graph 3: Long-term trend in $PM_{2.5}$ annual average since 2018*). Delhi requires as much as a 62 per cent reduction in its annual $PM_{2.5}$ annual average level to meet the national ambient air quality standard.

Usually, every year, burning of crop residues in the surrounding states of Punjab and Haryana are blamed for poor air quality during early part of winter. However, over the years the fire incidents have declined.

Graph 3: Long-term trend in $PM_{2.5}$ annual average since 2018



Note: Average, maximum and minimum $PM_{2.5}$ concentration is based on mean of daily values recorded at the 37 CAAQM stations given it has adequate data since 2018.

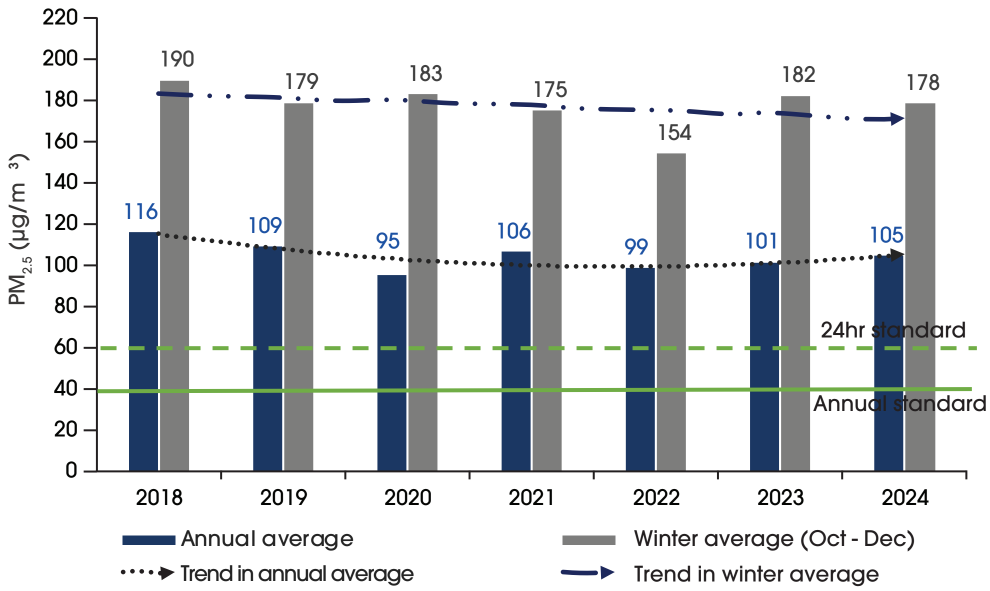
Source: CSE analysis

During the winter of 2024–25, the air quality of Delhi had turned poor to very poor even when for most part, the contribution of farm fires remained low. Between Oct 8 and November 30 – the main crop-residue burning season – farm fires contribution was 20–25 per cent on on five days, and 30 per cent and above on four days. On most days the contribution had been less than 10 per cent or even 5 per cent. This shows the pronounced impact of pollution sources in the city and the surrounding ares. Delhi cannot hide behind the smokescreen of farmfires any more (see *Graph 4: Trend in $PM_{2.5}$ winter average and annual average*).

Monitoring enables identification of hyperlocal pollution hotspots: In 2018, the Supreme Court had directed implementation of pollution hotspot plans for hyperlocal action across different neigbourhoods to reduce high exposures. The definition of the hotspots area after location-wise air-quality analysis showed that while the overall ambient concentration of $PM_{2.5}$ in the city was much higher than the national ambient air quality standards, the levels in some locations were higher than even the city average level. About 13 such hotspots were identified by EPCA and mandated to implement plans to address local pollution sources, which included unpaved and poor road conditions, open burning of waste including industrial waste and congestion among others.

These original hotspots continue to show a mixed air quality trend. In the meantime, however, more and newer hotspots have proliferated indicating rapid spatial spread of polluting activities in the city (see *Graph 5: Air quality trend in the pollution hotspots of Delhi*).

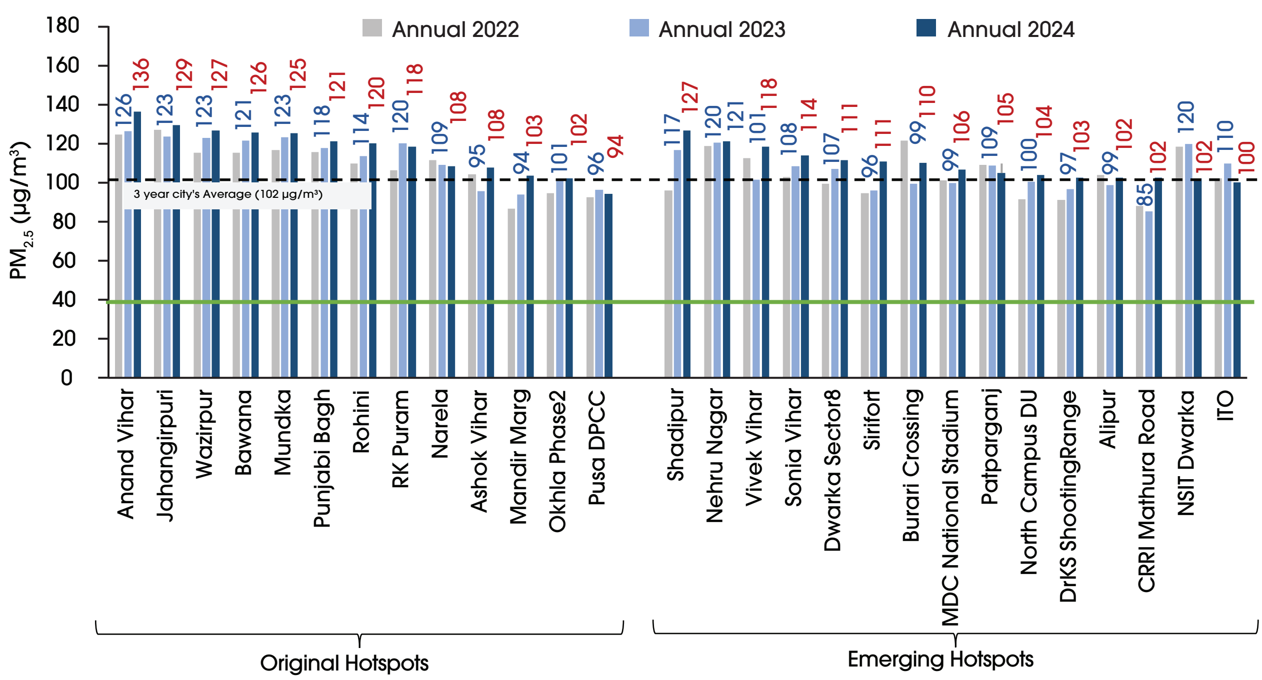
Graph 4: Trend in $PM_{2.5}$ winter average and annual average



Note: Average $PM_{2.5}$ concentration is based on mean of daily values recorded at the 37 CAAQM stations given it has adequate data since 2018.

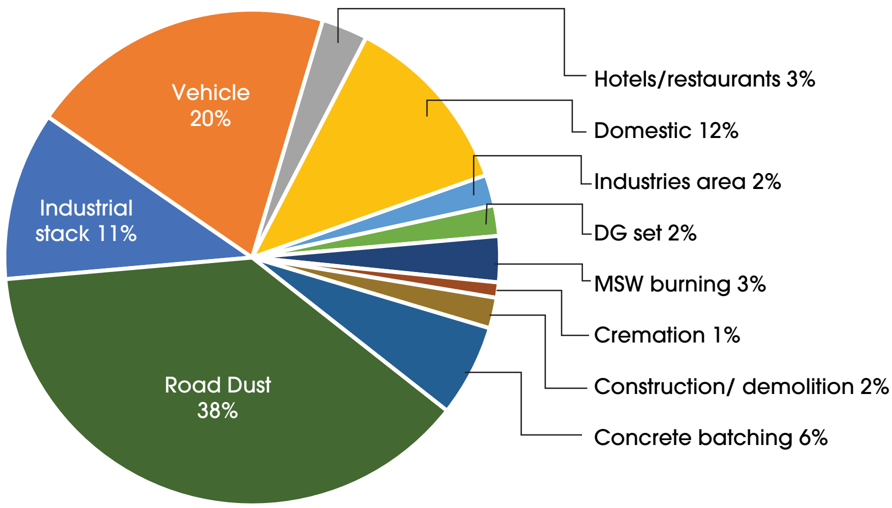
Source: CSE analysis

Graph 5: Air quality trend in the pollution hotspots of Delhi



Source: CSE analysis

Graph 6: Delhi emission inventory of $PM_{2.5}$



Source: IIT Kanpur, 2015

Between 2022 and 2025, identification of hotspots has enabled local action to address widely dispersed hyper-local sources of pollution.

BUILDING SCIENCE FOR AIR QUALITY MANAGEMENT: ASSESSING AIR POLLUTION SOURCES

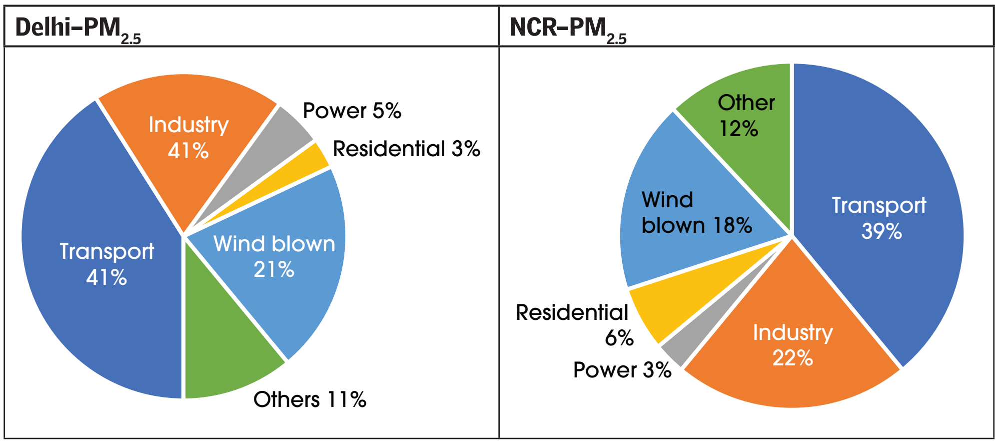
Profiling air pollution sources and relative contribution to air quality: Air pollution science has evolved in the city and several studies have been carried out in 2015–18 to assess the contribution of different pollution sources to ambient air pollution concentration (source apportionment) and pollution load (emissions inventory) in the city.

In 2015, a source inventory and source apportionment study was carried out by the Indian Institute of Technology (IIT), Kanpur under the aegis of the Delhi government. The study assessed 13 key pollution sources and their relative contribution to different pollutants (see *Graph 6: Delhi emission inventory of* $PM_{2.5}$).[1]

The recent study for Delhi NCR in 2018 by SAFAR shows that the emission load from vehicles to $PM_{2.5}$ is 41 per cent in Delhi and 39.1 per cent in NCR (see *Graph 7: Emission inventory of* $PM_{2.5}$ *based on the 2018 SAFAR study for Delhi-NCR*). The $PM_{2.5}$ emission from transport sector was 25.4 per cent in 2010 which increased to 41 per cent in 2018 (an increase of 40 per cent). This could be due to overburden with four-wheeler cars. Emission inventory of NOx shows that 62.5 per cent is contributed by vehicles.[2]

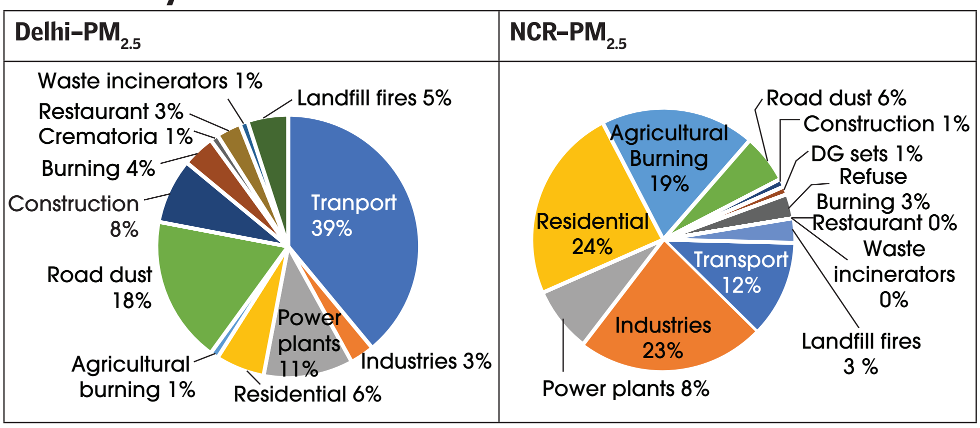
Another study by TERI-ARAI showed that transport sector contributes 38.8 per cent to $PM_{2.5}$ in Delhi and 12.6 per cent in NCR (see *Graph 8: Emission inventory of* $PM_{2.5}$ *based on the 2018 TERI-ARAI study*). The transport sector contributes 81.3 per cent to NOx emissions in Delhi.[3]

Graph 7: Emission inventory of $PM_{2.5}$ based on the 2018 SAFAR study for Delhi-NCR



Source: SAFAR, 2018

Graph 8: Emission inventory of $PM_{2.5}$ based on 2018 TERI-ARAI study



Source: ARAI and TERI, 2018

While these assessments have contributed substantially towards the decision-making process already, more updated assessments are needed to understand the changes on ground for further calibration of action. As a next step, Delhi requires new source inventory and apportionment studies for updated assessment of current profile of pollution sources to inform next-generation action.

Understanding seasonality of pollution patterns: Science has further deepened the understanding of the seasonality of pollution. There is also a strong seasonality in the pollution source profile. While influence of dust is very high – at 34 per cent – during summer months it can reduce drastically to 15 per cent during winter. But the relative share of combustion sources increase substantially during winter months. The share of vehicles can increase from 9–18 per cent in summer to 23–25 per cent in winter. The share of biomass burning can increase from 12–15 per cent in summer to 22–26 per cent in winter. It may also be noted that construction sector is an important contributor to the dust sources (see *Table 2: Percentage contribution of pollution sources to* $PM_{2.5}$ *concentration in Delhi*).

Significance of secondary pollutants: Delhi has the evidence on the magnitude of the problem of secondary particulates that enhance the overall particulate concentration in the city. Both the studies have pointed towards high impact of secondary particulates that are formed in the air when a range of gases that come from combustion sources react with each other to form secondary particulate. Their share can increase dramatically from 15–17 per cent in summer to 26–30 per cent during winter.

These studies have helped to understand the significance of the combustion sources and their contribution to both primary and secondary pollution. But it is more important to integrate this matter in the decision making process to target the combustion sources adequately to reduce primary emissions of gases.

Table 2: Percentage contribution of pollution sources to $PM_{2.5}$ concentration in Delhi

	Summer		Winter	
	IITK 2015 (in %)	TERI-ARAI 2018 (in %)	IITK 2015 (in %)	TERI-ARAI 2018 (in %)
Secondary particulate	15	17	30	26
Vehicles	9	18	25	23
Industrial	1	11	1	10
Coal + flyash	26		5	
Biomass burning	12	15	26	22
Construction dust	3	34	2	15
Soil + road dust	27		4	
Solid waste burning	7		8	
Others		5	4	

Source: IIT Kanpur, 2015, PM2.5 apportionment study, TERI-ARAI 2018: Source apportionment study

AIR-POLLUTION FORECASTING AND EMERGENCY ACTION

Genesis of air quality forecasting: The Indian Institute of Tropical Meteorology (IITM) developed the 'Air Quality Early Warning System' (AQEWS) around 2018 to provide dynamic daily air quality forecast for Delhi-NCR. This enabled advanced decision on emergency action during periods of anticipated adverse air quality.

Further, the System of Air Quality and Weather Forecasting and Research (SAFAR) estimated the contribution of farm fires to Delhi's air quality. By 2018–19, the SAFAR system was used to forecast air quality. The system provided location-specific information on air quality in near real-time and forecasts up to one to three days in advance. This could also assess the daily contribution of the crop fire in neighbouring states on Delhi's air quality. The implementation of emergency action as part of the Graded Response Action Plan (GRAP) during that period was linked with this forecast system. Subsequently, a dynamic model and meteorological forecast system was developed by the India Meteorological Department (IMD) and IITM-SAFAR in 2022. The modified system now forecasts pollution levels for the next three days. This advancement facilitates pre-emptive and preventive measures.

However, currently, GRAP is implemented with some variation now. If air quality index (AQI) forecasts do not indicate a threshold breach but extreme meteorological conditions or episodic events leading to an unexpected spike, the corresponding stage of GRAP is immediately implemented. As pollution levels are still very high with high winter average levels, the invocation of harsher measures are becoming frequent, unpredictable and more disruptive.

Assessing regional influence on local air pollution: It has now been possible to understand the transboundary movement of air pollution and the impact of regional pollution on the local air quality of Delhi. This had first emerged from the 2018 TERI-ARAI study that had shown that while the NCR can contribute up to 23–24 per cent of the Delhi's $PM_{2.5}$ concentration, Delhi also contributes to the air quality of Noida downwind – as much as 28 per cent during summer and 40 per cent during winter.

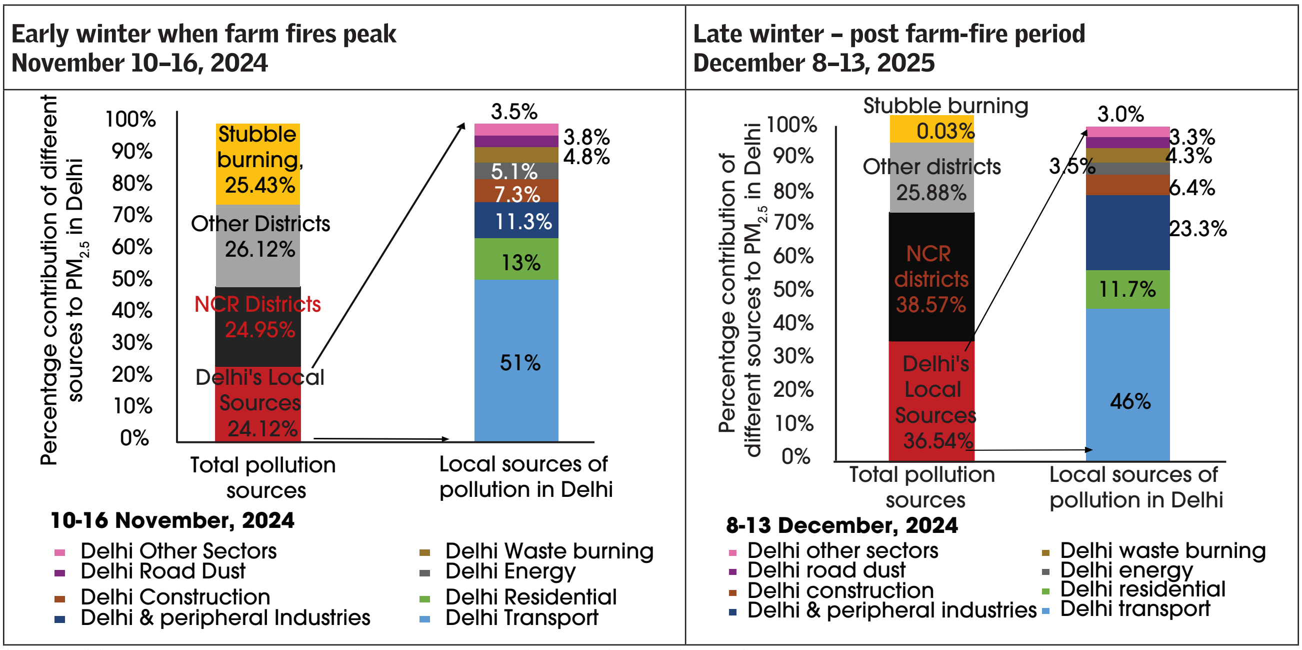
Subsequently, more dynamic assessment has become possible. The forecasting system has been further integrated with a Decision Support System (DSS) of IITM that provides both qualitative and quantitative information regarding contribution of different emission sources in the region during winter.

This provides quantitative information on contribution of emissions from Delhi's own pollution sources and that of the surrounding 19 districts in the National Capital Region (NCR), and also the contribution from biomass-burning in the neighbouring states.

This provides good insight into the changing nature of contribition of pollution sources to Delhi's air quality during winter (see *Graph 9: Dynamic forecasting in the relative contribution of pollution sources to $PM_{2.5}$ concentration during winter in Delhi*). For instance, during the early part of the winter when farm fires peak, the share of farm fire is about a quarter, followed by NCR districts and other districts at 51 per cent and Delhi's own contribution at a quarter. But post crop burning season, the share of crop fire is less than 1 per cent, the share of NCR and other districts is 64 per cent and contribution of local pollution sources in Delhi increase further to 36.54 per cent.

According to this dynamic forecasting of IITM, among the local sources, the top concerns are vehicles, Delhi and peripheral industries, construction, waste burning and residential fuel. The share of road dust is negligible during winter. Analysis of sample data from DSS shows that a substantial amount of pollution comes from outside. But even at 30 per cent, the contribution of local sources is significant, especially when it is considered that the city needs to reduce $PM_{2.5}$ levels by 62 per cent from a very high annual level of 105 microgram per cubic metre.

Graph 9: Dynamic forecasting in the relative contribution of pollution sources to $PM_{2.5}$ concentration during winter in Delhi



Source: CSE analysis based on data from the Decision Support System for Air Quality Management in Delhi of IITM

This science will have to be taken forward to strengthen regional airshed-level action in the larger airshed.

Data is from the Decision Support Systems (DSS) of IITM, which is part of their Air Quality Early Warning System and provides information on the potential emission sources to air quality in Delhi. This uses the online chemistry transport model Weather Research and Forecasting with Chemistry (WRF-Chem), and its modelling uses the available emissions inventory for Delhi and its surrounding 19 districts as well as the PM2.5 data from the Central Pollution Control Board (CPCB) monitoring stations and satellite imaging of pollution (see *Graph 9: Dynamic forecasting in the relative contribution of pollution sources to $PM_{2.5}$ concentration during winter in Delhi*).

INITIATION OF GRADED RESPONSE ACTION PLAN (GRAP)

Responding to the winter pollution crisis in 2014–16, the Supreme Court had directed the framing of a Graded Response Action Plan (GRAP) for emergency response during smog episodes in winter. GRAP was notified in January 2017 to classify action according to different grades of air quality (good, satisfactory, moderate, poor, very poor and severe) as per the National Air Quality Index (AQI) developed by the Ministry of Environment and Climate Change (MoEFCC).

The intent and the purpose of this was to ensure that when pollution is trapped and cannot disperse due to adverse atmospheric conditions, drastic temporary measures can prevent further loading of pollution. But it was also expected that the need for these harsh temporary measures that are disruptive and adversely affect business, earnings and livelihoods will diminish as the round-the-year efforts to reduce emissions gather momentum. However, GRAP measures have continued to remain the primary focus of clean air action.

At the early stages of GRAP when there was no forecasting system, measures earmarked for severe AQI category were implemented when severe pollution levels persisted for a minimum three consecutive days. This system gradually got linked with the Air Quality Early Warning System (AQEWS) of the Indian Institute of Tropical Meteorology (IITM).

Currently, GRAP measures are connected with continuous changes in AQI levels. This needs to be modified to be informed by the forecasting system to prevent disruptive action.

The GRAP framework that has originated in Delhi has been mandated for adaptation by CPCB in clean air action plans of all non-attainment cities under the NCAP programme.

MULTI-SECTOR ACTION

Industry and power plants

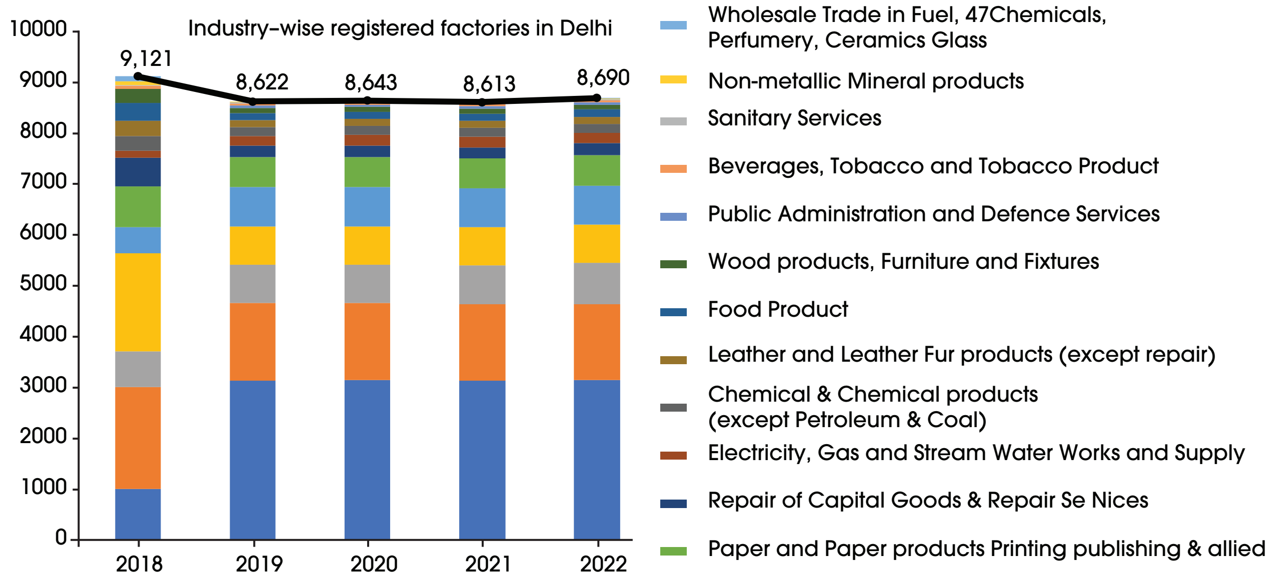
Relocation of polluting industries

The earliest effort to curb industrial pollution had started following the Supreme Court directives to shift big polluting industries out of Delhi. The Supreme Court had directed closure of 1,328 units in the hazardous category, which included hot mix plants, lead-smelting units, stone crushers, pesticides, heavy foundries, steel rolling mills, etc. Subsequently, the Delhi Pollution Control committee (DPCC) also issued closure orders to 118 more industrial units.

In fact, earlier, in 1987, the Central government issued the notification GSR 106(E) which declared the Union Territory of Delhi an "Air Pollution Control Area" under the Air (Prevention and Control of Pollution) (Union Territories) Act, 1981 Section 19 Sub-section (I) following which the Supreme Court issued a series of notifications in 1996–96 to phase out the polluting fuels from the capital region starting with the industry sector in the region. In 2000, the Supreme Court further directed closure of polluting industrial units in non-conforming/industrial areas under the supervision of Ministry of Urban Development. Based on the criteria of polluting industries, developed by this ministry and an expert committee of the government, 5,046 more units were closed down. DPCC had also identified 557 more units for closure and directed several industrial units to install pollution-control devices.

It was reported in the Delhi Economic Survey of 1990–2000 that immediately after that the ambient air pollution levels of suspended particulate matter in the industrial areas of Delhi reduced from 420 mg/m^3 in 1995 to 365 mg/m^3 in 1999 and in the residential areas it decreased from 409 mg/m^3 in 1995 to 351 mg/m^3 in 1999.[4] Those not meeting the various environmental norms have either closed or shifted out of Delhi to other neighbouring states.

Graph 10: Industry-wise registered factories in Delhi as on December 31, 2022



Source: Office of the Labour Commissioner, GNCTD, 2025

It may also be noted that this action had coincided with the introduction of unleaded petrol. Therefore as a combined effect, there was a drastic decline in the ambient air pollution levels of lead. In the industrial areas of Delhi lead levels reduced from 110 mg/m^3 in 1995 to 58 mg/m^3 in 1999 and in the residential areas it decreased from 155 mg/m^3 in 1995 to 46 mg/m^3 in 1999.[5]

Delhi has a number of industrial estates spread over an area of 4,647 acres. Currently the infrastructure and institutional setup is created and redeveloped through redevelopment of conforming and non-conforming industrial areas through Delhi State Industrial & Infrastructure Development Corporation Limited (DSIIDC) & Delhi Development Authority (DDA) in some of the industrial areas across the City.

There are 29 planned industrial areas and four flatted factory complexes and the state government has notified 25 non-conforming areas for redevelopment. As on December 31, 2022, there were total 393,877 MSMEs registered in Delhi. This includes 365,849 micro enterprises, 25,091 small and 2,937 medium enterprises[6] (see *Graph 10: Industry-wise registered factories in Delhi as on December 31, 2022)*.

There are no major industries in Delhi and the large-scale establishments not meeting the various environmental norms by the Central Pollution Control Board and Delhi Pollution Control Committee are either closed or shifted out of Delhi to other neighbouring states.

It is evident, however, that there are about a lakh of small unorganized units and large numbers of small-scale units, including plastic recycling units, that are not in the listed legal industrial estates but in unauthorized areas and peripheral areas that are challenging to monitor. Strategic interventions are needed to address these units.

CLEAN INDUSTRIAL FUELS – ENFORCEMENT OF APPROVED FUEL LIST

One big thrust of the judicial and executive action in Delhi so far has been to push for clean fuels in the industrial sector. Several measures have been taken in this direction, the driver being the issuance of the approved fuel list.

The regulation of permissible fuels in Delhi and the National Capital Region (NCR) has undergone significant changes since the initial notification on August 27, 1996.

On August 27, 1996, the Delhi Pollution Control Committee (DPCC) issued a notification under the Air (Prevention and Control of Pollution) Act, 1981, specifying a list of approved fuels for the National Capital Territory (NCT) of Delhi.[7]

The approved fuels included coal with low sulphur content (less than 0.4 per cent); fuel oil, light diesel oil (LDO), low sulphur heavy stock (LSHS) with sulphur content not exceeding 18,000 parts per million (ppm); motor gasoline (petrol); diesel; liquefied petroleum gas (LPG); compressed natural gas (CNG); kerosene; naphtha (for power generation); aviation turbine fuel; firewood (restricted to domestic use in rural areas and crematoriums); and biogas. This list had originally aimed to control air pollution by limiting the use of high-sulphur fuels.

The Supreme Court directive of October 2017 to prohibit the use of furnace oil and pet coke in Delhi, Haryana, Uttar Pradesh and Rajasthan catalysed the revision of the older approved fuels list to exclude these high-pollution fuels.

On June 29, 2018, the government of National Capital Territory of Delhi issued an updated notification amending the original 1996 list.[8]

The revised list of approved fuels included Bharat Stage VI compliant petrol and diesel with 10 ppm sulphur; LPG; natural gas/CNG; aviation turbine fuel; firewood for crematoriums and other religious purposes; wood charcoal for tandoors and grills in hotels, restaurants, banquet halls, and eateries equipped with emission control systems; biogas; refuse-derived fuel (only for waste-to-energy plants); and any other clean fuels notified by the Government of NCT of Delhi or the Government of India.

This has virtually banned use of coal, pet coke, furnace oil, and other dirty downstream fuels and recycled fuels like tyre oil. A small concession had to be made for use of charcoal only in tandoors and grills of hotels/restaurants/banquet halls/eating houses as there was strong plea to protect certain kinds of traditional cuisine. But the notification has asked for some kind of emissions control systems.

This action in Delhi was subsequently extended to include the entire NCR to harmonise the approved fuel list. In 2022, the Commission for Air Quality Management (CAQM)

Approved fuels in Delhi

The Delhi Pollution Control Committee published a public notice with the approved fuel list on 29 June 2018. This is a list of fuels that can be used in Delhi. Anything not on the list is banned.

- Petrol (BS VI with 10 ppm sulphur) as per the notification of Government of India as amended from time to time
- Diesel (BS VI with 10 ppm sulphur) as per the notification of Government of India as amended from time to time
- Liquid petroleum gas
- Natural gas/CNG
- Aviation turbine fuel
- Firewood for crematoriums and for other religious purposes
- Wood charcoal for tandoors and grills of hotels/restaurants/banquet halls/eating houses having emission channelization or control system
- Wood charcoal for use in ironing clothes
- Biogas
- Refuse-derived fuel (only for waste-to-energy plants)
- Any other clean fuel notified by the govt of NCT of Delhi/Govt of India subsequent to this notification

More recently in December 2022, the Commission for Air Quality Management in NCR and Adjoining Areas (CAQM) reminded all sectors including industries/industrial units to desist from using unapproved fuels including coal (except coal with low sulphur in thermal power plants) w.e.f. 01.01.2023 or face straightaway closure along with imposition of heavy Environmental Compensation (EC). The statutory directions of the Commission require complete elimination of use of coal and other unapproved fuels for various operations/ applications across all sectors (including industrial, commercial and miscellaneous applications), w.e.f. January 1, 2023 in the entire NCR.

Statutory directions have already been issued by the Commission regarding permissible fuels for industrial/ domestic/ miscellaneous applications in the NCR in terms of Direction nos. 64 dated 02.06.2022 and 65 dated 23.06.2022.

Statutory directions have already been issued by the Commission regarding permissible fuels for industrial/ domestic/ miscellaneous applications in the NCR in terms of Direction nos. 64 dated 02.06.2022 and 65 dated 23.06.2022.

Approved fuels mentioned in the Standard List mandated by the Commission in entire NCR are as follows:

- Petrol (BS VI with 10 ppm sulphur) as per Notification of Government of India as amended from time to time – vehicular fuel
- Diesel (BS VI with 10 ppm sulphur) as per notification of Government of India as amended from time to time – vehicular fuel
- Hydrogen/methane – vehicular and industrial purposes.
- Natural gas (CNG/PNG/LNG) – vehicular, industrial and domestic purposes
- Liquified petroleum gas (LPG) /propane/butane – vehicular, industrial and domestic purposes
- Electricity – vehicular, industrial, commercial and domestic purposes
- Aviation turbine fuel
- Biofuels (bio-alcohols, bio-diesel, bio-gas, CBG, bio-CNG) – for industrial/ vehicular/domestic purposes as applicable.
- Refuse-derived fuel (RDF) for power plants, cement plants, waste-to-energy plants.
- Firewood/biomass briquettes for religious purposes.

As per Direction No. 65 of the Commission, fuels permissible for selective industrial applications in NCR, only beyond the jurisdiction of NCTD, are as follows:

- Biomass/ agriculture refuse and pellets/ briquettes – for industrial boilers, power plants, biofuel projects, cement industry, waste to energy plants, etc.
- Biomass pellets/ briquettes – for tandoors and grills of hotels/ restaurants/ banquet halls (along with mandatory emission channelization/ control system) and for open eateries/ dhabas.
- Metallurgical coke – for industrial purposes in standalone cupola-based foundries.
- Low-sulphur fuels, namely LSHS, very low sulphur fuel oil and ultra-low sulphur fuel oil – for industrial purposes in metal smelting/melting/ refining/ heating furnaces and kilns

The Flying Squad of the CAQM are under instructions to conduct incognito visits to ensure compliance of Directions regarding use of approved fuels in the entire NCR. Violations and non-compliance of the directions issued by the Commission including use of unapproved fuels will straight away lead to closure apart from imposing Environmental Compensation (EC) and initiating prosecution action against the defaulters flouting the statutory directions.

issued a standardised approved fuel list in June 2022 for the NCR.[9] This additionally included hydrogen/methane and electricity. By 2023, out of 7,759 fuel-based industries in the NCR, 7,449 had transitioned to approved fuels, with the remaining 310 industries facing closure for non-compliance.[10]

Currently, coal is banned in entire NCR (except coal with low sulphur in thermal power plants) and use of unapproved fuels can lead to closure along with imposition of heavy Environmental Compensation (EC) w.e.f. January 1, 2023.

ELIMINATION OF POLLUTING INDUSTRY FUELS

Around the time when the approved fuel list was revised, in a landmark intervention against industrial pollution, the Supreme Court of India responding to the recommendations of EPCA, curbed the use of highly polluting petcoke and furnace oil. An investigation by the Centre for Science and Environment (CSE) had revealed alarmingly high sulphur content in these fuels – 74,000 ppm in petcoke and 24,000 ppm in furnace oil – both widely used in industries without emissions control systems. The court issued a far-reaching directive on October 24, 2017, banning the use of petcoke and furnace oil as industrial fuels for combustion in Delhi, Haryana, Rajasthan, and Uttar Pradesh. However, exemptions were granted to four specific end-user industries: cement, calcium carbide, lime kilns, and gasification who used petcoke as feedstock.

The ruling ignited further legal debates, with aluminium producers, calciners, and iron and steel manufacturers petitioning the court for permission to import petcoke. The matter remains under judicial review. Meanwhile, on November 17, 2017, the Supreme Court urged all Indian states to implement similar bans on these high-sulphur fuels.

The impact of these directives extended beyond domestic regulations. A decision was formalised to prohibit the import of petcoke into India, through a notification by the Director General of Foreign Trade on August 24, 2018. Additionally, the Ministry of

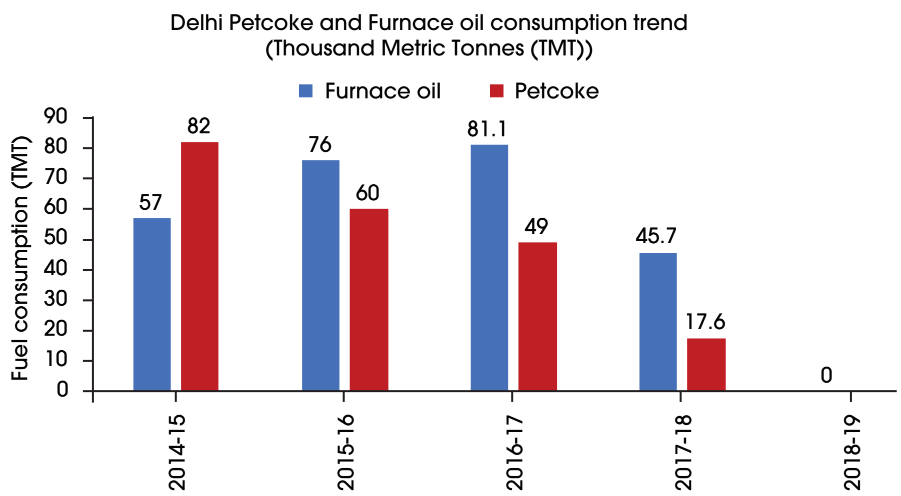
Environment, Forest and Climate Change (MoEFCC) initiated measures to restrict domestic use of petcoke to align with World Trade Organization (WTO) guidelines on keeping domestic policies aligned with the trade or import policy.

The Supreme Court's intervention on use of high sulphur fuels also exposed a significant regulatory gap – most industries in India lacked standards for sulphur oxides (SOx) and nitrogen oxides (NOx) emissions. This raised serious concerns about the impact of sulphur-rich fuels on air quality, particularly their contribution to sulphur dioxide (SO2) emissions and secondary particulate pollution. Recognizing the urgency of the issue, the Supreme Court issued another directive on December 31, 2017, mandating SOx and NOx emission standards for 34 industrial sectors nationwide. In response, the MoEFCC introduced the country's first-ever SOx and NOx regulations for 16 industrial sectors, marking a significant policy shift towards pollution control. However, challenges remain in ensuring enforcement, as State Pollution Control Boards (SPCBs) currently face capacity constraints in monitoring compliance with these new standards.

Since 2018–19, as per the data from the Ministry of Petroleum and Natural Gas (MoPNG) Delhi has reported zero consumption of both furnace oil and petcoke. The consumption of petcoke gradually reduced from 82,000 tonnes in 2014–15 to around 18,000 tonnes in 2017–18 and zero since 2018–19 (see *Graph 11: Delhi petcoke and furnace oil consumption trend (2014–18)*).

However, it is unclear if these fuels are discontinued in the unauthorised areas and in the small-scale units.

Graph 11: Delhi petcoke and furnace oil consumption trend (2014–18)



Source: MoPNG

MASSIVE EXPANSION OF PIPED NATURAL GAS (PNG) IN INDUSTRIAL AREAS

Before the approved fuels list, there was stiff competition from alternative fuels prices such as furnace oil (FO)/diesel, which had come down drastically due to lower crude prices. The crude oil prices continued its downward trend, recovering only after touching a low of US $26/barrel in February 2016. This led to a growing competition from alternative fuels in commercial and industrial segments of the city.

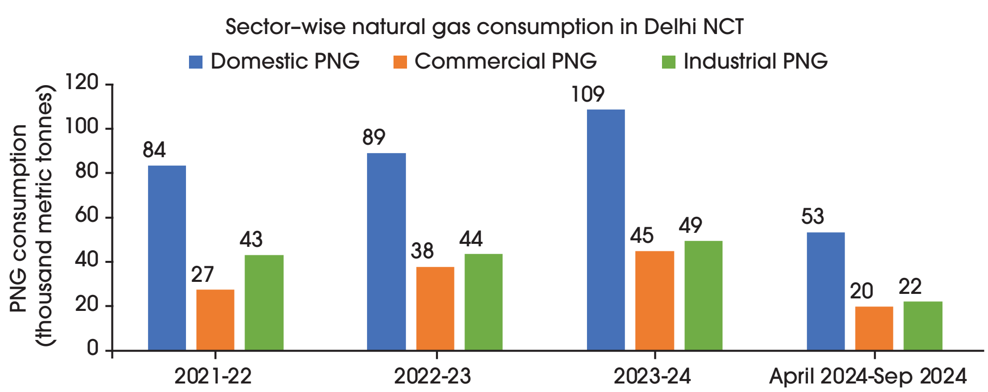
However, the government's decision to place City Gas Distribution (CGD) companies on the priority list for allocation of low-cost domestic gas for transport and PNG-domestic was a game changer. This gave an advantage to the CGD companies in competition with alternative fuels and also increased the preference for CNG vehicles.

Moreover, Delhi Pollution Control Committee (DPCC) has banned all other industrial fuels except PNG and has advised all industrial customers (wherever PNG is available) to switchover to PNG. Indraprastha Gas Limited (IGL), the authorized CGD entity in Delhi has efficiently coordinated to implement the mandate.

Correspondingly, the PNG consumption in Delhi's industry sector increased by 14 per cent between 2021–22 and 2023–24, increasing from 43,000 tonnes in 2021–22 to 49,000 tonnes in 2023–24, while in the commercial sector it increased by 67 per cent (see *Graph 12: Consumption trend for PNG in Delhi*).

Commercial PNG primarily serves industries like hotels, restaurants, shopping malls, hospitals, bakeries, small dairies, educational institutions, canteens and small-scale manufacturing units where large volumes of cooking, heating and power generation are needed.

Graph 12: Consumption trend for PNG in Delhi



Note: Data for 2024 is limited to six months

Source: MoPNG

Captive power generation and diesel generator sets: The additional challenge of pollution from use of captive use of diesel generator sets in the industry sector was addressed by the moving diesel genset segment to PNG. In 2023, CAQM directed switching over of DG sets to PNG and dual fuel (PNG and diesel) mode in Delhi and NCR.[11] IGL's PNG network is widely available among various Industrial and commercial clusters of Delhi with a focused approach to further expand/strengthen pipeline network by providing last-mile connectivity to the industrial and commercial establishments in existing areas where pipeline grid is available and expanded pipeline network can cater to other industrial areas. This has also been extended to residential areas.

In industrial and commercial segment 2,967 new registrations were completed during the FY 2023–24 and pipeline laying was started in new areas Chandni Chowk and Paharganj in Delhi.

IGL is also working in a collaborative and participatory approach with the state Pollution Control Boards, so as to work out an action plan to convert all industrial and commercial units to PNG (wherever IGL's PNG network is available).

According to Delhi's Economic Survey 2023–24, 1,866 industries were converted to PNG/ approved fuel and use of unapproved fuels to check industrial emissions.

During the last decade significant action has been taken to accelerate energy transition in the industry sector to eliminate dirty fuels, including coal, furnace oil and petcoke. The next steps need to target unregulated industries in non-conforming areas and peripheral areas.

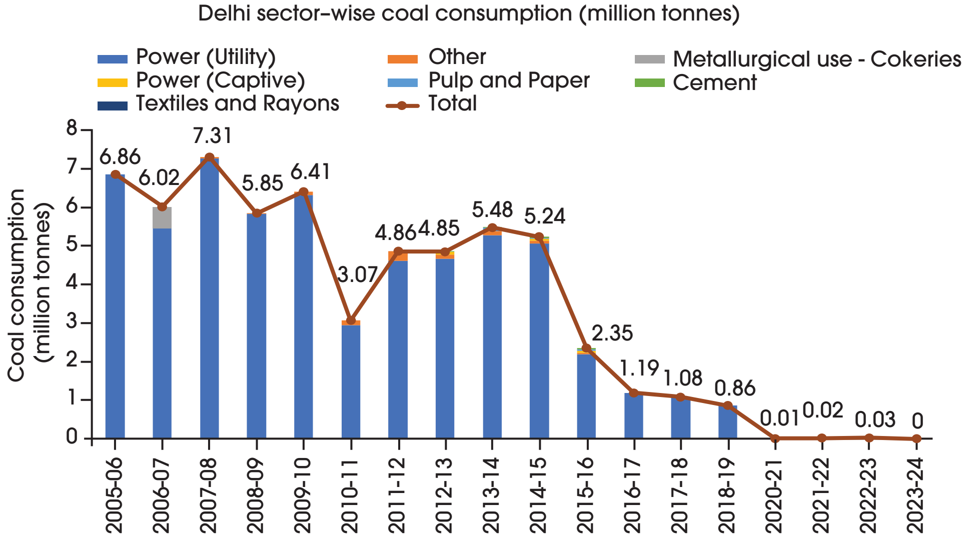
CLOSURE OF THERMAL-BASED POWER PLANTS

Over the years, Delhi has witnessed a drastic decline in coal consumption and this has been largely determined by the permanent closer of the three coal-based power plants in Delhi. The Indraprastha power plant was closed in 2009, the Rajghat plant closed in 2015 and, finally, the Badarpur plant was closed in 2018 as part of measures to control air pollution.

Currently, there are six gas turbine units that run on natural gas to generate electricity in Delhi. The installed capacity of this station is 282 MW. This action has enabled massive reduction in coal consumption in the city.

According to the data available from the Coal Controller's Organization, Ministry of Coal, there has been dramatic decline in coal consumption in Delhi. Its use has now been virtually eliminated (see *Graph 13: Consumption trend for coal in Delhi (2006–24)*).
This is the impact of implementation of closure of coal power plants and implementation of the revised approved fuel list of the Delhi government in the city. The impact of these measures are reflected in Delhi's coal consumption trends. Coal consumption has decreased significantly and in 2024 there is virtually no coal consumption reported in Delhi.

Graph 13: Consumption trend for coal in Delhi (2006–24)



Source: Coal Controller's Organization, Ministry of Coal

INDUSTRY AND POWER SECTOR – THE NEW AGENDA

Addressing industrial units in non-conforming and peripheral areas

While substantial energy transition has been achieved in the legal industrial areas of Delhi, there are challenges of industrial units, largely small and medium scale in non-conforming areas. The energy mix and process description of these units is still undocumented and unaccounted for and further investigation is required to enable affordable energy transition in these areas.

Implementation of the approved fuel list has remained challenging in unauthorized areas and in small-scale units. Delhi will have to make the mechanism for intercepting entry of dirty fuels and stopping their illegal use much stronger. This requires a thorough profiling and inventorisation of the air-polluting industries in the informal and non-confirming areas. The fact that their contribution still shows up as the second- or the third-highest contributor to air pollution during winter in the dynamic assessment of hourly changes in source contribution by the Indian Institute of Tropical Meteorology (IITM) requires immediate attention.

The basic requirement is to bring these units into the monitoring network by clarifying who owns it and to mandate them to display the consent to operate the certificate from the DPCC. Once in the monitoring network, they must adhere to authorised fuel and basic pollution-control norms.

ADDRESSING BURNING OF NON-HAZARDOUS INDUSTRIAL WASTE

In 2018 a field investigation by EPCA in Nagloi, Mundka, Tikri, Kamrudin Nagar, Ranshola, Hiran Kudana, Baprola and Bahadurgarh revealed the problem of illegal dumping and burning of plastic and rubber waste on agricultural lands in Tikri, Ghavera and Mundka, contributing significantly to local air pollution. The unorganised plastic market and dumping of municipal solid waste in Nangloi were identified as major pollution sources.

This led to the direction to the DPCC to close, penalise and ensure compliance that no waste would be burnt and the waste would be taken for safe incineration. Some pilot efforts were made to tie up with the incineration industry to collect the waste for disposal.

This matter will require continuous monitoring and vigilance and the requisite infrastructure to eradicate the problem of industrial waste burning. All industrial zones require an inventory of industrial waste generation. DPCC along with the industries and industry association need to develop industrial zone-wise waste management plan for safe disposal and ensure development of the requisite infrastructure for targeted recycling or safe disposal.

IMPROVE POWER CONSUMPTION MIX TO INCREASE SHARE OF CLEAN ELECTRICITY

Even though coal-based power generation in Delhi has been phased out, Delhi's increasing electricity demands are still met predominantly by coal-based power sourced from outside the city. Delhi currently has four main electricity distribution companies (DISCOMs): BRPL (BSES Rajdhani Power Limited), BYPL (BSES Yamuna Power Limited), TPDDL (Tata Power Delhi Distribution Limited) and NDMC (New Delhi Municipal Corporation), which purchase electricity from various power generators to meet the city's electricity demands (see *Graph 14: Source-wise power purchase in Delhi*).

It is however important to note that the share of RES and hydro-based power in the consumption mix is steadily increasing, which is an encouraging trend. This requires the stated policy to accelerate sourcing of renewable energy and increase its share in the grid in a time-bound manner. This is needed to reduce pollution impact of the growing energy needs in Delhi in the larger airshed.

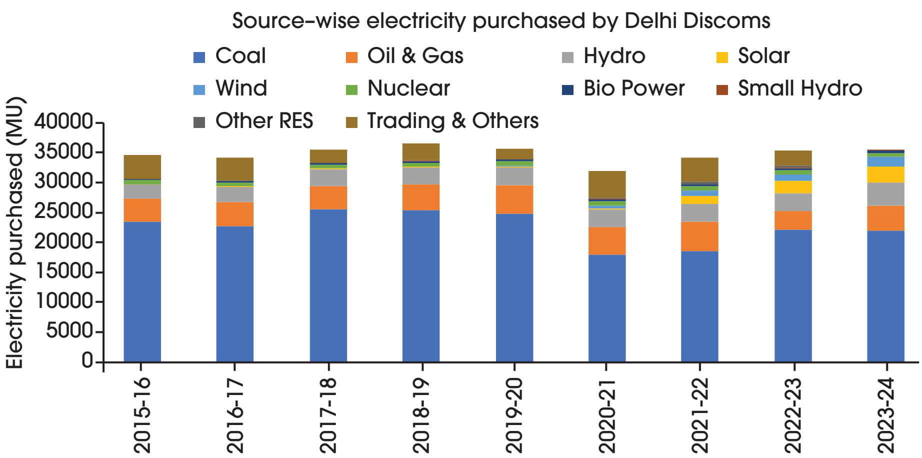
CURBING VEHICULAR EMISSIONS

While the year-long comprehensive emissions inventory and source apportionment studies in Delhi show that vehicles are among the top two pollution sources, IITM's dynamic estimates of hourly changes in source contribution during winter show that vehicles are the top contributors among the local sources of pollution in Delhi. This is also responsible for very high toxic exposures.

Currently, the transport sector of Delhi is the highest contributor to Delhi's local pollution. Since 2001–02, over 1.135 crore vehicles have been registered in Delhi. Since 2015–16, the yearly registration has been 600,000–715,000 vehicles per year, with a drastic dip during the COVID years due the strict restriction levied nationally (see *Graph 15: Vehicle registration trend in Delhi*).

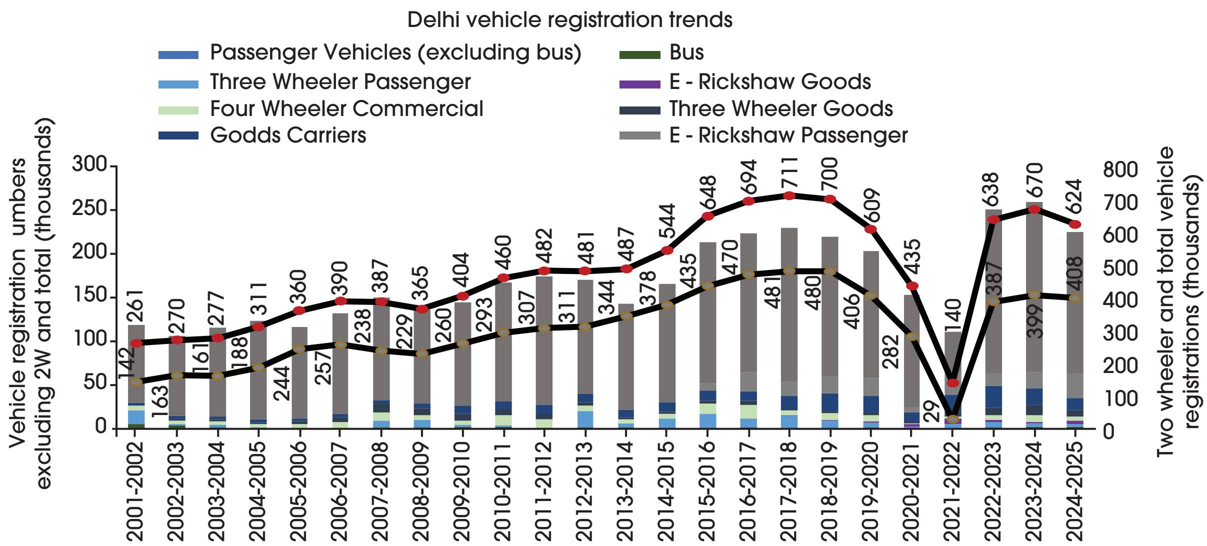
Owing to the quantum of vehicles added on the roads of Delhi, Delhi government had taken some of the most aggressive measures to improve the emission levels of the vehicles.

Graph 14: Source-wise power purchase in Delhi



Source: CEA

Graph 15: Vehicle registration trend in Delhi



Source: VAHAN database

THE LEAPFROG – ADVANCEMENT IN EMISSIONS STANDARDS

When clean air advocacy had started in the 1990s there was virtually no mass emissions standards for new vehicles in the country. During late 1990s, when rapid increase in the number of diesel cars was noted and the entire public transport and commercial transport were running on diesel, CSE's global review of evidence showed that the advanced countries were either cleaning up diesel rapidly or discouraging its use. Diesel emissions were considered one of the strongest carcinogens and high polluters.

When this matter was taken up in the Court by EPCA, the Supreme Court directed enforcement of Bharat Stage I emissions standards in March 1999 and subsequently Bharat Stage II in March 2000. This pushed the automobile industry to leapfrog within a short time span. As a result of this intervention in Delhi, other mega and capital cities also benefitted. Since then Delhi has always stayed ahead of other regions and introduced in advance the Bharat Stage III in 2005, Bharat Stage IV in 2010 and finally Bharat Stage VI (BS VI) for vehicles in 2020.

The submission from oil companies and the Ministry of Petroleum and Natural Gas (MoPNG) to the Supreme Court committing to the nation-wide introduction of 10 ppm sulphur fuels by 2020 had enabled the decision to introduce BS VI-compliant vehicles nation-wide from 2020 onwards. In January 2016, the Government of India had decided to skip BS V emission norms altogether and leapfrog directly to BS VI norms by April 2020. The 2017 notification asked for nation-wide introduction of BS VI emissions standards from April 1, 2020.

This also meant a dramatic improvement in the fuel quality. In 1998 the sulphur content in diesel fuel was 2,500 ppm; this has now reduced to 10 ppm, a 250 times reduction. Before BS VI-compliant fuels were introduced nation-wide in 2020, Delhi took the lead to become the first city in the country to switch to BS VI fuel (10 parts per million sulphur diesel) from April 1, 2018, two years ahead of the national schedule. This enabled the introduction of advanced emissions control systems in vehicles.

This leapfrog, like in the rest of the country, helped to reduce particulate emissions in new BS VI diesel cars by 91 per cent and in BS VI heavy duty vehicles by 94 per cent compared to BS III vehicles that were introduced in 2005. Similarly, nitrogen oxide levels in diesel heavy duty vehicles reduced by 91 per cent. The BS VI norms spearheaded adoption of more advanced diesel emissions control systems. These include advanced particulate filters to control particulate emissions and lean NOx traps, selective catalytic reducing system, and exhaust gas recirculation systems for NOx emissions control.

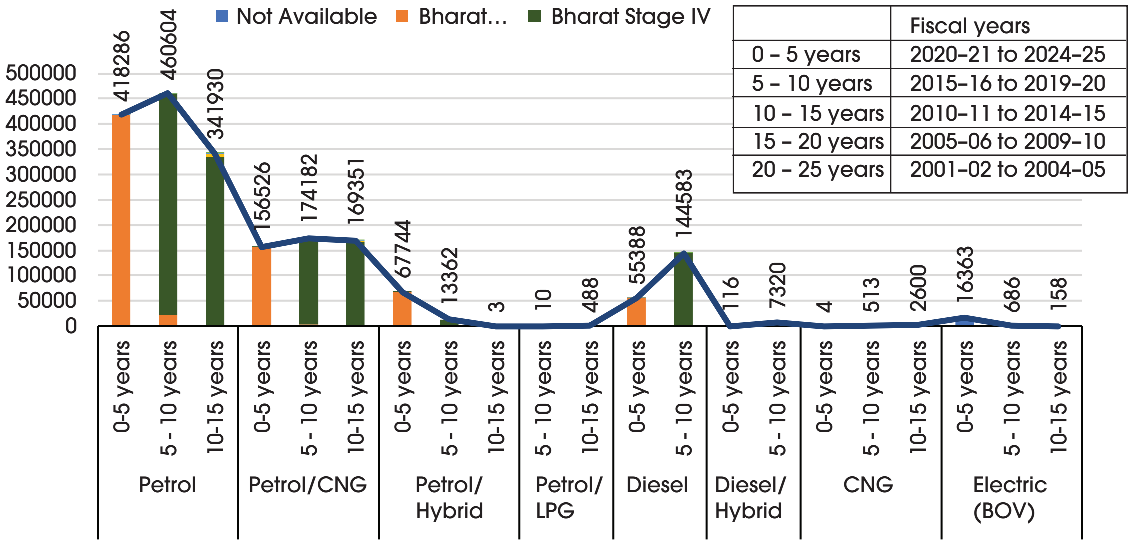
MASSIVE FLEET RENEWAL

The adoption of cleaner technology by Delhi's fleet is evident through its registration trends. In the last five years (2020–25), all the new private four-wheelers, two-wheelers, buses and goods carriers registered were predominantly BS VI. Pre-2010 vehicles including BSI, BSII and BSIII are nearly fully gone. The current fleet is dominated by the BS IV vehicles and a growing number of BS VI vehicles (see *Graph 16: Age-wise, fuel-norm-wise and fuel-wise registration of private four-wheelers in Delhi and Graph 17: Age-wise, fuel-norm-wise and fuel-wise registration of goods carriers in Delhi and Graph 18: Age-wise, fuel-norm-wise and fuel-wise registration of two-wheelers in Delhi).* The fleet renewal based on tighter standards has reduced tailpipe emissions substantially in Delhi.

RESTRAINING DIESEL VEHICLES AND DIESEL FUEL CONSUMPTION

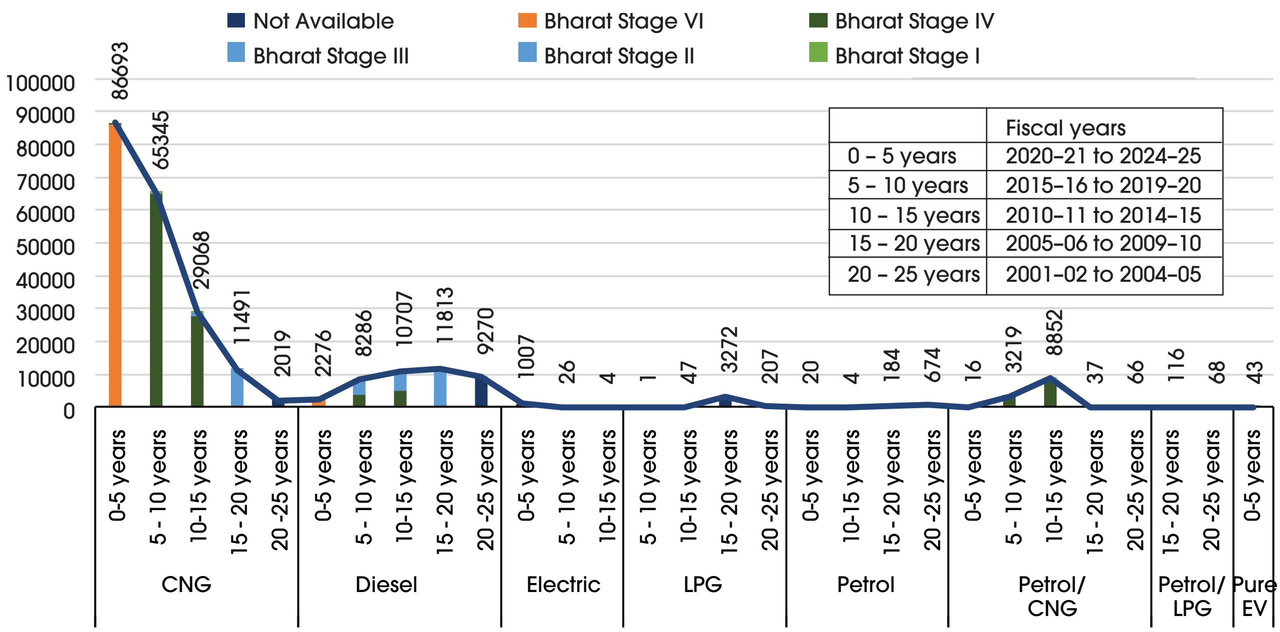
One of the key strategies for energy transition in the transport sector has been to reduce dieselisation of the vehicle segment and high speed diesel consumption in vehicles. This

Graph 16: Age-wise, fuel-norm-wise and fuel-wise registration of private four-wheelers in Delhi



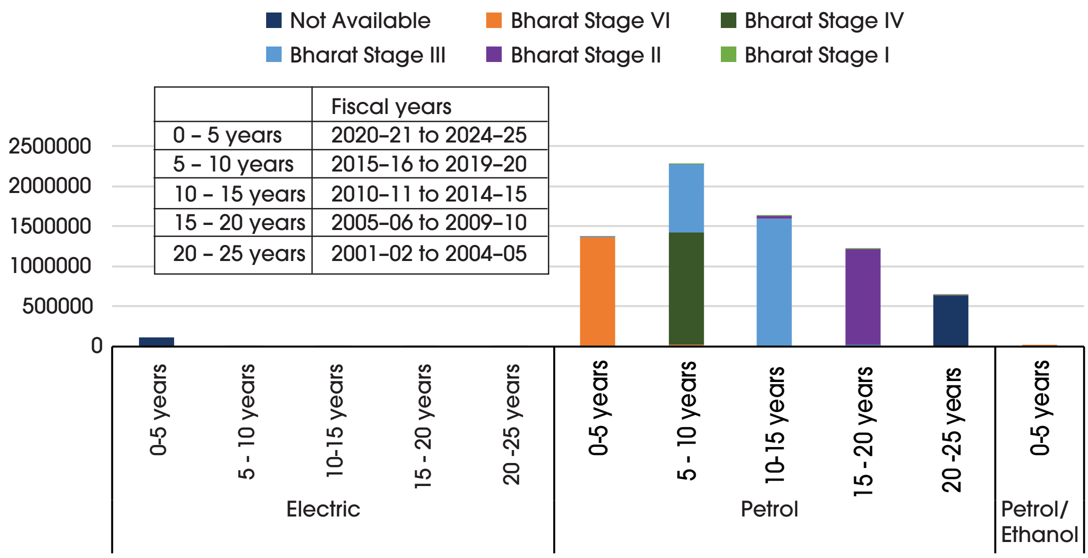
Source: VAHAN database

Graph 17: Age-wise, fuel-norm-wise and fuel-wise registration of goods carriers in Delhi



Source: VAHAN database

Graph 18:Age-wise, fuel-norm-wise and fuel-wise registration of two-wheelers in Delhi



Source: VAHAN database

has led to targeted measures over time to disincentivise diesel vehicles, restrict operation of diesel buses and diesel-operated heavy-duty trucks, disincentivise diesel cars and other commercial vehicles, as well as transport diesel consumption.

TRANSITION TO CNG TO CURB DIESELISATION OF VEHICLES

During 1998, when EPCA's deliberations with the state and central government departments brought out that it would not be possible to introduce Bharat Stage II emissions standards requiring 500 ppm sulphur diesel to align with the Euro II standards in force in Europe, a consensus decision was taken to recommend to the Supreme Court that compressed natural gas (CNG) be introduced for vehicles in the city.

In response, the Supreme Court in 1998 directed moving public transport stage carriage buses to CNG, increase the bus fleet to 10,000, replace pre-1990 autos and taxis with new vehicles using clean fuel, and set up 80 CNG stations by 2001. To counter opposition to the move from the automobile industry, bus operators and other detractors, the Supreme Court in 2001 deemed diesel bus operations as violation of court order and imposed penalty of Rs 1,000 per bus per day to be deposited in the Court itself. This led to the full establishment of the CNG bus programme in the city.

During the successive years, this programme was further expanded to include other local commercial vehicles. CNG also gained popularity in private cars as CNG prices were cheaper than diesel fuel. This also provided substantial emissions gains.

Due to combined and consistent action on diesel vehicles during the last two decades including advancement in emissions standards, CNG transition, environment cess on diesel fuel, big diesel cars and trucks and phase-out of 10-year-old diesel vehicles, have led to significant renewal of vehicle fleet and massive decline in the share of diesel vehicles in new vehicle sales.

Diesel car registrations had peaked in 2013–14, when it was as much as 41.36 per cent of all car registration in the capital. Since then the share of diesel cars has declined drastically and currently accounts for 5.87 per cent in 2023–24.

Moreover, with a massive CNG transition, a great part of the local commercial vehicles have also moved out of diesel. According to the Vahan database, the share of diesel commercial vehicles in the total commercial vehicle registration that was as much as 36 per cent in 2013–14 (when CNG transition was already underway) has now reduced to 4 per cent in 2023–24.

The overall reduction in diesel vehicles has reduced direct toxic diesel emissions drastically.

RESTRAINING DIESEL TRUCKS

The contribution of the heavy-duty diesel vehicles have been found to be significantly high in Delhi. According to the 2015 emissions inventory study of the IIT Kanpur, these vehicles contributed as much as 46 per cent of the total particulate load from vehicles in the city.

Since 2001, a series of directives from the Hon'ble Supreme Court have set a roadmap for addressing diesel emissions from heavy duty trucks in Delhi, which include:

- 6.12.2001 and 16.12.2015 directives banning entry of non-destined commercial traffic from entry into Delhi.
- 1.2.2005, 11.3.2005, 1.8.2005 directives to build the Western and Eastern Peripheral Expressway to provide alternative routes to trucks.
- 9.10.2015 directive imposing environment compensation charge (ECC) on all commercial light-duty vehicles and trucks entering Delhi.
- 16.12.2015 directive banning entry of vehicles registered in 2005 or earlier.
- 5.1.2016 directive on weigh in motion bridges and machines at the entry points of Delhi to check overloading.
- 22.8.2016 directive to SDMC to set up RFID based collection system at 13 entry points that cover 80 per cent of the commercial traffic.

As part of the Graded Response Action Plan, emergency restrictions on trucks are imposed during smog episodes in winter. As a combined impact of all these measures the real time data on truck entry monitored by SDMC has shown substantial reduction in truck numbers in Delhi.

Currently out of 124 entry points into Delhi, handheld RFID technology for cashless collection of ECC and toll tax has been introduced at all locations, including 13 border points being equipped with fully automated RFID systems. The CAQM directive of November 9, 2021 had asked SDMC to install automated infrastructure at additional

10 entry points – Noida Major, Loni Main, Dhansa border, Kundli II, New Seemapuri, Bajghera, New Kondli, Chander Nagar, Jharoda and Pul Prahladpur. Though handheld RFID is available at these locations, these are not as efficient and lead to congestion and pollution.

The cordoning of Delhi for regulated entry of trucks and payment of ECC is a step towards treating Delhi as a low-emissions zone. As the trucks largely operate under national permit, there are limited strategies available at the state level other than regulating their entry and overloading and rationalising logistical centres for trade. This segment requires attention.

In addition to the local regulations of truck entry and intra-city movement, the ongoing initiative of expanding highway-based CNG/LNG refuelling systems and charging infrastructure for electric vehicles needs to be accelerated to encourage shifting a substantial segment of long-haul trucking and other commercial vehicles to gas and electricity over the next five years.

IMPOSITION OF ENVIRONMENT COMPENSATION CHARGE ON TRUCKS

In 2015, the EPCA-CSE survey using round-the-clock monitoring video recording at fixed spots near selected entry points between June 29 and July 18, 2015 showed that a massive number of non-destined commercial vehicles were entering and leaving Delhi and criss-crossing the length of the city. It also came out that passing though Delhi was cheaper as the municipal toll to enter Delhi was lower than the toll rates on the alternative routes.

In response, on October 9, 2015, the Supreme Court imposed the Environment Compensation Charge (ECC) on daily entry of commercial goods vehicles entering Delhi. The Court fixed differential rates for vehicles that were empty/laden with goods, and also permitted exemptions for vehicles carrying "essential" goods.

To ensure efficient implementation and prevent malpractices in manual collection of ECC, on August 10, 2016, and in respond to the EPCA recommendations, the Supreme Court directed installation of Radio Frequency Identification (RFID) for effective and credible ECC collection. Each vehicle seeking to enter Delhi would have to pay online or make deposits at issuing points; vehicles would be pre-registered and this would allow for pre-2006 registered vehicles to be barred entry. It would also ensure that vehicles entry is tracked for destination. Thirteen key entry points which bring around 80 per cent of the truck traffic were identified to install RFID. EPCA had recommended implementation of RFID project for an additional 111 entry points.

Another follow-up survey by CSE in 2016 showed a decrease in truck traffic after the introduction of the system leading to reduction of as much as 30–35 per cent in PM and NOx levels in this vehicle category.

Subsequently, ECC collection has been expanded to 124 entry points by CAQM. But this is done by a handheld system. The RFID collection system is yet to be expanded.

There is no official data on the total amount collected from the ECC. According to media reports, however, until December 2021, about Rs 1298.38 crore has been collected. This would have multiplied significantly by now and is available for pollution control in the city.

PHASE-OUT OF OLD VEHICLES AND SCRAPPAGE OF END-OF-LIFE VEHICLES

A series of directives from the Hon'ble Supreme Court and the NGT have regulated the age of vehicles in Delhi. The NGT order of April 2015 has banned diesel vehicles older than 10 years and petrol vehicles older than 15 years in Delhi-NCR.

To maximise the emissions gains from this strategy and to reduce environmental impact from the unsafe disposal of junk vehicles, the state governments may additionally implement state-level scrappage policy for the end-of-life vehicles that cannot be used any more. The directives implemented so far in this direction are as follows:

- The Government of NCT of Delhi issued guidelines dated 20/02/2024 for impounding/ seizure/scrapping/release (with certain conditions and penalty) of end of life vehicles in public places to improve the air quality of the national capital. As per the guidelines, a penalty of Rs 10,000 for four-wheelers and Rs 5,000 for two-wheelers have been stipulated for owners of impounded vehicles before being released.
- Commission for Air Quality Management vide letter dated 25/05/2023 directed that appropriate action may be initiated against all End-of-Life Vehicles/ overaged vehicles either plying on roads or parked in public places in the NCT of Delhi.
- The Ministry of Road Transport and Highways on 15 March 2021 has issued G.S.R. 653(E) regarding the Motor Vehicles (Registration and Functions of Vehicle Scrapping Facility) Rules, 2021, dated 23-09-2021.
- G.S.R 220(E) regarding Concession in Motor Vehicle Taxes against submission of Certificate of Vehicle Scrapping, dated 26-03-2021.
- Sec 59 of the CMV(A) Act, 2019 that provides for fixing age and restricting plying of unfit vehicles.
- AIS 129 that defines the standards for manufacturers on reuse, recycling and material recovery from vehicles.

As of March 2023, over 5 million vehicles were deregistered in Delhi. Of the 5,338,045 vehicles deregistered, 4,698,391 were petrol-run, 415,362 had diesel engines, and 41,311 ran on CNG. There are concerns that these might still be operating. To address this, the Transport Department has now installed cameras in petrol pumps to introduce the programme of "No fuel to deregistered vehicles". Delhi government has also set up a vehicle scrappage centre for end-of-life vehicles and adopted a scrappage policy. But screening of vehicles to identify end-of-life vehicles is still weak. Thus the programme is unable to scale.

Due to advancement in emissions standards and quicker fleet renewal, fleet renewal has been quicker and there is already a sizeable shift to cleaner technologies. Analysis of vehicle fleet by age and by their status of emission standards show that BSI, BSII and BSIII – all pre-2010 vehicles – are nearly fully gone. The fleet is now dominated by the

BSIV vehicles and the growing number of BSVI vehicles. Due to unadjusted VAHAN database registration of a few old vehicles – older than 15 years – are still showing up.

But as per the order of the National Green Tribunal (NGT), more than 10-year-old diesel vehicles and 15-year-old petrol vehicles are not legally allowed in Delhi. The two-wheeler fleet has also shown significant shift to cleaner technologies.

In both private and commercial vehicles, the share of older vehicles has dropped significantly. Most of the vehicles are in the five-to-10-years age bracket while the number of vehicles below five years is also growing. Even though petrol and diesel vehicles older than 15 years and 10 years respectively are showing up in VAHAN database, technically and legallythese vehicles are not permitted to ply anymore.
However, even though large number of vehicles have been deregistered it is said that enforcement is not that stringent and these vehicles might still be running in the city.

Old interstate buses: In 2023, the CAQM has banned entry of pre-BSIV interstate buses to Delhi. Its enforcement is being monitored with the help of cameras in interstate bus terminus. The non-compliant buses are turned back (see *Graph 19: Age-wise, fuel-norm-wise and fuel-wise registration of buses in Delhi*)

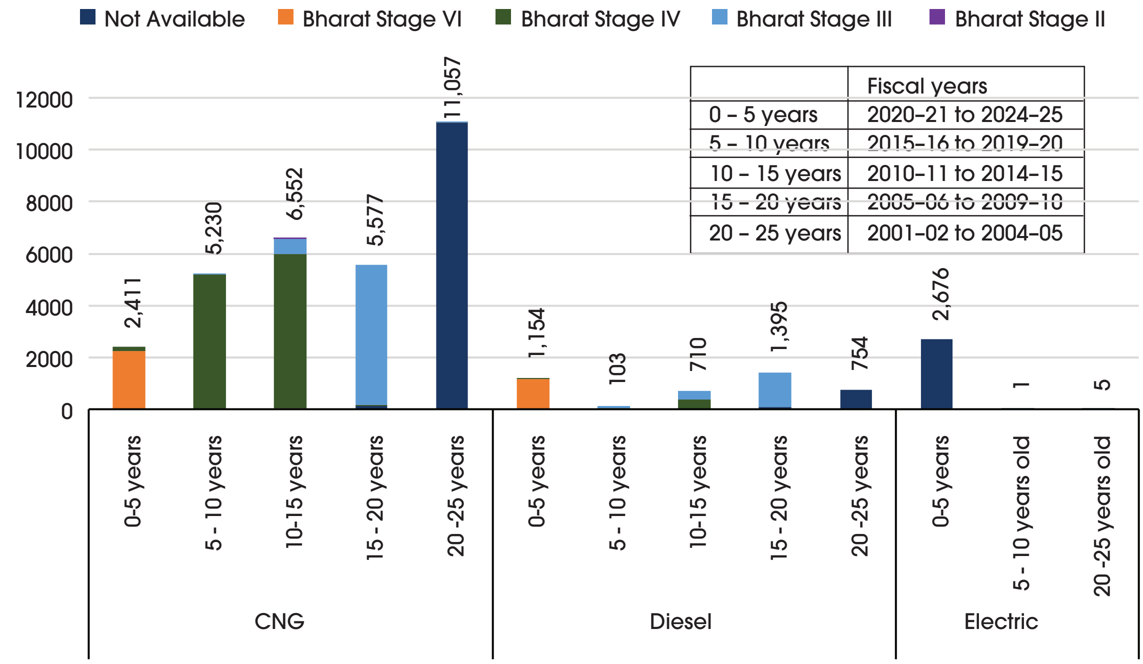
DISINCENTIVISING DIESEL FUEL AND VEHICLES WITH POLLUTION CESS

Toxic potential of diesel emissions was well recognized and the polluter pay principle was accepted by the Supreme Court and the city government.

Air ambience cess on diesel fuel: The Environment Department of the Government National Capital Territory of Delhi created the Air Ambience Fund in 2008 by levying 25 paisa cess on per litre diesel sale. This was imposed under the Air Act, 1982. A part of this fund has now been shifted to the Transport Department to fund the electric vehicle programme. It is interesting that during the time of peak dieselisation years of 2015–17, the annual collection from this cess was around Rs 61.85–56.62 crore. With lower diesel consumption now, the collection has reduce to Rs 36 crore.

Environment pollution charge on big diesel cars and SUVs: The Supreme Court order in December 2015 had directed imposition of environment pollution charge of 1 per cent of the price of the cars and SUVs with 2000 cc engines and above in Delhi and NCR. This is collected at the time of the purchase. These measures have helped to create dedicated funds. Despite strong opposition from the automobile industry, the apex court had imposed environment pollution charge on purchase of SUVs and diesel cars with more than 2000 cc engines. The revenue from this cess goes to the Central Pollution Control Board for pollution control measures and air-pollution-assessment studies. The amount collected from this source across NCR is still big, amounting to Rs 401.06 crore as in 2024, despite the reduction in diesel car registration in Delhi. This fund is being largely spent on research studies, technology trials, pellet plants, central control room, awareness activities etc.

Graph 19: Age-wise, fuel-norm-wise and fuel-wise registration of buses in Delhi



Source: VAHAN database

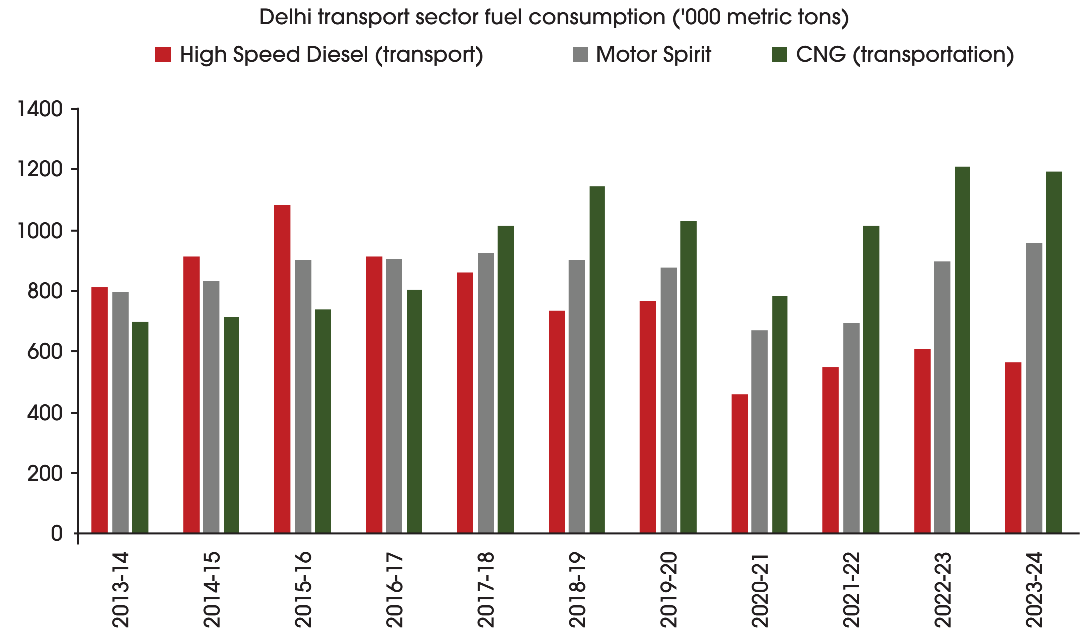
How have anti-diesel measures impacted energy transition?

Drop in high-speed diesel consumption: The impact is evident in the overall as well as transport sector diesel consumption. Between 2015–16 and 2023–24, Delhi witnessed a 59.3 per cent decrease in overall diesel consumption; whereas the CNG (transport) consumption increased by 61.5 per cent (see *Graph 20: Delhi fuel consumption ('000 metric tonnes*).

According to a PPAC study conducted in 2013–14, around 72 per cent of Delhi's total diesel was consumed by the transportation sector. However, due to strict measures for air pollution control in the industry sector, in 2019–20, around 92 per cent of the total diesel was consumed by the transportation sector.[12]

A comparison between fuel-wise energy consumed by the transportation sector excluding electricity, in 2015–16, the share of different conventional fuels in Delhi's transport sector energy mix was 40 per cent diesel, 30 per cent petrol and 30 per cent CNG. However, in 2023–24 the share was 20 per cent diesel, 32 per cent petrol and 48 per cent CNG.

Graph 20: Delhi fuel consumption ('000 metric tonnes)



Source: MoPNG, PPAC

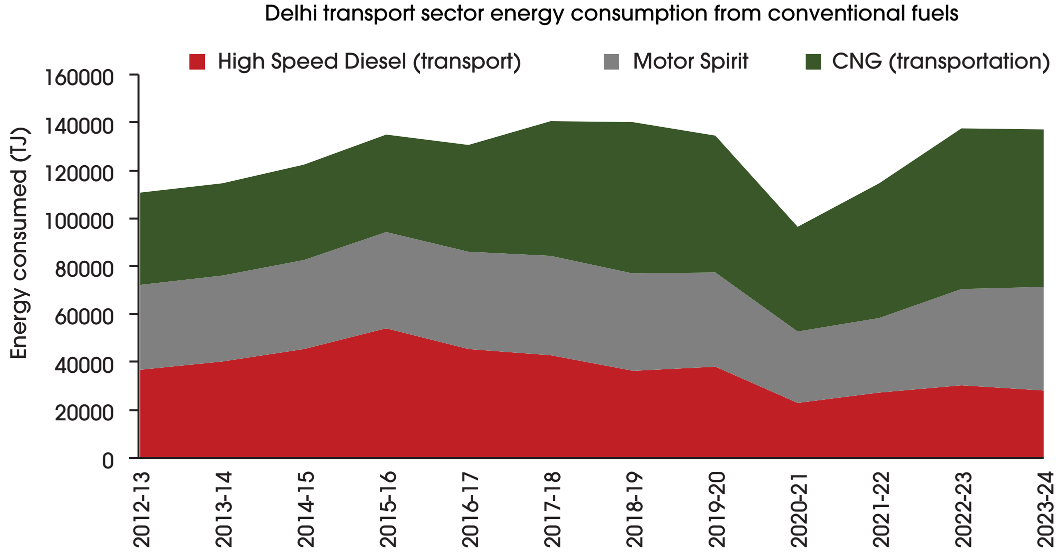
There was an increase of 1.4 per cent of total energy provided by conventional fuels for Delhi's transportation sector between these years (see *Graph 21: Energy consumption from conventional fuels in the Delhi transport sector (terajoules)*).

Declining share of diesel four-wheelers in new sales: As a result of series of measures initiated to discourage diesel vehicles, the share of registration of diesel four wheelers in the overall registration has reduced drastically from the time when anti-diesel measures were intensified (see *Graph 22: Sharp drop in diesel four-wheeler registration in Delhi*).

Share of electricity in transport sector increasing: The electricity consumed by the EV public charging stations (PCS) has continuously increased over the years. Notably, while the electricity consumption by the heavy duty PCS has increased owing to the increase in electric buses, the electricity consumed by other public charging station used for charging two-wheelers, three-wheelers and four-wheelers has decreased even though the number of in electric vehicles on road have increased. This might be because of increase in the adoption of residential charging stations (see *Graph 23: Power consumption in public EV charging stations in Delhi*).

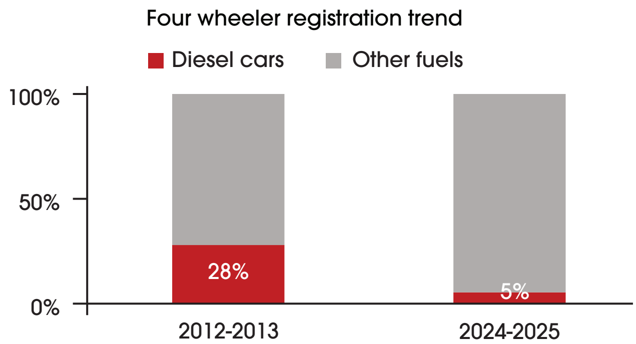
Clearly, the cumulative impact of the series of decisions taken to reduce dieselisation has catalysed significant energy transition in the transport sector.

Graph 21: Energy consumption from conventional fuels in the Delhi transport sector (in terajoules)



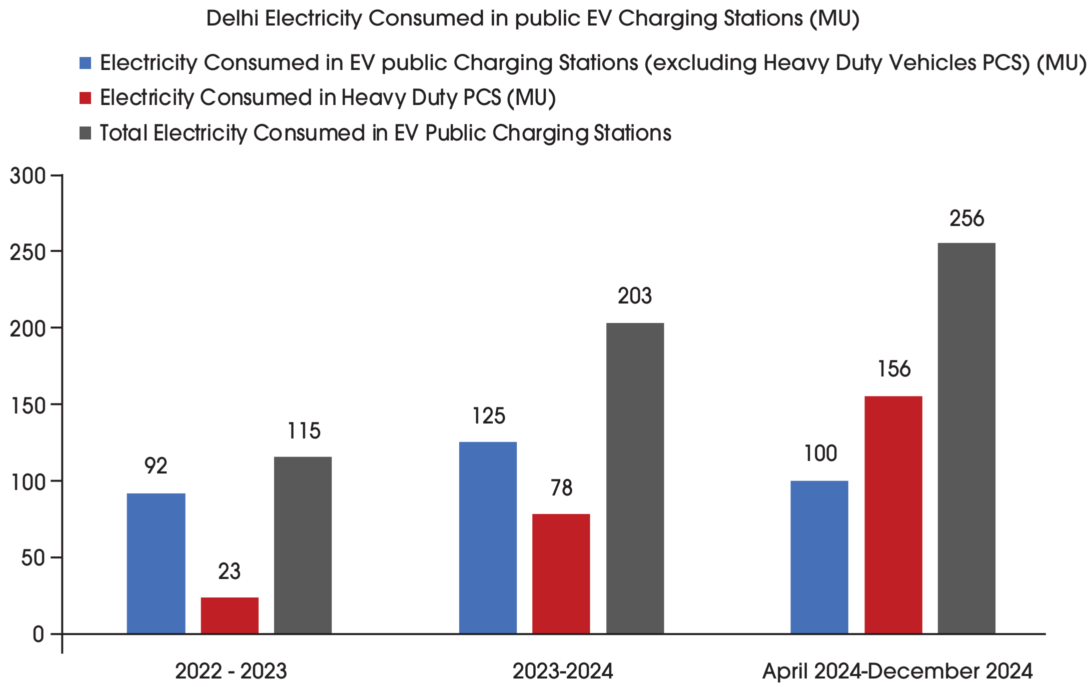
Source: CSE analysis

Graph 22: Sharp drop in diesel four-wheeler registration in Delhi



Source: Computed based on Vahan database

Graph 23: Power consumption in public EV charging stations in Delhi



Source: CSE analysis

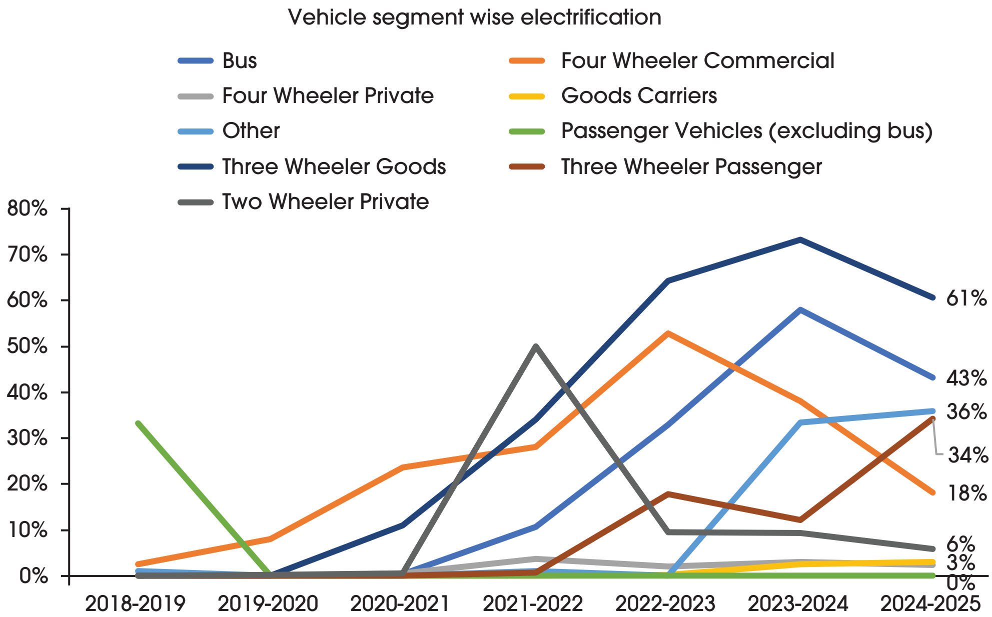
ELECTRIFICATION FOR ZERO TAILPIPE EMISSIONS

Despite the technology leapfrog in the internal combustion engines with BSVI technology and substitution of diesel with CNG in public transport, vehicles have remained the top contributor to Delhi's pollution. One BS IV diesel vehicle may emit particulate matter equivalent to around 5.5 BS VI diesel vehicles. But the increase in sheer number of BSVI vehicles can undo the gains from improvement in one unit of vehicle. In one year, the total number of vehicles is increasing 1.3 times. Pollution challenge will remain tough if motorisation continues based on internal combustion engines. Delhi therefore requires significant transition to zero tailpipe emissions to cut emissions at source.

The electrification programme has started with the notification of electric vehicle policy of Delhi in 2020. This executive order had set a target of 25 per cent electrification of all new vehicle registrations by 2024. This policy also aimed to register a minimum 50 per cent of all new-stage carriage buses as e-buses, including both city fleet and fleet for last-mile connectivity. All delivery service providers were expected to convert 50 per cent of their fleet operating in Delhi to electric by 2023 and 100 per cent by 2025.

Against these targets, the actual penetration of electrification is close to about 12 per cent. This is dominated by the small-format vehicles of e-rickshaws, two-wheelers and three-wheelers. Electrification of four-wheelers is still very small. Electric bus numbers have begun to increase. Delhi's EV policies, incentives and charging infrastructure expansion

Graph 24: State of electrification of vehicle fleet in Delhi



Source: Vahan database

have contributed to this trend (see *Graph 24: State of electrification of vehicle fleet in Delhi*).

There is uneven growth across segments. E-rickshaws have consistently dominated the trend and has the highest adoption numbers. Growth peaked early in 2016–17, reaching 18,886 in 2023–24. Passenger auto-rickshaw electrification began late and started in 2020–21 but grew to 8,547 in 2023–24.

Two-wheelers show an exponential rise from 20 in 2014–15 to 38,135 in 2023–24. This is the fastest-growing segment, likely due to affordability and operational cost savings. There were 31 private electric cars in 2014–15 that has risen to 5,957 in 2023–24.

Even though the number of electric cabs have increased from zero to 2,919, it is still low.

The electric bus numbers have reached 1,907 and goods vehicles 468 in 2023–24. It is now necessary to further strengthen the electric vehicle policy to increase the EV adoption in the capital state.

There is considerable opportunity in the ongoing framing of the Delhi Electric Vehicle Policy 2.0 that will provide the roadmap until 2030. This targets two- and three-wheelers, public and shared transport and goods vehicles for an ambitious target. It is reported that by 2027, it aspires to achieve 95 per cent electrification of all new vehicles other than N2 and N3 vehicles. It aims to provide fiscal and non-fiscal incentives over and above that is available under the national government's incentive programmes to bring further price parity. It has further proposed to combine incentives with phased mandates for commercial and goods vehicles and delivery service schemes to be electric. It is also proposed that car ownership beyond a second car need to be electric. This will be further supported by scrappage incentives and financing schemes and exemption from road tax and registration fee. The state EV fund will be further strengthened with additional taxes/cess on internal combustion engines. The proposed new policy has also proposed substantial expansion of the EV charging infrastructure.

This policy with detailed roadmap, targets and milestones can be a game changer. It will also be very effective if along with the vehicle segment-wise target set, sales mandate for the original equipment manufacturers (OEMs) are also notified. This can support the transition by accelerating product innovation and diversification to win consumer confidence, and reduce cost pressure due to competition between OEMs.

In view of the new EV policy in the making, it is necessary to ensure that no action is pre-empted to undermine this ambitious programme. The demand incentive schemes should be linked only with battery operated electric vehicles with zero tailpipe emissions. The Supreme Court on April 9, 2025 has stated that vehicles to be acquired by the Governments and public sector organisations should be only electric vehicles. An official proposal is expected to be submitted on this. The target and mandate and government support for electric vehicles for zero emissions transition is necessary given the pollution crisis in the city. The public support programme should not be diluted with internal combustion engines. Already, remote sensing measurement of the real-world emissions from the internal combustion engines in Delhi has shown that on-road vehicles including the CNG vehicles are emitting much higher in the real world driving conditions.

ADVANCING ON-ROAD EMISSIONS MONITORING

While introduction of BS VI norms has enabled a paradigm shift in the way we manage emissions from vehicles powered by internal combustion engines, this has also created pressure for more improved on-road emissions monitoring and management to ensure that the advanced-emissions-control systems remain durable and effective during the useful life-of-vehicles on road and real-world emissions remain under control.

The Supreme Court in its orders (dated January 17, 2017 and February 6, 2017) directed the EPCA to inspect Pollution under Control (PUC) centres located in the NCT of Delhi and also those in the districts of the NCR. EPCA appointed teams, including CSE, to conduct the audit. This had brought out the gaps in the system and the need for further improving it and also upgrading the system with remote sensing measurement for improved fleet screening and more effective identification of the worst polluters on the road.

This was further reiterated by the Supreme Court directive in July 2024 that while referring to the earlier directives of 2018 and 2019, as well as the recommendations from its former monitoring body EPCA in 2018–19, had directed the Ministry of Road Transport and Highways (MoRTH) to implement RSD programme and has sought priority implementation in Delhi and NCR. On May 10, 2018, it was stated that remote-sensing screening of emissions would be of considerable utility in Delhi.

In 2018, the ICAT had carried out pilot measurements with remote sensing devices. On July 29, 2019, based on the recommendation from EPCA, the Supreme Court issued notice to the Ministry of Road Transport and Highways (MoRTH) to frame the rules for implementation of remote sensing and directed the Department of Transport, NCT of Delhi to implement this.

Since then, the MoRTH has framed the Automotive Standard Rules 170 but is yet to notify them to enable implementation. This is holding back the implementation of the programme in cities. This is urgently required for efficient screening of large number of vehicles with advanced emissions control systems that cannot be monitored adequately under the PUC testing regime.

MOBILITY MANAGEMENT – A MAJOR GAP IN ACTION

Mobility crisis eroding emission gains from technology improvement: Mobility management has been one of the most difficult challenges in Delhi. Even though from time to time the Supreme Court has intervened to address mobility management, its application has remained very limited in scope. Unlike technology transition, which has gathered some momentum in Delhi, mobility transition has been much slower. As a result, the emissions benefits from technology transition are at risk of being negated due to explosive motorisation, growing congestion, massive daily entry of vehicles from the surrounding NCR, growing travel distances and travel trip generation, and declining share of public transport ridership and active mobility.

As per the information available from the multiple sources, over a decade private vehicle modal share (motorised trips only) has increased from 38 per cent to 49 per cent. Modal share of bus transport has declined. Due to urban sprawl, the average trip length has also increased substantially. A CSE analysis has found that during congestion, traffic speeds can reduce by as much as 41 per cent during morning peaks and 56 per cent during evening peaks. This increases idle emissions. Even though several good practices and policies related to public transport systems and vehicle-restraint measures have begun to take root, the scale and scope of action is very limited.

PUBLIC BUS SERVICES: SLOW STEPS

Renewal of bus fleet and technology upgradation: Over the last two decades Delhi has gone through successive stages of bus fleet renewal. In the first phase, following the Supreme Court interventions in 1998, the entire diesel bus fleet was replaced with CNG bus fleet. During the 2010 Commonwealth Games, another fleet renewal followed when the old style “bus body on a truck chassis” was replaced and augmented with specially designed urban buses for improved attractiveness and comfort to attract ridership.

Currently, the CNG buses are being phased out steadily to be replaced with electric buses. Delhi has taken the initiative to also fund procurement of electric buses by utilizing the state budget, and not rely only on Central funding. Delhi’s state EV policy in 2020 targeted 50 per cent of its bus fleet to be electric by 2024. In July 2022, Tata Motors bagged an order of 1,500 electric buses by DTC under a larger tender floated by Convergence Energy Services Limited as part of the E-Bus Grand Challenge. This expansion positioned Delhi as the city with the highest number of electric buses in India. Later, in 2024, Delhi added another 320 buses, driving up the electric bus fleet to 1,970 buses, and marking up 27.2 per cent of its total bus fleet. By 2025, Delhi aims to convert 80 per cent of its bus fleet to electric.

Not enough buses despite the increase: Even though bus technology upgradation is underway in Delhi, it has taken a while to increase the bus numbers. The original Supreme Court order of 1998 on CNG had also asked for augmentation of bus numbers to 10,000 in Delhi by 2021.

Currently, Delhi Transport Corporation (DTC) – a State Transport Undertaking – and Delhi Integrated Multimodal Transit System (DIMTS), a public sector company, manage the Cluster Scheme on behalf of Transport Department of Delhi, and are responsible for intra-city daily stage carriage services in Delhi. Delhi's bus fleet size by July 2024 was 7,683, including both DTC and DIMTS fleets. This still falls short of the Supreme Court target given in 1998.

That makes the number of buses per lakh population equal to 47 buses, which makes Delhi fall short of the Level of Service (LoS) category 2, as per the Ministry of Housing and Urban Affairs's (MoHUA's) Service Level Benchmarks (SLBs) for public transport in mega cities (cities with population greater than 4 million). According to the definition of the SLB document, LoS 2 for public transport means, *"The City has public transport system which may need considerable improvements in terms of supply of buses/coaches and coverage as many parts of the city are not served by it. The frequency of the services available may need improvements. The system provided is comfortable."*

To achieve the status of LoS 1 in the bus system, which is considered to be a *"good public transport system"* as per the SLBs indicators, the fleet size needs to be increased to at least 60 buses per lakh population in Delhi. This translates to close to 10,000 buses in Delhi, not too far off from the Court's directive 27 years ago.

In 2022, Delhi's Transport Department had aimed for a fleet size of 9,930 buses, which shall include 6,990 electric buses, making the e-bus share 70 per cent in the mix. The target was set for end of March 2025. The last known e-bus procurement done by the department was for 320 e-buses in July 2024, taking the count to 1,970 electric buses in the mix. The electric share in the fleet was 25.6 per cent.

Considering that Delhi is aiming to achieve LoS 1 as a priority, while fulfilling the electrification target of 70 per cent in its fleet set by the government, Delhi needs an additional fleet of 4,926 electric buses (over the current 1,970), while phasing out 788 existing CNG buses in the favour of electric buses. This will drive up the fleet size to 9,851 buses, with 6,896 electric buses.

Bus ridership is sub-optimal: Even though bus numbers have begun to grow, ridership is falling consistently. In the last decade, the annual average growth rate of ridership declined by 2 per cent. The highest decline was during COVID-19 lockdown (60 per cent decline), and compared to pre-pandemic levels, the ridership is 18 per cent. In the last year, between 2021–22 and 2022–23, the total bus ridership saw an increase of 62 per cent in Delhi. The mode share of buses in Delhi is 14 per cent (as of 2018), after including non-motorised trips in modal share calculations.

Inadequate service level: Even though work has begun to improve the service efficiency and passenger convenience through rationalization of routes parallel to metro lines, introduction of integration of smart cards for ease of ticketing across mass transit services, free bus rides for women passengers and construction and modernisation of new depots for better management of buses etc., this is not adequate to reverse the declining trend in modal share.

Traffic congestion during peak hours continue to reduce bus service level, by decreasing frequency, reducing reliable services, and increasing chances of bus bunching, which leads to low passenger load per bus. CSE has also analysed the available data from "Open Transit Data", which shows that up to 50 per cent bus stops in the city have a long waiting time (higher than 15 minutes) while about 3.5 per cent have a waiting time that is unpredictable (standard deviation from planned waiting time can be more than 100 per cent).

METRO RAIL SYSTEM – NEEDS INTEGRATION

Delhi now has a multi-modal system for mass commuting that include buses and the Metro rail system. Metro rail caters to more than 46 lakh passenger journeys every day (as of 2022–23). Metro has a 9.5 per cent modal share in the city (as of 2018), after including non-motorised trips in modal share calculations. Metro trips have the highest average trip length of 16.7 km followed by buses (14 km).

The National Capital Region (NCT) of Delhi is the only region in the country which currently has network design for its metro rail. The current operational network stands at 362.27 km (including 58.6 km of adjoining national capital region), across 10 operational corridors, giving it a coverage of 32 per cent of Delhi's population (calculated as per population density of wards) within 800 m of its metro stations, and about 10 per cent within 400 m. After the completion of currently under-construction Phase IV of the project, the network will be expanded to 463 km, making it one of the longest metro networks in the world.

DMRC, a joint venture between the Government of India and the government of the National Capital region, has demonstrated adoption of innovating financing models such as the public–private partnership (PPP) model for station retail, and advertising to generate revenue as well as to keep fares subsidised. The project was financed by leveraging international funding from institutions such as the Japan International Cooperation Agency (JICA) to finance initial phases.

In measures already taken, DMRC has integrated the metro stations with feeder bus services, auto/e-rickshaws and cycles for the ease of last-mile connectivity of its commuters. Recently, they have also installed charging infrastructures and swapping stations at metro stations to support Delhi's effort towards electric mobility transition.

The ridership data suggests that DMRC has performed quite well in terms of passenger per kilometre of operational route, which is comparable to the biggest metro systems at a global scale. Delhi's average ridership per day per kilometre is 12,771. The figure for the largest metro rail system in the world, in Shanghai, is 12,069. Compared to other countries with the largest metro rail networks, Delhi fares well – Beijing Metro: 15,575; London Underground: 8,034; Madrid Metro: 8,191 passengers per km.

DMRC's efforts towards green technology transition to obtain energy from sustainable sources makes them the first rail-based organisation in the world to claim carbon credits. Delhi metro receives 35 per cent of its total energy from renewable energy sources with a capacity of about 50 MWp. Apart from installing rooftop solar panels at metro stations and depots and procuring solar energy from an off-site solar plant.

DMRC launched a dedicated data portal providing open access to information on routes, schedules, ridership, and environmental metrics, contributing to greater transparency. The "Open Transit Data" portal, a joint effort by IIT Delhi and Delhi's Transport Department, makes bus and metro transit data feed available in public in the standard General Transit Feed Specification (GTFS) format.

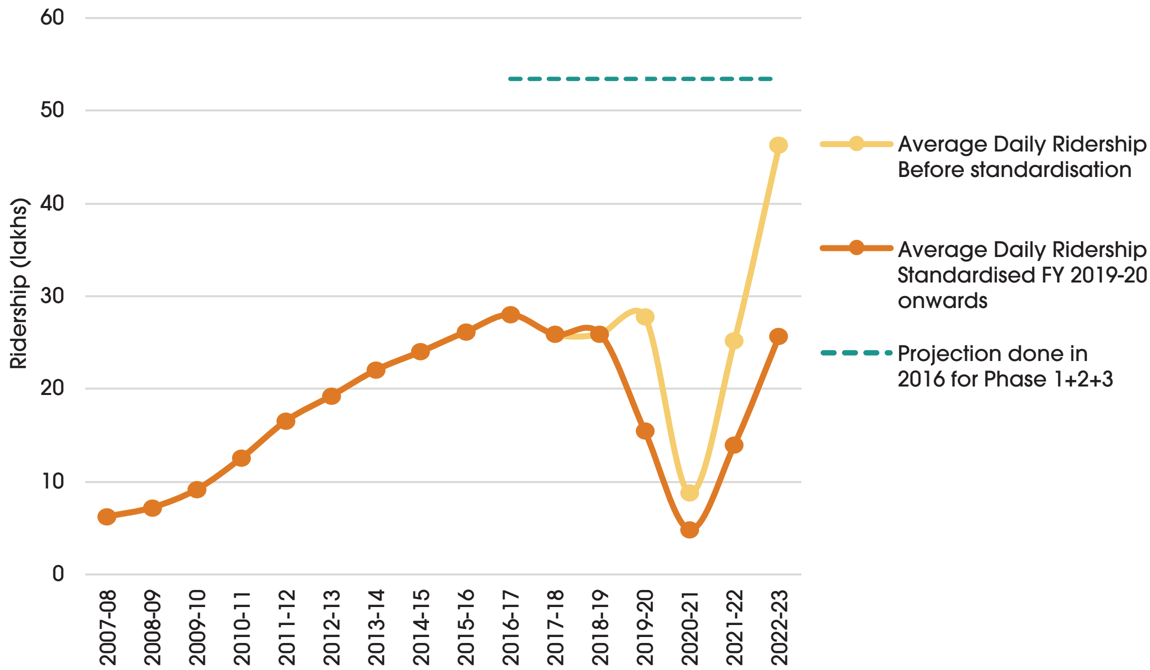
However, significant challenges remain in ensuring an accessible and efficient public transit system. In recent years, it was observed that while the operational network has seen an increase, the average ridership per km has not been proportional to the increase in network. Moreover, an assessment of the GTFS data (waiting times specifically) reveals that only 4.6 per cent stations of onward journey and 9.9 per cent stations of return journey presented an ideal scenario in which the wait times are consistently low on the stops.

Ridership augmentation can be achieved by improving accessibility to already built metro stations, increasing frequency and enhancing service levels at stations, physical multi-modal integration between transit stations/stops and last-mile connectivity, and planning dense development over long corridors to capture adequate land value and population.

Metro ridership required to reach projected level: DMRC in FY 2019–20 changed their method for calculating ridership for the metro system. Instead of the number of full trips (entire journey from origin to destination), the "passenger journeys" are considered, which translates journeys in terms of the number of corridors used by a passenger. This inflates ridership numbers by counting a single passenger multiple times if they use more than one corridor. It also makes year-on-year comparisons misleading, as earlier data based on full trips cannot be directly compared with the new method. It also distorts the perception of actual metro usage, making it harder to assess network efficiency, crowding patterns, and the true impact of metro expansion. Another drawback is that other travel modes cannot be directly compared to the DMRC ridership, making modal shift assessments difficult.

Passenger kilometres (PKM) is a better metric for measuring metro ridership because it provides a more accurate reflection of system usage and travel demand. Unlike passenger journeys, which count transfers as separate trips, PKM measures the total distance travelled by all passengers, offering a consistent and comparable indicator over time. This

Graph 25: Metro ridership data standardised, 2007–23



Source: CSE calculation

metric accounts for the actual utilization of the network, making it useful for evaluating service efficiency, capacity planning, and fare revenue assessment.

As per the latest information shared by DMRC, during FY 2023–24 (till October), the average PKM per day for the metro network was 540 lakhs. For the same period, the average passenger journeys made in metros per day was 62 lakhs. NIUA estimated the average trip length of metro trips to be 16.2 km in 2018 in Delhi.

Based on these figures, the average number of full trips made in the metro were 33.3 lakhs per day. This means that an average of 1.8 interchanges occurred during the period for DMRC to estimate 62 lakh passenger journeys per day. The passenger journey data can thus be used to demystify the metro ridership data in the Economic Survey of Delhi (see *Graph 25: Metro ridership data standardised, 2007–23*).

DMRC projected the ridership of its network in 2016 after completion of its first three phases to be 53.47 lakhs per day. However up until a year after 2017–18 the expectation had only been achieved by 47.45 per cent. In fact, this number still remains to be reached.

DMRC ridership needs to increase by 27.76 lakh trips per day (average) or 450 lakh passenger kilometres per day (average) to only meet the projections done in 2016.

MULTIMODAL INTEGRATION

The only way to maximise ridership of all mass commuting modes – including buses, metro rail and para-transit – multi-modal integration (MMI) is required for seamless and cost-effective transfer from one mode to another mode. Delhi has adopted city-level MMI policy and regulations. These have been developed by the Unified Traffic and Transportation Infrastructure (Planning & Engineering) Centre (UTTIPEC) under the Delhi Development Authority.

This is needed to not only improve access to transit modes and enable seamless changing between modes, but also to reduce the cost of interchanges for affordable journey. In fact, CSE estimates show that total journey cost increases substantially for public transport compared to private transport due to hidden cost of time taken and waiting/interchange, especially for buses in Delhi. For personal vehicles, costs include fuel cost and time taken. The comparative median value of cost of using cars is Rs 35/km in contrast to Rs 40/km for buses, and Rs 47.5/km for metro in Delhi.

MMI is implemented in the following three critical ways:

i) physical integration in which all drop off and pick-up facilities of all modes of transport are brought close through MMI design in which bus and para-transit stops get the highest priority and are brought closest to the metro stations in a well-designed manner (for instance, bus stops are within 50 metres). But private car parking get low priority and are placed after the public transport stops – a little away from the metro stations but within walkable distance.

ii) Information integration is achieved with the help of digitization in which passenger information systems for all modes are shared for ease of access.
iii) Institutional integration and fare integration of buses, Metro etc. is a way to reduce inter-change penalty by integrating the fare systems of all modes.

APPLICATION OF MULTI-MODAL INTEGRATION IN DELHI

- **Physical integration:** Delhi Metro Rail Corporation (DMRC) has prepared detailed MMI plans and begun execution in 40 stations in consultation with the traffic police, Transport Department and the Public Works Department, 2019. UTTIPEC has approved multi-modal integration plans for 40 metro stations of Phase-3 metro lines. DMRC is developing metro stations as per the MMI design to physically integrate all modes – para transit, buses, pedestrian access and car parking – for seamless transfer and easy access. Some of these stations include Chhattarpur and RK Ashram Metro. In about eight metro stations, feeder bus services have been integrated.
- DMRC has been allotted 136 e-autos by the Transport Department for last-mile connectivity. Electric auto rickshaw services have been integrated in three metro stations and for this purpose battery-swapping facilities are being set up. E-auto services from metro stations is being introduced on a pilot basis in Dwarka.
- **Information integration:** Information systems on inter change of modes and connecting infrastructure has begun. DMRC is providing voice information for metro passengers about feeder services and information standees are placed. However,

this needs to be further developed and expanded for all modes. Technological advancements have been possible through the One Delhi App. This integrates real-time information through mobile apps and digital platforms for various transport modes. This is designed for real-time tracking, estimated arrival times, and route planning for integrated journeys.

- **Institutional integration**: All transport intuitions are made stakeholders for MMI and for any developmental activities required. This requires the approval from Lieutenant Governor of Delhi through UTTIPEC. Further, Transport Department and DMRC complement each other for these initiatives.
- **Fare integration:** Common Mobility Card (CMC) and TUMMOOC have been implemented to enable seamless travel across metro and buses. The process is also underway to National Common Mobility Card (NCMC).
- **Delhi-NCR regional integration:** Emphasis on regional integration with neighbouring cities like Gurgaon, Noida and Ghaziabad.
- **Development of the Regional Rapid Transit System** (**RRTS**) for faster connectivity between NCR cities. Feeder services should be provided between Sahibabad RRTS Station to Sarai Kale Khan multimodal transit complex. NCRTC will provide space for halting of bus at station during operation, as per requirement. Sarai Kale Khan RRTS station will be a mega multi-modal transit hub of NCR, where all the three priority RRTS corridors will converge and integrate with the existing Delhi metro station, Nizamuddin Railway Station and ISBT.

Even though steps have been taken towards multi-modal integration, a lot more is needed to develop the requisite infrastructure and systems for city-wide implementation.

TRANSIT-ORIENTED DEVELOPMENT (TOD)

Yet another critical aspect of urban transport infrastructure is adoption of transit-oriented development (TOD) policy and principles to prevent lock-in of pollution in the transport infrastructure. Delhi has adopted state level TOD policy and made it a part of the Master Plan 2040 as well. This aligns with the national TOD policy. All the new development and redevelopment are expected to follow this policy to bring people and jobs closer to mass transit through a planned densification process through integration of land use and transport systems in the city.

Through an urban regeneration process, targeted areas close to transit areas are redeveloped or regenerated to develop as compact, walkable neighbourhoods with mixed-use developments to bring residential, commercial and retail components together to reduce distances between residence, jobs and recreation as well as support augmented use of public transport, walking and cycling. These are designed to reduce private vehicle dependency by curtailing and capping parking spaces (as provided for in the Delhi Master Plan 2040 along with public transport intensification plan).

Even though the first draft TOD Policy for the city of Delhi was released in 2012 (DDA, 2012) as an addendum to the Master Plan Delhi-2021, it was notified with many revisions in 2015 (DDA, 2015) and has been further refined in 2019 and 2021.

Delhi's first TOD project at Karkaduma Metro Station did not see much light of success due to poor implementation. However, a lot of learnings from it helped to formulate an enabling framework. DDA has identified five metro stations for TOD-style development which includes Mayur Vihar Extension, Dwarka Sector 18, Sarojini Nagar, Dwarka Sector 21 and INA market area. However, it is too early to assess their adequacy and the level of success. But it is noteworthy that these approaches have begun to take shape.

TOD can also unlock the latent economic potential and land values in the city. It will facilitate the development/regeneration of select nodes/areas in the city through planned intensification of uses and activities, infusion of new infrastructure and improvements in the public realm. This will also allow the city to capitalise on the large-scale investments being made in the public transit infrastructure including Metro Rail, Regional Rapid Transit System (RRTS), etc., by facilitating the improvement of old housing stock in addition to creation of new housing stock and economic centres around strategically located transit nodes and opening up opportunities for value capture. This has powerful potential to reduce automobile dependence and attendant pollution and congestion.

These are important steps forward that needs massive upscaling to improve public transport accessibility, public space regeneration, upgradation of walking and cycling infrastructure, vehicle restraint measures in compact neigbourhoods. But this has not received adequate attention for upscaled implementation through a planned redevelopment process.

SLUGGISH PROGRESS IN PEDESTRIAN INFRASTRUCTURE Walking and cycling can be the dominant zero-emission mass mode within shorter-distance ranges. Moreover, augmented use of public transport requires extensive safe walking access. As per the Economic Survey of Delhi 2023–24, Delhi has a total road network of 18,594 km. The majority of it is under the Municipal Corporation of Delhi or MCD (68.3 per cent), followed by Delhi State Industrial and Infrastructure Development Corporation or DSIIDC (13 per cent) and Public Works Department (7.4 per cent), among others. The summary of road audit mentions that PWD and MCD roads did not undergo the study.

According to the Road Safety Audit done by IIT Delhi in 2024 as per the instructions of the Supreme Court Committee on Road Safety, only 56 per cent roads in Delhi have a footpath, and only 26 per cent out of the existing ones meet IRC guidelines of width and height of footpaths.

It is evident that as per the level of service of pedestrian infrastructure defined by the Ministry of Housing and Urban Affairs (MoHUA) Delhi is in service category 2 level. This means "the City has pedestrian facilities which may need some improvements in terms of improvements in intersections, footpaths, and street lighting as some parts of the city are not served by it. The footpath available needs improvements."

Initiatives to improve pedestrian infrastructure: In 2021, Delhi government announced scheme to redevelop 540 km of road network with pedestrian facilities. The full scope of this plan has not been realised on the ground except a few stretches that include Chirag Delhi to Sheikh Sarai in South Delhi, which is almost 800 metres long;

some stretches of Outer Ring Road, Aurobindo Marg in South Delhi and in other parts of Delhi, have been redesigned with wide walkways and cycle lanes (see *Chirag Delhi–Sheikh Sarai stretch with redeveloped pedestrian facilities*).

The city authority has also taken several initiatives to improve the pedestrian infrastructure in the city. Some of the notable projects include pedestrianisation of Ajmal Khan Road from Karol Bagh Metro Station to Desh Bandhu Gupta Road, an almost 1 km stretch, and redevelopment of Shahjahanabad Area–Chandni Chowk area etc. In both the cases the busy commercial areas were redesigned with wide pedestrian walking ways, integrated utilities, public amenities and designated parking locations etc. (for transformation see *Before and after images of Chandni Chowk*).

Similar efforts were made to pedestrianise the busy 1-kilometre pedestrian stretch of the Ajmal Khan market in Karol Bagh in West Delhi. Car parking was removed from the area and the area was connected with remote parking area with e-rickshaw shuttles. Due to its close proximity to metro line it was possible to access this area by public transport and walk. The street was regenerated with pedestrian amenities, greenery and recreation spaces. However, lack of adequate support from the shopkeepers and administrative disdain this has started to degenerate (see *Box: Pedestrianisation: Undoing the gains*).

Lack of attention to pedestrian infrastructure and pedestrianisation to create hyperlocal low emissions zones is a big gap in the clean air action plan. The new action agenda has to implement a network of walking and cycling infrastructureand targeted pedestrianisation of key commercial areas to promote low-emission zones in the city, which can also incentivise use of public transport and clean vehicles in those targeted zones.

Before and after images of Chandni Chowk

Source: Urban Design Lab

Chirag Delhi–Sheikh Sarai stretch with redeveloped pedestrian facilities

Source: The Economic Times

PARKING MANAGEMENT AS A VEHICLE-RESTRAINT MEASURE

Mobility crisis cannot be addressed if growing usage of personal vehicles that contribute to congestion and pollution cannot be tamed. Towards this end, parking policy and management as a demand management measure are considered the first-generation restraint measures. This matter was taken on board by the Supreme Court for the first time in 2006 when all municipal bodies were directed to provide parking plans as a demand management measure. EPCA had conveyed that parking for personal vehicles cannot be considered public good and it should be provided based on user pay principal. This was consistent with the National Urban Transport Policy 2006. However, it was too early for the municipalities to develop a restraint policy when their focus was on supply side management.

Subsequently, the Lt Governor committee of 2014 and Master Plan of Delhi 2021 took on board Parking Management Districts approach for optimal use of scarce public land and parking management strategies on the "user pays" principle while meeting the needs of all road users.

In 2019, Delhi government notified the Delhi Maintenance and Management of Parking Rules, 2017 along with guidelines for the Parking Management Area Plan under Section 212 of the Motor Vehicle Act 1988. This is the first-ever legislative backing for parking management as a vehicle-restraint measure in the country. This mandates all urban local bodies, including land-owning agencies, to implement local area-specific integrated parking management area plans (PMAPs). This requires ward-wise identification and demarcation of legal on-street and off-street parking, penalty on illegal parking,

Pedestrianisation: Undoing the gains

Even after making investments and massive planning efforts to reclaim streets from cars and create pedestrian plaza and zero emissions streets, the initiatives are not sustained and made accountable. This is showing up in the much-acclaimed pedestrianisation of Ajmal Khan Road in West Delhi and the fissures that are beginning to appear in the pedestrian streets of Shahajanabad.

Ajmal Khan Road was Delhi's first big test of pedestrianisation. Launched in May 2019 as a 1.7-km open-air mall closing Karol Bagh's spine to private vehicles, it won awards and briefly showed cleaner air and quieter streets. Yet by 2025 the ban has largely collapsed – cars belonging to business now occupy half the pedestrian pathway, benches lie unused when SUVs surround them, and most bollards have been pushed aside. On Mondays – when formal stores shut and informal pathri stalls take over – the same space fills with walkers and stalls, proving that footfall returns the moment vehicles leave (see Comparison of an Ajmal Khan street on a regular day versus an off days when roadside stalls are open).

Traders who rely on curb-side parking blame the ban for revenue loss and have lobbied hard for its rollback, while the promised multi-storey car park is a scorching five to ten minutes' walk away and still incomplete. Police presence is token; maintenance is negligible; and without shaded walkways or shuttle links the design fails when Delhi's 45°C summer hits. In short, Ajmal Khan Road's hardware arrived long before a workable regime for parking management, heat comfort or stakeholder compensation.

Comparison of an Ajmal Khan street on a regular day versus an off day when roadside stalls are open

Shop-owner's vehicles block half of the passenger pathway.

Roadside stalls are arranged to facilitate shopper's movement.

prohibition on parking on footpaths, in green areas, near intersection, on emergency vehicle lane; variable parking pricing, sharing of parking facilities for optimised usage, integrated management of on-street and structured parking, proof of parking for transport vehicles among others.

Following this notification, the Supreme Court had directed implementation of three pilot schemes during 2019–20 as per the new rules in Lajpat Nagar III (South Delhi

Shahjahanabad's Red Fort–Fatehpuri corridor, popularly called the Chandni Chowk pedestrian zone, opened in September 2021 after the Public Works Department (PWD) spent roughly Rs 100 crore burying cables, laying granite promenades and installing boom barriers that should have kept cars out between 9 a.m. and 9 p.m. Initially the makeover won praise, but three years on the granite is cracked, litter piles up, and two-wheelers slip past unmanned barriers (see Status of implementation of makeover in Shahjahanabad).

The facility-management contract lapsed on September 7, 2024; since then PWD and the Municipal Corporation of Delhi have argued over who must sweep the street, while the Shahjahanabad Redevelopment Corporation (SRDC) pleads with Delhi Traffic Police for stricter control. Even the deployment of 75 home-guard volunteers in December 2024 has not stopped violations, prompting repeated High-Court admonitions.

Status of implementation of makeover in Shahjahanabad

Even though four-wheeler and larger vehicles are scarce, two-wheelers are both parked and on-road.

Most of the original design and infrastructure is still intact.

PHOTO CREDITS: KALYANI TEMBHE, CLEAN AIR AND SUSTAINABLE MOBILITY, CSE

Municipal Corporation); Kamla Nagar(North Delhi Municipal Corporation); and Krishna Nagar (East Delhi Municipal Corporation). Based on the successful implementation of these plans, the apex court had directed city-wide implementation in 2020.

In 2024, the Commission for Air Quality Management (CAQM) had further issued advisories to the need for urban local bodies to develop structured parking plans for implementation in Delhi and NCR. Further, the High Court of Delhi has also intervened in March 2025 to seek implementation of these plans. As of now, 14 PMAPs are available for public review on the Municipal Corporation of Delhi's website. Despite this progress, challenges remain. The PMAPs are yet to be implemented.

Parking measure as an emergency action: During winter, when pollution levels peak due to atmospheric conditions, the Graded Response Action Plans (GRAP) – temporary measures to prevent further loading of pollution when high pollution levels are already trapped due to calm conditions – are invoked, and parking prices are hiked as a temporary measure. But such an action cannot be effective in the absence of implementation of a Parking Management Area Plan (PMAP). Abundant unregulated and free parking available can undercut such measures.

While Delhi has yet to further strengthen its implementation strategy, the parking rules and the pilot schemes provide important lessons for other cities to develop parking policy as a vehicle-restraint measure.

REGULATION OF INTERMEDIATE PUBLIC TRANSIT SERVICES

Intermediate or informal public transport (IPT), or paratransit is a component of the transit system which provides mobility services to meet the demand gap between the private and the formal public transportation systems. In India, IPT largely refers to cabs, auto-rickshaws, and e-rickshaws.

In its 1998 order to convert all public transport in Delhi to CNG by 2001, the Supreme Court did not only include buses but also auto-rickshaws and taxis plying the city which were then running on diesel. Additionally, the number of auto-rickshaw permits specifically were frozen to the number of auto-rickshaws then plying in Delhi (which was 83,000, later dropping to 55,000 in 2011). The court order was issued to control pollution from auto-rickshaws, which at the time was estimated to be 80 per cent of all vehicular pollution in the state.

Later due to an appeal from the Transport Department, the cap on permits was extended to 100,000 in 2011. According to the department, the move was required to control incidences of overcharging and service denials since a fewer auto-rickshaw numbers and increased travel demand had led to a monopoly of few owners renting out vehicles.

As per the auto-rickshaw permit list published by the Transport Department, 74,151 permits have been taken up. However, sources have mentioned that 95,000 have been issued already. Regardless, in 2021, the Transport Department declared that 4,261 permits in the capital are up for grabs, out of which 1,406 will be reserved for women.

Interestingly, all of these ~4200 permits are reserved for electric autos and the department has stated that all the new or renewed permits should be issued for electric passenger three-wheelers only, and this will be like a lifetime permit as long as the vehicle is fit to ply on the roads of Delhi.

In the 2010s after the onset of cab-hailing services such as Uber and Ola (now augmented with more players such as Rapido, BluSmart, and so on), most taxis in the region were replaced by vehicles owned by these services. The draft motor vehicle aggregator scheme 2023 asks for phased targets of electrification from ride-hailing services for 100 per cent fleet electrification in four years. Companies and verticals such as EcoMobility, BluSmart, and Uber Green are deploying electric only fleet for passenger vehicles.

To fast-track transition to electric and newer technologies, the IPT segment will require strengthening in both fiscal and non-fiscal incentives, stronger industry participation for product development to support mandate for e-only registration, reliable charging ecosystem support, standardised charging rates and equipment, financing mechanisms, enabling a second-hand market for used vehicles, stringent oversight in the retrofitment market for quality control and assurance and strong process of certification and standard setting, and creating awareness to build public support for electric passenger and good carrier services.

Even though the charging stations are quite numerous, only a few areas have dense charging facilities. Other areas need adequate and equitable distribution of charging infrastructure. To cater to the requirements of this segment, which is hugely price sensitive, requires affordable electricity and also security for the vehicles; informal parking-cum-charging places have emerged in different parts of the city. These are informal setups in open but enclosed areas where e-rickshaws and e-autos pay for parking and charging and can park and charge during the night and day as needed.

However, the city requires a strong inter para-transit (IPT) deployment scheme to integrate public transport and strengthen last-mile connectivity.

WASTE AND CIRCULARITY

Construction and demolition waste – staying ahead

Delhi has taken significant steps to remediate construction and demolition (C&D) waste and provides an important learning curve for other cities. A detailed case study has been presented on this case in the sectoral overview of this report. However, the key elements of progress are highlighted here.

There are two critical elements of C&D waste management, i.e., i) good practices in construction activities to minimise generation of dust, and ii) Management of C&D waste to process and recover resources of value for recycling and reuse. Both the strategies need to be strengthened to promote clean construction practices.

Construction dust management: Dust generation during construction and its impact on local air quality can be enormous. The key sources of dust during construction include sand, grit, conveyor systems, truck movement, soil excavation, site clearance, material handling and storage, and mobile plant – bulldozer, crane, crushers, piling, building demolition, and concrete batching, among others. Each of these stages require dust-control strategies. The construction dust can also be highly toxic.

Delhi's battle with construction dust dates back to 2014 when the EPCA noted an order by the NGT dated 10.04.2015 in O.A. No. 95 of 2014. These directions were circulated vide an order dated November 26, 2014 and December 4, 2014, which included the steps to control construction dust. Non-compliance could lead to immediate stoppage of construction Delhi and NCR.

A Supreme Court order dated 16.12.2015 subsequently came with a checklist of measures as given by the Central Pollution Control Board to be taken to mitigate dust pollution. This firmed up norms for dust control from construction and related activities. Violation of these norms would result in heavy penalties.

In November 2016, following an emergency level of pollution in Delhi, EPCA also developed an accountability mechanism to identify the agency and actions that have been taken to check pollution from construction activities.

The essential features of dust control included transport of material that can be easily wind borne and need to be covered by a sheet; raising the barricade along the perimeter; wind breakers of appropriate height (one-third of the height of the building and maximum of 10 metres to be provided; mounting of dust barrier sheet on scaffolding around the site; inclusion of dust mitigation practices in their Environmental Management plan; paving or black topping of roads leading to or at construction site; excavation of soil with adequate dust mitigation measures; loose soil, sand, construction and demolition waste or any other construction material to be covered; water sprinkling to be adopted; and cutting and grinding of building materials in open area are not allowed.

The GRAP measures have further included dust-control measures at construction sites and also stoppage of all construction activities when the air quality index hit emergency levels. These measures sought for i) action taken by development authorities, and municipal corporations for the construction projects with area between 20,000 sq. metres to 150,000 sq meters; ii) action taken by SPCBs for the construction projects with area greater than 150,000 sq. metres not following the environmental clearance guidelines; iii) SPCBs to bring list of all construction projects in NCR having area greater than 150,000 sq. metres.

DPCC launched an anti-dust drive in 2021. As part of this, all projects involving construction or demolition with a plot area of 500 square metres or more must register on DPCC's designated web portal. These project proponents must carry out a dust self-assessment/audit fortnightly and upload that report on the web portal. While all project must install $PM_{2.5}$ and PM_{10} sensors at their site, these must be linked to a live dashboard on DPCC's portal to provide real-time air-quality data at and around those sites.

Subsequently in 2022 the CAQM policy sought monitoring of C&D sites and further refinement of the web portal for online monitoring of dust mitigation in C&D sites and registration of all projects for Construction and Demolition activities on the web portal in plot areas of >500sq. metres. It further defined dust-control measures and sought deployment of adequate numbers of anti-smog guns, water sprays, and wind fencing. It has also mandated registration of large projects on a web portal, use of water suppression and avoiding dust-generating activities on days with high wind speed.

The construction industry is hugely impacted by the GRAP measures during winter when construction activities are stopped during severely polluted days.

C&D WASTE MANAGEMENT

Catalysed legal enabler for use of C&D recycling waste in construction: The collection, processing and recycling of C&D started in Delhi in 2009–10 during the Commonwealth Games. Backed by surveys undertaken by MCD and IL&FS Environmental Infrastructure & Services Ltd. (IEISL) way back in 2004 and 2005, the first C&D recycling plant in India was established in Burari, Delhi, in 2009, with a processing capacity of 500 TPD. The 2010 Commonwealth Games became a significant catalyst for clearing the city's debris from the construction of infrastructure for the Commonwealth Games 2010.

During 2013–14, a roadblock was brought to light by a CSE investigation which found that IS: 383-1970, the Indian standard for concrete aggregates set by BIS, allowed only "naturally accessed material" for concrete production. EPCA took up this matter with BIS. Following this, BIS updated IS 383: *Coarse and Fine Aggregate for Concrete Specification*, officially acknowledging recycled C&D waste as a legitimate alternative to natural aggregates in concrete mixes. These developments helped to increase the demand for C&D waste recycled products within the market.

Mandating uptake of recycled material in new construction: Only processing of C&D waste to create value added goods without a strategy for their uptake cannot work. Therefore, the Department of Urban Development, GNCTD, made it mandatory for all municipal and local government bodies in Delhi, including the Public Works Department (PWD), Department of Irrigation and Flood Control, DSIIDC and Delhi Jal Board, to use recycled C&D waste products for construction and maintenance projects. This solved the problem faced by the plant for uptake of recycled products.

On January 14, 2020, the Delhi Pollution Control Committee (DPCC) issued directions under Section 5 of the Environment (Protection) Act, 1986 to various government departments and agencies, urging them to expedite and maximize the utilization of recycled materials from C&D waste processing facilities operating in Delhi. These steps aimed to ensure compliance with the targets set by the Ministry of Housing and Urban Affairs (MoHUA) for the use of recycled C&D materials. Subsequently, letters were issued by the Secretary (Environment) cum Chairman of DPCC to agencies such as NHAI, NBCC, CPWD, and DOA, emphasizing the need to increase the lifting and utilization of these recycled materials to achieve the mandated goals. Further directions followed on February 9, 2021, reinforcing these measures to drive progress.

Expansion of C&D collection capacity: One of the biggest challenges that recycling plants face nationally is inadequate feed stock due to poor waste collection and transportation. Delhi has made efforts to ensure extensive coverage through a widespread network of 132 collection points distributed across the city's three ULBs and 272 wards/

circles, providing easy access to waste-disposal facilities for residents, contractors and construction personnel.

The Municipal Corporation of Delhi (MCD), with 250 wards, has 106 designated collection centres with 61 more planned in the future. The New Delhi Municipal Council (NDMC), which oversees 14 circles, has 25 collection centres. The Delhi Cantonment Board (DCB) which has eight circles, has one designated collection centre. This ensures that nearly every two wards have a designated point for C&D waste, demonstrating a deliberate effort to ensure convenience and accessibility citywide. More collection points are being added regularly through the years. This has yielded positive results, with the MCD reporting a 38 per cent reduction in illegal dumping from October to November 2023. Delhi has utilized digital platforms to inform and engage its citizens. The city has used a mobile phone app and website to enable this. Both the platforms have the MCD helpline phone number that can be used to place C&D waste collection request.

Expansion of C&D waste processing capacity: Delhi has steadily expanded its waste-processing capacity by over 11 times from where it started initially – 500 TPD in 2009. There are five recycling plants in the city with a combined processing capacity of 5,150 TPD, which is the highest in the country.

However, the city's decentralisation aspect remains partially unfulfilled as it still does not have a permanent C&D recycling plant to cater to the southern part of the city. In 2024, the municipality floated a tender for a recycling facility to be set up on a 7-acre plot of land in Tehkhand, Okhla. The plant will cater to the south and central zones of Delhi, cutting down the travel distances of debris further within the city.

C&D waste management also got an extra boost under the Swachh Survekshan 2021, which improved the ranking methodology for cities. The ranking points for C&D waste management was doubled to 100 points, creating greater incentives for the cities. It also moved away from the blanket and singular requirement of recycling plants. It set criteria for management infrastructure. Cities need to have C&D waste collection system, notify charges for C&D services, and segregate waste in five streams. It also set waste processing efficiency criteria. The ranking points are to be awarded based on percentage of collected waste that is processed and reused. Non-structural applications of C&D waste don't require the specialized processing.

C&D WASTE MANAGEMENT: UNFINISHED AGENDA

Despite such massive expansion of C&D infrastructure unsegregated waste continues to remain a challenge in the city. Waste reaching C&D recycling plants is often not segregated and require extra inputs to process such as wet processing which is cost and resource intensive.

Quantify C&D waste: The city requires comprehensive assessment and quantification of C&D waste generation, utilization and disposal to plan adequate infrastructure and system for management. It needs to implement network of collection points and GPS enabled transportation system linked to recycling facilities. Integrating the informal sector may help to improve efficiency of the system and make the process more cost effective.

Incentivise segregation and uptake of recycled material: In the new agenda for the C&D waste management this needs to be taken forward to incentivise utilisation by increasing the target for use of recycled products. All government constructions may be mandated to use at least 20 per cent of recycled C&D waste products. All renovation projects involving demolition, even in private sector, may be mandated to use at least 20 per cent of recycled C&D waste products.

Address the cost of recycled product: At the city level, the tipping fee for delivery of C&D waste to the recycling plant, terms and conditions of civic body with the concessionaire may be designed to keep the price of C&D waste recycled products about 20 per cent lower than the corresponding conventional products. Moreover, at the Central government level, the GST on recycled products need to reduce. Currently, GST on C&D recycled products is 18 per cent as opposed to 5 per cent on virgin materials. This increases cost and impedes effective utilisation of recycled products. The tax burden on the value-added products of the recyclers need to be reduced.

Incentivise the construction industry: The bulk waste generators need to manage their own waste on-site through reuse and decentralised recycling. There is also a tremendous need to increase public awareness and build capacity on the waste stream and its management. This also needs preventive measures to reduce C&D waste generation: The management plan of the construction needs to adopt proactive prevention of waste through on-site construction management. The construction managers need to advance waste utilization plan on-site.

Regulate demolition of structures as well: Many cities including do not record demolition and therefore demolition permits are not usually issued to govern the process. Quick demolition without resource recovery to save time can be wasteful and polluting. This requires resource recovery standards and guidelines for demolition.

MUNICIPAL SOLID-WASTE AND OPEN BURNING – SLOW PROGRESS

Management of waste streams and addressing open burning of municipal solid waste have remained one of the critical gap areas in Delhi. Even though the Central government programme Swachh Bharat Mission 2.0 (SBM 2.0) is the primary driver of change, the real-world change on ground falls short of the target. The SBM 2.0 has set a target for a "garbage-free" India that include strategies remediation of legacy waste and establishment of infrastructure for municipal solid waste treatment, processing, recovery, and recycling. The mission aims to divert 80 per cent of waste from landfills by 2026. This requires massive efforts to collect 100 per cent waste from all households and processing to prevent their dumping. If open dumping in public spaces and also in landfills and dumpsites can be prevented the problem of waste burning can also be eliminated.

Against this backdrop, the Delhi government plans to target landfill sites with plans for eco-parks and enhanced waste-to-energy utilisation. This includes timely removal of the legacy waste from the existing landfill sites. It is estimated that about 11,342 TPD of MSW is generated daily and 7,542 tonnes are processed, i.e., about 66.5 per cent. The rest is dumped in landfills. The performance of different municipal bodies vary – the New Delhi Municipal Council (NDMC) has achieved 100 per cent segregation and Delhi Cantonment has also achieved about 90 per cent segregation. But the Municipal Corporation of Delhi (MCD) with the largest number of households within its jurisdiction falls woefully short at 56 per cent. There are still large areas of informal settlements that are not covered by the formal municipal services. As of 2024, about 41 per cent of the legacy waste has been remediated. Even though 50 per cent of MSW is biodegradable, the processing capacity is only 23 per cent.

The key strategy adopted for remediation of legacy waste in Delhi is incineration of waste to generate electricity. About four waste-to-energy plants have been set up. The critical challenge is that of mixed waste as feedstock with low calorific value that result in incomplete combustion and contribute to toxic emissions. Instead Delhi with such an extensive CNG network could have opted for bio CNG plants to feed the gas pipelines. That would have been a much cleaner strategy and that would have also earned enormous revenue.

Clearly, the infrastructure development or waste management and processing remains inadequate. The next generation action therefore needs to incentivise segregation of waste, eliminate tipping fee for mixed waste and linked it only with segregated waste, enforce user charges that are currently extremely meagre, and strengthen the compliance strategy for the bulk-waste generators in the city. Use of mixed feedstock in waste-to-energy plants need to be eliminated while opting for other processing methods to generate cleaner products like bio CNG.

USE OF SOLID FUELS IN HOUSEHOLDS – COMPLEX CHALLENGE

The dynamic forecasting of contribution of pollution sources in Delhi by IITM shows a substantial share of residential biomass burning. This is one of the most complex dilemmas of Delhi as energy poverty continues in the capital city.

Even though officially the LPG connections have expanded under Central government schemes, with near 100 per cent coverage, the annual LPG refills that are needed for sustained use are not fulfilled. The available information shows that there is shortfall in refill targets. Despite the subsidy, poor households cannot often afford LPG and fall back on mixed fuel use. Moreover, the informal sector as well as construction industry, which attract large numbers of migrants, have limited access to LPG connection. This will require more inventive fiscal strategy at the local level even though this is a national challenge requiring inventive solutions to enable affordable and sustained access to clean fuel for all, especially poor and very poor households. However, restrictions on firewood and coal in eateries under the approved fuel list have reduced solid fuel usage in the city.

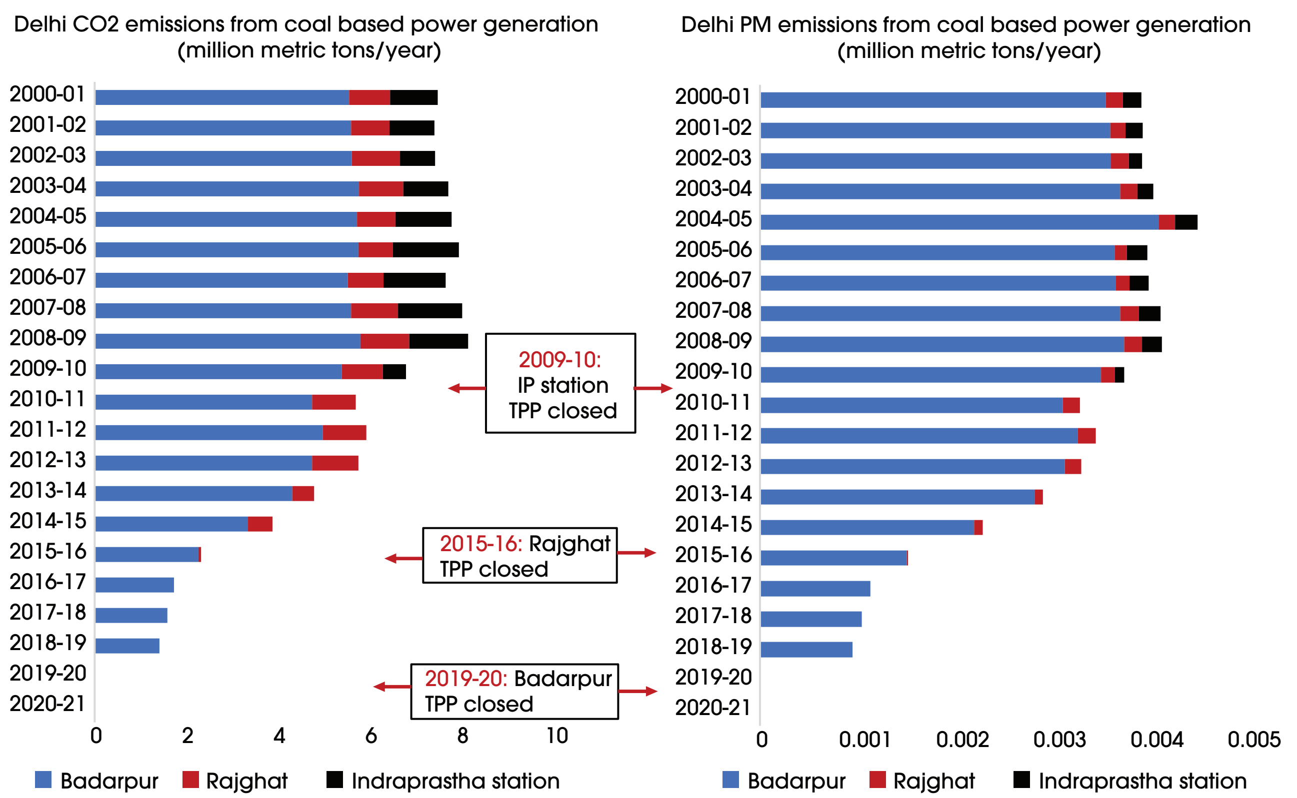
DELHI'S WIN – EMISSIONS CO-BENEFITS FROM TECHNOLOGY AND FUEL TRANSITION

While Delhi's air quality management is an ongoing agenda, it is important to take note of the air quality benefits from the long-term action. The multi-sector interventions have enabled co-control of toxic local air pollution and also greenhouse gas emissions, providing both public health and climate change mitigation benefits.

There has been substantial reduction in the PM and CO_2 load from industry and transport in the capital city due to interventions that have enabled energy transition in both industry and transport sectors. As noted earlier, these measures have led to banning of coal in industry and power sectors and reduction of diesel consumption in the transport sector. These have enabled co-control of both local air pollution and warming gases, providing substantial co-benefits.

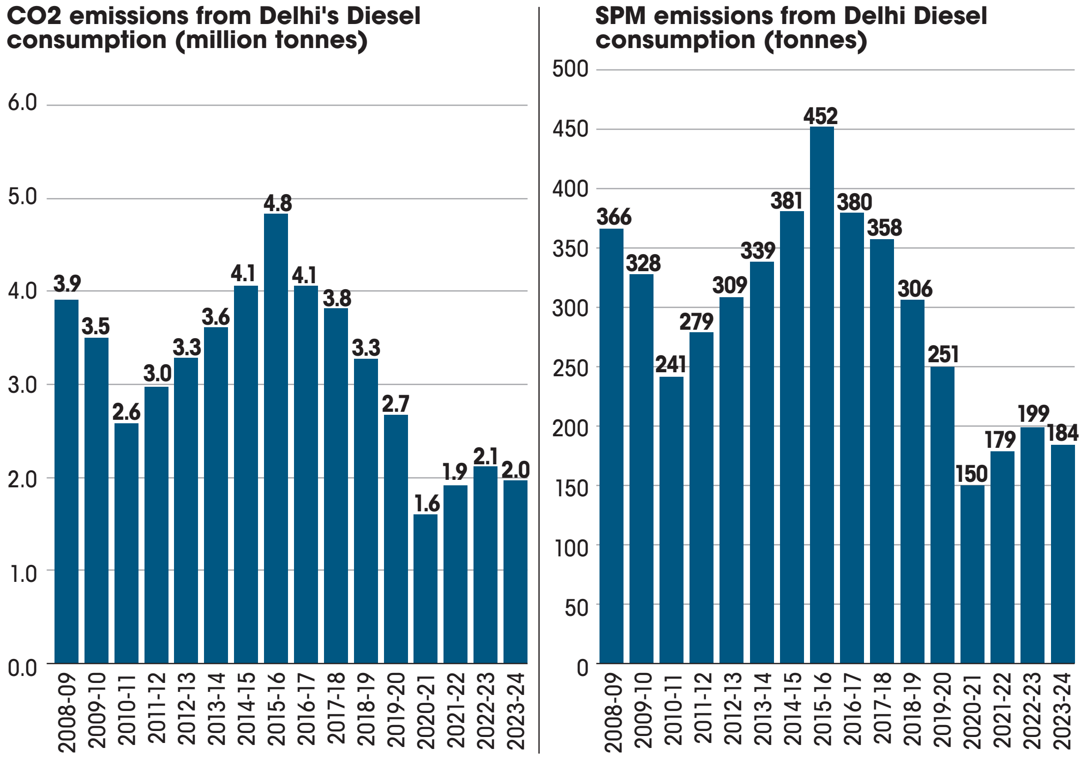
The minimisation of coal consumption in Delhi due to closure of the coal-based thermal power plants and ban on industrial coal, have reduced both particulate load and CO_2 load. With gradual and phased closure of coal power plants, it is possible to track the progress in emissions reduction in the city (see *Graph 26: CO2 and PM emissions from coal-based thermal power plants in Delhi)* It is important to note that the complete closure

Graph 26: CO_2 and PM emissions from coal-based thermal power plants in Delhi



Note: This assumes thermal power plants had air pollution control devices with at least 90 per cent efficiency.
Source: CSE analysis based on CEA data

Graph 27: CO_2 and PM emissions from diesel consumption in Delhi



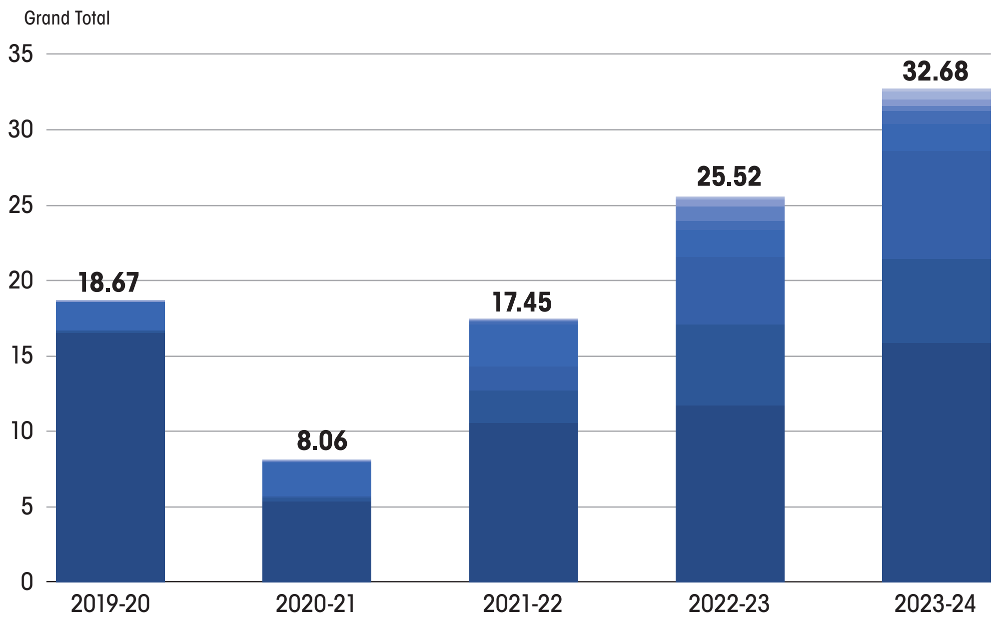
Source: CSE analysis based on PPAC data

of any given TPP is a gradual process wherein the most inefficient generating units are decommissioned first; which is evident how the emissions for all the three TPPs of Delhi decreased gradually.

Along with the decommissioning of coal-based power plants, coal was phased out of Delhi's industry sector too. In 2007–08, the relocation of metallurgical cokeries itself removed 1.5 million tonnes of CO_2 and 1,710 tonnes of PM annually. As discussed earlier, as per the data of the Central Electricity Authority (CEA), Delhi has reported near zero coal consumption since 2015–16, with only a few tonnes consumed in 2020–23. Coal has witnessed a significant decrease after the implementation of approved fuel list in 2018. Moreover, Delhi also saw a gradual decrease in diesel consumption after various policy measures disincentivised diesel consumption. The impact of these actions was mirrored in the corresponding decrease in the load of CO_2 and particulate pollution from diesel combustion (see *Graph 27: CO2 and PM emissions from diesel consumption in Delhi).*

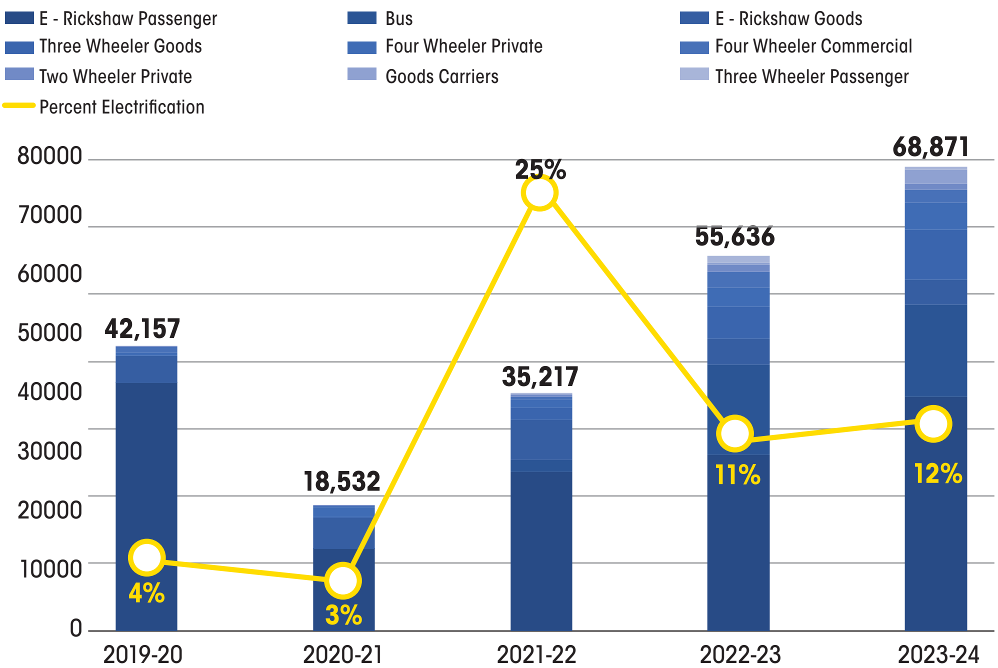
The impact of the technology and fuel transition in Delhi's transport sector is evident through the PM and CO_2 avoided over the years. In 2023–24 alone, Delhi's fleet avoided 32.68 metric tonnes of tailpipe PM and 68,871 metric tonnes of CO_2 due to electrification. It is important to note that Delhi's ICE fleet has already transitioned to BS VI and hence the PM and NO_X emissions from the new fleet has decreased significantly as compared to the corresponding BS IV and BS III fleet (see *Graph 28: PM avoided due to Delhi's transition to ZEV* and *Graph 29: CO2 avoided due to Delhi's transition to ZEV*).

Graph 28: PM avoided due to Delhi's transition to ZEV



Source: CSE analysi

Graph 29: CO_2 avoided due to Delhi's transition to ZEV



Source: CSE analysis

DELHI'S DILEMMA AND THE NEW AGENDA FOR ACTION

Delhi's multi-sector clean air action so far has been the most diverse, structural and systemic in nature in several cases, and relatively more comprehensive compared to most other cities in the country. Its legacy action has specifically targeted energy transition in the transport and industry sector that has been taken forward. This is showing up in the energy consumption trends in these sectors with potential emission reduction benefits.

While this has helped to bend the long-term pollution curve, the clean air target is still way off. Delhi still requires another 62 per cent reduction to meet the national ambient air quality standards for $PM_{2.5}$.

This presents a strong lesson for other cities regarding the scale and speed of change needed. The clean air action is still an unfinished agenda in Delhi.

The new agenda has to build scale and speed for the following action:

Address the gaps to address transport emission

- **The electric vehicle policy 2.0 under preparation needs to deliver on its proposed target of 95 per cent fleet electrification by 2030 for zero emissions transition:** Adopt vehicle segment-wise targets, mandate annual zero emissions vehicle sales, adopt state-level incentive programmes, strengthen charging infrastructure, adopt tax measures to disincentivise internal combustion engines, adopt enabling financing strategies, and implement battery recycling system. This must not be diluted by linking state incentives and priority measures with the intermediate internal combustion technologies and fuels. The state incentives and priority need to be linked with fully battery operated electric vehicles.

- **Advance on-road emissions monitoring by introducing remote sensing monitoring for effective screening and identification of worst emitters.** Connect vehicle inspection with the automated testing centres for identification of end -of-life vehicles.

- **Strengthen the electric bus programme and significantly improve service level of bus service city-wide:** Make DTC and DIMTS liable for targeted improvement in bus ridership that is monitorable and verifiable. Only monitoring number of kilometres per bus per day will not help. Advance bus infrastructure and ITS system to upgrade passenger information system ensure reliable services especially during peak hours, and improve safe access.

- **Upscale multi-modal integration for city-wide implementation:** Integrate metro and bus service with advanced last-mile connectivity (feeders and para-transit) for seamless journeys. Ensure physical integration of all metro stations, information integration for improved passenger information and service for all modes, and fare integration to reduce interchange penalty and journey costs and make public transport affordable for all.

- **Mandatory implementation of ward-wise parking management areas plans to manage and reduce demand for parking and promote low emission zones:** Implement ward-wise PMAPs to identify and demarcate legal parking areas, penalise illegal parking, prohibit parking on footpaths, green areas, on emergency vehicle lanes, near intersections etc. Implement variable parking and eliminate free parking city-wide. Implement proof of parking policy linked to PMAPs. Promote shared usage of parking facilities to optimise use. Simultaneously, implement low emissions zones in targeted areas to encourage use of clean and zero-emission vehicles and intensify public transport services. Mandate sustained upkeep and maintenance of the pedestrian zones and infrastructure and not let the systems degenerate. Hold implementing agencies accountable.

- **Implement transit-oriented development policy in all redevelopment and new development areas:** Redevelop and regenerate influence zones around the key metro stations and transit lines to get more people to live closer to the transit lines, regenerate the area to make it more walkable and cyclable with improved infrastructure, make metro stations and commercial nodes more accessible, change the urban and road design to make it people friendly and more transit oriented in compact neighbourhoods.

- **Develop financial plan for implementation** of the requisite public transport infrastructure to upgrade service level to make the systems more financially sustainable.

Addressing gaps in industrial pollution control

- Strengthen piped natural gas network adequately to ensure 100 per cent coverage of all industrial units. Promote electrification of industrial process as applicable.

- Adopt a natural gas pricing strategy to keep the cost of natural gas affordable on a longer term basis.

- Bring industrial units in peripheral and non-conforming areas within monitoring system and mandate display of consent to operate certificate from Delhi Pollution Control Committee: This can help to enable implementation of clean fuels and emissions control approaches all across.

- Inventorise all industrial units across all land-uses.

- Implement industrial non-hazardous waste management plan to prevent open dumping and burning of industrial waste.

- Strengthen smart monitoring of industries

Waste management and circularity – upscale action

Municipal solid waste

- Enforce the mandate to meet the target of 80 per cent diversion of MSW from landfills and dumpsites by expanding capacity of waste processing for material recovery
- Mandate 100 per cent collection of segregated MSW from all households including informal areas. Integrate informal waste collectors with the formal system through cooperative models or any other innovative model.
- Expand processing capacity of wet and dry waste.
- Stringent implementation of the obligation of the bulk waste generators for collection, segregation, transport and in-situ processing of waste.
- Tipping fee should be linked with segregated waste collection and not collection of mixed waste.
- Expand collection of user fee to mobilise resources for waste infrastructure development.
- Quantify and characterise real-time waste generation in each ward and make **the** data trackable online.
- Prioritise circular economy with compressed biogas generation from municipal **solid** waste to inject the CNG pipeline instead of waste to energy plants. Ensure use of 100 per cent segregated waste as feedstock in the existing plants with stringent emission control system.

Construction and demolition waste – further strengthen the system

- **Maximise capacity utilisation of all C&D processing plants.** This requires stronger collection system, segregation, GPS enabled tracking of C&D waste transport, and stringent enforcement for bulk waste generators to transport waste to the plants or designated collection modes.
- **Mandate at least 20 per cent of the material in new construction to be recycles material in both government and private construction.** Issue certificates as proof of usage of recycled material.
- **Rationalise collection points to reduce distances for waste collection and transportation.**
- **Mandate waste management plans for approval of building projects.**
- **Incentivise industry to segregate and reuse waste.**
- **Issue demolition permits.**

- **Quantify and characterise C&D waste.**

- **Stringent regulations will be imposed on construction sites to enforce strict compliance with pollution control measures.**

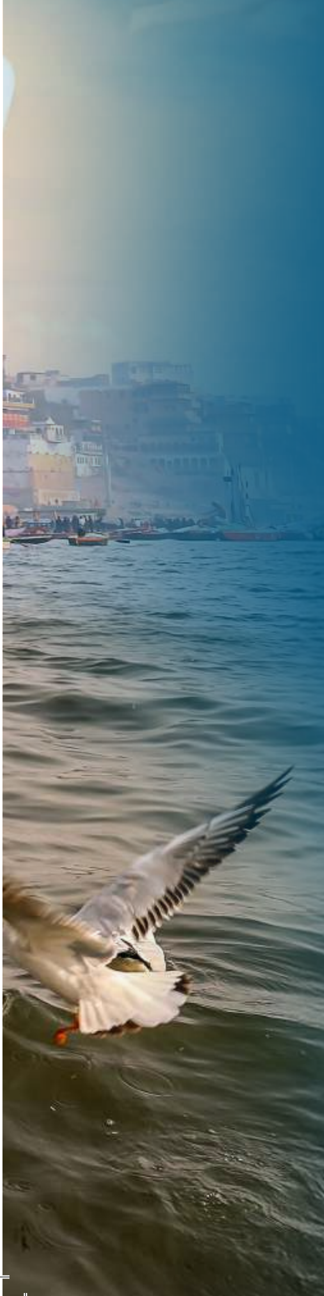
Eliminate use of solid fuels in households

- **Implement financing systems to upscale and ensure sustained use of affordable LPG in households**: Government policies have helped to upscale use of clean household energy like LPG in the city. But its use is not consistent in a large number of households as evident in the lower rate of annual refills. The night shelters and rental housing for the migrants can be equipped with LPG connected kitchens.

- **Implement financing systems to upscale and ensure sustained use of affordable LPG in households**: Government policies have helped to upscale use of clean household energy like LPG in the city. But its use is not consistent in a large number of households as evident in the lower rate of annual refills.

Strengthen regional airshed-level air-quality management

- While Delhi needs to upscale its multi-sector strategy to address the remaining gap areas, this needs to be co-joined with larger regional-level implementation of priority strategies in the NCR region and beyond to reduce the influence of transboundary movement of pollution on local air quality.



VARANASI

LEVERAGING URBAN RENEWAL FOR CLEAN AIR

As it has done in several other non-attainment cities, the National Clean Air Programme (NCAP) has played a catalytic role in seeding the comprehensive air quality management programme in Varanasi.

This has led to the expansion of air quality monitoring network and emissions source assessment, aiding in the development of clean air action plan to initiate multi-sector action.

Yet, the notable aspect of the Varanasi experience is the convergence of the NCAP initiative with the urban redevelopment and renewal programme targeting the core city area and the river bank re-development that has drastically reduced air pollution and dust levels.

In a city where the contribution of dust to particulate pollution is close to 84 per cent, only a system and urban infrastructure-based development project can control this problem.

This is also a lesson for other cities that are battling dust pollution by resorting largely to mechanical sweeping, water sprinkling and road repair.

But dust control is a much bigger agenda—as Varanasi has demonstrated—requiring an eco-system approach through urban redevelopment and greening agenda while combining other multi-sector action.

INTRODUCTION

Varanasi, located in the eastern region of Uttar Pradesh, has drawn a lot of attention for consistently scoring high for improving air quality under the performance-linked 15th Finance Commission funding and ranking high for taking sectoral action in the Swachh Vayu Survekshan ranking, since the launch of National Clean Air Programme (NCAP).

Under the NCAP programme, Varanasi has reported 68 per cent reduction in PM10 level in FY 2023–24 as compared to FY 2017–18. Under the Swachh Vayu Survekshan ranking, Varanasi was ranked third under the Category 1 cities in 2022 and achieved an award of Rs 0.5 crore. Subsequently, it remained within the top 12 cities in 2023.

Varanasi has been selected as a case study primarily because this city has demonstrated how urban redevelopment and urban renewal process can be leveraged to contribute towards air quality improvement, while the NCAP formalized the composite city-based air quality management programme to initiate multi-sector action.

The beginning of the NCAP programme had coincided with the redevelopment of core city area around the temple zone and the river bank. This led to the restoration and redesign of the river bank, rebuilding of core area around the temple zone, regeneration of the public spaces, reorganization of the informal and formal activities, redevelopment of roads, improvement in ghat infrastructure and public amenities at a scale.

Moreover, NCAP interventions also coincided with the convergence programmes in other sectors including Swachh Bharat Mission 2.0, along with Swachh Survekshan ranking, Smart City programme for smart infrastructure development and FAME II incentives for electric vehicles. These programmes have further leveraged private sector investments in infrastructure development. This alignment has catalysed infrastructure development for processing and recycling of construction and demolition waste (C&D) and municipal solid waste, expanded the electric vehicle fleet for zero emissions transition, expanded public transport systems, among others.

The significance of this convergence action is evident from the fact that between FY 2019–20 and 2024–25 (as of 16 May 2025), Varanasi received Rs 362.21 crore, out of which it has spent Rs 181.37 crore—about half or 50.7 per cent has been utilized. In addition to the specific action funded under this programme, a range of other measures that have become scalable were supported by the sectoral schemes and funding.

There is an emerging lesson from Varanasi for the rest of the cities. Varanasi's experience demonstrates that dust management—which is a concern in many cities, especially in North India—requires infrastructure-level action. The influence of dust on air quality can be sustainably reduced only with urban renewal programmes and infrastructure redevelopment. This is an important learning for a large number of cities that are tying up enormous amount of NCAP funds with the minimalist approach of mechanical road sweeping, water sprinkling, pothole fixing, etc. as their primary approach.

Varanasi has successfully demonstrated that dust management is linked with the larger urban infrastructure development, regeneration of urban spaces, augmentation of urban greens, and redevelopment of roads that ensure proper paving and development of footpaths and road shoulders. It cannot be reduced to only enforcement measures and cosmetic sweeping that most other NCAP cities have tried to do. Varanasi has strategically connected pollution control efforts with the urban redevelopment agenda.

This role of urban renewal in controlling dust emissions is logical from the perspective that the emissions inventory study that was carried out by the Indian Institute of Technology (IIT) Kanpur,[1] found that road dust contributes as much as 84 per cent to PM10 and 60 per cent to PM2.5 levels. This highlights the large impacts of revelopment projects on overall dust emissions.

From the perspective of convergence, it may also be noted that the Rs 3,880-crore development projects, that were launched recently by Prime Minister Narendra Modi in Varanasi, will include infrastructure development, among others. Therefore, the framework of interlinking clean air indicators with priority infrastructure development projects can be further strengthened to deliver on clean air objectives. This can be guided by the key policy principles to enable upscaled energy transition in industry, transport, and households; mobility transition and upscaled circular economy.

The NCAP interventions have also catalysed science-based air quality management in the city by expanding air quality monitoring network, enabling pollution source assessment, and catalysing action in different sectors. The city has transitioned from ad hoc approaches to air quality management to formalized and science-based air quality management systems.

The first phase of the NCAP has laid down the foundation for clean air action in the city. This can be taken forward to upscale multi-sector interventions and also address combustion sources including vehicles, industries, waste burning and household air pollution.

EXPANSION OF AIR QUALITY MONITORING NETWORK

At the time of the launch of the NCAP programme, Varanasi had only one air quality monitoring station in Ardali Bazar. Post 2021, the network was expanded to include three more stations. They are located in Maldahiya, Bhelupur, and the Institute of Environment & Sustainable Development in Banaras Hindu University (IESD BHU).

Currently, the four monitoring stations are concentrated mainly in the southern part of the city. Nearly half of 78-km^2 area of the Varanasi Nagar Nigam is within the direct orbit of these monitoring stations. About 70 per cent of the municipal area is built up. As per the population criteria of deciding the number of monitoring locations in a city, or according to the *Indian Standard IS 5182: Part 14–Methods for Measurement of Air Pollution* (2000, reaffirmed in 2019), a minimum of 10, or six additional air quality monitoring stations are required in this city. Future expansion plans can, therefore, include northern and western regions of the city (see *Map 1: Initial stage of expansion of air quality monitoring stations in Varanasi*).

According to the Portal for Regulation of Air Pollution in Non-Attainment Cities (PRANA) portal, one more Continuous Ambient Air Quality Monitoring Station (CAAQMS) has been proposed by the Central Pollution Control Board (CPCB) under the CPSU CSR scheme—for which the timeline will be provided by CPCB. The Uttar Pradesh Pollution Control Board (UPPCB) has also set up five manual air quality monitoring stations, along with one CAAQMS. Furthermore, 30 air pollution hotspots have been identified across the city to enable focused monitoring and targeted interventions for air quality improvement.

It has been further reported on the PRANA portal that the Nagar Nigam has installed 15 sensor-based air quality monitoring devices at various locations throughout the city, including public parks, as part of the Smart City initiative. However, there is no information regarding usability of this data and quality control of the data.

LONG-TERM AIR QUALITY TREND IS DOWNWARD

Expansion of air quality monitoring network has improved data availability, especially that of PM2.5 data, enabling better air quality trend assessment.

Trend in PM2.5 levels: More recent year-on-year air quality trends since 2017, (when only one monitoring station was set up in the city) and the trend since 2022, (when all four air quality monitoring stations were set up), reveal that the average annual PM2.5 levels (based on the oldest station) show a 80 per cent improvement since 2017 overall.

Since 2022, when all the stations were taken into account, the city recorded a 63 per cent reduction in its PM2.5 levels *(see Graph 1: Long-term trends in PM2.5 annual average since 2017)*.

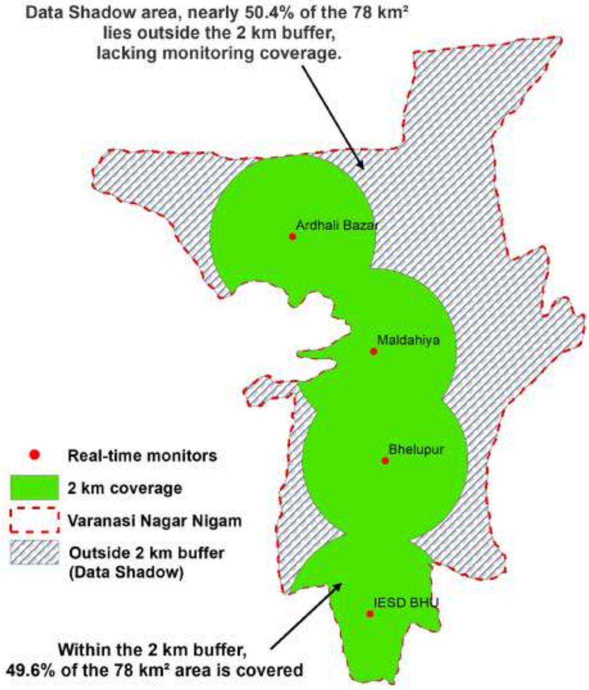
Long-term trends in PM10 levels: Between 2017–18 and 2021–22, PM10 levels in the city dropped by an impressive 50 per cent, from 230 µg/m3 to 114 µg/m^3 *(see Graph 2: Long-term trends in PM10 annual average)*.

Building on this progress, Varanasi has further reduced PM10 levels by 59 per cent, reaching 73.5 µg/m^3 in 2023–24 from the base value of 180 µg/m^3, showcasing significant improvements in air quality.

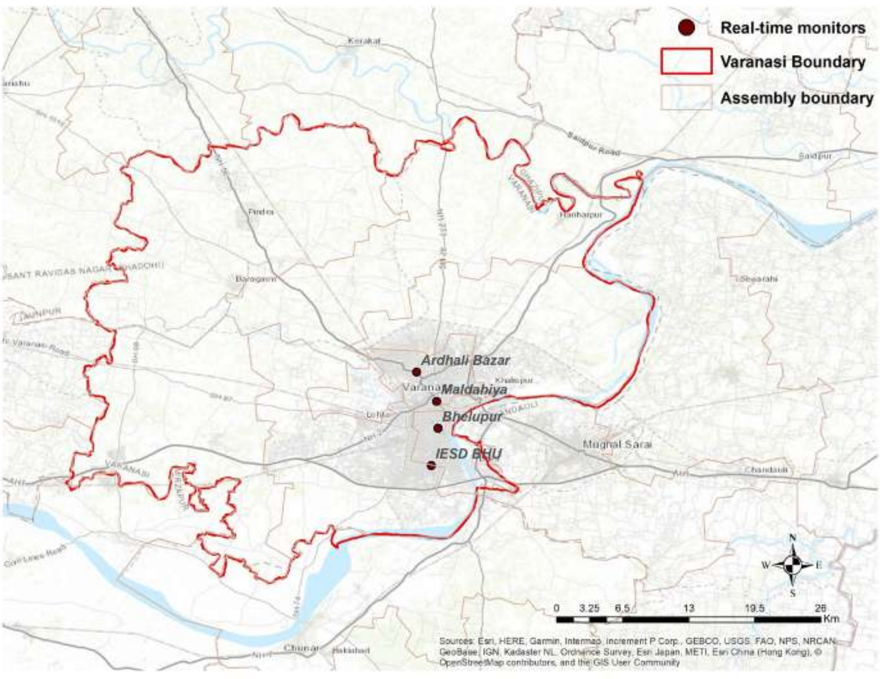
Additionally, CPCB data indicates that overall, the city's air quality has seen a remarkable improvement of 62 per cent, with city-wide PM10 levels dropping from 134 µg/m^3 in 2021 to just 51 µg/m^3 in 2024 (*see Graph 3: Long-term trends in PM10 annual average (location-wise*).

Map 1: Initial stage of expansion of air quality monitoring stations in Varanasi

The real-time monitoring station in Varanasi currently covers the 49.6% of the total km^2 area of Varanasi Nagar Nigam under 2 km buffer zone, leaving the remaining 50% of the area outside the direct coverage of the monitors.

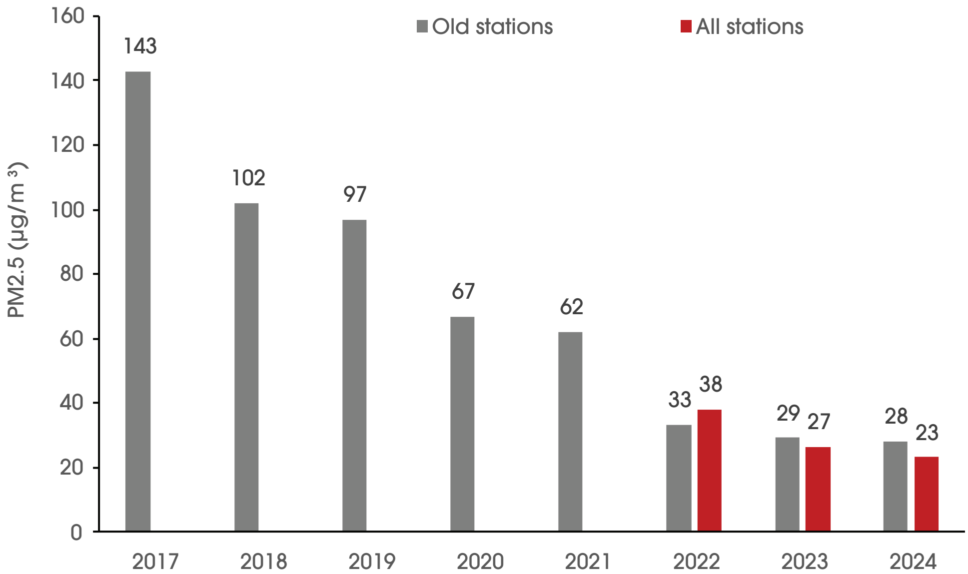


Spread of monitoring stations



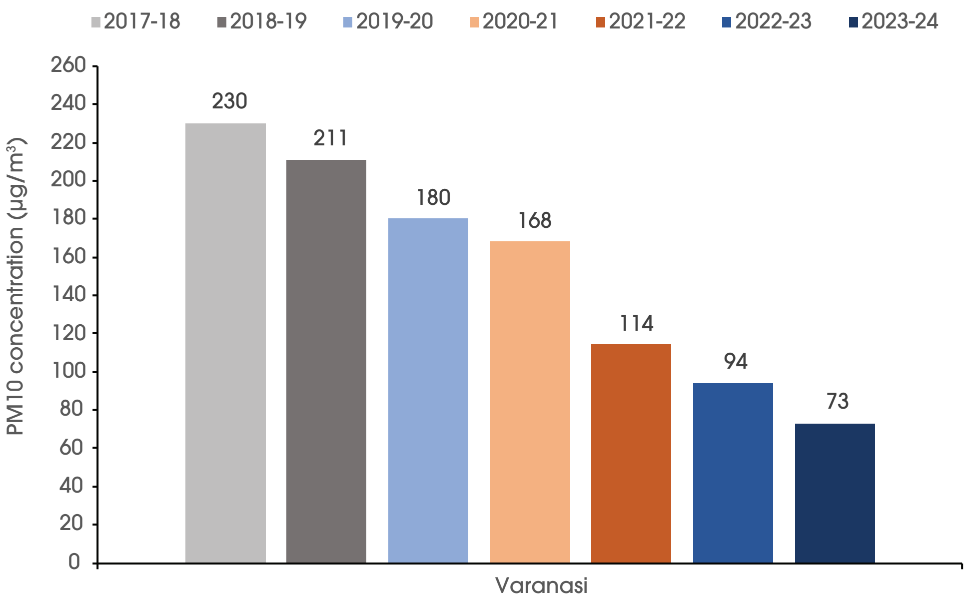
Source: CSE's analysis based on the Central Pollution Control Board database

Graph 1: Long-term trends in PM2.5 annual average since 2017



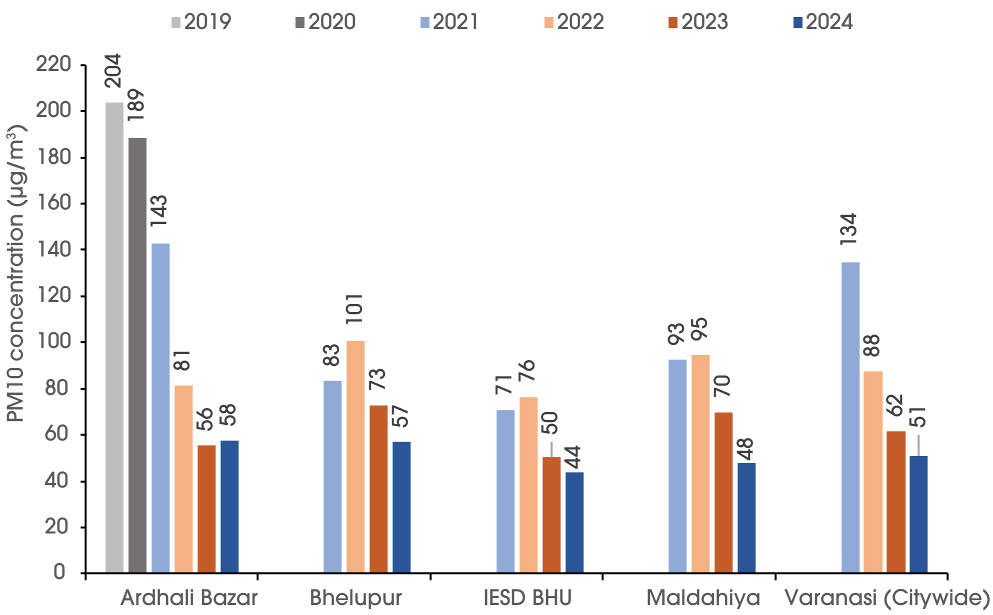
Note: Average PM2.5 concentration is based on the mean of daily values recorded at the four CAAQM stations as it has adequate data since 2022. The oldest station is Ardali Bazar.
Source: CSE analysis of CPCB real-time data

Graph 2: Long-term trends in PM10 annual average



Source: CSE's analysis of data from PRANA portal

Graph 3: Long-term trends in PM10 levels (location-wise annual average)



Source: CSE's analysis of CPCB real-time data

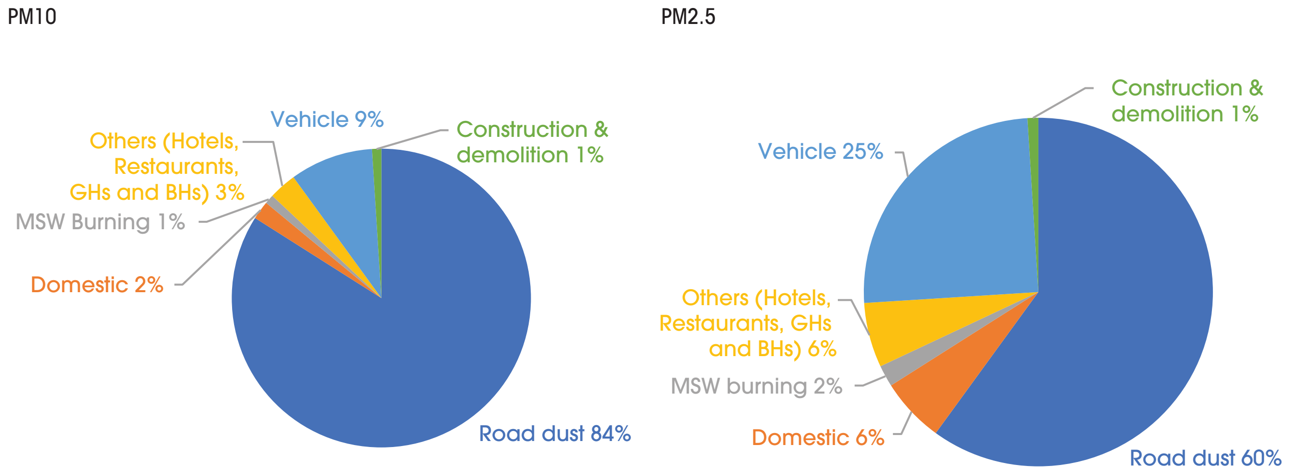
UNDERSTANDING POLLUTION SOURCES

Dedicated funding under NCAP has enabled source apportionment and emission inventory studies in 2020 that have helped to profile the nature and contribution of pollution sources in Varanasi.

A source inventory and source apportionment study was carried out by the Indian Institute of Technology (IIT) Kanpur.[1] The emission inventory study found road dust to be the top contributor to the PM10 load or coarser dust followed by vehicles, with a relative contribution of 84 per cent and 9 per cent, respectively. While for PM2.5, the share of road dust reduces to 60 per cent followed by vehicles with 25 per cent contribution (see *Graph 4: Emission Inventory of PM10 and PM2.5*). Industry has not showed up as a contributor. Other sources include use of solid fuels in households and eateries, waste streams of municipal solid waste, and construction and demolition (C&D) waste.

There is also a strong seasonality in the pollution source profile. While the influence of soil and road dust is very high on PM10 load during summer months at 51 per cent, it can reduce drastically to 17.9 per cent during winters. However, the share of combustion sources increases substantially during winter months. The share of biomass burning can increase from 12.5 per cent in summers to 27.5 per cent in winters. The share of vehicles can increase from 9.4 per cent in summers to 12.2 per cent in winters.

Graph 4: Emissions Inventory of PM10 and PM2.5 (IIT Kanpur)



Source: IIT Kanpur and UPPCB, 2024

Table 1: Percentage contribution of pollution sources to PM2.5 and PM10 concentration in Varanasi

	Summer		Winter	
	PM2.5	PM10	PM2.5	PM10
	IITK 2020 (in %)	IITK 2020 (in %)	IITK 2020–21 (in %)	IITK 2020–21 (in %)
Biomass burning	28.3	12.5	29.9	27.5
Vehicles	17.7	9.4	14.3	12.2
Industrial	1.1	0.5	1.2	1.3
Coal + Fly ash	12.6	20.3	15.6	18.9
Secondary inorganic aerosols (SIA)	7	3.3	19.9	18.5
Construction material	3	2.1	0.7	1.9
Soil + road dust	29.2	51.2	17.6	17.9
MSW burning	1.1	0.6	0.7	1.9

Source: IIT Kanpur and UPPCB 2024, PM2.5 and PM10 Source apportionment study.

It may also be noted that secondary inorganic aerosols (SIA) is an important contributor during winters. High and consistent contributions of secondary aerosols suggest the high emissions of precursor gases from different sectors, i.e., combustion sources, industries, brick kilns, biomass, MSW burning, domestic at far distances at regional level from the receptor sites (*see Table 1: Percentage contribution of pollution sources to PM2.5 and PM10 concentration in Varanasi*). Going forward, these sectors will require strict attention.

In summers, factors such as soil and road dust, vehicles and biomass burning activities contribute 75 per cent to PM2.5 load. However, during winters, the contributions of coal and fly ash, soil and road dust, and construction material reduce significantly in PM2.5 by 62 per cent, when winds are low and prevalent atmospheric conditions are calm.

The high contribution of soil and dust (in PM10 and PM2.5), biomass burning, coal and fly ash, and vehicles at most of the sites, envelop the entire region with PM pollution.

SCOPE AND SCALE OF MULTI-SECTOR INTERVENTIONS

Redevelopment of river bank and roads

Varanasi has strategically connected the redevelopment of the river bank and core area with pollution control. This has enabled convergence funding and better leveraging of the redevelopment projects to deliver on the clean air objectives—especially in dust control that contributes 84 per cent to the PM10 load and 60 per cent to the PM2.5 load. Road dust is a mix of fine particles that accumulate on roads due to vehicle movement, tire and brake wear, construction activities, and wind-blown soil. It is mainly generated through mechanical processes, such as friction, re-suspension, and atmospheric deposition rather than direct combustion. However, the dust can turn toxic with coating of combustion emissions from vehicle exhaust, waste burning, industrial emissions, and other urban activities. To address this, the city has implemented several strategies.

A massive road redevelopment plan and a regeneration of the ghat areas along the banks of river Ganges have contributed substantially to road dust reduction. The riverfront development in Varanasi spanned over a 6.8-km stretch (from the confluence of Asi drain in the south to the Varuna river in the north) along the Ganga river that included environmental improvements, social infrastructure development to improve the quality of life and revitalize the area. This led to cleaning up of the riverfront, rehabilitation and resettlement of riverbed dwellers, the creation of parks and public spaces, and other amenities.

Between 2020 and 2023, the municipal authorities focused on road redevelopment, repairs and maintenance of roads. Nearly all of the city's 270 km of roads have been made pothole-free. Additionally, about 12 km, out of 13 km of road shoulders (over 95 per cent), have been repaired. Roads have been blacktopped and paved. Comprehensive end-to-end pavement work has also been carried out that has benefitted other road users.

This has been combined with enforcement measures such as regular street sweeping and water sprinkling and these regulations have been implemented on 1,280 km of roads, covering 97 per cent of the total road length. Additionally, water fountains have been developed in key locations to further reduce airborne dust.

The major road development projects include Kashi Vishwanath Corridor Redevelopment and Varanasi Ring Road project. The Kashi Vishwanath Corridor Redevelopment project happened during 2019–2021, and has significantly improved accessibility and footfalls while drastically reducing dust generation. This includes end-to-end paving, landscaping, and enhanced waste management systems. The scale of the project expanded from the earlier 3,000 square feet (sq ft) to a massive 5 lakh sq ft.[2]


End-to-end road pavement at Hiramanpur, Varanasi


Ring road construction at Sarnath, Varanasi

Similarly, the construction of the Varanasi Ring Road has significantly eased traffic congestion and reduced emissions from idling vehicles by providing an alternative route for transit traffic.

Expanding green infrastructure–greenbelt development: The clean air plan also paid attention to urban greening and dust barriers. About 4.5 km of roadside and divider areas have been developed as greenbelts. This effectively covers a great part of the planned area. Additionally, vertical gardens have been developed at key locations, including Duda Office, Chauka Ghat underbridge, Nadesar, Varunapar Zone, Acharya Ram Chandra Shukla Chauraha, Lahurabir Chauraha, Padam Shree, and Nagar Nigam Head Office.


Landscape beautification at Namo Ghat

These green installations are expected to mitigate road dust emissions but also reduce heat impacts and enhance aesthetics.

According to the PRANA portal, about 218,936 trees have been planted in recent years. It has progressively advanced from 81,843 plantations in 2020–21, to 69,600 plantations in 2021–22, and 67,493 plantations in 2022–23. To protect the saplings, 6,300 iron tree guards have been installed across the city.

To further afforestation efforts, the Miyawaki forest system has been implemented (between 2021-22 and 2023-24) at three key sites: Central Jail, Beniyabhag Park Smart City, and BHU Kamachha. About 1.70-hectare plantation was developed using the Miyawaki technique, which consists of about 171,000 plants. Additionally, a total of 12,818 iron tree guards were installed to support urban afforestation and to protect newly-planted trees. Vertical gardens and urban landscape projects have been implemented as well.

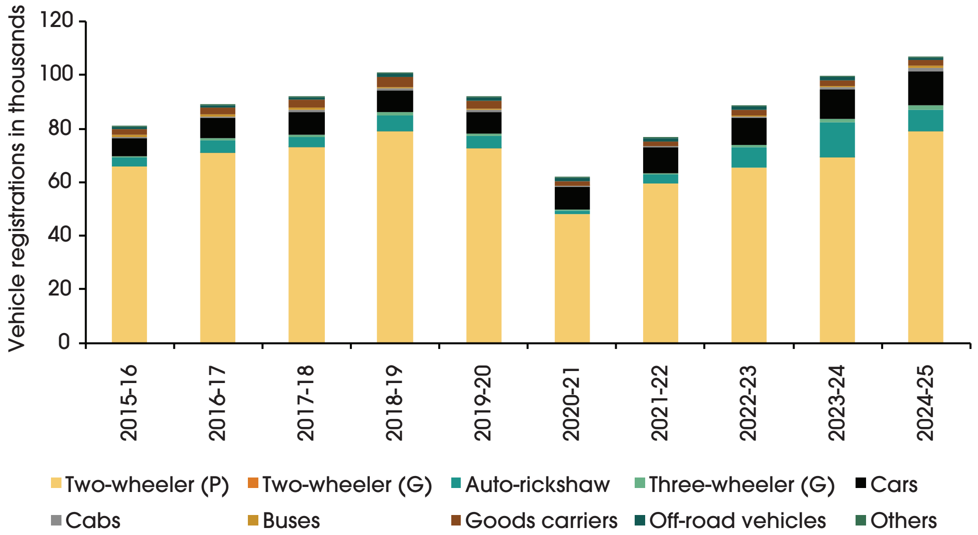
Silt management along the Ganga: The interventions have also addressed the unique aspects of the local problem, which is the impact of river silt.

Large-scale silt removal operations have been conducted along the ghats to prevent dry dust from becoming airborne. Landscaping efforts at Namo Ghat and other public spaces have also enhanced environmental aesthetics. Silt management along the Ganga river has become a priority and is a major annual exercise for the Varanasi Nagar Nigam (VNN). This process helps to remove thick layers of silt from the ghats and the resultant dust pollution.

CURBING VEHICULAR EMISSIONS

The NCAP interventions have also catalysed interventions in other sectors including transport which is among the top two polluters in the city. Vehicular emissions are the second-largest contributor after road dust. Vehicles release significant amounts of fine particulate matter and pollutants, which not only degrade air quality but also contribute to high exposures.

Graph 5: Trend of segment-wise total vehicle registrations in Varanasi, 2015–2025



Source: Vahan Dashboard

Motorization in Varanasi has steadily intensified over the last decade, primarily driven by the rise in personal transport modes (see *Graph 5: Trend of segment-wise total vehicle registrations in Varanasi, 2015–2025*). Two-wheelers remain the dominant category, consistently contributing the highest number of new registrations each year. Despite the dip in vehicular usage during the COVID-19 pandemic, the overall upward trend has resumed. Cars also show a consistent increase.

Meanwhile, the entry of cabs and a marginal rise in three-wheelers indicate changing commuting needs and a shift toward shared mobility. Auto-rickshaw registrations have increased multiple times since 2020–21, suggesting a higher demand for intermediate public transport. Buses and goods carriers, however, have not seen proportionate growth.

Several initiatives to curb vehicular pollution have been augmented under the NCAP that has enabled substantial improvement over the baseline action pre-2019.

Emissions monitoring of on-road vehicles: From a minimal programme to inspect and monitor on-road vehicles, Varanasi has augmented capacity for the pollution under control certificate programme—idle emissions testing system—and established 62 Pollution Under Control (PUC) centres. According to the estimates provided by the Road Transport Office, for Swachh Vayu Survekshan 2024, Varanasi has 5.3 centres per 100,000 vehicles. These centres are now integrated with a centralized server to improve compliance tracking.

The city is also maintaining a record of PUC compliance and as per available information, about 66.92 per cent of vehicles currently meet PUC certification standards. As investments for infrastructure development is expected to skyrocket, it will be beneficial to link investments in the transport sector with advancement in on-road emissions monitoring, like remote sensing monitoring for efficient identification of the worst polluters on road.

Steps have been taken towards advancing vehicle inspection programme for commercial vehicles and vehicle scrappage programme. One Automated Testing Station (ATS) and one Registered Vehicle Scrapping Facility (RVSF) have been approved in Varanasi. However, they are yet to become operational.

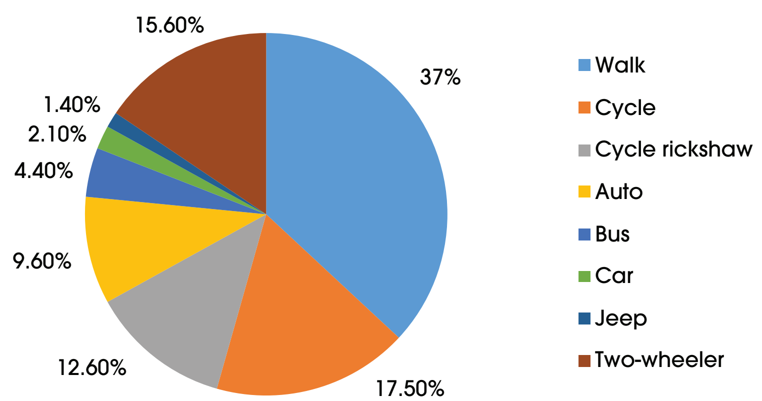
While progress is noticeable in this segment, it will be further impactful to strengthen the audit of the PUC system and also operationalize the automated testing centres to identify unfit and end-of-life vehicles for scrappage and material recovery.

ENHANCING PUBLIC TRANSPORT

In terms of urban commuting, Varanasi has a strong baseline of usage of sustainable transportation modes. Walking, cycling, and use of para transit like autos and buses make up for 80 per cent of all mode share, according to the report Mobility Interventions and Strategies for Varanasi, 2014. Varanasi is a densely populated city with around 1 million people residing is a 82 sq km area. To put that in a context, Bhubaneswar, with a similar population, is spread across 161 sq. km area—almost double the area of Varanasi.

This keeps the average travel trip length short. In fact, the average trip length of Varanasi is less than 5.3 km. This promotes walking, cycling and usage of cycle rickshaws and autos that is already reflected in the modal share (see *Graph 6: Modal share of Varanasi*).

Graph 6: Modal share of Varanasi



Source: Mobility Interventions and Strategies for Varanasi, 2014

Development of formal bus system: Post 2019, or the NCAP phase, the city saw a development of the formal bus transport system. Varanasi has expanded its public transport system, with 3,168 operational buses—equivalent to 264 buses per 100,000 people.

The NCAP phase has seen yet another convergence with the FAME II demand incentive programme for electric vehicles (EVs) of the Government of India. This has helped to expand the electric bus programme in the city. Varanasi operates 50 electric buses. An e-bus charging station has also been set up in the Mirzamurad area of Rajatalab tehsil, with two substations (160 kVA each), capable of charging 30 e-buses simultaneously. These buses run on 10 routes in the city. However, there is no information on the trend in bus ridership.

Traditionally, the city has been primarily dependent on the para transit, including autos etc., to meet the mobility demand. With mooting of the bus programme, there is considerable scope of rationalizing the bus routes and para transit routes for a seamless journey and efficient last mile connectivity. This will require improved operational framework to enhance bus ridership and also bus electrification target. To improve service levels of the buses and the overall quality of the bus service, global positioning systems (GPS) enabled passenger information system, well-equipped bus stops, digitization of services, can be further leveraged.

PROMOTING ELECTRIC MOBILITY

Electric vehicles or zero tailpipe emissions transition holds significant promise for the city.

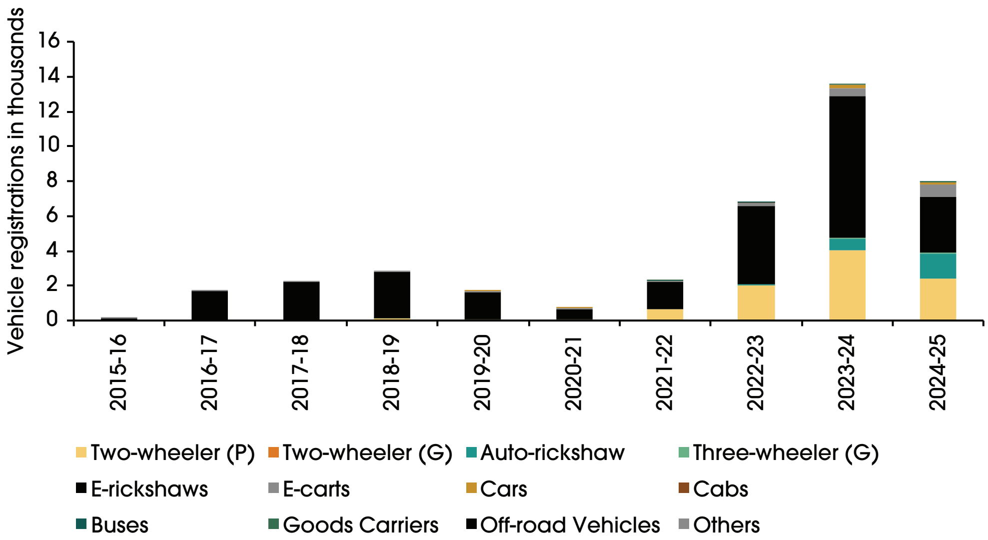
Varanasi's electric vehicles (EV) are currently being driven by the e-rickshaws and e-two-wheelers. In 2024–25, e-rickshaws dominated the EV portfolio. With e-rickshaws included, EVs account for a sizeable share of new registrations in 2024–25. However, there is a clear shift underway, as two-wheelers and auto-rickshaws begin to assert themselves in the EV market (see *Graph 7: Trend of segment-wise EV registrations in Varanasi, 2015–2025).* Electric two-wheeler registrations, although still representing a smaller share of total two-wheeler registrations, have surged in absolute terms in recent years.

Auto-rickshaws showed a dramatic increase in EV uptake in 2023–24 and 2024–25. Three-wheelers in general, both for passengers and goods, are also growing, although at a slower pace. The negligible number of electric cars and cabs underlines the challenges in personal EV adoption for four-wheelers—likely due to high costs, lack of infrastructure, or limited incentives. This mirrors the national challenge.

However, the city still faces infrastructure challenges. Currently, only three EV charging stations are operational, covering just 33.3 per cent of the required network, whereas at least nine stations are needed for a full city-wide coverage.

At this stage of motorization, a city-based EV policy setting, vehicle-segment-wise timebound targets and a mandate for annual registration and sales of EVs can lead to high level of electrification and enable zero emissions transition. Zero tailpipe emissions trajectory will be critical to combat air pollution and toxic exposures.

Graph 7: Trend of segment-wise EV registrations in Varanasi, 2015–2025



Source: Vahan Dashboard

VEHICLE RESTRAINT MEASURES—PARKING STRATEGY

The NCAP indicators for progress reporting requires development of parking policy as a demand management measure to restrain traffic and congestion.

Varanasi Smart City has developed three strategic parking facilities across the city. The Godowlia multi-level parking is a dedicated two-wheeler multi-level parking with G+4 structure and a capacity of 375 two-wheelers. Equipped with a vehicular lift system, it allows seamless parking on any floor. Two basement parking facilities have also been established—one at Town Hall and another in Benia Bagh park. The Town Hall facility accommodates 230 four-wheelers and 160 two-wheelers, while the Benia Bagh parking can hold 470 four-wheelers and 130 two-wheelers.

However, these initiatives on structured parking lots are yet to be linked with a parking policy and ward-wise parking management area plans that are required to create inventories of both on-street and off-street legal parking areas and demarcation of the legal parking areas after taking care of the other road users. As per the good practices emerging in other cities, such a policy is needed to prevent parking in green spaces and on footpaths, on emergency vehicle lanes in narrow roads, and near intersections etc. This needs to be combined with variable parking pricing, penalty on illegal parking and linking proof of parking certificate to link vehicle registration with availability of legal parking areas. These measures can help reduce parking demand and on-road congestion and also leverage the smart parking lots to reduce congestion and emissions.

Roadside parking at Babatpur in Varanasi

The new smart multi-level parking lots need integrated management, along with the on-street parking, to make on-street parking more expensive to improve utilization of the structured parking lots and reduce encroachment on roads. Otherwise, the vehicles will continue to park on roads, obstructing the smooth traffic flow. Parking demand will continue to accumulate and haphazard parking worsens the traffic congestion in key commercial zones, and also on roads near the smart parking structures.

GREENING THE BOAT FLEET—FLOATING CNG STATION AT NAMO GHAT

Varanasi is a riverine city, and given the religious significance of the Ganga river and high tourist footfall, there is a considerable boat traffic as well. These were originally powered by diesel fuel and their emissions have bearing on the air quality and exposures.

The Namo Ghat has been redeveloped by Varanasi Smart City as its first model ghat. A major innovation is the establishment of a floating CNG station at Namo Ghat, enabling the conversion of 735 diesel-powered boats to CNG and significantly reducing emissions along the riverfront.

For years, boatmen at the ghats relied on old and inefficient diesel engines, contributing to pollution and high operational costs. Now, these engines are being replaced with modern CNG engines and kits, leading to lower emissions.

The world's first floating CNG Mother Station at Namo Ghat, operational since December 2021, was constructed using the innovative 'Self-Adjusting Fixed Type Jetty' technology, a patented technique developed by IIT Kanpur-incubated Acquafront Infrastructure. With a compression capacity of about 15,000 kg of CNG per day, the station can fuel around

Floating CNG station–Namo Ghat

1,000–1,500 boats daily. The boats currently operating in Varanasi can accommodate about 15–80 passengers, with engine power ranging from 5 HP to 20 HP.[3]

To further enhance accessibility, a CNG Mobile Refueling Unit (MRU) has been set up at Ravidas Ghat—the first-of-its-kind facility in India. This unit allows CNG to be filled in cascades at Namo Ghat and transported via waterways to Ravidas Ghat for boat refuelling, with a daily capacity of 4,000 kg, catering to 300–400 boats.[4] As of 2021–22, about 583 motorboats had been converted to CNG, and by November 2023, this number had risen to 735 out of the 890 boats registered with the VNN, marking a significant step toward cleaner and more sustainable water transport in Varanasi.

ADDRESSING DISPERSED POLLUTION SOURCES—CREMATION PRACTICES

To address the substantial air pollution caused by traditional wood-based cremation practices, Varanasi has taken proactive measures to minimize emissions while preserving its cultural heritage. The historic Manikarnika and Harishchandra Ghats, where thousands of cremations take place annually, have been upgraded with eco-friendly electric and CNG-based cremation facilities, significantly reducing particulate and gaseous emissions.

Additionally, the city has established a dedicated animal carcass incinerator at Karsada, ensuring a responsible and environmentally-sustainable disposal of animal remains.

GENESIS OF CONSTRUCTION AND DEMOLITION (C&D) WASTE MANAGEMENT

The massive urban redevelopment project in the core temple area and along the river bank has catalysed formal construction and demolition waste (C&D) management system in Varanasi. C&D waste generated from buildings, renovations, and demolition activities poses significant environmental and health risks, if not managed effectively. Uncontrolled C&D waste is a major contributor to air pollution, releasing fine dust particles that degrade air quality and exacerbate respiratory issues. In rapidly-developing urban areas, frequent short-term construction activities make this a key source of ground-level emissions.

The city is aligning with the C&D Waste Management Rules, 2016. Substantial progress has been noted in the C&D waste management systems in Varanasi. In fact, the Varanasi redevelopment project has catalysed this initiative. When older structures were demolished near the river bank, the first recycling plant was set up in order to process the waste material. Since then, several steps have been taken to improve the regulations and management of this stream of waste. Some of the key elements of the programme have been important steps forward.

As per the Varanasi Nagar Nigam (VN), the city generates about 65–70 tonnes of C&D waste daily, achieving a 100 per cent collection and processing rate, ensuring that all 65 tonnes collected each day are effectively utilized. Additionally, 90 per cent of active construction sites in the city comply with the CPCB guidelines for dust mitigation, reinforcing sustainable construction practices.

Several steps have been taken to accelerate C&D waste management:

Banning of illegal dumping of C&D waste: A penalty order from the Urban Local Body is in place for the illegal dumping of construction and demolition (C&D) waste, and discarding such waste on streets or roads can result in a fine from the Nagar Nigam.

Developing primary and secondary collection systems: The Varanasi Nagar Nigam (VNN) has designated 31 C&D waste collection points spread in five zones including Varuna Pur, Adampur, Dashashwamedh, Kotwali and Bhelupur. The waste generator deposits the C&D waste at these locations—these points are often located in the vicinity of solid waste dumping points or *kuda ghar*. Each zone has about six to 10 collection centres.

There is no door-to-door service available for small waste generators but the recycling plant can send their vehicles in case there is a bulk waste generator who requests for it. There are two helplines for C&D waste management which can connect the plant operator or the VNN. As per the C&D recycling plant operator, the VNN plans to launch a door-to-door service for small waste generators as well.

The C&D plant operator sends their vehicles to these designated primary collection points to collect waste. The plant has three GPS-enabled tractor trolleys for this purpose. The plant also hires more vehicles if there is increased demand.

User charges and tipping fees: There is currenlty no provision for the VNN to charge the small waste generators. However, it pays Rs 525 for every tonne of C&D waste as tipping fee. Of this, Rs 173 is processing fees while Rs 352 is for transportation, indicating that transportation is a major component of the tipping fee cost. Waste generators can directly deposit malba at the plant for which they are charged Rs 173 per tonne as processing cost.

C&D waste recycling: The C&D recycling plant is located in Ramana in south of Varanasi, close to the Grand Trunk road. It is operated by Indo Enviro Integrated Solutions Private Limited. The plant can process 200 tonnes of C&D waste per day but in reality, it receives around 70-80 tonnes per day (TPD). One of the reasons is the collection by the informal

Recycling of C&D waste in Ramana

(left to right) Collection points at Machodari road near circuit house, Bisweshwarganj, and near Hartirath road

sector that often uses C&D waste for land filling purposes. The plant produces four products after recycling of C&D debris. These include soil, aggregates of sizes 40–150mm, 10–40 mm and 5mm (brick powder). There are three registered vendors who pick up these products and sell in the market.

Collection points need clear signages for people to be aware. We visited some of the 31 collections points. Most of these collection points are easy to miss as there are no boards or banners mentioning that they are designated points. All points need clearly demarcated area between Municipal Solid Waste (MSW) and C&D waste and to prevent roadside dumping.

It was observed that, in some collection points, the C&D waste and solid waste were dumped together. For efficient utilization of C&D recycling plants, segregation of waste is necessary.

It is also necessary to bring demolition within proper regulations. The city is experiencing significant demolition activity along the Lahartara road.

Effective coordination and supervision by the Varanasi Development Authority, Uttar Pradesh Housing Board, Varanasi Municipal Corporation, Urban Development Department, PWD, and the UPPCB is evolving to ensure that C&D waste control measures are enforced.[5] Furter coordination among these agencies can make the agenda stronger.

MANAGEMENT OF MUNICIPAL SOLID WASTE (MSW)

The growing population and rapid urbanization have led to a significant rise in waste generation. Emissions from open burning of waste and spontaneous burning in dumpsites and landfills, along with mismanagement of the dust caused by C&D activities contribute heavily to the concentration of air pollution. Waste management has to ensure proper quantification of waste generation, 100 per cent door-to-door collection of segregated waste in all neighbourhoods (including informal settlements), material recovery and recycling, minimize fresh dumping of waste in landfills, and full remediation of legacy waste.

The Solid Waste Management Rules, 2016, along with the Swachh Bharat Mission launched in 2014, have acted as major drivers for improving waste collection, transportation, treatment, and disposal, to create garbage-free cities. Moreover, the NGT order in O.A. No. 606/2018 has directed all states and Union Territories to submit action plans for implementing the Solid Waste Management Rules, 2016.

There are other local catalysts as well. The Urban Development Ministry in 2014 had set up a steering committee to take forward the Kyoto-Varanasi partner city agreement, which aimed to modernize the infrastructure related to waste management, among others.[7] The emphasis of this strategy was to minimize waste generation, reuse, and recycle of waste.[6]

However, the city's solid waste management (SWM) system has shown tremendous improvement under the Swachh Bharat Mission (SBM), shifting from scattered dumping to door-to-door collection, segregation, and covered transportation via GPS-tracked vehicles. The local bylaws were framed under the SWM Rules 2016, imposing spot fines and engaging Swachhata *grahis* for awareness and monitoring. Various waste processing systems such as composting, RDF production, and material recovery facilities were developed with the PPP's model upgrading infrastructure.

The city generates around 950 TPD of solid waste, of which 94.94 per cent is collected, and 85.78 per cent is processed from 75 wards out of the 90. The installed capacity to process the current generation of waste is 1,215 TPD, which is less than the required 1,500 TPD capacity. The total legacy waste the city holds is 275,000 tonnes, out of which 20 per cent has been processed.

SWM waste processing plant in Varanasi: As per data by the PRANA portal, in 2016, the VNN established a sanitary landfill and a composting plant with a capacity of 600 million tonnes (MT) per day at Village Karsara (South west of Varanasi) to improve solid waste management. It is operated by Eastern Organics Fertilizer Pvt. Ltd. It receives nearly 800 TPD of MSW. Around 125–145 trips are undertaken each day for this waste to be transported from the city to the plant.

The plant employs multiple trommels which help in segregating the waste in multiple sizes. The plastics of certain sizes retrieved from the waste segregation is sent as RDF. As per the Nagar Nigam representative at the plant, a major issue is that about 30–40 per cent of the waste received at the plant is construction and demolition (C&D) waste, and hence, this reduces the efficiency of the operations and damages machinery meant for lighter waste categories of MSW. This can delay the work by days on a few machines. Some of this C&D waste is transported to the C&D recycling plant which is roughly 12 km away.

The plant is currently undergoing renovations to increase its capacity and has not started working on production of compost waste yet. The waste-to-energy plant is also not functioning currently. Varanasi has seen a massive change in its cleanliness as per locals in the past six to seven years. Some of the designated *kuda ghars* show proper demarcation.

Sanitary landfill site at Village Karsana

Solid waste dumping points at Circuit house, Machodari road

Building circular economy: Various activities are undertaken by the Varanasi Nagar Nigam (VNN) under the convergence funding of the NCAP, which includes setting up of various plants such as establishment of a CNG/ biogas plant at Shahanshahpur with a capacity to process 90 TPD of waste. It generates 3,150 kg of CBG and releases other by-products such as 15 tonnes of fermented organic manure which can be further utilized.

The city also has a waste-to-charcoal plant at Ramna, under the project Harit Koyla Pariyojana, with a capacity of 600 TPD and a daily production of 200 TPD of charcoal. It also has three material recovery plants of 2 TPD each. The city has established three bio-methanation plants for segregated organic waste.[9]

As per the PRANA portal, a 24-TPD waste-to-energy plant was set up by NTPC. The Indian Oil Corporation also contributed to waste-to-energy efforts by establishing three plants, each with a capacity of 5 TPD at Bhelupur, Paharia Mandi, and Adampur in Varanasi.

Similarly, for treatment of biomedical waste, four Common Bio-medical waste treatment facilities (CBWTFs) are operational in and around Varanasi.

Even as the waste management infrastructure is beginning to take shape, management strategies will have to be further strengthened to ensure 100 per cent collection and processing efficiency and eliminate open burning of waste. Additionally, four industrial units have been identified as operational generators of hazardous waste. Collectively, these industries generate about 50 metric tonnes of hazardous waste annually. To ensure the safe and compliant handling of this waste, all four industries have obtained authorization from the State Pollution Control Board under the Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016. Accordingly, formal disposal systems have been secured for the scientific treatment and safe disposal.

USE OF SOLID FUELS IN HOUSEHOLDS AND EATERIES

The IIT Kanpur study shows that the contribution from the domestic sector to PM2.5 load is about 6 per cent, 16 per cent to SO2, and 4 per cent to NOx emissions.

There has been substantial expansion of LPG connection and piped natural gas network in Delhi, especially under the central government schemes of Pradhan Mantri Ujjwala Yojana (PMUY) and direct benefit transfer to LPG consumers (PAHAL). LPG penetration has increased substantially. According to the Petroleum Planning & Analysis Cell of the Ministry of Petroleum & Natural Gas, a total of 558,638 households in Varanasi have legal LPG coverage. Based on the Census 2011, 85 per cent of the households use LPG for cooking and the remaining uses wood, crop residue, coal and cow dung.

Households use mixed fuels due to delayed refills and unaffordable price points, especially in economically weaker/slum areas where wood and dung are used as fuel for cooking. On the other hand, restrictions on the use of firewood and coal in hotels and eateries (except for wood charcoal, which is allowed for use in tandoors and grills) have minimized the use of solid fuels in this sector.

IIT Kanpur, while doing the source apportionment and emission inventory study, has calculated the PM2.5 emission load from the domestic sector—which includes LPG at 47 per cent, wood at 24 per cent, dung at 14 per cent and coal at 11 per cent.

This is a matter of equity in which poor households cannot afford even the subsidized LPG. The central government will have to consider how to make clean fuel more affordable and accessible.

Several programmes, schemes and funding strategies related to urban redevelopment, road infrastructure, waste management, and transportation strategies have joined to contribute towards clean air objectives in Varanasi. As more urban infrastructure development is planned in this city in the future, more explicit and deliberate mainstreaming of clean air indicators become necessary to maximize clean air gains from the new investments.

VEHICULAR EMISSIONS

TECHNOLOGY ROADMAP AND URBAN MOBILITY STRATEGIES

Effective control of vehicular emissions requires a comprehensive strategy including clean vehicle technology, fleet electrification, integrated public transport, walking and cycling infrastructure, low-emissions zones, and on-road emissions monitoring. However, no city has implemented all these together at scale. Some cities, though, have adopted more cohesive mobility strategies.

Kochi integrates metro, electric water metro, e-feeder buses, and cycle lanes, powered by renewable energy. Srinagar utilises the Smart City programme to build pedestrian infrastructure, regenerate public spaces, and develop electric transport. Mumbai has built the largest municipal e-bus fleet using Finance Commission grants, while Bengaluru's rationalised bus hubs attract commuters.

Bhubaneswar's Mo Bus system has modernised and electrified city bus services rapidly. Surat uses IT to boost bus operations and ridership; Gujarat applies innovative fiscal strategies for funding. Kerala's Grama Vandi rural services are community-led and supported by panchayats and private partners. Chennai advances pedestrian infrastructure systematically, and Gurugram and New Town Kolkata work on street reclamation.

Only hill regions like Shimla, Gangtok, and Mizoram have enforced the Proof of Parking Policy to curb vehicle ownership. Delhi remains the only major city with notified parking rules, though enforcement is weak. While PUC emission testing is status quo, Kolkata leads in remote sensing.

The five years of NCAP implementation have also coincided with the steady expansion of EV programme, supported by the national-level demand-incentive programmes, with the potential to contribute to zero emissions transition in polluted cities.

INTRODUCTION

Under the National Clean Air programme (NCAP), vehicular emission control requires a more comprehensive attention. Vehicles are among the top polluters and are responsible for high toxic exposures in most cities. The NCAP must play a decisive role in bending the vehicular emission curve through rapid technology development, fleet electrification for zero-emissions transition, and fleet renewal. Simultaneously, it must also play a role in the reversal of the declining trend in modal share of public transport, walking, and cycling. Both technology and mobility measures are needed to build solutions to scale and meet clean air targets.

Although the Central Pollution Control Board (CPCB) has provided a range of indicators to track progress for vehicle technology roadmap, on-road emissions management, and mobility management, on-ground interventions are limited to a few strategies of uncertain scale and scope. (see below: *Transport sector: CPCB indicators for interventions and progress*). Several indicators provided can be grouped as enforcement measures, infrastructure, and system measures. But these indicators are often not linked to specific targets.

While these indicators need further refinement to align with the principles of the existing and new generation transportation and urban development policies, as well as emissions regulations in the sector; cities also need to be more comprehensive in their approach to implementation while prioritising key interventions for sustained scalability and replicability.

If not addressed with scale and speed, there will be massive lock-in of pollution, carbon and energy intensity in the explosive motorisation, growing dependence on personal vehicles, vehicle-centric road infrastructure design and untamed road-based freight movement, that will be difficult to undo. According to the International Energy Agency's *Energy Outlook 2021*, energy demand from road transport in India could more than double over the next two decades under current policy settings.[1] On the other hand, as evident from the assessment of the United Nations Environment Programme (UNEP) in 2015, the modal share of public transport will continue to decline, while trip length and trip rates will continue to grow in sprawling cities—inciting more transport demand and use of personal vehicles in India.

There is an opportunity for NCAP to align with the sectoral policies and funding strategies to protect and augment the inherent strength of India's baseline for walking, cycling, and public transport modal share, as is evident from the 2011 Census, which remains the most elaborate document available till date to represent national-level statistics. This shows that almost 71 per cent of the work trips are made through walking, cycling, intermediate public transport (such as autos and taxis), buses, trains, etc. About 58 per cent of work-related trips in urban India have average travel distances of 5 kilometres for their work. Even if there is a negative trend in these positives since 2011, this strength is still big enough and needs to be leveraged, protected and strengthened to prevent lock-in of pollution in the transport infrastructure.

Vehicular pollution: CPCB indicators for reporting progress in the sector

At the beginning of the NCAP, sector-wise indicators were provided by the CPCB to the state governments to report progress based on the implementation of the clean air action plans. These are extensive indicators to drive action. These can be further refined and prioritised considering the sectoral policies and best practices. However, currently, the cities are largely focused on enforcement measures while making slow progress on infrastructure and systemic changes for upscaled transformation.

1. Technology roadmap and fleet renewal

1.1 Improve and strengthen PUC programme

- Monitor the number of Pollution under Control Certificate (PUC) and regularly check vehicular emission.
- Audit and reform the PUC certification.
- Link PUC centres with remote server and eliminate manual intervention in PUC testing.
- Integrate on-board diagnostic (OBD) system fitted in new vehicles with vehicle inspection.

1.2 Vehicle labelling or sticker programme

1.3 Freight transport

- Schedule freight movement during off-peak passenger hours and restrict the entry of heavy vehicles during the day.
- Provide truck rest areas/parks along national and state highways to prevent entry of trucks into cities during peak hours.
- Plan for truck traffic diversion.
- Check overloading using weigh-in-motion bridges / machines and weighbridges at entry points.
- Define routes, permits, fares, vehicle design and safety standards.
- Set vehicle technology standards for para-transit vehicles.

1.4 Clean fuel and fuel quality

- Check fuel adulteration and conduct random monitoring of fuel quality data.
- Implement alternative clean fuel policy for vehicles.
- Implement bio-fuel policy.

1.5 Parking management

- Prevent parking of vehicles in the non-designated areas.
- Develop multi-layer parking infrastructure.
- Penalise parking of vehicles in non-designated areas.

1.6 Strengthening of public transportation

- Regulate the taxi industry.
- Assess and introduce a city bus system.
- Introduce appropriate fleet size of small buses and desirable bus type replete with GPS tracking, electronic ticket vending machines (ETVMs) for fare collection and passenger information systems.
- Develop route plan for bus operation; target trunk roads.
- Intermediate public transport (IPT) and bus system.

- Introduction of new electric buses (with proper infrastructure facilities such as charging stations) and CNG buses for public transport which will reduce plying of private vehicles on road and help to curb tail-pipe emissions.
- CNG infrastructure for auto gas supply in the city and transition of public transport vehicles to CNG mode. Introduction of e-buses for public transport in metro cities.
- Steps for promoting battery operated vehicles like E-rickshaw/E-cart.

1.7 Traffic congestion
- Conducting audit of traffic intersections and install functional traffic signals.
- Synchronise traffic movements/Introduce intelligent traffic system for lane-driving.
- Plan for construction of diversion ways/ bypasses to avoid congestion.
- Plan for widening of road and improvement of infrastructure for decongestion of road.

1.8 Launch public awareness campaign for air pollution control, vehicle maintenance, minimising use of personal vehicle, lane discipline, etc.

1.9 Emission monitoring instrument
- Conduct periodic calibration test of vehicular emission monitoring instrument.
- Check the calibration of emission monitoring equipment, housed in Emission Testing Centres (ETCs), once every six months to know the status of equipment.

1.11 Phasing out old vehicles and vehicle scrappage policy
- Implement inspection and maintenance for all BS-II & BS-III vehicles.
- Restrict on plying and phase out commercial diesel vehicles older than 15 years.
- Enforce laws against visibly polluting vehicles, for example, removing them from roads, imposing penalty, and launching extensive awareness drive against polluting vehicles.
- Initiate steps for retrofitting of particulate filters in diesel vehicles, when BS-VI fuels are available.
- Raise fines on vehicle owners (not drivers) where visible smoke is emitted and noticed.
- Examine existing framework to remove broken down buses or trucks from roads and create a system for speedy removal and ensuring minimal disruption to traffic from such buses or trucks.
- Restrict use of two-stroke and three-stroke vehicles in phased manner.

1.12 Non-motorised transport
- Introduce cycle tracks alongside roads.
- Prepare and implement zonal plans to develop an NMT network.
- Compact city development to reduce distances and improve access.

There is an enormous opportunity in the vehicle technology and fuel quality roadmap; after leapfrogging directly to the Bharat Stage VI (BS-VI) emissions standards, India is now gearing up for BS-VII notification for the internal combustion engines and zero emissions transition with electric vehicles. The opportunity also lies in adoption of stringent on-road emission surveillance system to weed out the worst polluters and fleet renewal by phasing out old and unfit vehicles.

Each of these strategies will have to be designed and planned as per the relevant policies, regulations and regulatory targets, and robust service-level benchmarks in the sector.

Therefore, the selected case studies represent different strategies related to technology roadmap and mobility management to present what is needed to define the scope of action, reduce vehicular pollution, and meet clean air targets.

TRANSPORTATION AND MOBILITY STRATEGIES

In NCAP cities, and particularly in the cities funded by the 15th Finance Commission grant, several sectoral programmes with dedicated funding are underway that are shaping the transport and mobility agenda. Some of those key programmes include Smart City programme, AMRUT programme and PM e-Bus Sewa scheme under the Ministry of Housing and Urban Affairs (MoHUA), along with FAME II and PM e-Drive for electric vehicles led by the Ministry of Heavy Industry. These programmes together are helping to create the portfolio of mobility solutions in the cities.

The available evidence shows that there are very few urban transportation and urban mobility initiatives that have been funded directly with NCAP or 15th Finance Commission funding. There are a few big instances where deliberate efforts have been made to invest NCAP funding for an upscaled programme.

For instance, in Maharashtra a deliberate decision was taken to invest nearly 80 per cent of the 15th Finance Commission funding for expanding electric bus programme for zero emissions commuting in its non-attainment cities. Similarly, Chennai, that has got a smaller amount under the NCAP fund, has used part of the funds for its mega street projects to improve walking and cycling infrastructure. Howrah, a non-attainment city in West Bengal, has created walking infrastructure of ten kilometres with NCAP funding. These examples, along with some other small-scale initiatives, show some leveraging of NCAP funding.

Yet, the cities that have been selected as case studies to demonstrate good practices have leveraged convergence funding that are available in the sector. The NCAP therefore needs a framework to strongly mainstream air quality indicators in all potential convergence programmes and use its own funding strategically to enable and catalyse reform-based action in the sector to maximise air quality gains.

The selected case studies represent different sub-segments of transport sector interventions and are grouped as follows: i) Public transport strategy, that includes improvement in overall public bus transport system and services, application of information technology (ITS) to improve bus operations and commuter services, and state level fiscal strategy to promote bus transport, ii) Multi-modal integration, iii) Walking and cycling infrastructure and low emissions zones like pedestrianisation, and iv) Vehicle restraint measures like parking policy.

The case studies are further grouped into two categories; as those who have taken more composite approach to transportation management and integration for city-wide implementation, and those cities that display good practices in specific strategies like fiscal strategy or ITS strategy in the sub-sector that are also important for effective implementation and transformation. The case studies highlight the scope of integrated planning and design, strategic funding, alignment with sectoral policies and guiding principles to create and accelerate urban mobility systems to reduce emissions at source.

All case studies are presented with the caveat that all the initiatives are work in progress and at different stages of implementation. These are not complete nor have they achieved the full maturity and comprehensiveness city-wide as desired. But the changes are moving in the right direction.

Also as noted earlier, nearly all transport and mobility interventions reviewed have been driven by the convergence of diverse programmes and funding schemes that complement the NCAP strategy. This inter-linkage needs to be strengthened further by defining the catalytic role of the NCAP funding in the mobility sector.

COMPOSITE ACTION

KOCHI: TOWARDS MULTI-MODAL PUBLIC TRANSPORT SYSTEM ON RENEWABLE ENERGY

Driver of change: Kochi does not fall in the category of non-attainment cities under the NCAP. But it has demonstrated strategies that are needed to upscale diverse set of public transport infrastructure and enable multi-modal integration to create the opportunities for increasing mobility services. It has also demonstrated how transportation systems can be co-joined with a clean energy transition.

The origin of the concept dates back to the early 2000s, when the policy conversation had started on the perils of congestion. In 2001, the State government of Kerala had planned to prepare a master plan for the Kochi city—a major port city in Kerala, which is a trade hub with a growing IT sector and thriving tourism. This has bearing on the population profile, travel demand, and tourism footfall in the city. However, this has also developed as a disintegrated urban form that spreads along the major traffic corridors. Moreover, mainland Kochi is surrounded by large number of islands divided by the backwaters that are also dependent on the mainland and generates substantial waterway traffic that also need to be connected with the mainland transport system.

Way back in 2021, The RITES Ltd in its baseline report called Comprehensive Traffic and Transport Study (CTTS) for Greater Cochin Area, 2001 had asked for public transport improvements, including route restructuring, CNG conversion of buses, and the need for a mass rapid transit system (MRTS). It had further identified two MRTS corridors—

Kalamassery to Tripunithura (Phase-1) and Aluva to Kalamassery (Phase-2)—and evaluated their economic and financial feasibility.

Subsequently, a City Development Plan (CDP) was prepared in 2007 to access financial assistance under the Jawaharlal Nehru National Urban Renewal Mission (JNNURM). The CDP had also underscored the problems of traffic congestion in two major east-west corridors, declining modal share of public transport, lack of organised para transit, growing number of vehicles beyond road capacity, encroachment, inadequate pedestrian infrastructure, chronic parking shortages, among others. This once again established the need for a rail-based mass transport system.

Catalyst role of Kochi metro rail—Going beyond the land-based metro system: It however, took more than a decade to initiate and operate the MRTS system in the city. Eventually, the joint venture between Kochi Metro Rail Limited (KMRL) and Delhi Metro Rail Corporation (DMRC) was created and this also became the special purpose vehicle (SPV) for implementation, operation, and maintenance of the metro project.

The metro began operations in 2017 with 11 stations between Aluva and Palarivattom. The entire first phase of metro has now been completed, and 14 more stations have been added—spanning over a total of 28 kilometres.

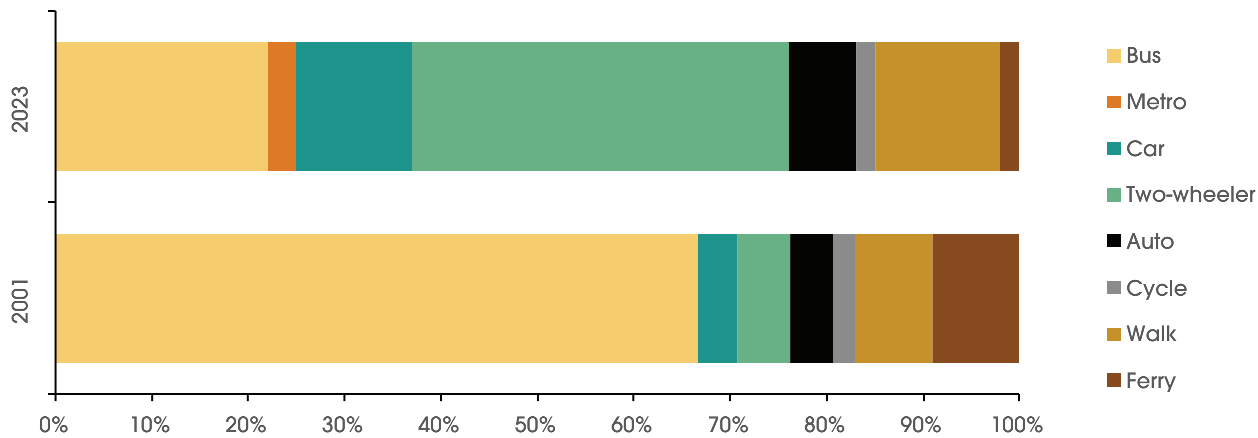
It is important to note that by the time metro became fully operational, the city had lost considerable share of public transport modal share. The 2001 RITES study had shown that despite the challenges, the public transport share (including walk and cycle trips) was as high as 66.6 per cent. But by 2023, this share reduced to 25 per cent, as per the new Comprehensive Mobility Plan prepared by Urban Mass Transit Company for KMRL in 2024.

During the two intervening decades, the share of two-wheeler trips had increased from 5.5 per cent in 2001 to 39 per cent in 2023, and car trips from four per cent to 12 per cent. According to the detailed project report (DPR) prepared by DMRC in 2011, 47.3 per cent residents in the city did not own a vehicle. Over 10 per cent owned cars, and about 20 per cent owned two-wheelers. But by 2023, as is evident, only 11 per cent households were left that did not own vehicles, more than 74 per cent households had two-wheelers, and over 22 per cent had a car. This speed of change was overwhelming.

Therefore, the Kochi metro had arrived against this backdrop of declining modal share of public transport. The challenge for the new system is therefore that first it has to stabilise the existing modal share of public transport, quickly recover and then increase the modal share public transport and also modernise the system.

Therefore, the three per cent of modal share that the Kochi metro could achieve in 2023 is only a beginning of a process to recover the public transport ridership. (see *Graph 1: Modal share of passenger trips in Kochi, 2001 and 2023*).

Graph 1: Modal share of passenger trips in Kochi, 2001 and 2023



Source: KMRL 2024, RITES 2001

It is also clear that the potential of this recovery will depend not only on the performance of the metro itself but on how well this system is integrated with other modes with good accessibility. This framework is beginning to take shape in Kochi.

Enabling multi-modal integration and creating UMTA: It is notable, how KMRL itself has stepped in to be the authority to operate and maintain different transportation systems taking shape in the city. It was in KMRL's interest to integrate existing and upcoming transport systems in the city to improve utilisation of metro. Thus, KMRL itself became the UMTA for the city. In 2012, KMRL had submitted a request to the Transport Department, Government of Kerala, to form a Unified Metropolitan Transport Authority (UMTA) for Kochi for integrating various transportation modes like the waterways, private buses, state-owned intercity buses, auto-rickshaws, metro rail and so on. During the metro corridor construction phase, KMRL was looking at maximising its ridership, and to achieve that, it needed to integrate its corridors with other transport services.

Innovative approach to connect the mainland with the islands and waterways: Traditionally, regular inter-island ferries were operated by Kerala Shipping and Inland Navigation Corporation (KSINC), the State Water Transport Authority (KWTA), and private agencies. The key routes connected High Court Jetty and the Ernakulam Central Jetty at Park Avenue. The junkar ferry, for the trans-shipment of vehicles and passengers between the various islands, are operated between Ernakulam and Vypin, and between Vypin and Fort Kochi. But these services were plagued by unreliability and lack of passenger safety.

There was a need for a water transport system that is sustainable in this fragile ecosystem of waterways, as well as formally managed under the purview of urban mobility authorities for reliable, efficient, and integrated system to improve connectivity between the mainland and the islands.

This led to the innovative approach of introducing an electric ferry system called "water metro". KMRL decided to own and operate this service. This included the enhancement of existing ferry services by increasing the frequency of services, using more advanced boats, renovation of existing boat terminals and construction of new jetties.

With DMRC managing the surface metro's development, KMRL had the bandwidth to explore complementary sustainable transport solutions, leading to the conceptualisation of the Kochi water metro. This parallel planning allowed for a holistic, multi-modal transport vision, integrating both land-based and water-based systems.

The State government took the initiative to source funds and contribute as well. The project was largely funded by a German banking group called KfW or Kreditanstalt für Wiederaufbau (translated as "Credit Institute for Reconstruction"), who sanctioned a soft loan covering 75 per cent of the cost in 2016. The rest 25 per cent was contributed by the State government. Kochi Water Metro Limited, a special purpose vehicle (SPV) formed for the project, is owned 74 per cent by the Kerala State and 26 per cent by KMRL, that is responsible for its operation and maintenance.

Currently, five routes are operational and 17 boats are plying out of the planned fleet of 78. When fully operational, it will connect Kochi's ten island communities with the mainland through a fleet of 78 battery-operated electric hybrid boats, operating from 38 terminals and 16 routes, spanning 76 kilometres. Extensive surveys and consultations with panchayats and municipalities have guided land acquisition and operational planning. Environmental clearance, though challenging, was eventually secured, validating the project's sustainable framework.

Augmentation of ridership of water metro: Since its launch in April 2023, the water metro has achieved significant milestones, with cumulative ridership reaching one million in six months, two millions in 12 months, and three millions in 18 months. This includes both island communities and the tourist traffic.

Kochi's water metro had a target to reach 7,000 passengers daily. The current average of daily ridership has breached the 6,000 mark during weekdays, and 10,000 average daily ridership mark during weekends. In December 2024, the system recorded its highest ridership ever in a single day, crossing 15,000 mark.

Innovated boat technology to reduce emissions and improve services: To make water metro more attractive, clean and zero emissions, and competitive, KMRL has introduced electric boats. This is supposed to be the largest fleet of electric boats for inland waterways in India. This replaces the diesel-run polluting boats that have high toxic exposures.

Additionally, to address the inherent slowness of water transport, KMRL has designed boats that can operate at a speed of 8–10 knots (15–19 kmph), requiring a 74 kWh battery. For routes parallel to roads, higher speeds would necessitate larger batteries, but the trade-off between passenger load and battery weight was a constraint. The placement of charging stations was determined by travel times and route lengths. The solution was to implement opportunity charging, with ten charging stations across five routes.

Boats currently operate with 120 kWh batteries, charging up to 80 per cent in just 15–20 minutes using 300 kW chargers. The battery type, Lithium Titanium Oxide (LTO), provides durability with 32,000 cycles under warranty.

The boats' design avoids creation of big waves, enhances efficiency by saving propulsion energy, preserves marine life, and prevents shoreline erosion, which protects fishermen's livelihoods. Additionally, KMRL has also promoted water transport as a social space to enrich the commuting experience. Efforts have also been made for gender-friendly spaces in the boat. Floating jetties have been adopted to accommodate differently-abled and elderly passengers with reduced mobility. A significant community request has been for service expansion to more areas.

Towards integration with other modes: Mobility hubs in Kochi are pivotal infrastructure points designed to integrate various modes of public and private transportation, enhancing connectivity and streamlining commuter journeys across the city.

Vytilla mobility hub, the largest and most prominent, serves as a model for such integration. It brings together the Kochi metro, long-distance and intra-city bus services, and water transport, creating a seamless interchange point. Amenities like parking facilities, retail outlets, and waiting areas enhance commuter convenience. Integration with existing transport networks was prioritised by locating water metro terminals near bus stops and metro stations. Accessibility has been the key focus.

The Vytilla mobility hub conveniently integrates public transit modes and intermediate para-transit. On the left is the metro rail station as seen from the water metro station; on right, the bus stand as seen from the IPT halt-and-go point.

Feeder systems for integration: Yet another step taken is the integration of electric feeder buses and shared auto-rickshaws to strengthen last-mile connectivity for metro commuters.

The feeder service began in 2018 with a license-based model involving ten privately owned buses. In the first phase, this limited effort connected the metro stations to the airport. Subsequently, KMRL launched 15 new electric buses using a soft loan, with infrastructure and bus ownership retained by KMRL. A private company provides ticketing solutions, staffing, and an Intelligent Transport Management System (ITMS) collects data while KMRL handles revenue collection and pays a per-kilometre cost. Maintenance is covered through an annual maintenance contract (AMC) with the original equipment manufacturer (OEM).

These 9-metre buses operate on short routes of up to five kilometres. Infrastructure includes charging depots and 120–180 kW chargers at key metro points like Aluva, Kaloor, and Vyttila. Automation and ticketing enhancements aim to phase out conductors gradually.

KMRL is set to introduce electric feeder buses on two more routes that connect the water metro stations, including the High Court–MG Road section, to further boost ridership, and reach the 7,000 daily passengers' target.

KMRL also attempted to rationalise bus routes with private operators, but this effort is yet to materialise. Longer routes are under Kerala State Road Transport Corporation (KSRTC), limiting competition. Approximately 700 private buses operate within Kochi.

Electric auto-rickshaw feeders: They complement the network of metro rail. In this innovative model, seven unions have been consolidated to form the Ernakulam Zila Auto Driver Cooperative Society (EZADCS), initially operating 30 e-autos provided by GIZ on a license fee model.

EZADCS was expanded by renting an additional 75 e-autos from KMRL, paying a daily rent of Rs 250, and charging fees at metro-based stations (Rs 9/unit) or private locations (Rs14–15/unit). With a range of 130 kilometres, these autos efficiently cover 120 kilometres daily.

Charging points are available at five metro stations. Formalising unions into a cooperative fostered smoother operation, with a unified ITMS supporting UPI, debit, credit card, and metro card payments, and GPS tracking for autos. Key routes include connections from the airport and medical college to metro stations.

The consolidation of auto-rickshaw unions into the EZADCS has formalised employment, provided access to financial benefits, and improved collective decision-making.

Fare integration and mobility hubs: KMRL has also adopted a single card called the Kochi1 card, single timetable, and a singular command and control. The debit card along with the Kochi1 mobile app allow passengers to plan their journey. It can be also utilised for internet transactions and will introduce the click-and-collect feature soon where goods ordered online can be collected in the metro stations.

Google and KMRL have announced a partnership to enhance digital ticketing options for metro users through Google Wallet.

Metro fares have remained unchanged since 2017 despite a network extension to 28 kilometres, with another 11.2 kilometres planned as part of Phase-2 of the metro network, which is expected to be completed by 2028. Services run from 6 AM to 11 PM, with 30–35 per cent of payments are made digitally.

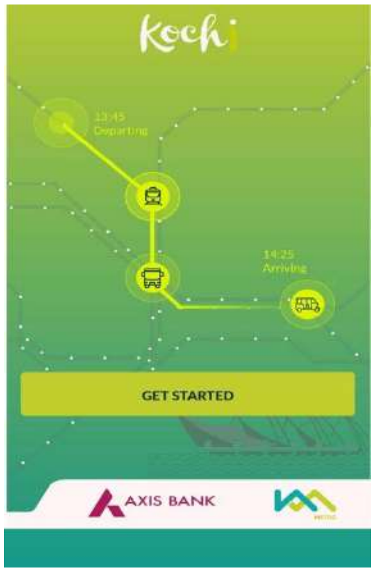
Connecting public transport with clean electricity: Currently, 52 per cent of all energy for metro and station operations comes from solar energy sources that is generated by KMRL. There are rooftop solar power system in metro stations as well as ground-mounted and grid-connected solar systems. The combined capacity is 5.389 MWp.[2]

Similarly, for the water metro, as solar panels on boats are not practical, KMRL is developing a solar farm to meet 100 per cent of its energy needs. This initiative aligns with India's goal of renewable energy, as well as that of transitioning all inland waterways to electric by 2047.

Mobility benefits of this improvement: There are positive signs of resurgence of public transport usage especially after a prolonged erosion of public transport modal share in the city. The average daily ridership of the Kochi metro rail has increased consistently. After the dip during the pandemic year (2020–21), passengers have returned, and within two years, the numbers have exceeded the pre-pandemic levels. Ridership has increased

Payment mechanism (Kochi1 card) and transit app (Kochi1 app), on the right, for the ease of commuting.

Source: Krishna Jith - Issuu



Source: Appadvice

by 250 per cent in 2023–24, as compared to the first year after inauguration (2017–118). While the initial years were loss-making, the system has earned operational profits during the last two years (2022–24).

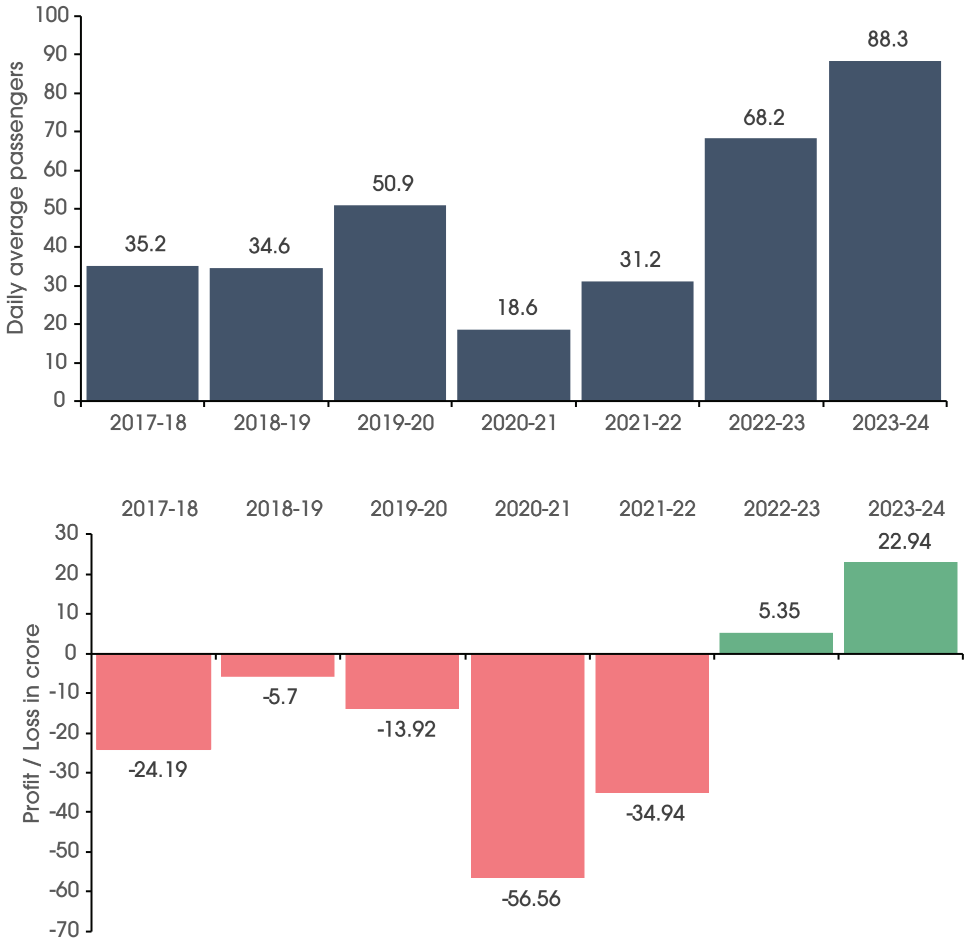
The electric feeder buses launched on routes such as the Aluva-Airport, Kalamassery-Medical College, Kalamassery-Cusat, Kalamassery-Infopark, and Kakkanad Water Metro Terminal-Infopark-Collectorate have increased the commuter patronage of Kochi water metro, especially on the Vyttila-Kakkanad route with a ten per cent rise in ridership. The cumulative average daily ridership of e-feeder bus services has now touched 3,000. On the Inforpark route, for example, the ridership of these electric buses has gone up from 40 commuters per bus to 220.

Recognising the potential for replication of the Kochi metro model, KMRL has identified at least other 40 Indian cities where replication of a similar system is possible.

Combining with non-motorised transport corridor and accessibility: To improve accessibility to the metro rail system, non-motorised transport (NMT) corridors have been created alongside the Kochi metro and on 500-metre zone and within two-kilometre buffer area on either side of the metro route. These aredesigned to improve walking, cycling facilities, and bicycle parking facilities. The NMT corridors on Aluva-Edappally stretch, Kaloor-Kadavanthra Road, and Manorama Junction-Thripunithura S.N. Junction are underway. A 350-kilometre walkway and cycle track are being piloted in Shihab Thingal Road in Parampally Nagar, Kochi.

Public outreach and consumer awareness: As per KMRL's consumer survey conducted of metro rail users, 12 per cent of the passengers are "extremely satisfied", and 83 per

Graph 2: Daily average passengers and operational profit/ loss trend of KMRL metro rail



Source: KMRL annual reports

cent are "satisfied". In comparison, four per cent of the respondents are dissatisfied with the last-mile connectivity. Survey respondents were asked to evaluate the existing connectivity of various public transportation options to and from metro stations. They rated their satisfaction with the connectivity of short-distance public transportation (such as feeder buses and local buses) to the metro, the connectivity of long-distance public transportation (such as trains and long-distance buses) from metro stations, the connectivity of Kochi water metro services to metro stations, and the connectivity of intermediate public transport options (such as autos, taxis, shared bikes, and cycles) to the metro. The commuters are most satisfied with the short distance public transport mode access to and from the metro stations, and intermediate para-transit is a close second.

Social equity: KMRL's social inclusion initiatives include employment of women through Kudumbashree for roles such as ticketing and housekeeping, as well as transgender persons for customer facilitation. As boat driving requires specialised licenses, training programmes for women are underway. A significant part of its management operations is handled by women.

Emissions benefits from integrated pubic transport: According to the Kochi Metro Ridership Improvement Survey, 52 per cent of new metro users used to ride buses, 19 per cent used two-wheelers, 10 per cent drove cars, and the rest relied on autos or walked.[3] To understand the full spectrum of benefits, both conservative (survey-based) and ambitious (private vehicle-heavy) modal shift scenarios have been analysed. For the ambitious shift scenario, it was assumed that 30 per cent of the current metro users would have opted for two wheelers, 30 per cent for cars, 20 per cent would have commuted via auto and the remaining 20 per cent would have opted for bus.

Emissions analysis combines ridership reported by KMRL, average trip length, modal shifts, and BS-VI-compliant emission factors.[4, 5] Even after accounting for feeder transport emissions, the impact remains impressive. Tailpipe PM from electric feeders was excluded, while CO2 and NOx emissions from grid electricity were included where relevant.

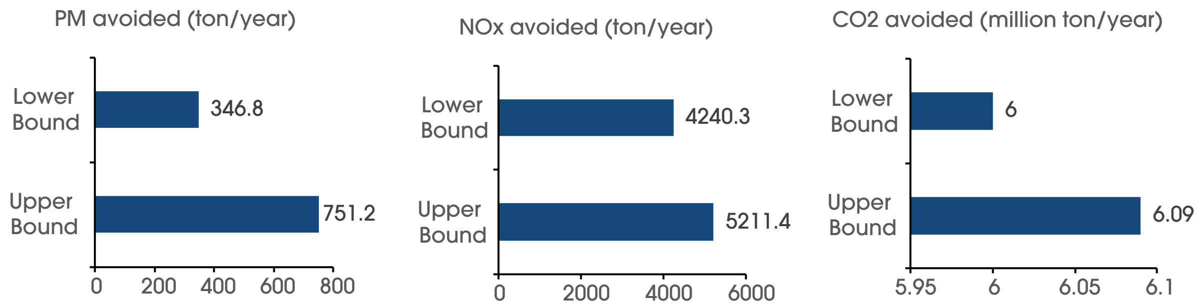
To understand the full spectrum of benefits, following range were modelled:

- The lower bound scenario used real-world data—average trip length of 6.65 kilometres, survey-reported modal shifts, and predominantly electrified feeder systems (e-buses and e-autos).

- The upper bound scenario assumed a more ambitious shift from private vehicles—30 per cent from cars, 30 per cent from two-wheelers, and longer average trip lengths of 10 kilometres, with fossil-fuel-based feeders.

The estimated daily emissions avoided range as—PM: 950.01–2,058.00 kg/day, NOx: 12,439.20–14,277.70 kg/day (adjusted for 55 per cent solar metro energy), CO2: 16,446,337.9–16,679,040.0 kg/day (adjusted for solar share and feeder impact). (See *Graph 3: Emissions avoided due to Kochi multi-modal integration (MMI)*)

Graph 3: Emissions avoided due to Kochi multi-modal integration (MMI)



Source: CSE analysis

This robust spectrum highlights that even under conservative assumptions, the benefits of mode shift and electrified last-mile connectivity are substantial—and when paired with bolder modal transitions and longer commutes avoided, the climate dividends increase dramatically.

It is important to note that if the feeders were powered by fossil fuels, the city would face a net increase in emissions—313.2 kg/day of PM, 4,536 kg/day of NOx, and 3,636 ton/day of CO2. This stark difference underscores the strategic importance of the upscaled mass commuting systems.

The gaps and way forward: The comprehensive multi-modal integration model that the Kochi metro rail represents—including alignment of land and water metro with bus and auto-based feeder systems, electrification of bus fleet, walking and cycling access and powering of the system with clean renewable electricity—has enormous potential to transform mobility.

With this model to drive zero-emission mass commuting and integration of public transport with last-mile mechanisms, Kochi can undo the steady decline in public transport share over time. However, reversing decades of private vehicle dependence requires more aggressive upscaling of city-wide infrastructure, and vehicle restrain measures such as parking management plans, low-emission zones, and "streets for all" approach to accelerate the change.

One major gap lies in the full-scale electrification of feeder services. While significant progress has been made through initiatives like the EZADCS and KMRL's electric feeder bus fleet, further expansion and operational scaling are required.

Another issue is the substitution effect. Over half of metro users previously travelled by bus, a relatively clean mode of transport compared to cars. While integration is important, the focus should shift toward drawing users from private vehicles to maximise emission benefits.

Furthermore, pedestrian infrastructure in the city remains underdeveloped. Poor sidewalks, unsafe crossings, and limited accessibility reduce the attractiveness of walking, thereby weakening first- and last-mile connectivity. Lastly, decision-makers need better data. A lack of real-time and disaggregated data—such as station-level ridership, energy usage, and detailed feeder patterns—limits the potential for targeted interventions and continuous improvement.

Realising the full potential of this system requires strategic investments in electric feeder fleets, walkability, and robust data systems. Moreover, planning must also focus on attracting and retaining users who might otherwise rely on personal vehicles.

Rapid reforms are needed in other public transport systems, like buses, to accelerate the development of electric bus feeders, intermediate paratransit, and non-motorised transport. Inefficiencies in the bus network continues to persist making buses less reliable

for daily commuters. Private buses will also have to be integrated with the overall system integration. Efforts to rationalise bus routes have faced significant resistance from private operators, particularly in monopolised routes of the Vyttila circular transport system. Nationalised routes managed by KSRTC further limits the flexibility of public-private partnerships. Bus route optimisation needs to be implemented effectively.
Shared auto services in Kochi are underdeveloped due to the lack of a supportive regulatory framework. Efforts to formalise shared auto services have been delayed, pending the outcomes of judicial committee deliberations.

Even though the KMRL has taken on the role of coordination to facilitate multi-modal integration, which is commendable; the city still requires a strong, unified transport authority for coordinated decision-making across all mode segments. The Kochi Metropolitan Transport Authority (KMTA), though established, requires more autonomy and resources as a unified body to oversee integrated transport management effectively.

A more empowered UMTA could streamline operations across different modes, address monopolistic practices, and facilitate comprehensive transport planning. KMRL is an SPV dedicated to metro rail with shareholding stake in water metro. It can be challenging for KMRL to be responsible for city-wide integration of all modes and management.

While it is notable that the Kochi water metro has become solvent enough to begin repayments within a year of operations despite a planned 20-year repayment schedule. In fact, ridership has grown steadily, reaching over three million within 18 months, but sustaining this momentum is critical.

Moreover, metro fares have remained unchanged since 2017, potentially impacting revenue generation. A balance between fare affordability and financial viability needs to be achieved to ensure long-term financial sustainability.

SRINAGAR: MOBILITY MANAGEMENT—COMPOSITE APPROACH FROM THE BEGINNING

Srinagar is one of the non-attainment cities under the NCAP, and is mandated to implement clean air action plan. However, as noted in several other cities, it is the convergence schemes and programmes such as Smart City Mission that have played a more deterministic role in upscaling the mobility and transportation initiatives.

The funding under NCAP is smaller. Between 2019 and 2023–24, total funds released to Srinagar is Rs 90.87 crore. Out of this, only Rs 28.45 crore or 31.31 per cent have been utilised. It is not clear exactly how these funds have been utilised. But with respect to the transport sector, reporting on the PRANA portal indicates central funding for electric buses under PM e-bus Sewa scheme, and some additional projects including decongestion of traffic hotspots, shifting of congested markets, and preparation of feasibility report for traffic signal management.

The key catalyst in the transport sector has been the Smart City Mission, launched in 2017 by the Ministry of Housing and Urban Affairs (MoHUA) for urban renewal and retrofitting to promote core infrastructure, and improve services by applying smart solutions. Srinagar Smart City project was approved in the Round 3 challenge held in April 2017. Srinagar is one of the 100 cities selected that has demonstrated effective leveraging of this programme for significant upscaling of the transport initiatives with appropriate planning and design that has delivered on the clean air objectives.

The massive initiative rolled out for transport and mobility management under the Smart City Mission withdrew an allocation of Rs 900 crore—ten times more than the NCAP allocation for overall clean air action. But the bearing of this project on the air quality is not reflected in the clean air action narrative.

This initiative was launched against the backdrop of increasing dependence of private vehicles leading to congestion in the central business district (CBD) area and rapidly deteriorating non-motorised transport network. This city also draws massive tourist footfall that creates additional pressure on the mobility infrastructure.

Unlike the fragmented, small-scale and limited transport and mobility initiatives in most Indian cities, Srinagar has demonstrated the value of taking a combined and composite approach to all key components of mobility including public transport systems, walking and cycling infrastructure and accessibility, multi-modal integration, public place regeneration, parking restraints, and development of waterways from the very beginning.

Strengthening the institutional framework for planning and implementation: The Smart City programme has created opportunity for institutional reforms. Like other cities under the Smart City Mission, the Srinagar Smart City Limited (SSCL), an SPV was also incorporated on September 8, 2017 under the Companies Act, 2013. But this empowered body with representatives from key departments under the Chief Secretary, Government of J&K, has played a significant catalytic role. One organisation and its dedicated planning vertical therefore could take the lead across multiple areas such as pedestrian infrastructure, ghat redevelopment, river waterfront redevelopment, public bicycle systems, and work cohesively with other mobility networks. This could take comprehensive project development approach.

This institutional framework and institutional capacity-building enabled contextual planning and prioritisation on non-motorised transport (NMT), public spaces, and local transport modes like *shikaras*; strengthened core urban mobility in central business district; built technical and professional expertise; and enabled comprehensive project development approach .

The SSCL also became one of the few cities in the country to create a planning specific vertical and to build technical and professional capacity with transport planners, urban planners, and urban designers for carrying out urban mobility projects. This has further enabled structured departmental coordination that aligned Public Works Department (PWD) for roads, Jhelum waterfront region, power development department and the telecom department for street lights, power lines and, telecom lines.

Upscaled street development and regeneration for improved accessibility and upscaled pedestrian movement: The urban rejuvenation project was designed with two verticals—area-based development and pan-city solutions. While city-wide NMT plans were prepared for the city, the CBD area was prioritised and multiple NMT projects were concentrated in this area.

The significance of this approach stems from the fact that the mobility studies in Srinagar, such as the one conducted by LEA Associates, a global consultancy and advisory group, have concluded that the average trip length in the city is less than five kilometres, much lower than Tier I cities like Delhi (10.9 kilometres), Chennai (9.9 kilometres), Bengaluru (16.8 kilometres); and Tier II cities such as Pune (7.07 kilometres) and Jaipur (5.5 kilometres). This is due to the city's small size, leading to a more compact urban layout, socio-economic practices which require less travel outside city limits, and the high influx of tourists around the year.

Parallelly, the focus remained on redevelopment of ghats along Jhelum river, Jhelum waterfront redevelopment, establishment of a formal public bicycle sharing network, and creation of public spaces across the city and along Jhelum.

Between 2021 and 2022, projects worth about Rs 600 crore were already tendered out and work had begun. By contrast, from 2017 to 2021, only Rs 170 crore worth of money was spent by the organisation out of the total Rs 900 crore.

Network of walking and cycling infrastructure with Complete Streets design: Improvement of pedestrian and cyclist infrastructure took centre stage, with over 100 kilometres of network chosen for improvement and upscaling using Complete Streets design framework to prioritise the needs of all users. This means designing streets that allocate equitable space to pedestrians, cyclists, public transit, and vehicles, while accommodating people with disabilities.

Safety is a key focus, with features like wide sidewalks, protected bike lanes, safe crossings, pedestrian islands, and traffic-calming measures to reduce accidents and conflicts.

The design promotes multi-modal integration, ensuring seamless connectivity between different transportation modes. This includes dedicated bus lanes, bike parking at transit hubs, and shared mobility zones. The central business district was chosen as the priority area. This includes the Lal Chowk area, Maulana Azad Road, Residency Road, Polo View High Street, to name a few.

The design elements for these roads include a multi-utility corridor to accommodate electrical and civil utilities, a uniform central verge or median with landscaping, widening of footpaths, addition of a cycle track, addition of parking bays for paid on-street parking, pedestrian crossing and kerb ramps, and tactile tiling for differently abled.

In the vicinity, road stretches such as Hari Singh High Street and Goni Khan Maharaj Bazar Street were also chosen to follow the same street layouts. Since these areas are also

Table 1: Ideation of projects was done with the following principles in mind

Complete Streets design	Redevelopment of public spaces (Jhelum waterfront and ghat restoration)
• Pedestrianisation with universal access • Cycle tracks with introduction of public bicycle sharing (PBS) system • Uniform carriageway design • Utility rationalisation • Junction improvement • Road signage	• Traffic-free zones • Green spaces • Seating spaces • Play zones • Illumination and lighting • Façade improvement
Improved physical integration between spaces (alongside NMT network)	Improved urban mobility services (alongside NMT network)
• Bridges • Kerb ramps • Table tops	• E-rickshaw • E-buses • E-boats

Source: SSCL

popular market destinations, addition of multi-utility zones to include vending zones, and pedestrian friendly infrastructure such as street furniture was also done. The old Srinagar area was identified to be redeveloped and integrated with the CBD redevelopment network. Interventions included façade upliftment, cobbling of inner streets as a soft-measure to pedestrianise and reduce bypassing vehicular traffic, and redeveloping major roads to follow the Complete Streets design formula. Some of the roads in the area which were redeveloped are the Nallah-E Mar Road, Zaina Kadal Ali Kadal Road, and Jamalatta Nawa Kadal Aali Kadal.

Development of public spaces: The choice of areas to develop or redevelop as public spaces was strategic and built around either the Jhelum river, or along the redeveloped street network to make streets more NMT friendly. Srinagar's Lal Chowk with its iconic clock tower, and a major socio-cultural hub, was taken up for rejuvenation to make it more pedestrian friendly, by redeveloping the NMT infrastructure. It is adding textured pavement to restrict and calm vehicular traffic, adding bollards for pedestrian and cyclist safety, redesigning the central plaza which was previously unused due to haphazard parking along its circumference, leading to blockages for both shops and pedestrians, and redesigning the famous clock tower (colloquially called the "ghanta ghar") to a fresher, more modern aesthetic.

Jhelum waterfront development: The composite approach included the Jhelum waterfront redevelopment project—the biggest ever public space transformation. The waterfront redevelopment included landscaped ghats, pedestrian-friendly pathways, and public spaces, blending heritage conservation with modern amenities. This transformation has improved accessibility, promoted tourism, and created vibrant community hubs along the river. Work on the left bank has finished and on the right bank is in progress. Such transformation contributes towards zero emission commuting.

Before and after—Complete Streets design in CBD area

Maulana Azad Road

Residency Road

Polo View High Street

Photos: SSCL

Proposed road layout and design view for Goni Khan Maharaj Bazar Street

Photos: SSCL

Existing and proposed—Complete Streets design in Seher-E-Khas area

Nallah-E Mar Road

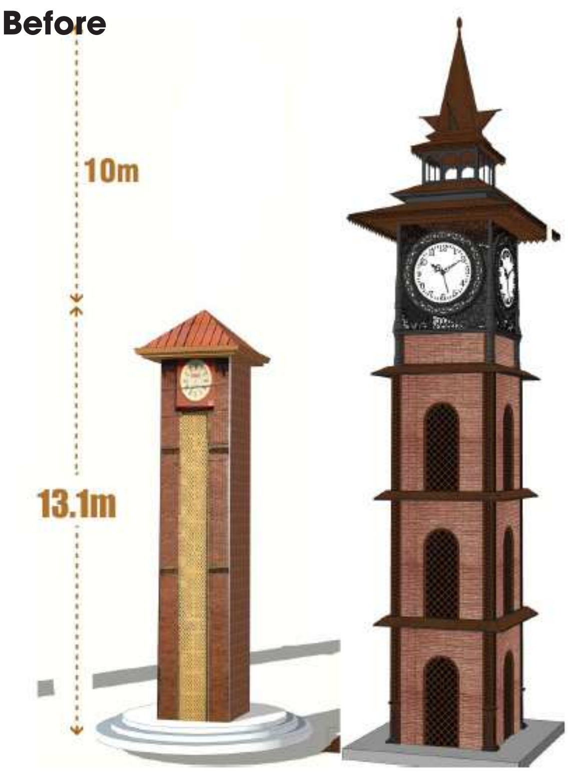
Zaina Kadal Ali Kadal Road

Photos: SSCL

Jamalatta Nawa Kadal Aali Kadal

Lal Chowk redeveloped—After completion

Lal Chowk



Ghanta Ghar (clock tower)

Photos: SSCL

Jhelum waterfront redeveloped (left bank)—After completion

Complete Streets design principles incorporated along the bank

Reclaimed land from the bank used for widening pedestrian walkways, providing cycle tracks and landscaping

Street furniture and gazebos created for the community and tourists

Inauguration welcomed by the residents

Photos: SSCL

Shehr-e-Khas area also saw massive redevelopment of public spaces, especially around ghats. SSCL chose a catchment area of 300–500 metres around the ghats for interventions, which included cleaning, reconstruction, remodeling, restoration, and provision of amenities such as ticket counters, vending kiosks, street furniture and seating areas, ramps and tactile pavements for accessibility, landscaping, signages, among others.

Since the ghats are also anticipating arrival of electric boats to operate on water transport routes, e-boat charging infrastructure was also provided. These ghats fall along the river edge in Sheher-e-Khas. Dukaan-e-Sangeen Ghat and Pathar Masjid Ghat are two examples. These spaces prioritise walking and cycling by incorporating dedicated

Redevelopment and restoration of Dukaan-e-Sangeen Ghat and Pathar Masjid Ghat along Jhelum in Sheher-e-Khas
Photos: SSCI

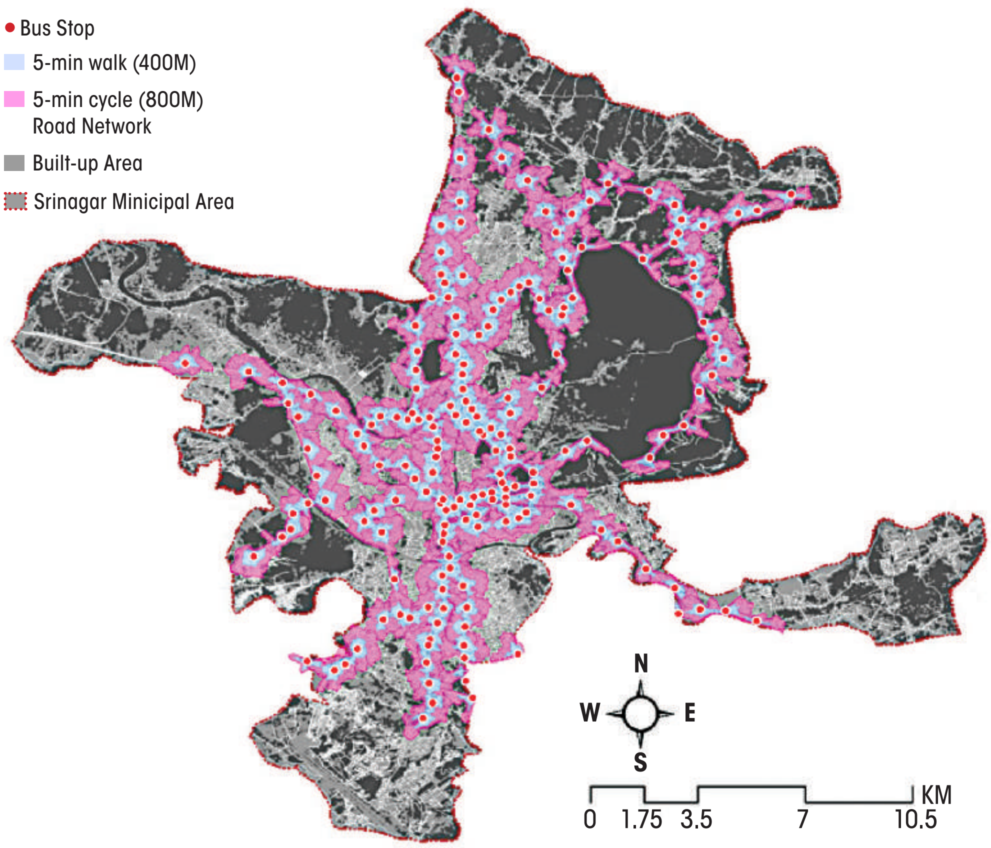
pathways and shared zones, creating a safe and attractive environment for NMT users. The integration of electric boats at redeveloped ghats further supports sustainable transit by offering eco-friendly options that seamlessly connect with walking and cycling routes. By reducing dependency on motorised vehicles, these initiatives not only promote greener travel but also address congestion in sensitive urban areas.

Integrating electric mobility—Electric bus-based public transport: Urban redevelopment and rejuvenation was combined with electric mobility to maximise benefits. Prior to the introduction of electric buses, Srinagar's intra-city public transport system was predominantly operated by private bus operators who operated minibuses and larger buses on fixed routes. The system faced challenges of irregular schedules, overcrowding, and aging of vehicles—making the system less reliable.

The SSCL supported a study by LEA Associates that estimated that the city would require at least 250 buses to cater to the additional demand. SSCL therefore planned to operate a public bus service, comprising of electric buses. A trial run of six e-buses procured under the smart city project was conducted.

Following this, in November 2023, a fleet of 100 electric buses were inaugurated for city bus services under SSCL's vertical. These buses were initially planned to operate on 11 intracity routes and two intercity routes, which has now increased to 16 routes in the region, out of which ten routes are intercity, running back and forth between Jammu and Srinagar; and 6 routes are intracity. The 100 buses were procured as per a gross cost contract (GCC) model based on a period of 12 years of operation. These include 75 buses that are nine-metre long with 200-kilometre range, and 25 buses that are 12-metre long with 220-kilometre range. In real world operations, the range varies between 150–165 kilometres. These were cost-effective as these could be procured at Rs 48 per kilometre (for 9-metre buses) and Rs 55 per kilometre (for 12-metre buses). Innovatively, these buses

Map 1: Electric bus routes in Srinagar operated by SSCL



Source: Prepared by CSE using SSCL data

are equipped with a heating, ventilation, and air conditioning (HVAC) system that can heat the bus.

The new bus system could immediately create a ridership of three to five lakh passengers. The bus numbers are still limited with frequency of 15–30 minutes that leads to low average daily ridership of 60,000 passengers. To address this, the SSCL plans for 100 more buses under the PM E-Bus Sewa.

Further service-level improvements have been possible with tracking and payment solutions to operators. If the service levels are below the standards set by SSCL, a penalty mechanism is in place. The focus is on improving schedule adherence, frequency of buses, especially during peak hours. Currently there is only one depot in Srinagar with the chargers, which increases the dead kilometres. More locations are being planned with opportunity charging. About 360 more new bus stops are being constructed that will have public information system (PIS).

The substantial improvement is evident in the service coverage analysis of the network, which shows 19 per cent of the built-up area is accessible on a five-minute walk (400 metres), and 59 per cent of the built-up area is a five-minute cycle ride away from accessing the bus system. This also suggests that users may need to rely on intermediate modes, such as cycling or informal transport, to access the bus system efficiently. Expanding service coverage through additional routes or optimising stop locations could improve accessibility and encourage greater public transport usage.

Electric bus fares in Srinagar are notably low. especially for longer distances. Srinagar prioritises cost accessibility, potentially as a strategy to boost ridership and encourage public transport use.

Integrating water transport with land transport: SSCL is leveraging the inherent strength of the water transport in Srinagar and is procuring 32 electric boats under gross cost contract model (GCC) to integrate interconnected water transport routes close to 80 kilometres in total in the Jhelum river and the Dal Lake. For boarding and alighting, restoration of 45 ghats have been carried out to provide amenities including ticketing system and charging infrastructure of the boats. This is in the tendering stage. The boats will operate on five routes, three of which will cover the Dal Lake. Currently, about 2,500 shikaras are operating in the lake for tourism purpose and not for public transport.

A common mobility card for payments, called the National Common Mobility Card (NCMC), can be used for payments both for the water transport e-boat service and e-bus service, as measure for fare integration between the two. The card was conceived by the MoHUA under "One Nation, One Card" and launched in 2019. The water transport routes are also integrated with bus routes and bus stops for physical integration between the two modes.

Integrating public bicycle sharing (PBS), public electric bicycle sharing (PeBS), and e-rickshaws: Further leveraging is seen in the integration of the public bike sharing system. This is a network of 200 docking stations built near ghats, bus stops, and at newly developed public spaces and street network to inculcate the use of non-motorised transport for regular trips and as first- and last-mile for public transport trips. The stations have a mix of manual and pedal-assisted (electric) bicycles. There are 1,100 bicycles in the network, out of which 200 are pedal-assisted. Pedal assisted bicycles can be both pedaled or driven manually. The range of the electric bike is between 35 and 60 kilometres, and rental prices can range based on the required specification by the consumer.

The manual chartered bikes can be rented on the Chartered Bike app. These docking stations do not have personnel to assist, and instructions on renting the bike are available at each station. Locks are built into the vehicle which can be controlled using the app. Curve docking stations have personnel assigned, who assist with the renting process, as well as in an event of faulty equipment, which is promptly addressed by replacing the cycle. Battery swapping is available at each docking station in case the battery depletes. Both cycles have an on-board GPS based tracing system.

Manual chartered cycle and curve electric cycle at docking stations.

SSCL also has formalised the e-rickshaw segment to act as a feeder for public transport. However this was not a standalone project of SSCL, and was done in partnership with the district administration. In this project, 750 e-rickshaws are to be employed to 55 routes, which were prepared by SSCL as per the planned and existing public transport routes. Out of these, about 600 are already plying in the city.

Vehicle restraint measures: It is notable that at the early stages of planning and implementation, Srinagar has also integrated parking as part of the overall plan to initiate locally appropriate parking management area plans and priced parking that can act as a restraint measure.

It is important for other cities to understand these design features for implementation. As part of the Complete Streets design, parking spaces were allotted next to pedestrian infrastructure after leaving offsets on both sides as pedestrian islands for carriageway access to pedestrians to cross the streets. On-street parking at each location is managed and is paid parking, that generates parking revenue.

On-street parking is a lot more expensive than parking in off-street spaces, which has led to reduction in on-street parking pressure. On-street locations allow parallel parking only, which further leads to reduction in number of available parking slots on the roads.
Another important step is provision of textured pavement at all developed public spaces and plazas on roads which allow both pedestrian and vehicle movement. This is a more subtle yet effective measure, which act as a natural deterrent to speeding, making drivers more cautious. Provision of such infrastructure also takes away the sense of entitlement from a motorised vehicle driver on the road, and makes them give precedence to pedestrians.

Impact of the interventions in Srinagar: It is notable that the impact of the wide-ranging interventions and a composite approach taken to include all aspects of transportation systems (road-based and waterways) and mobility strategies (walking, cycling, public place rejuvenation, parking management, etc.) is showing up. It has not only improved public transport ridership and footfalls in regenerated areas, but also catalysed redevelopment and private sector-led revamp of areas and buildings.

It has not yet been possible to quantify the full impact in terms of increased footfalls and ridership of public bike sharing, bus transport and waterways. But limited data and anecdotal evidence indicate appreciable change. As noted earlier, the shift from informal, unorganised minibuses to 100 modern, zero emission electric buses marks a major upgrade. Within the first month of its introduction, it served five lakh passengers, and in the next eight months served another three lakh passengers. However, more work is needed to improve the service level—current frequency is between 15–30 minutes. It is possible to increase the ridership from the current average daily ridership of 60,000 passengers.

In fact, the composite initiatives have also triggered a wave of redevelopment initiatives and investments by private players. Business owners along the upgraded corridors have renovated older structures, aligning building façades with the area's improved aesthetic. The newer façades have also let the owners to delve into more lucrative business opportunities.

New establishments were acquired by private companies for business opportunities along the redeveloped areas. One prominent example is the initiative shown by the Radisson, to buy a property on the left bank of the Jhelum river, after the water front development was complete, for constructing into a hotel and spa. The commercial property was previously disputed and abandoned, and was losing out on the potential of tourist influx in that area.

Business hours have increased by 3–4 hours; it was observed earlier that shops were closing down due to lower footfall of shoppers after 6–7 PM, while currently shops remain open till 10 PM.

On the left is on-street parking as part of Complete Streets design; and on the right is off-street parking location managed by Parkadda.

After the ghats were restored, Uber took an interesting initiative of introducing shikara bookings online on their app, at competitive pricing with traditional shikara owners. Booking on an aggregator app is laced with other safety features such as tracking the ride, grievance redressal in case of emergencies or lost personal belongings, and so on.

House boats have been a part of Srinagar's identify and tradition since the 19th century during the British colonial period. At that time, the Dogra rulers of Jammu and Kashmir prohibited foreigners from owning land in the region. To circumvent this restriction, British officials and visitors began constructing houseboats on the lakes. Today these boats are occupied by locals, and most provide lodging services for tourists.

To keep the tradition intact, SSCL during the inception of its water redevelopment project also planned to reconstruct the stairs which lead to these houseboats; a simple gesture that is the definition of inclusive planning, which has now led to the residents of these floating homes landscaping these entrances to the boats, adding an aesthetic flavor to the bank.

Emissions benefits: Due to a lack of detailed data on the impact on walking and cycling, use of waterways and other interventions, it is not yet possible to estimate the detailed emissions benefits. However, it is possible to estimate how the increase in electric bus fleet has contributed towards the co-benefits of reduced particulate matter and heat trapping carbon-dioxide.

With a daily ridership of approximately 60,000 passengers, the buses operate across 16 routes, helping bridge mobility gaps in a city where most trips occur in the central business district. CSE has estimated the environmental impact of this electrification initiative through two lenses: emissions avoided from (i) fleet electrification and (ii) modal shift to electric buses.

The deployment of electric buses in 2023–24 resulted in annual emission reductions of 0.03 tons of tailpipe PM, 4.4 tons of tailpipe NOx, and 4,401 tons of overall (tailpipe and grid) CO_2. In 2024–25, with the expanded fleet, an additional 0.01 tons of PM, 1.2 tons of NOx, and 1,241 tons of CO_2 were avoided.

Assuming a daily ridership of 60,000 passengers and average trip length of five kilometres, to estimate modal shift benefits, two scenarios are considered—the lower bound assumes users previously relied on small BS-IV diesel buses, autos, cars, and two-wheelers in proportions reflected in the 2017 Comprehensive Mobility Plan (CMP). The assumed modal share for this scenario is 40 per cent small buses, 15 per cent autos, four per cent two-wheelers, seven per cent cars, and 34 per cent walking or NMT (excluded from emissions calculation).

The upper bound assumes a greater shift from personal and para-transit vehicles, using the following assumed modal share: 30 per cent small buses, 20 per cent autos, 20 per cent two-wheelers, 10 per cent cars, and 10 per cent walking or NMT.

Economic and social instances of impacts of city-wide mobility interventions

Creation of new business opprotunities and livelihoods for locals after waterfront redevelopment


Uber saw an opportunity to invest in water transport in Srinagar after ghat revamp


Houseboat owners reciprocating the initiative of "inclusive planning" and revamping areas around the bank

Revamped building façades in Lal Chowk to add lucrativeness to the business

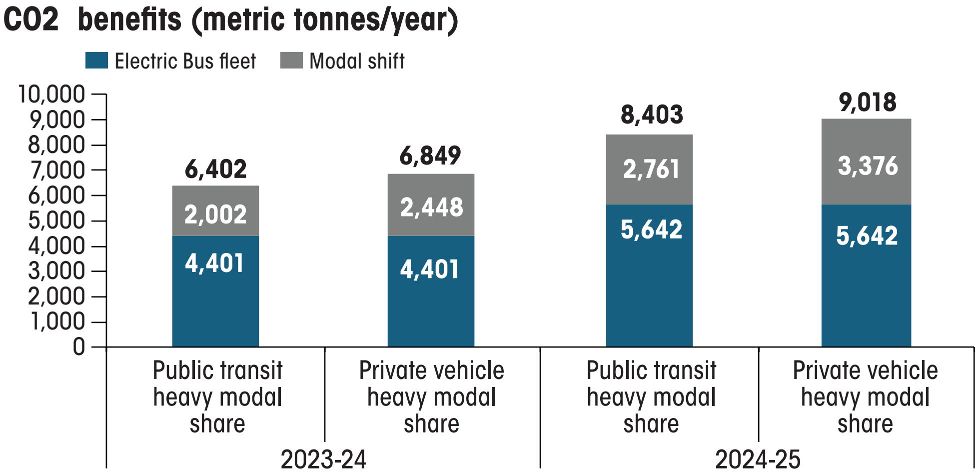
The combined benefits of fleet electrification and modal shift in Srinagar are significant. When accounting for both the shift from polluting modes and the lower carbon intensity of electric buses, the city avoids between 8,403 to 9,018 tons of CO2, 19 to 22 tons of NOx, and 0.3 to 0.5 tons of PM annually. This is happening even though the local electricity grid emits only 200 g CO_2/kWh because around 67 per cent of the electricity consumed by the city is hydro and RES based.

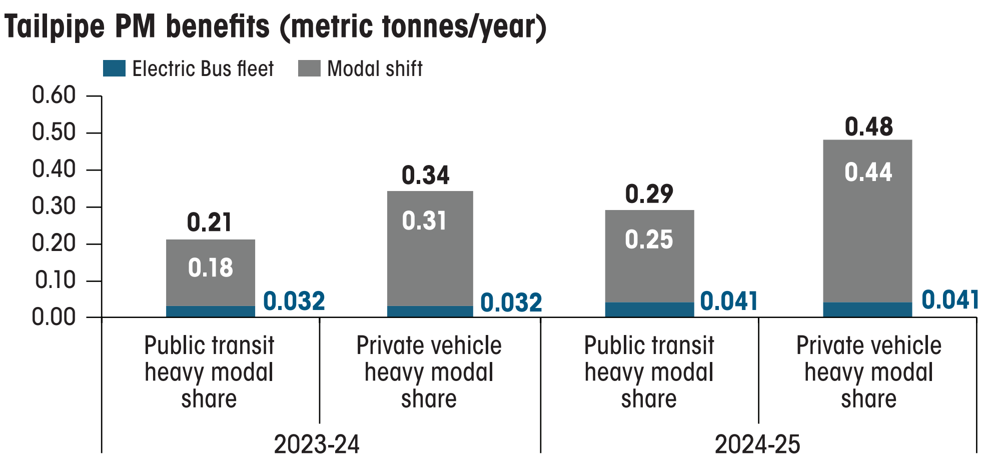
These benefits are particularly impactful in a geographically constrained and ecologically sensitive urban area like Srinagar, where air quality and environmental preservation are of paramount concern. (See *Graph 4: Emissions avoided due to ZEV buses in Srinagar*)

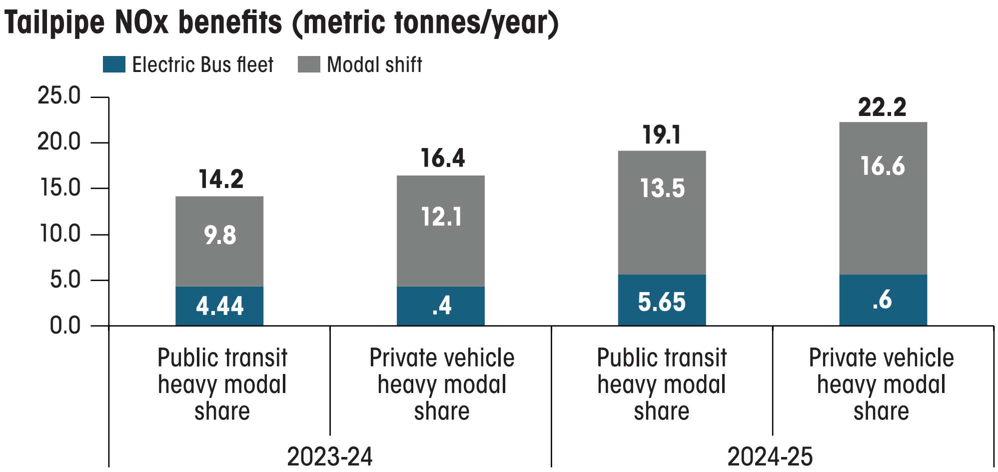
These reductions contribute directly to improved air quality, public health, and climate mitigation. The results highlight the potential of electric mobility in small and mid-sized Indian cities, especially when paired with compact urban forms and targeted infrastructure improvements. To build on this momentum, future expansion of the fleet, operational efficiency such as the development of new depots and reduction of dead kilometres, and continued non-motorised transport (NMT) integration will be key to deepening impact.

Public outreach and public participation: Public participation and consultation were deemed crucial before implementing street redesign and public space development projects in a city like Srinagar. Engaging stakeholders, including shopkeepers, commuters, and local businesses, fosters a sense of ownership and trust in the proposed changes, reducing

Graph 4: Emissions avoided due to ZEV buses in Srinagar







Source: CSE analysis

resistance during implementation. Public input can highlight seasonal mobility patterns, such as the impact of harsh winters on transportation, for creating resilient and context-sensitive designs.

Multiple rounds of consultation particularly with the traders' associations and business owners in the areas of intervention helped to diffuse opposition. These groups were initially reluctant to cooperate, claiming business will be impacted massively if parking removed and vehicle restrain measures tightened. The resistance was especially strong in areas which were going to not allow vehicles to enter at all, such as the Polo View High Street pedestrianisation zone.

Similarly, citizens in general were also consulted on various projects across the city via a perception survey event called "Sundays for Srinagar". Project proposals were put on display at different locations in the city, especially along the riverfront, showcasing the before and after images rendered on design software for comparison. This positive communication loop saw multiple stakeholders from other regions in the city to come up asking for similar redevelopment in their areas. The Lal Chowk area, which was initially not part of the list of areas of intervention also came forward. The stakeholders thus became enablers.

REINVENTING BUS TRANSPORT

Public transport especially bus transport and multi-modal integration are included in the reporting parameters provided by the CPCB to track progress in implementation of mobility strategies. Within this framework, the bus systems and deployment become important, as these are the spine of public transport due to their flexible operations that connect diverse set of neighbourhoods to meet the dynamic and changing travel demand across different land-uses. This has the strongest potential for provisioning of clean and zero emission mass commuting in cities with effective air quality benefits.

Yet in most cities, bus transport reforms draw little attention as a clean air action. There is usually sporadic reporting on the number of new buses purchased including electric buses under different central and state government schemes. The strategies for implementation are not defined in full scope to cover the key service-level benchmarks needed for developing infrastructure and systems and therefore leveraging of the funding needed. Accordingly, institutional and financial strategies are not worked out for long-term sustainability at the state level.

Only in few cases the same central government schemes and funding like the demand incentive support for the electric buses or limited instances of state government support are better leveraged for effective reforms and augmentation of the systems and services.

It is this learning that is important for all other cities that have invested in bus transport. Often cities lack the perspective, approaches, and planning strategies to have a cohesive approach to improve bus transport and ridership. This needs to be addressed as bus transport despite being a clean air solution, is under enormous financial and operational stress. Growing losses of bus ridership across all state transport undertaking is symptomatic of this challenge. If this is not fixed, then increasing investments in electric buses cannot help to deliver on clean air as with reduced ridership only empty kilometres will increase.

The bigger challenge is that bus transport despite being a state government subject, has not received adequate financial or regulatory support to strengthen the system. In most cases, buses are operated with minimal service level governed by permit system and revenue earning requirements. Systems and infrastructure are not planned adequately for overall service improvement despite the installation of central government backed ITS systems for improving service operations or central government guidelines on service-level benchmark.

Given the enormous resource requirements for the bus infrastructure development, the 15th Finance Commission fund alone cannot cater to the requirement. But it can make conditional demand for reforms by tying up a part of the funding with strategic requirements. The NCAP led funding can leverage convergence funding from other programmes and private sector to demand a cohesive roadmap for rebuilding bus systems and services.

This also requires clarity about the scope and scale of bus system reforms and road map development in cities. This can be guided by the good practices and customised and innovative local area solutions that are emerging in a few cities that are both NCAP or non-NCAP cities. There is a mix of case studies that include some of the older and established bus systems like Mumbai, Bengaluru, and Gujarat cities like Ahmedabad and Surat who have legacy advantages of long-term reforms and of taking an eco-system approach as well as initiating more recent and incremental innovations to meet the newer demands. There are also cities like Bhubaneswar that do not have legacy advantage but have initiated new and cohesive systems with success and innovation. Some cities may not have demonstrated a cohesive approach but may have demonstrated innovative service or a fiscal strategy that provides and important learning.

All cities need to develop a framework for overall ecosystem improvement in bus systems and infrastructure for service level and leverage NCAP along with other funding sources to upscale implementation.

MUMBAI AND NON-ATTAINMENT CITIES OF MAHARASHTRA: LEVERAGING CLEAN AIR FUND TO UPSCALE ELECTRIC MOBILITY

Urban local bodies (ULBs) in charge of public transport: Among the 17 non-attainment cities in Maharashtra, the million-plus urban centres that received funding under the 15th Finance Commission have effectively leveraged clean air grants to scale up their electric bus programmes. This has been possible in Maharashtra primarily because municipal corporations are empowered to run buses backed by the Maharashtra Municipal Corporations Act, 1949. This Act provides the legal framework for establishing and managing municipal corporations, including their role in public transport. The State government also devolves powers and responsibilities to municipalities, allowing them to implement schemes for various functions, including transport.

Therefore, the direct routing of the 15th Finance Commission fund to the municipal corporations has created opportunity to link that funding with bus transport augmentation based on electric buses. This has been a win-win.

It is reported that about 80 per cent of the total 15th Finance Commission fund and the state has been earmarked for electric buses and requisite infrastructure development. The three big cities of Maharashtra—Mumbai, Pune and Nagpur—have got the maximum funds, Rs 938.59 crore, Rs 271.3 crore, and Rs 142.05 crore respectively. This is over and above what these cities have received under the FAME II and PM e-bus Sewa programmes.

Table 2: Funds released and utilisation under XV-FC, 2020–25 (as of May 16, 2025)

Cities	Fund released (in crores) 2020-25	Fund utilised (in crores)	Fund utilisation (per cent)
Mumbai	938.59	574.64	61.22
Pune	271.3	222.57	82.04
Thane	78.13	NA	NA
Aurangabad	68.3	54.44	79.71
Nashik	91.55	50.43	55.08
Nagpur	142.05	69.59	48.99
Nashik	1.55	50.43	55.08
Ulhasnagar	2.1	22.52	1072.38
Vasai-Virar	72.35	71.38	98.66
Navi Mumbai	9.45	52.92	>100.00
Badlapur	2	8.91	>100.00

Source: PRANA portal

While most NCAP cities have utilised the15th Finance Commission's air quality grants largely for stop-gap surface-level pollution abatement strategies and enforcement including dust control, like mechanised road sweeping, water sprinklers, or constructing traffic infrastructure, among others, Maharashtra has taken a different path.

This demonstrates prioritisation of focused strategies for a scalable impact especially in the combustion sector.

15th Finance Commission fund augments electric mobility: The catalytic role of 15th Finance Commission fund in upscaling of the electric bus programme is evident in the experience of the Brihanmumbai Electric Supply and Transport (BEST) undertaking which has spearheaded one of the largest municipal electric bus procurement programmes in the country. This is of a bigger scale than that of the other Maharashtra cities who have also utilised their funds for electric bus programme.

The BEST, though an autonomous body, operates under the broad financial and administrative purview of the Brihanmumbai Municipal Corporation (BMC), which has routed the clean air fund to BEST. Mumbai's electric bus journey began in 2017–18 with a modest start—six electric buses were purchased outright with Rs 10 crore of capex support from the BMC. These buses were primarily intended to test the feasibility of electric bus operations.

Under the Government of India's FAME I scheme, BEST began to adopt the Gross Cost Contract (GCC) model—primarily a wet lease mechanism in which operators take on the responsibility for vehicle procurement, maintenance, charging infrastructure, and driver salaries; while the government pays per-kilometre charges. Forty buses were added under this model. With FAME II, a more ambitious phase in 2021 brought in 340 additional electric buses through demand incentives, cost subsidies, and infrastructure support. This demonstrates effective on-ground deployment of these central incentives.

However, the most transformative step was taken in 2022, when BEST, backed by the BMC, decided to use its NCAP allocation under the 15th Finance Commission to fund the electric bus procurement incentives to operators under the state electric vehicle policy. Of the Rs 992 crore earmarked for Mumbai under the 15th Finance Commission's clean air fund, Rs 493.38 crore has already been transferred, and Rs 268 crore has been committed to procure 560 single-decker and 50 double-decker electric buses through GCC contracts. The remaining funds, together with the current procurement, are expected to add a total of 2,100 single-decker and 200 double-decker buses to BEST's bus fleet. This will add up to lead to 50 per cent electrification of the bus fleet.

State-level initiative keeps procurement affordable: The current fleet size of BEST stands at 2,683 buses, out of which around 900 are electric. Only six of these electric buses are owned outright—the rest are operated under the GCC model. Notably, BEST has opted not to join CESL's centralised procurement strategy of demand aggregation, preferring instead to float its own tenders, benchmark prices independently, and set contractual terms best suited to Mumbai's unique operating conditions. This autonomy has allowed it to optimise efficiency and ensure that contract costs remain low even three years into operations.

Each electric bus is supported by financial incentives under the Maharashtra State Electric Vehicle Policy—Rs 17.5 lakh for single-decker and Rs 19.5 lakh for double-decker buses. The incentive is structured in tranches—20 per cent disbursed at contract signing, 40 per cent at delivery, and the final 40 per cent after six months of successful operation. The winning bid for the tender quoted Rs 46.81 per kilometre. This is significantly lower than the operational costs of diesel (Rs 70 per kilometre) and CNG (Rs 80 per kilometre) buses. Without incentives, the submitted bids were around Rs 56 per kilometre, underscoring the critical role of state-supported incentives in bringing prices down. Importantly, the bid covers all lifecycle costs—electricity, drivers, maintenance, and even battery replacement, which typically occurs after six to seven years due to degradation.

Under the GCC model, the OEMs are responsible for every aspect of the bus's lifecycle, including driver salaries and the cost of electricity. The two manufacturers awarded contracts were Olectra for single-decker, and Switch Mobility for double-decker buses.

Charging is done at depots, and route planning ensures that most buses can return to their base mid-day for two to three hours without needing in-route opportunity charging. This is possible because majority of BEST routes are short—largely serving as feeders to the suburban rail and metro systems—and the real-world range of the buses is upwards of 260 kilometres per full charge, well beyond the minimum requirement of 200 kilometres at 80 per cent state-of-charge specified in the contract. BEST has set a target of 100 per cent electrification with additional plans to scale further.

Despite these successes, challenges remain. Congestion continues to reduce operational efficiency and leads to energy loss due to SOC depletion in traffic. Another significant hurdle is the slow delivery rate of electric buses. OEMs face difficulties scaling up production because of semi-automated assembly lines and global supply chain disruptions—issues made stark during the COVID-19 pandemic and in conflict-affected regions where key components are sourced.

The original target was to deploy all 2,300 buses by the end of FY 2023–24, but delivery delays have already pushed timelines by over a year. Additionally, as ridership in Mumbai surges, touching 30 to 35 lakh passengers daily, the demand for more buses, particularly those integrated with the expanding metro system, has intensified.

BEST's vision for the future is ambitious. By 2027, it aims to expand its electric fleet to between 6,000 and 8,000 buses. It has also set a target of 100 per cent electrification of the bus fleet. The expansion of Mumbai metro lines and the integration of feeder routes are expected to increase bus ridership even further, making electric buses an indispensable component of Mumbai's public transport backbone.

The groundwork laid through NCAP funding, coupled with strong municipal and state-level policy support, has created a blueprint that other Indian cities can replicate. Instead of treating clean air funds as one-off grants for cosmetic interventions, Maharashtra has turned them into long-term investments in sustainable public mobility. By using NCAP as a financing instrument to electrify public transport, the State has not only aligned climate, health, and transport goals—but redefined what clean air action can look like in India's cities.

BENGALURU: BUILDING ON LEGACY STRENGTH TO PUSH FORWARD BUS REFORMS AND ELECTRIFICATION

Bengaluru is a non-attainment city under NCAP. The city is also in the grip of high pollution and crippling congestion that reflects heavy dependence on personal vehicles, insufficient public transport coverage, and limited support for last-mile connectivity and non-motorised mobility options. This leads to a range of negative consequences—from productivity losses and increased fuel consumption to higher emissions and deteriorating quality of life for residents.

Despite the odds, Bengaluru has built its legacy strength to expand its bus transport systems that has gone through successive stages of reforms over time to improve the level of service, and also maintain solvency. While this initiative holds promise of reversing the modal share in the city and contain congestion, its effectiveness will also depend on the supportive measures to restrain personal vehicle usage.

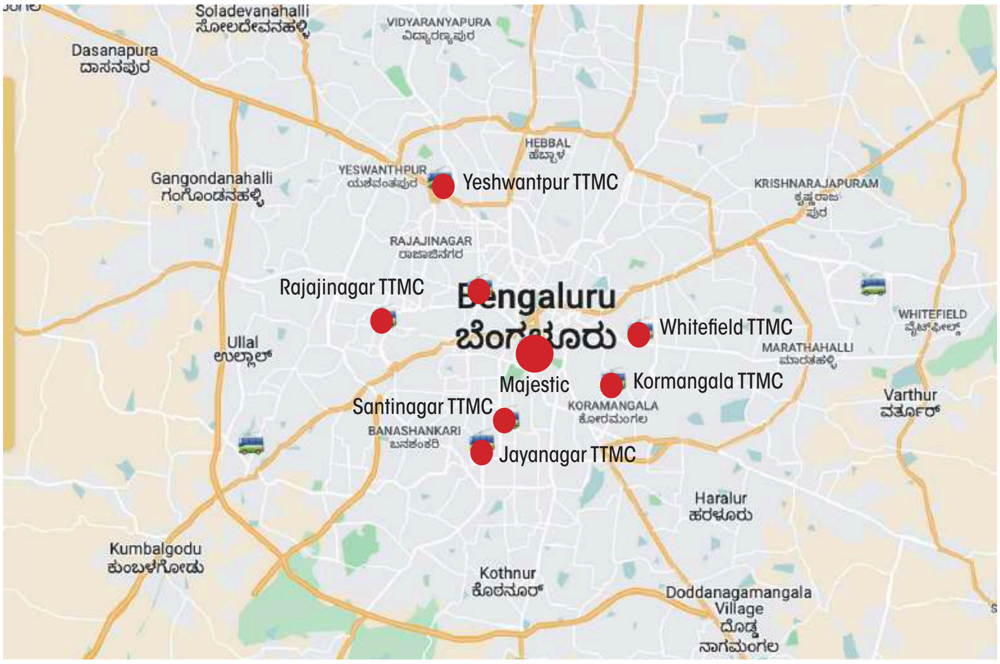
The Bengaluru Metropolitan Transport Corporation (BMTC) which is one of the three subsidiaries of Karnataka State Road Transport Corporation, has been at the forefront of this transformation. BMTC is the sole public bus transport provider for Bengaluru, serving urban, sub-urban and rural areas. With a fleet of over 6,500 buses and operating around 50 square kilometres of the city, BMTC is a critical component of Bengaluru's public transport ecosystem.

Route distribution model and requisite infrastructure development: The BMTC route model operates a mixed route system combining hub-and-spoke and point-to-point services to enhance coverage and ridership. There are ten traffic and transportation centres (TTMC) that act as hubs for the city where the passengers can interchange the buses to reach their respective destinations. The TTMCs strategically located across Bengaluru are designed to handle high passenger volume, and to act as an interchange for buses. These centres serve as key nodes that facilitate seamless connectivity between different parts of the city. These centres also house facilities for ticketing, passenger inquiries, and scheduling, ensuring a commuter-friendly experience. They are also sources of revenue from renting out of office spaces and eateries designed and integrated in the facilities.

Dynamic response to changing urban conditions: Over the years, BMTC has launched route rationalisation efforts to eliminate underperforming routes and reduce redundancy in the network. This is particularly important as the city's population grows, and some routes may overlap or no longer serve the changing patterns of commuter demand effectively. BMTC also, from time to time, takes professional help to rationalise its routes.

The rationalisation of the Big 10 routes was taken up in 2016 to optimise the service. The objective has been to improve operational efficiency, increase coverage, and better serve the needs of commuters by focusing on high-density areas and major city hubs. Routes were carefully restructured to provide faster connectivity between important locations such as business districts, residential neighbourhoods, IT hubs, and educational institutions.

Map 2: BMTC's route distribution model: hub-and-spoke



Source: BMTC

BIG 10 buses

Vayu vajra: Airport service

Ordinary or black-board buses

Vajra services: AC services

Source: BMTC

Big 10 routes (G1 to G12), connect the central business district with the suburbs. Each route runs on one main road for the full length, whereas Big 10 routes (B3), runs through the city centre, connecting a main road on one side of town with the corresponding other side.

As a result, the BMTC Big 10 buses now serve as key transportation corridors, offering fast and reliable travel with fewer stops and high frequency. Some of the most popular routes include Route 201, connecting Majestic to Whitefield; Route 500, linking Kempegowda bus station (Majestic) to ITPL; and Route 325, which connects Kempegowda bus station to Jayanagar. The rationalisation of these routes also focused on making the service more accessible and user-friendly, ensuring that passengers could easily reach important areas without long delays.

BMTC's buses operate in a hub-and-spoke model, with few point-to-point services, with major transit hubs serving as central points of connectivity to a series of smaller, suburban routes. Further, it also shifted a portion of its resources to shorter, high-frequency routes including 30–35 kilometres and 10–12 kilometres of average route lengths for 12-metre buses and nine-metre buses respectively.

HSR bus routes: Community-oriented solutions

The BMTC feeder bus services in HSR Layout are a proven case for community engagement in the public transport initiatives. The government organisations involved the community in implementing a solution that is needed for the community. The HSR Citizen Forum (HCF) and HSR Cyclists Group (HCG) played pivotal roles in shaping the intervention, anchoring it in local needs and priorities. This initiative is city's first intra-neighbourhood service in the city.

This feeder services were launched under the Directorate of Urban Land Transport (DULT) Sustainable Mobility Accords (SuMA) initiative. Household survey indicated that about 96 per cent of respondents faced difficulties in accessing public transport facilities. HSR team conducted a neighbourhood level community consultation. Feeder bus service loop in HSR Layout connecting all the sectors emerged as a top choice.

It was eventually taken to DULT by HSR team and DULT conducted local area mobility parameters (LAMP) audit in the neighbourhood and suggested BMTC to provide feeder bus services in the layout. However, BMTC was initially not convinced to operate buses in the neighbourhood, expecting losses in the services while looking at its socio-economic profile as it is one of the elite class residential neighbourhoods in the city. Therefore, DULT offered financial help through viability gap funding (VGF) for the services.

On August 1, 2023, the BMTC feeder bus service was launched on loop service route HSR-FDR-1 and 1A (HSR feeder) in clock and anti-clock wise directions with a route length of around right kilometres. The origin and destination

points of route is Agara bus stop on outer ring road (ORR) with 18 stops on each direction. It is connecting all the sectors of the neighbourhood (intra-neighbourhood) and connecting with major BMTC transport nodes at Agara and Mangammanapalya to connect other parts of the city (inter-neighbourhood).

The route is operating with 168 full trips daily with ten nine-metered non-AC buses with a peak time and off-peak frequency of ten minutes and 15 minutes respectively. The bus fare was fixed flat of Rs 10 and allowed the rules of Shakti Scheme to avail free services for women passengers.

HSR team initiated campaigns. The key innovative strategies are broadcasting the feeder services by utilising the BBMP garbage pickup autos which reached every doorstep of the neighbourhood, awareness campaigns in schools and colleges, public campaigns, poster campaigns at public spaces including government offices, shops, restaurants, temples, parks, etc., promotional bus ride with local MLA, street plays, social media campaign, among many examples.

This increased the use of feeder bus services in the neighbourhood over the months to 1.21 lakh ridership per month in June, 2024 from around 45 thousand in its inception in August, 2023. It reflects around 200 per cent increase of ridership within a year of time. DULTs technical and financial support and BMTCs operational support and Bengaluru Traffic Police (BTP) support were enablers.

Photos: hsrcitizenforum[6]

Towards integration—Metro feeder services and integration with Namma metro: Since the metro has been in place in the city, metro feeder buses have been introduced by eliminating some long bus routes. This connects key areas of the city with metro stations, creating an integrated and seamless public transport experience. BMTC is operating with 190 fleet of nine-metre buses, connecting 40 out of the 57 Namma metro stations with various parts of Bengaluru. These feeder buses serve over 100,000 passengers daily.

Integrating fare systems: BMTC is also working with Namma metro to integrate fare systems that can reduce interchange penalty and keep journey cost affordable. BMTC is looking at introducing a single journey ticket for both buses and metro services, allowing passengers to switch seamlessly between modes of transport without the need for multiple tickets. This integration is expected to reduce the hassle of managing multiple tickets and improve the overall passenger experience. Furthermore, BMTC is also considering the introduction of the National Common Mobility Card (NCMC), which will allow passengers to use a single card for all modes of public transport across the city.

Customising services—Serving each one in its unique way: An innovative approach is the stratified bus services to cater to the needs of the different socio-economic groups. These buses are branded and planned differently for different routes and socio-economic groups residing including Vayu Vajra services for Airport passengers, Vajra services offer AC ride services for the high pay commuters seeks comfortable and convenient services, ordinary or black-board buses for providing affordable services to the commuters, etc.

Modernisation of fleet and technological advancement: BMTC has also modernised its operations through the integration of technology. The implementation of electronic ticketing machines (ETMs), automatic vehicle location systems (AVLS), and CCTV surveillancehas significantly improved fleet monitoring, safety, and operational efficiency. This provides real-time data on bus operations, allowing for better management of fleet, utilisation, service punctuality, and passenger safety. This move towards digitisation has made BMTC's operations more transparent and efficient, ensuring that the buses are running on time and that passengers have access to accurate information.

BMTC's Namma BMTC app and the integration of information on Tummoc journey planner provide commuters the real-time bus tracking, fare payment, and trip-planning options, making public transport more accessible and user-friendly. These technological innovations have allowed passengers to seamlessly plan their journeys, boosting confidence in BMTC's services.

Building skilled workforce and structured management: A considerable attention has been given to the institutional capacity building. The corporation has over 6500 employees, including drivers, conductors, technical staff, and administrative personnel. One of the critical factors in ensuring smooth operations has been the emphasis on continuous training. BMTC has invested heavily in training programmes for its drivers and conductors. More than 9,000 drivers have received specialised training on road safety, driving standards, and customer service through programmes run by the transport management centre (TMC). This investment in human capital has directly impacted the quality of BMTC's services. This is also a reason why BMTC would prefer self-management of the system as opposed to the GCC model.

Role of the State government is supporting bus programme: While central government support has been available from time to time through different schemes and programmes, the State government has also provided the necessary backing for fleet expansion, infrastructure development, and the promotion of sustainable transport initiatives. Notably, the State government's support for the Shakti Scheme, which provides free bus rides for women, has helped boost ridership and made BMTC's services more inclusive. The Karnataka State government has also supported adoption of green technologies.

Addressing affordability—Passes to strengthen patronage of buses: BMTC offers a range of passes and discount schemes designed to make public transportation more affordable and convenient for various groups of commuters. These passes cater to different categories of passengers, including daily travellers, students, senior citizens, and people with disabilities—ensuring everyone can access affordable mobility in the city. Students, in particular, benefit from discounted fares, while women can also access special monthly passes at a lower cost before the travel is made free under the Shakti Scheme.

For organisations, BMTC provides corporate passes, offering bulk discounts for employees of companies or businesses who wish to use BMTC buses for their daily commute. It also offers AC bus passes for those seeking a more comfortable commuting experience. Another notable option is the BMTC multi-ride pass, which allows commuters to purchase a fixed number of rides (e.g., 10, 20, or 30) at a discounted rate. This pass is flexible for those who use public transport regularly but do not need an entire month's pass.

Branding the journey: Colour-coded buses and signage
Photos: BMTC

NIMBUS bus priority lane services—19 kilometres long bus-only lane implemented on IT corridor: The NIMBUS bus priority lane is an initiative of the BMTC in collaboration with the Bruhat Bengaluru Mahanagara Palike (BBMP), Bengaluru Traffic Police (BTP), and Directorate of Urban Land Transport (DULT). It is specifically implemented along the outer ring road (ORR), spanning from Central Silk Board to K.R. Puram railway station and Baiyappanahalli, which is one of the major transportation hub— integration of railway station and metro stations.

This stretch was strategically chosen as it serves as a critical corridor connecting Bengaluru's tech hubs in the north, east, and south, catering to over 10 lakh jobs. The ORR is one of the city's most congested roads, with increasing travel times year-on-year, making it an ideal candidate for such an intervention. Branding—naming the lane, tagline creation and colour coding the buses and signages—was given great importance along with road marking, physical segregation and signage placement on the corridor

The initiative involves over 800 buses operating across the ORR, facilitating more than 4,500 trips daily, with peak-hour services deploying over 80 buses. Popular routes like 500A, 500C, 500D, and others ensure seamless connectivity for commuters. Key measures under the initiative include the creation of a dedicated bus lane in both directions, redesigning junctions to improve traffic flow, and enhancing bus shelters to provide safety and comfort to passengers. By prioritising bus movement, the project aims to reduce travel times, improve reliability, and encourage a shift towards public transportation. This has an average speed of 10–15 kilometre per hour and 35–45 per cent of travel demand on the ORR is met by BMTC services.

Innovating revenue generation for sustainability: Beyond transportation, BMTC is also exploring ways to generate additional revenue using its property. Many bus depots and major bus stations are in prime real estate areas, and BMTC is increasingly turning to real estate development to create additional income streams. By leasing or developing land around bus stations, BMTC has been able to generate significant revenue, which can be reinvested into improving services and expanding the fleet.

BMTC also generate revenue by renting its buses to IT offices, schools and other SRTCs apart from renting buses for private occasions to the general public. This can be looked as a branding novelty of BMTC apart from still providing public transport.

BMTC is transforming its operations with an emphasis on sustainability, efficiency, and passenger-centric services. By integrating technology, rationalising routes, improving safety, and expanding its electric fleet, BMTC is positioning itself as a forward-thinking transport provider in Bengaluru. With plans for enhanced metro integration, fare streamlining, and new revenue models through real estate, BMTC is poised to continue its critical role in meeting the transportation needs of Bengaluru's growing population.

Implementation of passenger information systems (PIS) at major bus stops and on buses—this system helps passengers track buses in real time, ensuring that waiting times are minimised, and the system is especially useful during peak hours or bad weather conditions. BMTC has already implemented PIS at 400 bus stops across the city and plans to expand this network further.

BHUBANESWAR: SEEDING AND UPSCALING MODERN CITY BUS TRANSPORT

The case of bus transport in Bhubaneswar, the capital city of Odisha, is a critical learning curve for the other metropolitan cities that are embarking on new formal public bus services. This is particularly important now when many smaller cities with no formal bus system yet will be seeding new programmes for electric buses under the PM e-bus Sewa of the Government of India.

Bhubaneswar illustrates a case in which a new bus system was created in 2018 and within a short time frame it could show a major turn-around in fleet expansion, ridership, technological innovation, electrification, diversification of services, improvement in quality of services, strong public outreach strategies to make the service attractive, and inclusive strategies for job creation that are pro-women and pro-poor. Joining all these dots become necessary to make a difference.

It has succeeded in creating new bus ridership in a city that formerly had no structured and organised bus transport systems, and personal vehicles—cars and two-wheelers—accounted for 62 per cent of all trips while buses account only eight per cent.[7]

This is a critical intervention point for clean air that is also included in the clean air action plan of Bhubaneswar under the NCAP. But Bhubaneswar is not a recipient of the 15th Finance Commission funding and has received only a small fund under the overall NCAP. However, Bhubaneswar integrates the status of the implementation of its bus transport system in its progress reporting, considering it to be a strategy for clean air.

Rapid development of the dedicated public Mo bus service from a nascent stage: In 2018, the Capital Region Urban Transport (CRUT) launched Mo bus service to replace old bus services of BPTSL. CRUT was established by the Government of Odisha under the Housing and Urban Development Department (HUDD) as an SPV to enhance and streamline public transportation services. Mo bus services were designed to operate initially with 200 bus fleet on 21 intracity and intercity routes in the urban areas of the capital region of the state including Bhubaneswar, Cuttack and Puri. CRUT has been awarded area permits to operate in Bhubaneswar Urban Transport Area (BUTA), Cuttack Urban Transport Area (CUTA), and Puri Konark Urban Transport Area (PUTA).

Its coverage includes intracity and intercity routes in urban areas of the capital region, encompassing Bhubaneswar, Cuttack, and Puri. CRUT's ownership is shared between public and private stakeholders in a 75:25 ratio. Key public stakeholders include the Bhubaneswar Development Authority, Cuttack Development Authority, Puri-Konark Development Authority, and Bhubaneswar Smart City Limited.

These Mo bus services are operating with both standard 12-metre and midi 9-metre buses, and AC and Non-AC buses. In the year 2022, CRUT launched 50 electric midi-buses (30

BMTC: Post-pandemic recovery of operational and financial performance (2017–18 to 2024–25)

The period from 2017–18 to 2024–25 has been a difficult phase for most bus transport undertakings across the country especially as this phase was disrupted by the COVID-19 pandemic that had severely impacted both operational and financial performance of the transit agencies.

However, the Bengaluru Metropolitan Transport Corporation (BMTC) has navigated this turbulent phase to reverse some of the downward trends.

Fleet expansion and Infrastructure growth: BMTC has expanded and optimised its infrastructure, as evidenced by the increase in the number of depots from 44 in 2017–18 to 50 in 2024–25. This expansion has improved service accessibility leading to more efficient deployment. However, BMTC had added few new vehicles in the pandemic years (2020–21), which led to a sharp drop in overall fleet growth during that period. Notably, 325 new EVs were added in 2024–25 alone. However, the fleet size started to recover after the electric bus numbers began to increase.

Growing electrification of bus fleet: To promote zero emission commuting, the corporation has introduced 90 non-AC nine-metre electric buses that are operating as metro feeder services. Under FAME-II scheme, 300 non-AC 12-metre electric buses are being operated in the city. An additional 637 non-AC 12-metre electric buses have been introduced under the FAME-II scheme. Another 287 electric buses will be gradually introduced into service. By October 2024, 1,027 electric buses were operating in the city, and 760 electric buses were planned to be added to BMTC's fleet (320 AC buses and 148 non-AC 12-metre buses) under the Special Assistance to States for Capital Investment 2023–24 scheme from DULT funds. By operating 1000 EV buses, around 51,000 litres of diesel is saved for BMTC every day, avoiding 1.38 lakh kilograms of CO2 emissions—demonstrating the co-benefits of clean energy transitions.

Improving fleet utilisation: Fleet utilisation post-pandemic has shown improvement, increasing from a low of 60.4 per cent in 2021–22 to 88.9 per cent in 2024–25, which highlights more efficient use of available buses. This also suggests that BMTC has improved its scheduling and operational management, leading to a more effective use of the bus fleet in terms of daily kilometres travelled.

To maximise the efficiency of its fleet, BMTC operates a mix of regular services and specialised routes. While the regular bus services typically cover 20 to 30 kilometres per route; more specialised services, such as those connecting major transit hubs like metro stations, cover shorter distances, around 11–14 kilometres, but run at higher frequencies. The average utilisation per bus is around 200 kilometres per day, but certain buses in the fleet, especially those on night-out schedules, may run up to 225 kilometres per day. This balance between regular routes and specialised feeder services helps ensure that the fleet is fully utilised without compromising on service quality.

Increase in operational bus schedule: A key operational metric is the schedule performance, which saw a decline during the pandemic but has since made a strong recovery. For instance, the total number of schedules operated peaked at 6,190 in 2018–19, dropped to 5,313 in 2020–21, and then steadily recovered to 5,702 by 2024–25. This recovery reflects BMTC's gradual return to normal operations, though it is still short of pre-pandemic levels.

Effective kilometres per day: This has seen a significant rebound, from 5.88 lakh kilometres during the pandemic in 2020–21 to 11.1 lakh kilometres in 2023–24—nearing the pre-pandemic levels of 11.42 lakh kilometres in 2017–18. This increase in kilometres travelled daily reflects an improved service capacity and higher frequency of operations. However, the total fleet held by BMTC showed a reduction post-pandemic (down from 6,677 vehicles in 2017–18 to 6,102 in 2024–25), primarily due to the scrapping of old and inefficient vehicles.

Decreased breakdowns and accidents and increased service reliability: One of the most positive trends over this period has been the decline in breakdowns and accidents. Breakdown incidents dropped drastically from 2,024 in 2017–18 to just 56 in 2023–24, indicating better vehicle maintenance and higher reliability of the fleet. This is a significant achievement for BMTC, especially as breakdowns directly affect service delivery and customer satisfaction.

Similarly, accident rates have also been kept under control, with the number of accidents in 2023–24 remaining low at 82, compared to 293 in 2017–18. These improvements in operational safety are crucial for both customer confidence and reducing operational costs associated with damages and insurance claims.

Revenue trends: BMTC's traffic revenue is one of the most telling indicators of its financial health. Despite fluctuations, traffic revenue saw growth over the years, with a major dip in 2020–21 during the pandemic. Traffic revenue, which had peaked at Rs 1,83,884.04 lakh in 2018–19, plummeted to Rs 69,976.42 lakh in 2020–21, a drop of over 60 per cent. However, the subsequent years saw a strong recovery, with traffic revenue increasing by 31.8 per cent in 2021–22 and 24.8 per cent in 2023–24, signalling an effective rebound in passenger demand. This has been attributed to the Shakti Scheme where 33 per cent increase in ridership was seen after implementing the scheme by BMTC.

By 2024–25 (up to August), BMTC's traffic revenue was Rs 90,887.06 lakh, a year-on-year growth of 11.5 per cent, highlighting a gradual yet consistent recovery in fare collection. Despite these improvements, non-traffic revenue has been highly volatile, especially government reimbursement, which reached a peak of Rs 99,939 lakh in 2020–21, as part of pandemic relief packages, but drastically dropped to Rs 8,257.55 lakh in 2024–25. This reduction exposes BMTC's vulnerability to changes in government support and underscores the need for more stable, non-governmental revenue sources.

Cost management and financial losses: The cost of operations has consistently risen over the years, reaching Rs 3,18,925.04 lakh in 2023–24, compared to Rs 2,44,461 lakh in 2017–18. This increase can be attributed to rising fuel prices, inflation, and the general cost of maintaining a large public transportation fleet. Although BMTC made efforts to cut down on costs in 2020–21 (with a reduction of 24.4per cent), the overall cost structure remains unsustainable given the current revenue patterns.

Despite the increase in operational efficiency, margins have remained persistently negative. The margin on traffic revenue continued to remain in the red, with a loss of Rs 1,16,504.33 lakh in 2023–24, indicating that BMTC's farebox revenue alone is insufficient to cover its operational costs. Similarly, the margin on gross revenue was negative across most years, reflecting the wider financial imbalance between income and expenditure.

The cost per kilometre (CPKM) continued to rise, reaching 8,010.2 paise per kilometre in 2024–25, indicating a rising financial burden on BMTC. However, the earnings per kilometre (EPKM) in terms of traffic revenue has been improving, from 4,237.5 paise in 2017–18 to 5,351.1 paise in 2024–25, suggesting that the corporation is becoming more efficient in generating revenue from its operations.

Improving the safety in the public transport: Over the past few years, the corporation has seen a significant reduction in accidents. This has been achieved through a combination of driver training programmes, increased monitoring of vehicle speeds, and regular safety audits. BMTC has partnered with the traffic management centre (PMC) and Bengaluru Traffic Police to provide continuous training to drivers and conductors. Additionally, BMTC sends about 50 drivers per day to the traffic management centre for refresher training, with over 9,000 drivers having participated in these programmes over the years.

Effective utilisation of human resources and fleet: Traditionally, BMTC buses were operated in a "double-crew" setup, where each bus had two drivers and two conductors for a single route. This was typically used for longer routes to ensure the buses could operate continuously throughout the day. However, to optimise resources and reduce operational costs, BMTC has been transitioning to "single-crew" operations, where one driver and one conductor are assigned to a bus. This has led to a reduction in the overall need for additional manpower, contributing to cost savings. As part of its effort to optimise fleet management, BMTC has increased the number of buses operating on "single-crew" schedules. For instance, around seven to eight per cent of double-crew schedules have been converted to single-crew, thus lowering the manpower requirements while still maintaining service quality.

Community engagement and participation: BMTC has regularly engaged with citizens to better understand their needs and incorporate their feedback into the planning and design of services. Public consultation processes have been particularly valuable in deciding on new bus routes and infrastructure projects. BMTC regularly conducts survey-driven route design that helps in identifying areas with high demand and creating routes that effectively serve those communities. Initiatives such as "Bus Day" have helped raise awareness about the benefits of public transport, while also encouraging people to switch from private vehicles to buses. Through campaigns and outreach programmes, BMTC has created a stronger community connection to public transport, making it an attractive and reliable option for daily commuting.

seats) into Mo bus services, in addition to the current fleet of conventional (diesel-run) buses. Mo bus routes not only catered to the mobility needs of the local people, but also that of the tourists. The brand "Mo bus" indicates "Mo" means "My" in the local Odia language. This instils a sense of pride and adoption of services.

Expansion of the electric bus programme: Electric buses have been inducted under the Mo bus service. About 50 electric buses are in operation. There are plans to further enhance the fleet by adding 200 electric buses and extend the services to underserved areas. This expansion is being supported by improved infrastructure, including enhanced bus depots and charging stations for electric buses, ensuring more efficient services.

It has also launched a unique service based on nine-metre AC electric double-decker buses. This has more seating capacity. Dedicated routes have been allotted to the buses. These double-decker buses operate on intercity routes, connecting key cities—Puri and

Newly introduced single- and double-decker electric buses under Mo bus services

Khurdha—to accommodate large ridership. The passenger survey shows that passengers have a positive outlook on the unique experience of traveling on the buses.

Technological upgradation for improved service level: Public transport becomes a clean air solution when co-joined with technology advancement for high-level service delivery. Therefore, smart technology integration that includes integration of the Intelligent Transport Management System (ITMS) to manage its operations effectively—with features such as GPS tracking, CCTV surveillance, and panic buttons in buses to ensure commuter safety—have contributed towards upgradation of the service level. This has enabled data collection based on the ticketing system related to age, gender, and disability and supported effective decision-making.

The Mo bus mobile application provides real-time information on bus locations, routes, and schedules, allowing passengers to plan their journeys more efficiently. The app has been made available on both Google Play Store and App Store for the passengers' easy access.

Further, to enhance commuter friendly bus services, Mo bus services are equipped with state-of-the-art features, including on-board Wi-Fi service, digital announcements, LED display board, surveillance cameras (CCTV), priority seats for women with children and older people, first-aid box, online ticketing systems, and an automated fare collection system.

State government support for the bus system: CRUT is also among very few transit agencies in the countries that has enjoyed strategic financial support from the State government. The Government of Odisha provides financial backing to sustain and expand the services while the private operators are responsible for maintaining the fleet and ensuring service delivery and revenue collection. Since the inception of the bus modernisation drive, the State government has strongly supported CRUT in both capital expenditure (CapEx) and operating expenditure (OpEx) funding for continuous and smooth bus operations. During the inception stage the State has provided low-interest loan for procuring buses and developing bus depot facilities to the selected operators. The State has also created a new budget stream to fund the unrecovered operational expenses—amount beyond the fare box recovery and other sources. So, every year CRUT provides the budget requirement and accordingly, budget amount gets allocated to them.

The approach balances government funding with public-private partnerships (PPP) to ensure quality service delivery, financial sustainability, and citizen satisfaction. While the funding is built on a mix of government support, fare revenue, and advertising income, the Government of Odisha is the primary financial backer for its operations and service expansion.

Operational model to expand ridership: CRUT has developed planning and scheduling of Mo bus services on the routes and hired bus operators on a fixed per-kilometre rate payments, agreed with official concession agreements. The operators are responsible for procurement, operations and maintenance of the buses, maintenance of depots, and recruitment of bus drivers.

The bus queue shelters (BQS) are fitted with Wi-Fi, public toilets, and PIS for real-time updates. Moreover, the BQS are equipped with modern user-friendly amenities to enhance the overall experience of commuters waiting to avail the transit services. The infrastructural initiatives, particularly the two state-of-the-art depots in Bhubaneswar, at Patia and Bhagabanpur, adhere to green building norms and promote sustainable ways of operating transit services, making them distinct and one-of-its-kind.

The revenue collection agencies are responsible for recruiting conductors and ensuring revenue collection with no leakage of revenue. Profits and losses incurred in operations are borne by CRUT with state government funding covering operational deficits and service expansion. In the 2023–24 state budget, Rs 200 crore was allocated to CRUT under urban road transport development.

Substantial increase in bus ridership: Since its inception in 2018, the Mo bus services emerged as prime mode of public transport in the region with its citizen-centric approach of services. The Mo bus' daily average ridership has increased to over 2,50,000 in 2023 from 33,326 in its inception year of 2018. This is a significant increase of 200 per cent in under five years, with 57 per cent of passengers reportedly shifting from private transport modes.[8]

This is attributed to the CRUT's innovative citizen-centric approaches and investments into continuous expansion of the network services. The fleet size has increased to 390 buses from 200 buses. Its operational routes have increased from 21 to 67, and the operational network has increased to over 500 kilometres. The expanded network has provided better connectivity between urban and suburban areas and facilitated the smooth movement of people across the region.

Integrating e-rickshaws as a feeder to the Mo bus services

This increased ridership also reflects high-level of commuter satisfaction. According to a survey conducted by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in 2019, about 91 per cent have rated the behavior of onboard staff as very good; 76 per cent have rated the comfort of the bus as high; 75 per cent noted that the services were punctual; 32 per cent of bus users transitioned from using private vehicles to CRUT services; 85 per cent of women Mo bus users rated the availability of priority seats as very good; and 98 per cent of elderly Mo bus users rated the ease of boarding and alighting as very good.
Likewise, a citizen perception survey conducted by IIT Kharagpur in 2022 revealed that Mo bus services are favored over private buses in Bhubaneswar for several reasons. Factors such as enhanced on-board safety and security, comfort, affordable fares, and broader route coverage across the city and its peripheral areas contribute to making it the most desirable mode of transport for citizens.

Reinventing last mile connectivity to improve access to Mo e-ride services: This is a unique strategy in which the bus service provider has also launched electric paratransit services to connect the Mo bus stations with neighbourhoods. The Mo e-ride services launched in 2021, operate 50 e-rickshaws from important Mo bus depots and stations as feeders to connect neighbourhoods.

These Mo e-ride services operate on fixed routes with assigned frequency, timing and fares, and have allotted pick-up points. These include 12 at Pokhariput, 22 at Chandrasekharpur, and 16 at Patrapada. Their schedule range is 80 kilometres per day. All the drivers of the services are women, transgender, and socially disadvantaged people belonging to the marginalised sections of the society. They have also been provided with light motor vehicle (LMV) driving training to join the service.

In addition to this, public bike sharing cycle or MO CYCLE stations have also been provided. There are 2000 cycles under its public bicycle-sharing programme in the capital region.

Increased safety and gender equity: The gender inclusivity policy has significantly contributed to female participation in the workforce. Notably, 50 per cent of the Mo bus guides or conductors, and 100 per cent of the Mo e-ride Sarathis or drivers are women. Among the Mo bus crew members, drivers are designated as 'Captains', conductors as 'Bus Guides' and Mo e-ride drivers as 'Sarathis' to build pride in job. In 2023, 40 per cent of the guides were women. This has also enhanced the safety of female passengers, resulting in a noticeable increase in female ridership, which now accounts for 30 per cent of the total number of commuters.

Initially, CRUT had encountered cultural barriers in recruiting female bus guides and e-ride drivers. Societal norms posed challenges. To overcome this, CRUT engaged proactively with self-help groups (SHGs) and transgender groups to convince and motivate them about the positive benefits, including enhanced household incomes, etc. There is 50 per cent reservation for women in jobs, such as Mo bus guides and 100 per cent reservation for Mo e-ride crew. Training programmes are organised to develop a skilled crew for Mo bus and Mo e-ride services.

Initiatives to popularise the bus ridership: Deliberately designed commuter-friendly initiatives have been launched to attract ridership. The automatic ticket vending machines (ATVMs) are equipped with advanced features to issue tickets with a variety of payment methods, including cash, UPI and coins, and provide detailed route information. These are placed at strategically chosen locations. Special rides are organised during high-profile events such as T20 or Paralympics matches, etc. "Mo Bus Mo Hero" awards are given to captains (drivers) and guides (conductors) who have shown exemplary honesty and returned valuables left by commuters, which builds commuters trust. 'Newspaper on Wheels' is among other outreach strategies.

Capacity and skill building: To address adequate staffing and to improve the operational efficiency and performance levels of the bus system, the 'Bus Captains' and 'Bus Guides' are given training in safe and efficient driving habits, gender-sensitive passenger management, handling of adverse situations, and assisting differently-abled citizens on a regular basis. CRUT was collaborated with Odisha Skill Development Authority (OSDA) to provide behavioral training to the guides and captains of Mo bus.

Deployment of bus service during natural disasters and pandemic: Soon after the establishment of Mo bus service, devastating cyclone Fani had struck in 2019 that caused extensive damage to the infrastructure including BQS, depots, etc. Thereafter, COVID-19 pandemic struck in 2020, that brought unprecedented disruptions in the bus services. During these times of crisis, CRUT adopted and innovative approaches of 'Grocery on Wheels' service, supplying essentials to containment zones using Mo buses and converted the BQS temporarily into vegetable vending zones. Further, it offered services to provide critical transit support for frontline workers during the pandemic.

Replicable model—Going beyond Bhubaneswar: Following the success in the Bhubaneswar, the State government has decided to expand the Mo bus services to other cities of the state. This expansion began in 2023 with the introduction of services in

Rourkela, and plans are in place to extend to nine additional cities including Sambalpur, Jharsuguda, Brajrajnagar, Belpahar, Berhampur, Gopalpur, Chhatrapur, Hinjilicut, and Digapahandi.

SURAT: INTELLIGENT TRANSPORT SYSTEM (ITS) FOR IMPROVED BUS OPERATIONS

A critical aspect of bus service modernisation is the application of the intelligent transport system and digitisation. It may be noted that under various central government programmes, including Smart City Mission, there has been significant investments into installation and integration of advanced public transit systems (APTS) in state transport corporations. If leveraged well, this has enormous potential to improve the internal efficiency of the bus transport operations and commuter services. This can increase operational efficiency, improve journey time, reliability, safety, reduction in accidents, assistance in traffic enforcement, provide real-time information to the public, enhancement of traffic signal efficiency, among others.

Yet, in most cities, the current level of application is very limited and it is grossly underutilised. This is used largely for tracking of bus kilometres for earnings and revenue purposes. But the bus agencies have not been able to develop adequate systems, networks, digitisation and data visualisation techniques and capability, for monitoring bus performance and optimise schedules for passenger information systems to improve service efficiency.

From this perspective, the city of Surat in Gujarat demonstrates the potential of its application. The SPV named Sitilink Limited oversees the city's longest dedicated bus rapid transit (BRT) system in India. It is operating 891 buses, of which 316 buses are on BRT and 575 buses are on city routes. The system serves an average daily ridership of around 2.75 lakh passengers and spans a total distance of 513 kilometres, including 108 kilometres and 405 kilometres of BRTS and city bus respectively.

Like many of the bus operating organisations, Surat's public transport system, including BRTS and city buses, struggled initially with inefficiencies due to a lack of data-driven management of routes and fleet operations. This had led to poor route planning, unreliable schedules, long wait times, and inconsistent cash handling, all of which resulted in low customer satisfaction and underutilisation of services.

To address these problems, city authorities introduced intelligent transport management system (ITMS) in 2016 with total cost of Rs 48.99 crore, automatic fare collection system (AFCS) in 2017 with total cost of Rs 80 crore and Surat Money Card.[9]

The introduction of ITMs has enhanced the potential of addressing several challenges:

- This provides passenger information system (PIS) to the public at various platforms—including BRTS station and city bus shelters. It has helped with real time tracking of bus data on Google through live bus tracking with automatic vehicle location system (AVLS).

- This enables security and traffic enforcement to address bus violations, tracking, route violation, schedule deviation, missed stop violation, non-stoppage violation, speed violation, etc.

- This allows incident management through operational incidents logged in the system, such as traffic congestion, accidents, riots, vehicle breakdown, fire incident, etc.

- This can provide information for commuters on schedule of BRTS and city buses through mobile application and website.

- Depot management system includes vehicle and driver allocation and ETM and conductor allocation.

- System based operator payment module includes buses running on scheduled trips. Trips are monitored from CCC for all routes and buses. Trips are reconciled on daily basis by authorities. Finalisation of trips and violations are monitored. Payment is done based on per-kilometre basis.[10]

The introduction of automatic fare collection system helps to understand passenger travel demand trends on different routes and address inconsistent cash handling that includes daily ridership and revenue, weekday, weekend schedule preparation, peak and off-peak ridership and revenue, highest and lowest ridership and revenue, route-wise and stop-wise, passenger-type wise, transit analysis—high and low footfall, revenue stations, etc.

Surat has developed and innovated the ITMS tools in several ways:

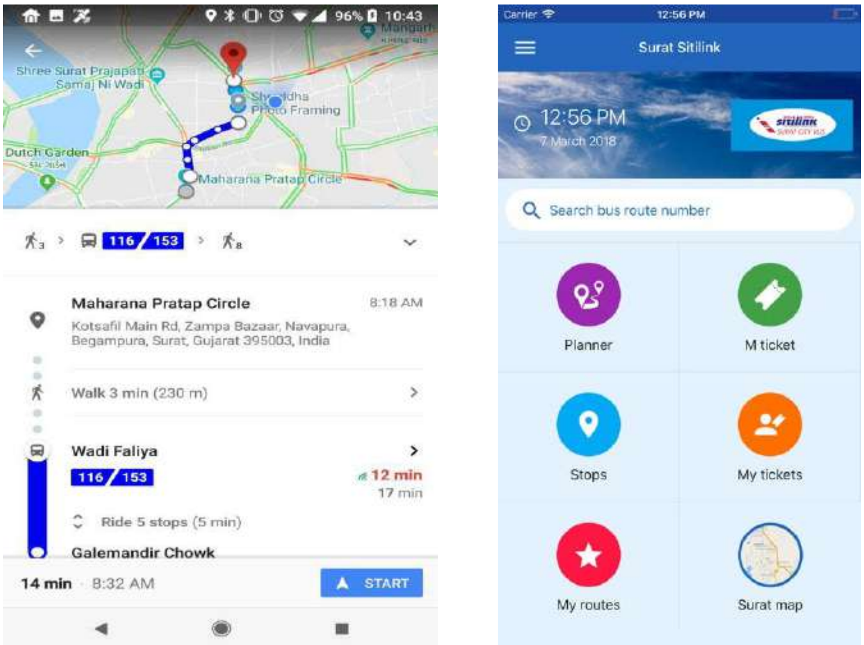
- It has implemented a vehicle planning and scheduling tool for dynamic scheduling of bus services by extracting data from ITMS and AFSC to optimise its bus services based on passenger demand.

- It has further developed dashboard that acts as an AI which is being used to study the real time demand of various routes and to assess the boarding and alighting pattern.

- It has developed five stages of integrated public transport system including physical integration, fare integration, infrastructure integration, ITS Integration and institutional integration of BRTS, city bus and HMC services.

- It has collaborated with Google to add real-time bus information in Google Maps. Through this initiative Surat has become the first city in Gujarat and second in India to launch real time transit information with Google Maps.

- It has developed Sitilink mobile application which offers its users to plan their journey in an efficient way. Surat Sitilink application provides multiple options including journey planners, m-ticketing, route and stops information, route map, etc.



Real Time transit information with Google Maps and Surat Sitilink app
Source: Google Maps, Sitilink (SMC)

- It has developed bus occupancy details under open-source data sharing and exchange platform called India Urban Data Exchange (IUDX) of Ministry of Housing and Urban Affairs (MoHUA).

- Surat Money Card aims to have a single payment instrument for all city-wide services. The card can be used to obtain SMC services and for payments outside SMC environment in retail, mall, restaurant, multiplex, etc.

How has the ITS initiative helped?
The ITS initiative in Surat presents an important learning for other cities. This improves operational cost savings and provides multiple benefits to the commuters. The key benefits are as follows:

- **Increase in passenger ridership**: The public transport ridership has increased from 28,000 passengers from its inauguration to 70,000 in 2017, 2,50,000 passengers in 2019, and 2,70,000 in 2022.

- **Modal shift:** 80 per cent of BRTS or city bus users have shifted from three-wheelers (shared auto-rickshaws), two wheelers (10 per cent), and non-motorised transport (2 per cent).

- **Increased user satisfaction**: An average of 9 out of 10 and 8.7 out of 10 passenger feedback ratings received for BRTS and City bus are and respectively in the quarterly surveys from its users.

- **Optimisation of bus fleet and dynamic bus scheduling:** It is more efficient in meeting the passenger demand. The city has observed cost savings of Rs 2.72 Crore annually by optimising the bus network.[11] For example: in the routes 206 and 216, the ridership on weekends used to be less compared to the weekdays. After the system was introduced, the ridership on route 216 has increased. Optimisation was done by increasing bus supply on weekends on route 216 and reducing the supply on weekends on route 206 by keeping the depot allocation same. Further, the schedule is developed with less headway during peak and high headway during off peak for efficient use of services.

- **Service reliability**: This has improved trips and schedule adherence up to 98 per cent and 97 per cent [12] respectively. This includes information on arrivals and departures of the buses.

- **Route performance analysis**: Analysis of information on BRTS and city bus system are carried out every three months to understand the route performance, vehicle utilisation, dead kilometre, revenue kilometre and other parameters for decision making.

- **Interchange station and infrastructure requirement**: This system has identified major interchange stations of BRTS with the help of origin and destination (OD) data. This has improved the infrastructure including ETM machine, two-turn stile for exit and entry with the help of OD data, requirement of staff and security guard to provide easy and convenient transport system to users.

- **Reduction in paper tickets**: ITS has enabled introduction of Surat Money Card, m-ticket, Sitilink Pass[13] which has reduced the need for paper tickets drastically.

CITIES OF GUJARAT: STATE-LEVEL FINANCING SUPPORT TO UPSCALE BUS OPERATIONS

Mukhyamantri Shaheri Bus Parivahan Yojana (Chief Minister Urban Bus Service Scheme): The bus operating agencies in most cities of India are grappling with several challenges, including low ridership, financial crisis, stressed bus operations and maintenance, dwindling bus fleet, declining service quality, longer waiting times, and issues with last-mile connectivity. Reversing these trends require massive resources and financing support, especially at the state level.

Yet very few states have designed state-level financial schemes to support and expand bus programmes across its cities. Even though bus transport is largely the responsibility of the state governments, the approaches are mostly very minimal and business as usual—limited to a few cities.

Considering the challenges of the bus operating organisations and to improve and expand public transport across cities of Gujarat, the State government of Gujarat has taken the initiative to launch the Mukhyamantri Shaheri Bus Parivahan Yojana (Chief Minister Urban Bus Service Scheme) in 2018.

The state-level scheme offered viability gap funding (VGF) to bus operations in eight municipal corporations and 22 municipalities with a population of more than one lakh that fall under the 'A' category cities. A budget of Rs 290 crore is proposed annually under the scheme for 7 years to address only the operations cost under public-private partnerships (PPP) mode. This scheme mandates that the transit authority or ULBs must match the VGF offered by the scheme with an equal amount of funding from their own resources.

The initiative aims to revitalise the public transit system by supporting transit authorities and ULBs in expanding the bus fleet, improving the frequency of services, and enhancing the overall service quality. The VGF is designed to increase the modal share of buses in urban commuting, making public transport a more reliable and attractive option compared to private vehicles.

The scheme has listed its grants distribution based on bus fuel type and city size, which are mentioned as follows:

- Municipal Corporations operating CNG bus services on a PPP basis now receive an increased grant of Rs 18 per kilometre, from the previously announced Rs 12.50. Additionally, the VGF cap has been raised to 60 per cent, from the previous 50 per cent. For CNG bus services in 'A' category municipalities, the grant is Rs 22 per kilometre, and the VGF cap has increased to 75 per cent from 50 per cent.

- Municipal corporations operating e-bus services under the PPP model are now receiving an increased grant of Rs 30 per kilometre, up from the original Rs 25. The maximum VGF reduction for e-bus services has also risen from 50 per cent to 60 per cent. In 'A' category municipalities, the state has decided to provide a grant of up to 75 per cent for E-bus urban transport services, with a maximum grant of Rs 40 per kilometre.

Benefits of the scheme

- **Expanded public transport service:** This has introduced 1,250 buses in 12 cities, including 382 electric buses and 785 CNG buses, against the sanctioned total of 1,759 buses. A part of the larger goal is to add 2,864 city buses under the gross cost contract model.[14] This modernisation of bus fleets has helped to improve public perception of public transport.

- **Improved financial health of the bus operating STUs/SPVs**: The government financial backup support for operational VGF per kilometre has helped to ease financial burden on the operators.

- **Cost-effective bus services:** The bus services become cost-effective for the citizens as there is no requirement to increase ticket fare like other loss making STUs and SPVs.

- **Positive shift in public transport usage**: Several cities have experienced increase in bus ridership because of this support. In Ahmedabad for instance, AMTS has witnessed increase in ridership to 5.75 lakh passengers per day on an average in 2022, from 5.2 lakh in 2020.

- **Cost savings**: The implementation of the scheme leads to cost savings through operational efficiencies and improvements. Surat Sitilink bus services have benefited Rs 10 lakh per bus in savings compared to diesel buses due to VGF of Rs. 25 per kilometre. This is given to cities for operations of e-buses. With the recent increase in VGF to Rs 30 per kilometre or the maximum VGF reduction to 60 per cent under the scheme, these savings are expected to grow further. It would have been the same scenario for all the other bus operating cities of the state.

This state-level scheme is unique in the recent years that has helped to provide financial relief to the bus operating agencies, allow them to upscale services, and build the confidence of OEMs and operators.

CIRCULAR BUS SERVICES IN THIRUVANANTHAPURAM AND COMMUNITY-BASED GRAMA VANDI PROGRAMME

Bus service is one of the most flexible systems that can respond to the dynamic changes in commuter demand. Considerable innovation in service deployment is possible to increase bus ridership. Only very few bus transit agencies have started to consider stratified and targeted bus services, or services that are responsive to community demand and experiment with fiscal strategy.

Kerala State Road Transport Corporation (KSRTC) is one such agency that has innovated such approaches. KSRTC has introduced two unique bus schemes—city circular service with hop-on hop-off model to enhance urban mobility in Thiruvananthapuram; and, Grama Vandi—a community led bus service.

City circular service: This is the first of its kind of initiative in the state's public transportation system. These services connect major destination points including government offices, hospitals, tourist attractions, and commercial areas in a circular route.

The first phase of this service has started on 13 routes and these run in clockwise and anti-clockwise directions. These are operated at fixed intervals of 15 minutes during peak hours to 30 minutes in off-peak hours. The minimum fare of the service is Rs 10 and the maximum is Rs 30. KSRTC also offers Good Day ticket, which allows unlimited travel in any city circular bus with a time limit of 24 hours. All the city circular services are given a unique colour to help passengers identify the destination of the bus.

As a result of this intervention, and as per information from UITP, passengers per day have increased from 3,000 to 40,000; with women and children markedly shifting to public transport. KSRTC is now planning to expand its services by adding additional eight more circle routes in the next phase in the city. It is also planning to introduce similar scheme in other major cities like Kozhikode, Kochi, etc.

Grama Vandi bus project: This is a unique initiative that is being implemented in collaboration with local self-government bodies and community sponsorship, to extend public transportation to underserved rural, peripheral and socially backward areas to connect with the cities.

The Grama Vandi project has adopted a unique model in which it is implemented in partnership with the local self-government bodies and panchayats, and involves public participation. Bus services are operated on routes and schedules proposed by local self-governments. The local bodies are required to cover the fuel expenses of the buses. If overnight stays are necessary, they are responsible for providing accommodation and parking security for the Grama Vandi staff. KSRTC is responsible for the provision of vehicles, staff salaries, maintenance, spare parts, and insurance.

Yet another unique feature is the provision of enabling community sourcing of resources. Local sponsorships are encouraged for service's financial sustainability. Private individuals and institutions are welcome to sponsor Grama Vandi buses, with opportunities to sponsor advertisements to be displayed on the vehicles.

This has helped to expand the bus service and helped to reduce the operating costs by 50 per cent. With 11 services operating at present, more than 5,500 passengers are using this daily. Services under the Grama Vandi project was initiated in Edavanna (Malappuram district), Elavalli (Thrissur), and Pathiyur (Alappuzha). As per the information available from UITP, with the help of these initiatives, the monthly revenue of KSRTC has increased from Rs 168.7 crore in April 2022 to Rs 243.35 crore in December 2022.`

WALKING AND CYCLING FOR ZERO EMISSIONS TRANSITION

Even though the CPCB has provided indicators for reporting progress on walking and cycling infrastructure, and improvement in accessibility to reduce pollution and congestion, these indicators do not get priority attention in the implementation of the clean air programmes.

Only intermittent reporting is available that shows small scale footpath development in a few cities. For instance, Howrah in West Bengal has reported a ten-kilometre stretch of walkway that has been developed. Even those cities that have made substantial efforts to build walking infrastructure like Srinagar (as noted earlier) under convergence funding, or cities that have implemented pedestrianisation projects, as in Bengaluru, Chennai, Delhi etc., have not connected these efforts with their clean air action planning.

One substantive effort was made in Bhubaneswar under the NCAP—to assess the potential of developing low emissions zones—as part of the clean air action plan. Accordingly, the Odisha state pollution control board has carried out assessment of five-kilometre radius area around the Lingaraj temple to develop the project proposal. But this has not been implemented yet. Somehow, the public transport and accessibility solutions for low to zero emissions commuting are not being defined and integrated with the clean air action plans adequately.

Even though several cities have initiated walking and cycling initiatives in small stretches these have remained small scale and are often retrofitted within a car centric urban design with signal free corridors, limited safe crossing facilities at grade, foot-over bridges to provide primacy to the vehicle movement, etc. As a result, the benefits of walking and cycling infrastructure cannot be maximised.

Even when some efforts are made to improve walking and cycling infrastructure and pedestrianisation in some stretches, their upkeep and maintenance remain a challenge and the initiatives are not sustained, as noted in the pedestrianisation of the Ajmal khan street in West Delhi.

Cities lack cohesive policies on walking, cycling, and accessibility infrastructure to improve neighbourhood scale accessibility and integration with public transport. There is barely any attempt to integrate the requirements of the National Urban Transport Policy, National Habitat Standards, or Transit Oriented Development Policy in urban redevelopment and road infrastructure projects. Appropriate street design guidelines are not adopted at the city level to address the key principles of accessibility. Even though there have been reforms after the metro policy of 2017 that require funding for these projects to combine walking and cycling infrastructure within a specified radius, these are not planned comprehensively for an upscaled implementation.

As a result, the good baseline of walking and cycling modal share as evident in the 2011 Census, is getting rapidly eroded. Rapid conversion of walking and cycling trips to motorised trips is locking in enormous pollution and carbon that are not accounted for in the clean air plans. These are not captured in the environmental impact assessment and transport impact assessment of the urban and transport infrastructure.

Benchmarking improvement in street networks for walking and cycling: The clean air plans under NCAP and its funding strategy need to mandate city-wide implementation of well-designed walking and cycling network, to connect neighbourhoods at a scale instead of focusing on only single corridor development. Specific sub-networks can be prioritised for phase in implementation under convergence funding. The reporting on the scale of implementation needs to be done against the larger plan and align all available sectoral funding around that.

- Designing of walking and cycling infrastructure need to display the following elements that are embedded in the National Habitat Standards and other relevant guidelines. These include, at-grade and safe access; continuous unobstructed lanes as much as possible, protected connectors on each side of right of way wider than 12 metres, with designed space for trees and vending zones; adequate spacing and numbers of street crossing facilities; grade separated structures like foot-over bridges should be avoided; comparative speed of modes should be reduced; properties should be built without setbacks and active frontage to promote safety and vibrant streets.

- While established legacy cities need massive retrofitting, redevelopment of roads, and regeneration of public spaces around transit lines; the new townships also need mandate for compact urban form with high street density, walking and cycling infrastructure and small block sizes.

- Clean air plan needs to mandate detailed street audits to identify the barriers and factors compromising quality of the infrastructure and accessibility to the public transport nodes.

- Mandate protection of these spaces from encroachment, parking etc.

- Develop monitoring system to ensure rules of usages of walking and cycling infrastructure are enforced.

Despite the challenges, it is necessary to highlight some of the good initiatives—even if small in scale—to demonstrate the scope of change needed to make a difference.

CHENNAI: COMPLETE STREETS APPROACH FOR ALL ROAD USERS

Chennai demonstrates the importance of adopting a non-motorised transport policy combined with targets and mandate to transform streets, to pedestrianise streets and upscale implementation.

Upscaling walking and cycling with mega streets project: In 2014, the Greater Chennai Corporation (GCC) became the first city in India to adopt an NMT Policy "to increase the use of cycling and walking by creating a safe and pleasant NMT network of footpaths, cycle tracks, greenways, and other facilities to serve all citizens" in the city. It marked a strategic shift in urban planning, moving away from car-centric development towards people-centric streets.

Between 2013 and 2019, GCC implemented a series of transformative interventions. Over 120 kilometres of city streets were redesigned to improve pedestrian access and safety. This included street improvements in the core city areas, upgrades at nearly 300 bus stops, and safety enhancements at 60 school zones. For this purpose, GCC adopted the Complete Streets guidelines to inform all future street design projects.

The 2014 NMT Policy planned to dedicate 60 per cent of its transportation budget towards walking and cycling infrastructure. A special projects department was established to steer the implementation of NMT projects. Further, monthly NMT sub-committee meetings were instituted to ensure coordination among departments and support informed, participatory decision-making. About 80 technical staff were trained on the Complete Streets principles in collaboration with ITDP and Anna University.

As an initial proof of concept, GCC collaborated with local architects to implement the first batch of redesigned streets. It witnessed a 50 to 200 percent increase in pedestrian footfall and significant safety improvements. By 2019, GCC had transformed more than 100 kilometres in length of the city streets with NMT featured streets.

A survey by the ITDP India in 2019 revealed that 95 percent of users felt safer on improved streets. Between 9 and 29 percent of pedestrians using the transformed footpaths stated they would have otherwise used a private motorised vehicle. This modal shift has led to the annual prevention of 4,200 to 12,000 tonnes of CO2-equivalent greenhouse gas emissions—comparable to taking 1,000 to 2,900 cars off the roads.

The study had estimated that this reduction in motorised travel also helped cut down PM2.5 emissions and prevent approximately 340 deaths from non-communicable diseases annually. One of the standout projects—the Pondy Bazaar pedestrian plaza—became a model for urban place making.[15] This includes Pedestrian Plaza at Sir Theyagraya road across three stretches—730 metres from Panagal Park to Thanikachalam Road junction; 380 metres from Thanikachalam Road junction to Boag Road junction; and 450 metres from Boag Road junction to Mount Road. This was initiated in 2018 with funding from Chennai Smart City Limited. This initiative has widened footpaths from two–three feet to six–ten feet. These have adopted universal street design, child friendly amenities, greening, and lighting strategies among others.

According to an assessment by the C40, pedestrian footfalls have increased substantially, especially with increase in vibrant street activities. Moreover, the retail shop owners have reported an increase in sales by 15–20 per cent during November, 2019 to February, 2020; as compared to the sales of the same period in 2017 and 2018. This has improved pedestrian safety in the area. An impact assessment revealed that 15 percent of plaza users were new pedestrians or had shifted from other travel modes, while property rents in the area increased by 20 percent.

Mega streets project: Based on the success of initial pilots, GCC began scaling up street transformation efforts with a city-wide approach—Chennai Mega Streets programme. It aligns with the Complete Streets approaches and aims to rejuvenate streets and neighbourhoods by linking above-ground and underground infrastructure. This ambitious project aims to develop a Complete Streets network with a minimum lifespan of 30 years.

Under the project, six diverse neighbourhoods from across the city—including Adyar, Anna Nagar, Mylapore, Nungambakkam, Tondiarpet, and Velachery—chose to reflect varying infrastructure conditions and socio-economic profiles, thereby supporting the institutionalisation of street design reforms.

This programme is one of several initiatives of the Chennai City Partnership under the World Bank-supported sustainable urban services programme (SUSP) and is being piloted through a project including upgrading 12 kilometre of local roads.

The project was incorporated in the Tamil Nadu state budget in 2020, securing dedicated funding for the preparation of detailed project reports and implementation.

Leveraging funding: This initiative demonstrates creative leveraging of available funding sources for the purpose of street redevelopment. Chennai has tapped into the NCAP funds, funding under state-level road infrastructure programme, and Nirbhaya funds for gender safety for their street initiatives. Chennai's mega streets project focuses on creating a network of high-quality and equitable streets and vibrant public spaces that are also zero emissions spaces.

BENGALURU: DEMONSTRATING RECLAMATION OF ROADS FOR PEDESTRIANS

Church Street First initiative: Bengaluru has demonstrated reclamation of roads from vehicles to create pedestrian time zones. Church Street First was initiated by the Directorate of Urban Land Transport (DULT) along with IISc Sustainable Transportation Lab (IST Lab.), Indian Institute of Science, Bengaluru, and Catapult UK under Clean Air Street pilot. This was to evaluate air quality and public perception regarding the pedestrianisation of an urban street and to enhance quality of life by developing citizen-centric street environment which prioritises green and active forms of transportation including walking, cycling while encouraging sustainable behaviours and restrict motor vehicle traffic.

Under this initiative, Church Street was closed for vehicular traffic on weekends, i.e., saturday and sunday, from 10 AM to midnight. Only pedestrians, bicyclists, and the electric vehicles of the participating innovators were allowed to ply for four months from November 2020 till February 2021.

An assessment of the benefits of this project by the Indian Institute of Science (IISc) has provided important insights.

Increased share of walking: As much as 92 per cent increase has been noted in average daily footfall from November 2020 to February 2021 (72,209 in November to 1,35,540 in February). About 117 per cent increase is recorded in peak-hour footfall (5–9 PM), from 5,752 in November, 2020 to 12,483 in February, 2021.

Moreover, pedestrian speed has decreased by 57.9 per cent during the four months due to higher footfall on the street, indicating vibrant street activity. As much as 98 per cent of visitors have supported pedestrianisation of the street.

Increasing the public transport footfall: M.G. Road metro station has an entry and exit to the Church Street which has witnessed 135–162 per cent increase in overall footfalls in weekends during February 2021, as compared to November 2020.

Shift in attitude of the shop owners: About 15 per cent reduction has been noted in the use of private motorised vehicles, including two- and four-wheelers, among the shop owners travelling to Church Street. Simultaneously, there was 11 per cent increase in the use of non-motorised and public transportation modes, such as walking, cycling, and the metro. As much as 81 per cent of the shop owners are satisfied with improved air quality during weekends of pedestrianisation.

About 35 per cent of shop owners have reported positive effects on revenue and customer footfall. There was initial resistance from traders due to fears of reduced footfall. But this was overcome through stakeholder outreach and public enthusiasm. This change has happened against the backdrop of the initial resistance from traders, who worried about reduced footfall to their establishments.

Air quality test bed: The Clean Air test bed was also incorporated as part of the Church Street First initiative. The goals of the test bed were to demonstrate innovative air quality and electric mobility technologies developed by innovators, and provide the latter an opportunity to deploy their solutions in a real-world scenario. Around 14 innovators were selected. Air quality monitors were used to calibrate the air quality on Church Street. Test rides were provided to the visitors on the electric two wheelers and three wheelers. The innovators collected feedback in real-time on the products.

Based on enthusiastic responses from citizens followed by politicians, DULT and BBMP have announced the expansion of the initiative to seven streets. It provides a blueprint for pedestrianisation across Bengaluru and other Indian cities.

NEW TOWN, KOLKATA: PROMOTING NON-MOTORISED TRANSPORT

New Town is a new township that has emerged at the periphery of the Kolkata Municipal Corporation boundary. Originally it was conceived as a gated development with super-size blocks of buildings, wide roads that are more car-centric and without integration with public transport network; subsequent efforts were made to develop people-friendly walking and cycling network to improve accessibility.

Under the stewardship of the New Town Kolkata Development Authority (NKDA), it has undertaken a Green Transport initiative to promote eco-friendly mobility. The residential population is approximately 50,000, with an additional 100,000 individuals commuting daily for work from surrounding areas.

The core focus of the project has comprehensively addressed construction of dedicated cycle tracks and footpaths, app-based public bicycle sharing (PBS) systems, and development of a network of EV charging stations.

Starting in 2017, the city completed 20 kilometres of cycle tracks and 100 kilometres of pedestrian-friendly footpaths, with plans to expand them further. The PBS system, launched in 2019 and operational since 2020, includes 100 pedal bicycles, 400 e-bikes, and 23 docking stations. It operates on a VGF model, with revenue covering 123 per cent of operating costs. The EV infrastructure is built in partnership with Energy Efficiency Services Limited (EESL), using a revenue-sharing PPP model, where land is provided by the city and EESL handles setup and operations.

This has helped to increase cycling ridership by 50 per cent from a very low baseline in two months. It involved community engagement, stakeholder consultations, surveys, and community events like cyclothons.

As per the estimates of the New Town Kolkata Development Authority (NKDA), the programme has seen over 51,000 registered users complete more than 2 lakh rides, covering a distance of over 5.6 lakh kilometres.

However, the initiative is facing challenges, as the current state of cycling infrastructure has significantly deteriorated. Many PBS docks are non-functional, e-bikes are unavailable or poorly maintained, and the cycling tracks are frequently encroached upon or unsafe.

Despite a promising and well-funded start with smart planning and public-private partnerships, the system remains underutilised and needs sustained maintenance, strong enforcement to prevent encroachment in the dedicated infrastructure, protection of assets, renewed community engagement, integration with public transit nodes, and stricter infrastructure governance.

JANPATH, UDYOG VIHAR, GURUGRAM

Gurugram is a non-attainment city under the NCAP with high contribution of vehicular pollution. Its transport infrastructure and road design with flyovers and underpasses, and signal-free corridors are predominantly car-centric—making walking and cycling considerably unsafe and difficult. The roads are also vulnerable to flooding. Therefore, it will take massive and comprehensive planning to regain the active mobility to support augmentation of public transport—both in the case of metro and in the implementation of the new bus programme.

From that perspective, the initiation of stretches of walking and cycling are important. One such instance is the development of one stretch of the Janpath road. The stretch initiative spans approximately five kilometres and its re-development commenced in 2020. The stretch features a significant presence of corporate companies and industries, followed by residential and institutional areas.

This is a unique initiative in which the government agencies, civil society groups, corporate groups and industry have come together to execute the project and mobilise private funding, including corporate social responsibility. Key stakeholders involved in this initiative include Gurugram Metropolitan Development Authority (GMDA), traffic police, the Raahgiri Foundation—a civil society group, and corporate or industry entities, such as Nagarro and Maruti Suzuki.

Financial assistance for the initiative was provided by the GMDA, along with corporate CSR funding from Nagarro and Maruti Suzuki through the Raahgiri Foundation. This is the kind of collaboration cities require for the successful implementation of the initiatives.

The car-free days and cyclothon programmes that preceded this initiative raised awareness about the necessity for walking and cycling tracks in the city.

The key features of this initiative include:

A Complete Streets design approach: It is required to meet the needs of all road users, including pedestrians, cyclists, motorists, and public transit riders, and to provide safe and convenient access to all.

Dedicated road spaces for walking and cycling: The adopted design includes dedicated pathways for pedestrians and cyclists, effective segregation from motorised vehicle lanes to facilitate safe and unobstructed movement, etc.

Accessibility and universal design: It was adopted to provide continuous, seamless pathways with consistent elements, visual continuity, and traffic calming measures. It includes warning tiles along edges, audible pelican crossings, ample and frequent crosswalks, table top crossings, safety bollards, and clear wayfinding and directional signage, etc.

Placemaking: It has promoted shared public spaces, active streets, and passive areas for rest and interaction. It incorporates zones for kiosks and hawkers to enhance street activity, as well as provisions for alternative uses, such as flea markets and street markets during holidays, and designated bus parking or market streets at night.

Conserving natural elements: The design safeguards existing trees, enhances stormwater filtration, integrates planting strips and bioswales, along with high albedo materials to improve environmental sustainability and urban resilience.

Challenges addressed during implementation:

Establishing infrastructure: One of the primary challenges involves relocating existing utility networks, including power lines and telecommunications cables, such as optical fibre. Additionally, the repair and construction of underground drainage systems presented further complexities, as these facilities were passing through the proposed dedicated area for walking and cycle tracks. This was done to avoid future complications and minimise disruption to the functionality of the walking and cycling infrastructure.

Building support of the corporate bodies: In the early stages of the project, some corporate organisations expressed doubts and uncertainty. However, after the initiation of the project, support could be built.

Development of one stretch of Janpath Road: Before and after
Photos: Raahgiri Foundation

Utilisation of the cycle lane: Some of the cyclists continue to prefer the main carriageway, instead of using dedicated lane. This is mainly due to the lack of awareness of this provision and its benefits, and the perception of speed on the track and its network.

Restricting the use of other motorised vehicle entry and parking: It is a challenge to restrict motor vehicles from using the walking and cycle track. Raahgiri foundation is deploying volunteers to assist traffic marshals for traffic management and maintaining smooth flow traffic on roads.

Outcomes of the initiative: After the initiation and completion of the project, efforts have been made to assess the benefits of the intervention.

Reduced road fatalities: Since the start of the initiative, zero fatalities have been reported. Pedestrian-friendly environment—which includes well-maintained sidewalks, clearly marked and raised pedestrian crossings, adequate street lighting, and minimal traffic congestion—have helped.

Social benefits: Active use of walking and cycling, presence of kiosks and hawker has made the area more active and livelier; safety for road users, particularly for women, has thereby increased. Additionally, corporate and industrial employees in proximity utilise the space for breaks and refreshments, contributing to increased community engagement. People and corporate companies prefer to shift to nearby areas to the road, which lead to a dramatic decrease in vacancy rates—from 30 per cent to less than 5 per cent.

Increased property rates: The initiative has yielded substantial economic benefits for all stakeholders along the road. Businesses, including offices and local vendors, have seen a rise in rental and property value around two to three times, and vacancy rates decreased from 30 per cent to less than 5 per cent.

Increased revenue of street vendors: Street vendors have also experienced a boost in business, benefiting from increased foot traffic and the appealing outdoor spaces that attract office workers.

Increased savings for the road users: Pedestrians are saving significantly on rickshaw fares as the safe and walkable infrastructure encourages them to explore the area on foot. Furthermore, the smoother traffic flow, resulting from reduced conflicts between pedestrians, cyclists, and motorists, has improved commuting times for drivers, enhancing overall efficiency and productivity in the area.

Environmental benefits: 385 fully grown trees were saved from being cut down. The extensive planting of trees and shrubs has significantly reduced dust pollution on the road, serving as a natural barrier against dust particles. During the heat wave in May, shaded pathways provided by the trees were found to be 23°C cooler than the surrounding asphalt road. Low-lying planting pits have been created to capture 70 per cent of rainwater, helping to reduce flooding and replenish groundwater through bioswales. The planting of trees and shrubs has greatly improved the visual attractiveness of the road, contributing to a more pleasant environment for all users.

Potential replication: The success of the initiative has prompted development authorities and corporate companies to come forward and expand its reach. Notably, the Gurugram Metropolitan Development Authority (GMDA) is actively working to develop walking and cycling lanes in various parts of the city, including sectors 102, 103, and 106.

Additionally, the Faridabad Metropolitan Development Authority (FMDA) has expressed interest in implementing similar initiatives on its roads. Furthermore, Safe Express Private Limited, located nearby, has offered CSR funding to support the development of similar projects in front of their office.

REINVENTING CYCLING: BICYCLE INITIATIVE IN BENGALURU

In most cities of India, finding space for walking and cycling has become a serious challenge, especially due to car-centric development approaches, and strong resistance from the car users who are not willing to share the roads with other sustainable modes of transport. Even a few cities that have attempted to create dedicated or protected lanes for cycling are under severe pressure to dismantle those systems and reclaim the space yet again for the personal vehicles and the carriageway of the roads.

Moreover, many of these projects are executed as part of the city beautification schemes—more for aesthetics than for functionality. As a result, there are design defects that impede optimum usage of these lanes. It is challenging to find good practice that has been implemented in scale and to promote cycling in cities.

Bengaluru is one such city that has made consistent effort to promote cycling with infrastructure development and campaigns. But this needs to be understood with the caveat that even though the interventions highlight good practice elements, the interventions are still not adequate to make a difference to the overall congestion level in the city.

After Bengaluru witnessed a sharp decline in bicycle usage, dropping from 16 per cent in 1981 to just 3 per cent in 2011, the Directorate of Urban Land Transport (DULT) launched the Cycle Day initiative in 2013 to revive cycling culture through community engagement. These events, organised in collaboration with citizen groups, aim to popularise cycling and reclaim streets for pedestrians and cyclists. Since its launch, over 550 Cycle Days have been held across 60 neighbourhoods, making it one of the country's longest-running open street events.

Building on this momentum, DULT introduced a range of cycling-supportive measures, including the launch of a public bicycle sharing (PBS) system, installation of cycle stands at key commercial and transit points, and allocation of cycle parking in area parking plans shared with BBMP. Collaborations with BMRCL have also led to the provision of bicycle parking at metro stations.

To promote cycling skills, DULT introduced 'Pedal Shaale', a free training programme in partnership with organisations like CiFoS, KBDA, and Decathlon. Additionally, 'Pedal Port' kiosks—equipped with repair tools and air pumps—were piloted at metro stations, beginning with a prototype tested during the Church Street First initiative in April 2021.

As part of the SuMA Doddanekkundi initiative, live bicycle counters were installed to measure cyclist volumes, aiding data-driven planning. DULT also partnered with the Karnataka startup cell to launch the Mobility Grand challenge, focusing on innovative solutions for maintaining and enforcing cycle-lane usage.

Cyclists were invited to map preferred routes using tools like Strava and GPS Visualizer, as part of the Cycle 4 Change Challenge, Bengaluru.

The 2020 comprehensive mobility plan (CMP) for Bengaluru has planned to develop 600 kilometres of cycle track network in the city by 2035. The initiatives of DULT and the active involvement of neighbourhoods and citizens will play a key role in achieving this goal.

These are steps in right direction. But these need massive programmatic and resource support to upscale the initiative and make city-wide transformation to create committed ridership.

ON-ROAD EMISSIONS MANAGEMENT

While new vehicle technology has advanced quickly with the direct leapfrog from the BS-IV emissions standards to BS-VI standards in 2020, the on-road emissions monitoring system has not evolved commensurately. Moreover, the fleet renewal strategies to replace old vehicles with new vehicles have also remained slow, leading to enormous pollution in the on-road fleet.

This has raised concerns around real-world driving emissions from on-road vehicles that are much higher than what they were originally designed to emit; and higher pollution from the older fleet.

Under the NCAP, CPCB has defined the scope of interventions for on-road emissions management including, strengthening of the PUC certificate programme, integration of on-board diagnostic (OBD) system fitted in new vehicles with vehicle inspection, vehicle labelling or sticker programme to identify older vehicles for fleet renewal, management of freight traffic (routes, overloading, bypass etc), and alternative fuel policy.

Though the scope of the interventions is not the most comprehensive, even those listed have remained very casual, without guidance on further advancement needed to align with the policy objectives. These have not adequately aligned with the current policies, regulations and funding strategies in the sector related to vehicle inspection, fleet renewal and scrappage, inspection in the automated testing centres for identification of end-of-life vehicles, and targeted upscaling of the fleet electrification and clean fuel programme.

BENCHMARKING GOOD PRACTICES FOR REDUCING TAILPIPE EMISSIONS

Each of the intervention points need to be benchmarked in relation to the policy goals and global good practices. These sub-sectors include:

1. Leapfrog to new generation on-road emissions surveillance system, like remote sensing measurements for fast screening of large fleet of on-road vehicles to identify the worst polluters, contributing maximum to the pollution load from vehicles. New vehicle technology and emissions control systems are undergoing massive transition. The current PUC certificate programme based on idling tests—especially smoke density test for diesel vehicles— is not adequate and appropriate any more. The PUC tests, even when performed correctly, cannot come close to capturing real-world driving emissions.

2. Rapid fleet renewal based on efficient identification of unfit and end-of-life vehicles in the automated vehicle testing centres. This is important for the processes of phase-out, and scrappage and material recovery. These need to be aligned with central regulations that have already been notified with respect to the fleet renewal and scrappage programmes, and develop state-level implementation strategy with targets and timeline. The NCAP needs to ensure that the strategies are well-defined for convergence funding and catalytic funding from the NCAP.

3. The third key intervention is the accelerated electrification of the vehicle fleet, segment-wise, to achieve a near-zero emission transition. NCAP needs to align with the state-level EV policies to ensure compliance with targets for electrification by leveraging demand incentive and supply side mandates, and time bound charging infrastructure development.

Several cities and states have implemented several pieces of all these strategies in varying scale and scope. Only a few demonstrate relatively more progressive action. Delhi has taken several measures related to old vehicle phase out, setting up of scrappage centres, addressing emissions from truck traffic and piloting of remote sensing measurements. These have already been presented in Delhi case study.

In most other cases, fleet renewal, on-road inspection, and vehicle fleet electrification are work-in-progress. Only a few initiatives indicate a broader directional change. Otherwise, there are still substantial gaps in action in most of these sub-sectors.

KOLKATA: REMOTE SENSING MONITORING OF ON-ROAD VEHICLES

Remote sensing technology(RSD) consists of a light source and detector, typically positioned on the roadside or overhead, which transmit a laser beam across the road to capture emissions data as vehicles pass. The system uses advanced spectroscopy to analyse exhaust plumes in less than a second, accurately measuring pollutants such as nitrogen oxides (NOx), carbon monoxide (CO), hydrocarbons, and even particulate opacity. Unlike the controlled environment of a PUC test, these readings are taken under real driving conditions, capturing the emissions profile of each vehicle in its natural environment.

This has enormous potential for on-road emissions management. This is a more efficient way of (i) identifying high-emission vehicles for targeted checks and repairs, (ii) screening of low-emission vehicles to avoid redundant inspections, (iii) profiling of fleet emissions to assess inspection programmes and technology performance, and (iv) controlling polluting vehicles in designated low-emission zones.

The system can scan thousands of vehicles daily, creating a robust emissions dataset. By linking emissions data to each vehicle's license plate, authorities gain information on vehicle make, model, fuel type, and compliance level. This enables authorities to quickly identify high-polluting vehicles, and minimise delays between detection and intervention. The detailed data can also inform policies like low-emission zones, targeting high-emission vehicles, and potentially improving public health and urban air quality.

Clean air action catalyses RSD programme in Kolkata: Kolkata is the first Indian city to implement remote sensing for vehicle surveillance on a limited scale. The adoption of RSD in Kolkata was catalysed by the directive from the Calcutta High Court in relation to the phase-out of older vehicles in 2009 to reduce air pollution. This directive had sought improvement in in-use emissions surveillance. Currently, Kolkata has two RSD devices and one mobile RSD unit.

According to the Department of Transport, West Bengal, these devices are capable of monitoring emissions of CO, CO2, HC, NOx. At the time of this assessment, two devices were operating for eight working hours and five days a week at strategic locations and were capable of screening at least 4000 vehicles daily.

Innovating enforcement strategy: In the absence of the central government guidelines, the state transport department has linked the compliance strategy with the PUC norms, as per the rules 115 and 116 of the Central Motor Vehicles Rules, 1989.

This system records and issues show-cause notices to vehicle owners whose vehicles are found to emit high emissions based on remote sensing measurements. The mobile remote sensing devices are placed in strategic locations by rotation. The devices detect emissions as vehicles are being driven on the road, cameras capture the number plate details and a computer records the emissions data along with the vehicle details.

The show-cause notices are sent directly to the vehicle owners. The notice carries a picture of the vehicle with the registration plate, date and location of testing, and the emission result.

The vehicle owners are requested to bring the vehicle to a specified inspection centre for further verification within 15 days. Failing that, the owner is liable to pay a fine under section 190(2) of the Motor Vehicle Act and further action as per law.

The system has faced barriers. When vehicle owners are intimated by the department about their polluting vehicles, they often challenge the department on the grounds that they have a valid PUC certificate and therefore they should not be penalised. This requires urgent notification from the Ministry of Road Transport and Highways (MoRTH) to provide the threshold limits for RSD application and guidelines for its adoption of a compliance programme. Such guidelines must clearly define how RSD should co-exist with the PUC programme.

Leads to more efficient emissions screening of on-road vehicles: At this stage, there is no formal system of putting out RSD data. But long-term data generation over the last decade in Kolkata is an opportunity to carry out fleet-wide, vehicle technology genre-wise, age-wise analysis for proper profiling of the on-road emissions behaviour. This can also be leveraged to inform the framing of the central guidelines and norms setting and support the finalisation of the draft Automotive Indian Standards (AIS) 170 for RSD.

However, this is a unique bottom-up initiative in which the city has taken the lead to demonstrate the potential and opportunity of this surveillance mechanism for identification of worst emitters on the roads. The Department of Transport, Government of West Bengal, has carried out analysis of some sample databases to show the possible ways of profiling.

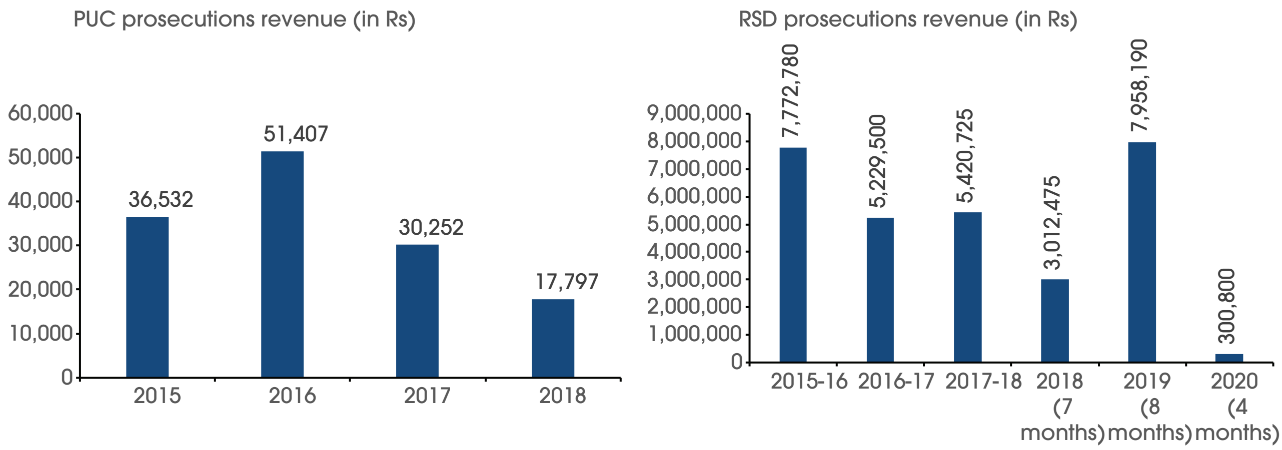
In 2020, the Department of Transport had carried out a limited analysis of about 19,0367 vehicles that were screened during the preceding four months. This showed that nine per cent of vehicles were high emitters. In another data set of 51 lakh vehicles that were tested between 2015 and 2020, about 3.4 and 3.7 per cent of vehicles were found highly polluting and about six to seven per cent were high emitters.

Predictably, diesel vehicles older than ten years emitted twice as much as those less than ten years old. Among petrol vehicles, those over 15 years old recorded three times higher emissions versus those less than ten-year-old. The category of diesel transport vehicles over ten years old had three times higher emitters than non-transport vehicles. Among them, 11 per cent of taxis, 10.1 per cent of goods vehicles, 7.7 per cent of buses and 5.1 per cent of omni buses were found to be high emitters. In more than 15 years old category, 10.1 per cent cars and 12.3 per cent omni buses were identified as high emitters.

This kind of emissions profiling and identification of worst emitters can help to identify the worst offenders. Global evidence shows that a small share of grossly polluting vehicles can be responsible for more than half the emissions load from the on-road fleet. If those vehicles can be identified efficiently and be dealt with, it can help to address substantial fraction of vehicular pollution. The PUC is not as effective in similar identification.

According to the West Bengal Transport Department, as RSD programme has helped to identify polluting vehicles more efficiently, prosecution of polluters has also improved. This is evident in the increased revenue—almost 200-fold increase after RSD deployment. For instance, in contrast to the manual PUC checks that had raised revenue of Rs 1.36 lakh between 2015 and 2018, RSD-supported enforcement has generated approximately Rs 297 lakh between 2015 and 2020. (See *Graph 5: Revenue generated from PUC versus RSD prosecution*).

Graph 5: Revenue generated from PUC versus RSD prosecution



Source: Department of Transport, Government of West Bengal

The West Bengal Transport Department has collected penalty charges of Rs 8 lakh during 2019–20. RSD has helped the regulators to improve emissions surveillance.

Planning expansion under the clean air programme: The Kolkata RSD programme is now more than a decade old. The monitoring instruments have out-lived their lives and require replacement and augmentation. Therefore, the Government of West Bengal considered expanding the RSD programme to all six non-attainment cities by procuring new machines. It was proposed that funding available under the NCAP and 15th Finance Commission will be leveraged to upscale this programme.

However, this could not be taken forward. Despite the implementation of the RSD programme to comply with the Calcutta High Court order and despite the Supreme Court directive to the MoRTH to notify RSD rules for its implementation, the central rules have not been notified yet. Any new purchase of machines will require certification from the testing agencies, like the Automotive Research Association of India (ARAI). Even though ARAI and others have begun the process of developing certification system, it is not complete yet.

Despite taking progressive action and demonstrating its efficacy for over a decade, further augmentation of the programme has hit a barrier in Kolkata. The central government needs to step in quickly to provide an interim mechanism to help this programme to continue in Kolkata while the final notification of the AIS 170 rules is awaited. This Kolkata programme can also be integrated with the national pilots that the MoRTH has proposed to generate data to arrive at a threshold level for nation-wide implementation of RSD.

Scalability and replicability: This programme has the potential for upscaling under the NCAP, as several state governments have proposed the introduction of RSD in their respective clean air action plans for non-attainment cities. The Supreme Court of India, in its order dated 10 May 2018, has highlighted Kolkata's remote sensing programme in the context of its implementation in Delhi. Building on its 2018 and 2019 rulings and recommendations from the former Environment Pollution (Prevention and Control) Authority (EPCA), the Supreme Court has further directed the Ministry of Road Transport and Highways (MoRTH) to prioritise RSD implementation in Delhi and the NCR region.

This directive has stemmed from a 2017 Supreme Court-mandated audit of Delhi NCR's PUC programme, which revealed significant shortcomings and the need for advanced monitoring. In response, MoRTH developed the AIS 170 standards for RSD, but these standards are yet to be notified, and gaps remain to be addressed

In this context, the central and state governments need to collaborate and coordinate to develop a plan to upscale RSD implementation. This approach will build confidence and capacity among local agencies, making RSD a viable, scalable solution for pollution control across Indian cities. This also requires MoRTH to clarify how remote sensing monitoring will co-exist with the PUC programme.

A guidance framework for RSD monitoring and technical regulations is needed. Amendments to the Central Motor Vehicles Rules (CMVR) are necessary to define the mandate, rules, and scope for RSD implementation and enforcement. This is urgently needed, as under the NCAP, several cities have proposed implementation of RSD programme.

VEHICLE FLEET ELECTRIFICATION AND NCAP

It is noteworthy that five years of the NCAP has coincided with expansion of the electric vehicle adoption in India. This expansion has been backed by the central government's demand-incentive programmes, which include FAME II, PM e-bus Sewa and PM e-drive. This has been an opportunity to expand zero tailpipe emissions strategy and replace internal combustion engines that are responsible for high exposures and pollution. During the five years of NCAP, as per the VAHAN dashboard of MoRTH, the share of electric vehicles has increased to 6.5 per cent in FY 2023–24.

The CPCB indicators for vehicular pollution control segment are not explicit. However, some cities have begun to report progress in terms of acquisition of the electric buses, and setting up of charging infrastructure.

Some of the cities in forefront—including Delhi, Bengaluru, Pune, among others—show fleet electrification share over 11 per cent. The share in other bigger cities is less than ten per cent with some variability. The fleet is currently dominated by electric two-wheelers. The cities in northern India show a strong present of e-rickshaws indicating the importance of informal and paratransit solutions in densely populated urban areas. Several small towns are dominated by e-rickshaws.

Considering the fact that the electric small format vehicles like e-two wheelers, e-autos and e-rickshaws are growing to replace internal combustion engines, its potential to reduce toxic air pollution is substantial.

Table 3: Million-plus NCAP cities phasing in electric buses (sanctioned strength by 2027)

up to 100 e-buses	101 to 250 e-buses	251 to 500 e-buses	501 to 2000 e-buses	More than 2000 e-buses
- Vijayawada	- Patna	- Surat	- Bengaluru	- Delhi
- Vishakhapatnam	- Rajkot	- Ahmedabad	- Pune	- Mumbai
- Bhilai	- Bhopal	- Indore		- Kolkata
- Raipur	- Gwalior	- Nagpur		
- Vadodara	- Jabalpur	- Hyderabad		
- Faridabad	- Nashik	- Lucknow		
- Dhanbad	- Navi Mumbai	- Srinagar		
- Jamshedpur	- Jaipur			
- Ranchi	- Agra			
- Chhatrapati Sambhajinagar (Aurangabad)	- Prayagraj (Allahabad)			
- Ulhasnagar	- Ghaziabad			
- Thane	- Kanpur			
- Vasai-Virar	- Varanasi			
- Ludhiana	- Meerut			
- Amritsar	- Dehradun			
- Jodhpur	- Shimla			
- Kota				
- Tiruchirappalli				
- Madurai				
- Asansol				
- Howrah				

Source: Compiled by CSE from various STU and government sources

The most substantial change is noticed in the electric bus programmes for mass commuting in some of the mega and big NCAP cities. Replacement of heavy-duty diesel or CNG buses with electric buses has enormous potential for reducing and avoiding toxic emissions. Nearly all 41 million-plus cities that have either already launched or are in the process of launching electric buses with sanctioned fleet. Cities like Delhi, Mumbai, Bengaluru, Navi Mumbai, Surat, Ahmedabad, Kolkata among others have begun to procure their sanctioned fleet (See *Table 3: Million-plus NCAP cities phasing in electric buses (sanctioned strength by 2027)*). Once this programme is fully established and its modal share increases, this can be an important opportunity to reduce vehicular emissions substantially in cites.

Innovation in charging infrastructure in cities range from public private partnership models to stations connected with solar power and use of old batteries for energy storage. Panaji, Goa offers 50 per cent funding under a cost-sharing model for setting up charging stations. Bengaluru has developed software applications that support effortless use of charging stations. Apps such as Static and EV Mitra by the Bengaluru Electricity Supply Company Limited (BESCOM) help EV users to personalise their experience, provide information on charging station location, availability, secure access through OTP or RFID to reserve chargers, reservation history, and offer multiple payment options.

In Delhi, apps—such as Battery Smart — Driver, Jio-bp Pulse Swap, and VoltUp—connect two- and three-wheeler drivers with battery swapping stations, allowing them to locate and access stations, view real-time battery status, and track swap history. The apps allow users to locate nearby stations, view battery status, track swap history, and search by location, battery model, or vehicle type.

Bengaluru's BESCOM has conducted a pilot for using second-life batteries to store solar energy and power a charging station. The Indian Institute of Technology in Jodhpur has developed an adaptor that allows EVs to be charged using solar power. The low-cost adaptor connects a solar panel to an EV charger, facilitating efficient solar energy use for EV charging.

A few cities like Delhi, Bhubaneswar among others are also promoting targeted electrification of vehicle segment like government-owned vehicles and fleet aggregators and deliveries.

As the EV programme in states currently is largely driven by the demand incentive programme of the central government, very few city-level initiatives and good practices are discernible. However, going forward, NCAP can play a significant role in demanding accelerated transition from internal combustion engines to contribute to the national minimum target of 30–40 per cent fleet electrification by 2030. Towards the end, city and region-specific targets may be set for each vehicle segment including two- and three-wheelers, cars, buses, and commercial vehicles. These targets must be backed by state-level incentives, supply-side mandates for manufacturers, and a time-bound plan for developing intra-city and inter-city charging infrastructure. The NCAP needs to catalyse firm mandate for zero emissions transition to control vehicular emissions at source.

INDUSTRY

BEST PRACTICES TO MITIGATE INDUSTRIAL AIR POLLUTION

Despite being a major contributor to urban air pollution, industrial pollution control remains underfunded and underreported within the NCAP, especially due to its exclusion from municipal action plans and fragmented implementation across state boundaries.

Gujarat has led the way with centralised boiler systems that replace polluting standalone units with cleaner, shared infrastructure. Widely adopted in Surat, this model has improved efficiency and sharply reduced coal use and emissions.

Rajasthan has pushed foundries to adopt cleaner divided-blast cupolas, while clusters like Agra are shifting to PNG- or electric-powered units—cutting coke use and improving air quality and efficiency.

The brick kiln sector, especially in Jhajjar, is adopting cleaner designs, better fuels, and tighter emission controls—showing what's possible when technology upgrades align with regulatory pressure, despite ongoing quality challenges. Replacing traditional kilns with Zig-Zag technology cuts emissions by 70 per cent and fuel use by 30 per cent, driven by stricter environmental regulations.

In Tamil Nadu's stone crushing sector, measures like full enclosure, atomisers, and circular power systems are reducing dust and energy loss—delivering visible improvements in local air quality.

A growing number of industrial enterprises are embracing circular economy practices—recovering energy and materials from waste. The spread of CBG plants, especially in Indore, reflects a shift toward decentralised solutions that curb pollution, generate jobs, and close the industrial waste loop.

INTRODUCTION

Industrial air pollution control remains one of the most neglected and least funded sectors under the National Clean Air Programme (NCAP). According to the PRANA portal, as of September 7, 2024, only Rs 60.75 crore— just one per cent of the Rs 11,211.13 crore released between FY 2019–20 and 2023–24—has been spent on industrial pollution control.[1]

This is often attributed to the fact that city clean air action plans are confined to municipal boundaries, while most industries are located beyond them. As a result, industrial pollution fails to receive primary attention. This interpretation remains a grey area, as the Central Pollution Control Board (CPCB) has issued a broad set of indicators for state governments to report progress in the industrial sector. These demand varied actions across diverse industrial categories within a city's influence zone, making uniform implementation challenging.

This is evident in the indicators listed by CPCB for reporting progress on industrial pollution control (*see Box: CPCB indicators for tracking progress on industrial pollution control*). The indicators cover intervention categories such as overall industrial pollution control, material storage and handling, clean fuels in industry, emission control in thermal power plants and brick kilns, dust and fugitive emissions in industrial areas and processes, control in iron and steel units and coke ovens, mining, waste incineration, industrial diesel generator sets, and adoption of renewable energy.

This clearly shows that the intent of NCAP is not to confine industrial pollution control to municipal limits, but to address emissions across a wide range of industrial sources. However, this has not been reflected in operational practice. Had these indicators, or even a focused set of priority indicators, received consistent attention at the state level, the impact could have been significant.

Moreover, the limited information available on the PRANA portal and through reporting by state pollution control boards and urban local bodies under NCAP shows that reporting on industrial indicators remains minimal. Most submissions are limited to routine regulatory actions such as stack emission inspections, challans, and closure notices.

One key area of intervention that most cities have reported is the notification of approved fuel list to promote cleaner fuels. But this reporting does not adequately capture the nature of fuel change and technology transition catalysed by this fuel policy. There is no information on industry-specific interventions to improve access to clean fuels, emissions control technologies, or the pricing of cleaner alternatives. Details are also lacking on actions taken in micro, small, and medium enterprises (SMEs) and in red and orange category industries.

CPCB indicators for tracking progress on industrial pollution control

At the outset of clean air action plan reporting, CPCB had provided an extensive list of indicators, signalling that the original intent was to ensure broad coverage across diverse intervention categories. The following is a summary of those indicators.

Industrial air pollution control: This set of interventions includes inspections, enforcement of emission norms (including SOx and NOx), relocation of polluting units, cleaner production and technology upgrades, installation of emission control systems, fugitive emissions control, non-hazardous waste disposal, hydrocarbon loss data sharing, and plant-specific action plans.

Controlling air pollution from thermal power plants and coal handling units: This includes regular stack emission audits for QA/QC; dust suppression through sprinkling at sidings, transport routes, and coal dumps; installation of ESPs with online monitoring on all boiler chimneys; use of low-sulphur fuel for sulphur reduction in fuel, and imported coal in thermal power plants; installing/upgrading pollution control systems in thermal and petrochemical industries; mandatory use of high-grade coal; installation of FGD units and implementation of new emission standards across power plants. It also involves tracking compliance and transition plans for each plant to ensure they meet the standards, penalising non-compliant plants, promoting cleaner technologies, prioritising cleaner units, shifting to wind and solar power, and permanently closing or converting old thermal power plants to cleaner fuels like natural gas.

Material storage and handling in industrial units: This includes storage and handling of Class-A petroleum products and solvents in tanks, storage of Class-B chemicals like Styrene and Xylene, solvent vapour treatment, and internal monitoring systems for cleaning major tanks containing Class-A substances and other chemicals such as Styrene and Xylene.

Clean fuel in industries: This includes introducing and shifting industries to cleaner fuels; converting from pet coke, wood, and coal to CNG/PNG; imposing an urgent ban on furnace oil, pet coke, and heavy metals; strict enforcement against illegal fuel use; establishing protocols for cleaner fuels and technologies; restricting unauthorised fuels in industries; reducing sulphur content in fuels; and directing the hotel industry to shift from HSD to natural gas.

Controlling air pollution from brick kilns: This includes adopting new technologies for brick kilns; identifying brick kilns and regularly monitoring them for designated fuel use and shutting down unauthorised units; converting natural draft kilns to forced or induced draft; exploring relocation of unauthorised kilns outside municipal limits; prescribing design specifications for improved kilns; and verifying compliance to ensure actual conversion.

Online Continuous Emission Monitoring System (CEMS) for industries: Provision to use CEMS data as legal evidence, with a policy framed in consultation with CPCB; implementation of CEMS across all targeted polluting industries; live camera feeds and enforcement action against non-complying units.

Controlling air pollution from coke ovens: As per this indicator, coal-fired boilers are to be converted to oil or gas-fired dryers, preferably using coal bed methane (CBM); adoption of coke dry quenching (CDQ) systems; increasing carbonisation chamber height; high-pressure ammonia liquor aspiration; wet oxidative desulphurisation of coke oven gas; and implementation of stationary land-based pushing emission control.

Controlling fugitive emissions from industrial processes: This includes adopting the use of hoods and enclosures for all process equipment, including blast furnace tapping operations and molten metal discharge; covering ladles with molten metal; implementing a scrap management programme to reduce contaminants in steel scrap and feed materials; using covered or enclosed conveyors and transfer points; enclosing emission controls for charging and tapping operations; minimising flanges by welding pipe connections and sealing flanges and valves properly; adopting wet coke quenching instead of conventional methods; using larger oven chambers and regulating internal pressure.

Controlling air pollution from iron and steel industries: This includes the use of desulphurised coal, pulverised coal injection, installation of coke dry quenching (CDQ) and top gas recovery turbines (TRT), adoption of coal dust injection (CDI), waste heat recovery in sinter plants and blast furnace stoves, use of byproduct fuels for power generation, switching from basic oxygen furnaces to direct reduction electric arc furnaces, and upgrading air pollution control systems.

Dust and fugitive emissions control in industrial areas: According to this indicator, all haul roads are to be paved, and ash dumps enclosed with permanent boundaries to restrict access. Ash processing must take place in covered areas, with dry ash collection systems installed and sale to cement mills resumed. All ash is to be disposed of through utilisation or sale. Thermal power plants are to undertake plantation drives using local species to increase green cover. Abandoned or inoperative mines are to be converted into water bodies, and coal or coke processing areas in coke units must remain covered.

Controlling air pollution from mining area: This includes the maintenance of roads in mining areas; development of greenbelts in activity zones and buffer zones around mining areas; adoption of good mining practices; and control of fugitive emissions in open-cast mines using mechanised sweeping and long-range fogging machines.

Controlling air pollution from generator sets: According to this indicator, only DG sets complying with emission norms, chimney/exhaust design, and acoustic enclosure standards should be allowed to operate. Their use in social events should be curtailed by providing temporary electricity connections. Access to reliable electricity must be ensured, DG set use in cellular towers discouraged, alternate power sources promoted, and rooftop solar programmes leveraged to reduce dependence on DG sets.

Controlling air pollution from waste incineration: This includes establishing a strong siting policy for waste-to-energy and biomedical incineration plants; implement CEMS for all incinerators and ensure emission data is publicly accessible on an open platform.

Renewable energy: Link energy requirements of solar power plants to zero-emission targets; identify commercial and industrial establishments for rooftop solar installation; map canals and open spaces for solar deployment; and conduct consumer outreach programmes to promote rooftop solar adoption.

Information on industrial pollution control is available only when a non-attainment city also functions as an industrial hub—but even in such cases, the reporting remains uneven across cities. For example, Angul, an industrial town in Odisha that topped the Swachh Vayu Survekshan, has shared some details on the PRANA portal. These include upgrades to air pollution control equipment to meet new standards, fuel transitions, desulphurisation of coke oven gas, waste heat recovery, use of waste gas for power generation, compliance of industrial DG sets with emission norms, and adherence to the MoEFCC's siting policy for waste incinerators.

More detailed information on industrial pollution control is provided only when a non-attainment city also happens to be an industrial city or town. But that is not uniformly exhaustive across all industrial cities. For instance, Angul, an industrial town in Odisha that topped the Swachh Vayu Survekshan rankings, has shared some details on industrial pollution control on the PRANA portal. This includes upgrading air pollution control equipment to meet new standards, fuel transitions, measures in the iron and steel industry such as desulphurisation of coke oven gas, waste heat recovery, use of waste gas for power generation, compliance of industrial DG sets with prescribed norms, and adherence to the siting policy for waste incinerators issued by the Ministry of Environment, Forest and Climate Change (MoEFCC).

However, it is important to note that due to underreporting on the PRANA portal, emerging good practices from various states are often not adequately reflected within the NCAP framework. Yet, independent investigations and information from state pollution control boards (SPCBs) and other official sources reveal a growing positive trend. These sources highlight proactive steps taken by environmental regulators, the judiciary's role in driving local action, and the adoption of good practices by industries themselves.

This is clearly illustrated by the clean fuel transition in Delhi and NCR; improvements in brick kiln technologies in states such as Uttar Pradesh, Bihar, West Bengal, and parts of the NCR; the introduction of a common boiler policy in Gujarat; control of fugitive emissions in Tamil Nadu and Maharashtra; advancements in furnace technologies in Uttar Pradesh and Haryana; widespread adoption of Continuous Emissions Monitoring (CEM) in Uttar Pradesh; better application of CEM systems in Odisha; and strengthened CEM capacity in regional offices across Rajasthan.

It would be beneficial to further strengthen the PRANA portal as a comprehensive repository of progressive and proactive measures taken by states and industries. This would help capture the learning curve and guide all states in shaping their roadmaps for clean air.

DRIVING CLEAN AIR ACTION IN THE INDUSTRY SECTOR

The emerging good practices in the industry sector have different drivers of change.

The regulatory and judicial drivers

Action on air pollution control in the industry sector is largely driven by the national emissions regulations and standards. However, India's environmental governance structure places significant responsibility on state pollution control boards (SPCBs) to regulate and mitigate pollution at the regional level. While the central government provides overall guidelines and emissions standards, the success of implementation largely depends on how actively and innovatively SPCBs operate.

While national regulations and emission standards provide a common baseline for all states, there is significant scope for proactive local action. States can adopt customised solutions tailored to local industry clusters, going beyond the minimum national requirements.

There are several instances of proactive efforts that the SPCBs and state environment departments have made to strengthen the policy terms for industrial action.

On the other hand, in several states, the judiciary, including the Supreme Court, High Courts, and the National Green Tribunal, has stepped in to enforce stringent industrial pollution controls, as seen in the Delhi case. These interventions help define the scope and scale required for lasting change.

There are several instances where SPCBs have taken proactive steps beyond basic compliance and enforcement, engaging with stakeholders to drive long-term, systemic improvements in pollution management. While a comprehensive review of all SPCB initiatives is not possible, selected examples are presented here to illustrate the nature of actions and innovations underway.

These interventions have strategically targeted pollution control in the challenging Micro, Small, and Medium Enterprises (MSME) sector, including small boilers in industrial clusters, furnaces in the foundry sector, fugitive emissions from stone crushers and mineral grinding units, common infrastructure for cluster-specific industries like metal works, and smart monitoring systems. These state-level proactive measures are critical and should be scaled across states through the NCAP framework.

It is also evident that the convergence funding framework has begun to take shape for the industrial sector, even though it is still at a nascent stage. In Uttar Pradesh, for instance, Smart City Mission funds have been used to develop common refuelling infrastructure for furnaces in Moradabad's metalwork industry. This serves as a significant example of how infrastructure funding can be effectively leveraged for industrial pollution control.

Proactive steps taken by the industry

While all industry segments across all states work to meet basic emission standards, some units emerge as front runners by adopting innovative approaches that set the roadmap for others in their sector. It is very important to understand the nature of these initiatives as the real solutions emerge from the details related to the technology adoption, changes in industrial processes, fuel change, among others.

In the industrial pollution sector, regulations and standards on emissions, energy efficiency, fugitive emissions control, waste circularity, and compliance are expected to be the key drivers of change, with the potential to also spur industrial investment. At times, fuel change is mandated, as seen in Delhi and the NCR, or in the phase-out of furnace oil and pet coke. In other cases, state governments offer fiscal incentives to encourage fuel switching, such as Delhi's support for industries transitioning to piped natural gas. Similarly, the West Bengal Pollution Control Board had earlier incentivised fuel shifts in industrial units within the Kolkata Metropolitan Region.

However, investments in industrial pollution control are largely expected to come from the private sector. Strategic funding may be available in select cases involving next-generation technologies, but this remains the exception rather than the norm.

The large and organised industries are primarily driven by regulations and emission standards to push investments in process development, adoption of advanced emissions control systems, fuel change that includes electrification of processes, energy saving methods, and waste circularity. This sector that is more amenable to smart monitoring, has the opportunity to adopt market-based approaches like emissions trading as in Gujarat etc. The responsibility of private sector investment to meet their environmental obligations is well established.

The bigger challenge lies in the MSME sector, which is integral to India's economy. With over 63 million enterprises spread across urban and rural areas, it requires targeted support and enabling mechanisms. The MSME sector contributes approximately 30 per cent to India's GDP and 45 per cent to total exports[1], employing more than 110 million people.[2] However, due to small capital, limited access to modern technology and emissions control system, financial constraints, and inadequate access to financial instruments, many MSMEs rely on outdated and inefficient production methods. This leads to high energy consumption and environmental pollution.

Regulatory enforcement becomes a challenge in this sector, as MSMEs are often dispersed across unorganised industrial clusters. This makes monitoring, compliance and enforcement challenging. These small-scale industries rely on outdated combustion processes that cause high emissions and energy wastage. This sector requires innovation for cost-effective and scalable solutions.

Addressing the MSME sector within the NCAP framework therefore becomes a priority to bridge the gaps in resources and capacity, and to find the effective enablers. MSMEs will require a dedicated financing mechanism to support the adoption of cleaner fuels and technologies, energy-efficient practices, cluster-based common pollution control systems, waste management and recycling solutions, and measures to control fugitive emissions.

From this perspective, this review of good practices has focused on the MSME sector to identify the priority measures for key combustion technologies (brick kilns, small boilers, furnaces), fugitive emission control (stone crushers), smart monitoring (continuous emission monitoring), and enterprises built on circularity of waste streams (compressed biogas), that can be made scalable under the NCAP programme. This captures both regulatory and industry good practices in each sub-sector.

This is not an exhaustive review of all industrial units that have taken proactive steps. It highlights a few representative examples that reflect the nature of technology adoption and innovation in production processes and operations, including emissions control, cleaner fuels, energy efficiency, self-monitoring, data generation, renewable energy use, and regulatory compliance strategies.

However, this review of practical, replicable, and scalable ground-level solutions, intended to capture the scope of change for cross-learning, does not endorse any specific technology or commercial interest. It merely illustrates the direction of change.

If these emerging good practices and more that are still taking shape are upscaled through the NCAP framework, the MSME sector can not only comply with environmental regulations but also enhance operational efficiency, reduce energy consumption, and improve overall productivity with economic gains. Disseminating such knowledge and supporting such initiatives is crucial for wider adoption, ensuring that more industries benefit from sustainable and efficient practices. This can help reduce not only toxic air pollutants but also heat-trapping carbon dioxide and black carbon.

BRICK KILNS

Sectoral challenges

The explosive growth of the construction industry has significantly increased the demand for bricks. Brick production largely falls within the informal small-scale sector, making regulation and compliance particularly challenging. These are dispersed sources but contribute enormously to ambient air quality. Their presence is particularly strong in the Indo-Gangetic Plain, especially across the states of Rajasthan, Uttar Pradesh, Bihar, and West Bengal. Given their small scale of operation, informality, limited capital, and dispersed locations, enforcing compliance based on emissions standards becomes challenging. It is not feasible to inspect such a large number of scattered stacks.

The most popular type is fired clay brick, usually red in colour, which is made from clay and then fired in a kiln. There are other types of bricks, usually classified as non-fired bricks (e.g. fly ash bricks, autoclaved aerated concrete blocks, etc.) which are produced using raw materials like fly ash, sand, lime, gypsum, cement, etc.

It is estimated that fired clay bricks currently constitute around 75 per cent of the market. Clay fired bricks are produced in small enterprises that are mostly located in peri-urban and rural areas. According to the information provided by All India Brick Manufacturer Association, there are around 121,000 registered kilns operational in the country. The production process is largely manual, and it is estimated that over 15 million workers are employed in brick manufacturing.

The manufacturing process of most commonly used red bricks has been a serious cause of environmental problems. They often rely on fuels like coal, wood, and hazardous waste, leading to high greenhouse gas emissions and toxic pollutants like dioxins and heavy metals. The inefficient burning process, particularly in older kilns, leads to energy wastage and the release of harmful pollutants.

The brick manufacturing industry is one of the five largest industrial consumers of coal alongside steel and cement, and is a major source of particulate matter emissions and GHG emissions. It also contributes to 60 percent of the total industrial emissions of black carbon.[3]

Traditional Fixed Chimney Bull's Trench Kilns (FCBTKs), which are widely used in brick manufacturing, are highly polluting. As a result, there is growing emphasis on adopting improved kiln technologies such as zig-zag firing, which enhance combustion efficiency, reduce emissions, and lower fuel consumption. Additionally, incorporating alternative fuels such as biomass and agricultural waste further supports cleaner and more sustainable operations. Zig-zag kilns are a more modern and efficient alternative to the older Fixed Chimney Bull's Trench Kilns (FCBTKs). They improve burning efficiency by arranging bricks in a zig-zag pattern, which helps in effective combustion and extends the high-temperature zone for cleaner burning. This design reduces harmful emissions such as black carbon and particulate matter by up to 70 per cent, and lowers fuel consumption by up to 30 per cent, resulting in significant energy savings. It also improves output quality, with over 80 per cent of bricks classified as Class 1. Zig-zag kilns typically emit less than 250 mg/Nm✼ of particulate matter and under 0.05 g of black carbon per kg of fired bricks. However, the technology demands skilled labour for effective operation and maintenance.

Regulatory drivers

Over time, both regulatory and judicial actions have begun to shape the direction of change in the sector, most notably through the Ministry of Environment, Forest and Climate Change's (MoEFCC) notification issued in February 2022. This notification allows new kilns to be only zig-zag technology, vertical shaft kilns, or kilns that run on Piped Natural Gas (PNG). They also require kilns to be at least 0.8 kilometres from orchards and residential areas. As per the order, approved fuels include coal (except in Delhi-NCR, where agricultural waste is permitted instead), firewood, agricultural residues, and PNG, while the use of hazardous waste and plastics is strictly prohibited. Kilns must also adhere to Central Pollution Control Board (CPCB) standards for construction and dust emission control set by various State Pollution Control Boards (SPCBs).

In response, brick kiln entrepreneurs are largely opting for zig-zag technology, as it primarily requires a change in brick setting. However, in many regions, there is no gas supply network, and gas remains a more expensive fuel option.

On the other hand, as evident in the case of Delhi-NCR, a substantial shift to zig-zag technology and biomass-based fuels has taken place, driven by stringent judicial directives.

Gaps in technology transition

Although a lot of brick kilns have been converted to zig-zag technology, the conversion often doesn't fully address the issues present in traditional FCBTKs. Many kiln owners have only made superficial changes, like altering the shape from oval to square, and modifying the walls. Stack emissions are still high due to poor conversion quality. This results in significant heat loss. The lack of proper infrastructure for storing green bricks increases energy consumption, as wet bricks require additional drying within the kiln. Fuel feeding practices also remain a concern. Only a few kilns follow continuous feeding, while most add large quantities of fuel at once and pause operations during peak summer. This leads to incomplete combustion, releasing unburnt carbon and particulate matter. Additionally, poor infrastructure and unpaved roads around kiln sites contribute to high levels of fugitive dust emissions. Uncertainty over land ownership further discourages investment in infrastructure improvements.

INDUSTRIAL GOOD PRACTICES

Even though regulatory compliance is still a challenge in the sector, a segment of the brick kiln industry has begun to respond to the tighter emissions regulations and adopting innovative and clean kiln practices. This is particularly evident in the NCR region. These proactive industry practices demonstrate not only emissions reduction potential but also resource, energy and cost saving benefits. This lesson can have a significant demonstration effect on other kiln owners. To effectively showcase this transformation, it is important to document and understand the nature of innovations and technological interventions adopted by a few selected good-practice kilns.

Reinventing the Kiln: Deswal Bhatta Co., Jhajjar, Haryana

A detailed case study of the Deswal Brick Kiln Co. (DBC) in Jhajjar, Haryana, examines the kiln's infrastructure, operational mechanisms, and monitoring practices to assess how they align with regulatory requirements and contribute to improved operational efficiency, cleaner fuel usage, and advancements in the production process.

Innovating production process: The kiln produces hand-moulded solid burnt clay fly ash brick. The soil/clay obtained from agricultural fields is mixed with fly ash from coal thermal power plants (20–25 per cent by weight) and recycled waste from the kiln i.e. ash and grog (1–2 per cent by weight). This dry soil-mix is put in soil-mix preparation pits, in which water is added and a JCB front hoe loader is used for mixing the soil-mix and water. After 24 hours the wet soil-mix is processed in a pug-mill for tempering and is then supplied to moulders for hand moulding. The freshly moulded green bricks, which contain around 25 per cent moisture, are dried under the sun. After drying, the resulting dry green bricks—containing 3–8 per cent moisture—are either transported to the dry green brick storage shed or taken directly to the kiln for firing.

The transportation of dry green brick is carried out on wooden pellets using a forklift truck. The bricks are manually stacked in the kiln and then fired. Once fired, the burnt bricks are sorted according to quality and stacked accordingly. Broken bricks, debris, and ash are crushed or powdered for recycling and mixed back into the soil blend. The kiln has also installed a 50 kWp solar PV system, which supplies electricity for operating the kiln fan, lighting, pumps, and other essential functions.

Design to control heat loss: While most brick kiln entrepreneurs struggle to reduce heat loss due to poor construction quality—which leads to higher fuel consumption—the DBC kiln has introduced structural innovations to address this issue. The kiln is built with thick, solid walls, with the main structure measuring 8.5 feet in thickness. The wicket gate features a double-wall closing mechanism, consisting of an inner wall of 3 feet, an outer wall of 3 feet, and 2.5 feet of insulation between them. The walls are well-maintained with clay plastering and plastic coverings, ensuring they remain free of cracks or leaks—crucial for maintaining efficient airflow in the firing zone. The shunt can now be positioned at only four designated locations, and the number of wicket gates has been reduced from 12 to 5. Additionally, the number of side *nalis* has been brought down from 24 to 4, significantly minimising flue gas leakage and improving overall kiln efficiency.

The outer walls of the kiln are made more durable by plastering them with cement, while the inner wall is coated with clay. A thick layer of sand between the inner and outer walls helps minimise heat loss. A shed has been installed over the *miyan* of the kiln, which helps reduce dust emissions, lowers fuel consumption, and improves thermal efficiency by limiting heat loss. It also creates a better working environment for labourers, contributing to increased overall efficiency of the brick kiln.

The upper area of the *miyan* has a properly cemented surface, making it easy to walk on and enhancing worker safety. The kiln floor is designed with a sand bed topped with aluminium foil, followed by another layer of sand and two layers of fired bricks. This layered construction helps minimise heat loss, thereby improving thermal efficiency.

The kiln is equipped with a mild steel (MS) stack on one side, designed with a uniform diameter to minimise emissions and prevent air leakage. To boost efficiency and control airflow, a Variable Frequency Drive (VFD) fan is used. Inside the kiln, a long preheating zone with limited flue gas entry points ensures smooth operation even during the monsoon season, helping maintain consistent performance despite changing weather conditions.

Cemented outer wall, fully paved surface, proper boundary, gate, and display board

Mild steel stack with a variable frequency drive (VFD) fan instrumental panel

The gates feature a display board with essential kiln details, including registrations with various government departments, the GST number, geographic coordinates, and contact information, all prominently displayed.

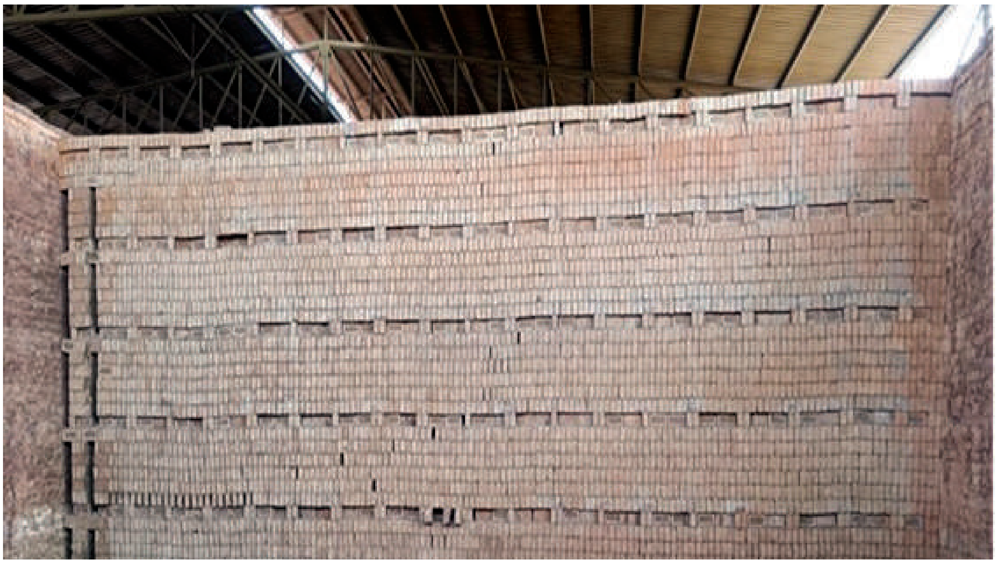
Fuel is stored in a designated, enclosed area covered by a shed. This storage includes briquettes and loose agricultural residue, the latter serving as a lubricant for the briquettes in the burning zone during fuel feeding, ensuring a smoother and more efficient burning process.

Fuel storage area with natural light access from the shed

Fuel feeding process with temperature measuring instruments and record keeping

Improvement in operational practices: The unit has been upgraded to enable continuous feeding of fuel—primarily biomass briquettes—using a funnel system. Approximately 3 kg of fuel is placed from a bucket into each fuel feed hole, ensuring steady and efficient combustion**.** The kiln has two fuel-feeding chambers, each with 57 fuel feed holes, totalling 114. The fuel feeding process follows a two-hour cycle, during which fuel is manually fed into all 114 holes. A dedicated moving box, equipped with necessary tools, is used to ensure continuous and efficient combustion of briquettes and sawdust. The fuel feeding area is well-maintained and insulated with a thick layer of soil to minimise heat loss. Detailed records of the feeding process are maintained to ensure proper firing, resulting in high-quality bricks, with approximately 90 per cent meeting the desired standards.

In brick stacking, the bricks are tightly packed together, with more than half of the space taken up by the bricks themselves. They are arranged on pallets, which are flat platforms,



Bricks arrangement for firing

Dedicated monitoring area

with only two small openings left for air to flow through. These pallets are then moved around using forklifts. This method helps to minimise dust generation. Additionally, the vehicles have speed controls to minimise damage.

Air quality monitoring at the kiln site: Robust monitoring practices are in place to ensure optimal kiln performance and environmental compliance. Flue gas analysis is conducted regularly, measuring levels of CO, CO_2, and O_2. By assessing the CO/CO_2 ratio, operators can evaluate the efficiency of fuel combustion and make informed adjustments to optimise fuel usage. There's a dedicated area for monitoring temperature and pressure for close observation of fan inlets, outlets, and port holes, enabling precise adjustments to fuel feeding rates for optimal performance. Insulated equipment, including shunts and tawa, help minimise heat loss. Shunt meters are used for precise management of flue gases, ensuring that the kiln operates efficiently and with minimal wastage of energy.

Sustainable practices to control fugitive emissions: A three-layer plantations around the kiln site offers multiple benefits; the outermost layer—typically tall trees—acts as

Green belt surrounding the boundary of the industry a barrier against wind and dust. The middle layer, consisting of medium-height shrubs and plants, further filters airborne pollutants and helps cool the surrounding area by providing shade and moisture. The innermost layer, with ground cover and smaller plants, helps stabilise the soil and absorb any residual emissions. This improves air quality and lowers ambient temperatures while enhancing visual appeal. Water sprinklers are used in areas prone to fugitive emissions.

The kiln is equipped with a basic yet effective wastewater treatment system with a capacity of 40 KLD, voluntarily installed by the owner. The treated water is reused for green brick making process and also for dust suppression through sprinkling within the kiln premises.

Use of renewal energy: Most brick kilns typically rely on diesel generator (DG) sets to power their ID fans and other equipment, contributing to air pollution. However, in this case study, the kiln—spread across 14 acres—has installed a 50kWh solar panel system. The panels are connected to batteries that store electricity, allowing brick production to continue uninterrupted even during power outages. The solar energy system powers essential equipment such as the ID fan and water pump, and also supplies electricity to the office and workers' residences. This has resulted in savings of up to Rs 34,000 per month on electricity costs, potentially adding up to over Rs 1 crore in savings over the next 25 years.

The brick kilns are powered by on-site solar panels

Improving energy efficiency: In Jhajjar, DBC has successfully demonstrated that zig-zag kilns can be powered entirely by biomass briquettes while still producing high-quality bricks. Approximately 90 per cent of the bricks produced are Class I, with very low Specific Energy Consumption (SEC) (less than 0.8 MJ/kg), making it highly energy efficient.

To achieve this, DBC implemented several key operational changes to the kiln. Bricks are now packed more tightly, and the fire's travel rate has been slowed to improve combustion efficiency. The fuel-burning ledge was modified to accommodate larger, less dense biomass briquettes, and a specially designed funnel is used to feed them into the kiln. The number of fuel feeding zones has been reduced from the typical 3–6 chambers to just two. Additionally, the chimney and draft system have been upgraded with the installation of an induced draft fan, a variable frequency drive (VFD) for improved fan control, and a metal chimney. These enhancements are essential for ensuring the effective combustion of biomass briquettes.

Good firing practices and adoption of standard operating procedures (SOPs) further improve efficiency. For example, using smaller pieces of biomass briquettes (5-10 mm) ensure complete combustion. To save energy, DBC prevents air leakage into the kiln and uses a low-speed fan with VFD control. They have also extended the pre-heating zone—a critical measure for kilns with only four flue gas openings and a single main channel connected to the chimney. Energy efficiency is further improved by placing a mild steel (MS) shade over the kiln.

Thus, the good practices include kiln modifications—such as upgrading the induced draft fan, adding VFD control, and installing a scientifically designed metallic chimney—and changes in operating practices like brick setting and fuel feeding. This has drastically reduced flue gas emissions load from 600–700 kg/day to just 10 kg/day.

Improvement in environmental and operational practices: The facility has increased the proportion of Class-1 bricks manufactured from 80 per cent to 90 per cent, indicating improved production quality.

DBC has spent a lot on infrastructure, quality conversion, and regular monitoring. The evidence of change is striking. According to an assessment by the Central Building Research Institute (CBRI), the particulate matter emission standard for brick kilns is 250 mg/Nm^3. In 2022, emissions from the DBC kiln were recorded at 163 mg/Nm^3. Following further modifications, this figure dropped significantly to just 52 mg/Nm^3 in 2023. Similarly, in 2022, DBC's emission load was 796 kg/day that reduced drastically to 4.02 kg/day after the changes were made. In 2024, IIT Delhi reported a slightly higher emission load of 10 kg/day. This is still drastically lower than the CPCB's particulate emission load reported for 2023 at 705 kg/day. Overall, DBC's emissions have significantly decreased.

Table 1: Improvement in technology and process

2022	2023	Benefit
Square-shaped stack which occupies high volume	MS stack that has less volume, with VFD technology	Reduced space requirements, increased energy efficiency, and decreased pollution load due to VFD
Length of pre-feeding zone is normal	Length of preheating zone was increased	Improved preheating efficiency and better temperature control
24 side *nalis* (side flue ducts)	Side *nalis* (side flue ducts) decreased from 24 to 4	Reduced heat loss and better fuel efficiency
12 wicket gates	Wicket gates reduced to 5	Simplified operation, reduced maintenance, and improved airflow management

Source: CSE analysis and details as provided by the industry

Table 2: Techno-economics of retrofitting an FCBTK into zig-zag brick kilns

Parameters	Initial FCBTK	Retrofitted zig-zag
Annual production	40 lakhs	40 lakhs
Coal consumption per lakh bricks	16 tonne	12 tonne
Class I bricks produced (percentage)	55–60	80–90 per cent
	Induced zig-zag	**Natural zig-zag**
BREAK UP OF THE COST		
Labour cost	Rs 5.5–7.5 lakh	Rs 5.5–7.5 lakh
Material (other than brick)	Rs 1–1.5 lakh	Rs 1–1.5 lakh
Equipment	Rs 2–2.5 lakh	Rs 2–2.5 lakh
Fan (with engine)	Rs 3–4 lakh	Not applicable
Chimney	Not applicable (same chimney can be used)	Rs 8–10 lakh
Bricks @ Rs 3/brick	Rs 6–9 lakh (for additional 2–3 lakh bricks)	Rs 9–12 lakh (for additional 3–4 lakh bricks)
Total	Rs 17.5–24.5 lakh	Rs 25.5–38.5 lakh
RETROFITTING BENEFITS		
Annual coal savings 160 tonne @ Rs 10,000 per tonne	Rs 16 lakh	Rs 16 lakh
Increase in revenue due to higher number good quality bricks (considering 8 lakh additional Class-I bricks annually) @ Rs 1 per brick	Rs 8 lakh	Rs 8 lakh
Annual expenditure on operation and maintenance of fan	Rs 2.5 lakh	
Total annual savings	Rs (16 + 8 - 2.5) = 21.5 lakh	Rs (16 + 8) = 24 lakh
Simple payback period	One brick season	One–two brick seasons

Source: CSE analysis based on inputs from sector experts

Cost effectiveness: Overall retrofitting Fixed Chimney Bull's Trench Kilns (FCBTK) with zig-zag kilns offers a practical and scalable solution for the industry. Both induced and natural zig-zag kilns reduce coal consumption significantly, cutting usage by approximately 25 per cent compared to traditional FCBTKs. This not only reduces operational costs but also lowers the pollution and carbon footprint of production. The retrofitting costs vary by kiln type but any cost surge is offset by substantial savings and increased revenue. On average, the initial cost of investment is recovered within one to two operational cycles.

Replicability and scalability: This case study from Jhajjar offers a clear pathway for other kilns to follow. Through the integration of advanced technologies, structural modifications, and robust monitoring, the kiln has achieved a substantial reduction in emissions. It is essential to develop guidelines for technology upgrades based on such good practices, making them scalable through a cross-learning process under NCAP. At the same time, the mandate for adoption and mechanisms for monitoring compliance across the sector must be further strengthened.

STAND-ALONE TINY INDUSTRIAL BOILERS

Sectoral challenges

Small-scale industries (SSIs) are integral to India's economy, with approximately 10.5 million units operating across the country, as reported by the Ministry of Micro, Small, and Medium Enterprises (MSME). A significant number of these industries rely on steam boilers for their processes, ranging from heating to steam generation. Currently, around four million steam boilers are in use across the country, with capacities ranging from less than two tonnes per hour (TPH) to over 15 TPH. Boilers with capacities below 2 TPH are classified as small boilers.

Small boilers are generally less efficient, with efficiencies ranging from 65 to 70 per cent, compared to 80–85 per cent for larger boilers. This inefficiency results in excessive fossil fuel consumption, predominantly coal, substantially contributing to environmental pollution. Emission standards for small boilers are lenient, and many operate without adequate air pollution control devices (APCDs), exacerbating environmental challenges. A 2020 study by the Centre for Science and Environment (CSE) found that in seven districts of Delhi-NCR, industrial boilers were the leading source of industrial air pollution. Over 50 per cent of these were small or mini boilers (less than two tonnes per hour), primarily used in small and medium-scale industries typically located in clusters.

These small boilers face multiple challenges, including low thermal efficiency, the absence of air pollution control devices, and the difficulty of monitoring such a large number of dispersed units. Although the permissible particulate matter (PM) emission limit for small boilers (less than two per hours) has been tightened from 1,200 mg/Nm^3 to 500 mg/Nm^3, enforcement continues to be a major challenge. Monitoring a large number of small boilers with limited resources is a significant hurdle for CPCB and state-level pollution control boards. The intermittent operation of small boilers results in emission

Table 3: Emissions norms for small boilers

Fuel type	Capacity (TPH)	PM emissions limit (mg/Nm_3)
Small industrial boilers (coal or liquid fuel)	Less than 2	500
	2 to less than 10	150
	15 and above	50

Source: Central Pollution Control Board

monitoring inconsistencies, as air with an oxygen content of 19–21 per cent flows into the stack after combustion of the fuel fired ends.

Many small boilers operate without air pollution control measures, resulting in significant emissions. These boilers typically run in batches, with each combustion cycle lasting 30–40 minutes, followed by manual fuel feeding. This operational pattern not only contributes to inefficient combustion and higher emissions but also raises serious safety concerns due to the lack of automation and proper safeguards. Small boilers typically fall outside the scope of the Indian Boiler Regulations (IBR) and are commonly used in small enterprises where adherence to IBR standards is not mandated. As a result, these boilers do not require safety certification from boiler inspectors. Several cases of boiler explosions are recorded every year, including causalities. The quality and availability of steam are technical constraints for small boilers. During boiler operation, fly ash is generated. Small boilers (less than 2 TPH) cost about Rs 7 lakh, while medium-sized ones (up to 10 TPH) cost over Rs 10 lakh.

This intermittent operation complicates emissions monitoring and renders the installation of Continuous Emissions Monitoring Systems (CEMS) technically and economically impractical. The CPCB and SPCBs face difficulties in monitoring emissions due to the sheer number of small boilers and operational constraints.

Regulatory drivers

National-level initiative: At the national level, the Central Pollution Control Board (CPCB) adopted a regulatory guidance framework in 2023 titled *Guidelines for Promoting Community Boilers for Clusters of Small-Scale Industries* to support pollution control efforts. The guidelines mandate that community boilers be integrated into the development plans of new or upcoming industrial clusters. For existing clusters, a feasibility study must be conducted to evaluate their suitability for such systems.

The guidelines are encouraging adoption of centralised common boiler system that is designed to generate and distribute steam to multiple industrial units within a cluster through a pipeline network. A common boiler is a separate entity, wherein a boiler of larger capacity is installed to cater to the requirement of a specific number of industrial units in the cluster. The system has an automated boiler control system and fuel feeding mechanism, and a proper emissions monitoring mechanism. It usually constitutes a large, high-pressure, coal-fired FBC boiler with state-of-the-art emissions control technology. Steam is generated in response to the demand of the industrial units.

These boilers generate sufficient steam to be provided to the entire cluster of industries through a large grid of pipelines. Steam must be produced at a certain pressure and temperature as per the requirement of the process and transferred to the shop floor.

Community-based common boilers offer significant improvements in efficiency, achieving 80–85 per cent thermal efficiency and reducing coal consumption by 25–30 per cent compared to small individual boilers, resulting in substantial cost savings. These systems are equipped with advanced technologies such as Fluidized Bed Combustion (FBC) and robust air pollution control devices (APCDs), enabling a 65–70 per cent reduction in industrial air pollution. Centralised monitoring simplifies regulatory compliance and reduces the oversight burden on enforcement agencies. Additionally, businesses benefit from a reliable, continuous steam supply, allowing them to focus resources on core production activities.

There are several other benefits including hassle-free operation, no downtime and improved availability of steam. Shutdowns are reduced, as common boilers with larger capacities require less frequent maintenance. Moreover, they create a single point of monitoring for State Pollution Control Boards (SPCBs), easing regulatory oversight without the immediate need to install Continuous Emission Monitoring Systems (CEMS). This increases productivity as small industrial units no longer need to manage their own steam generation. They can benefit from Electrostatic Precipitators (ESPs) with additional fields for improved emission control. Moreover, these units save costs otherwise incurred on at-stack air emissions monitoring. With the adoption of a common boiler system, the need for monthly or quarterly third-party monitoring is eliminated, further reducing operational and compliance burdens.

Industrial units that rely on a common boiler for steam do not need to obtain separate permissions for boiler installation, as the boilers are not located on their premises. This exempts them from boiler inspections, reducing both their regulatory burden and the oversight responsibilities of State Pollution Control Boards (SPCBs). Rather than monitoring multiple individual boilers, compliance can be managed centrally through

Table 4: Comparative cost-benefit analysis of using a small boiler vs. a common boiler

Parameter	Using small boilers (2 TPH)	Using common boilers
Boiler efficiency (%)	65–70	80–85
PM emissions (mg/Nm^3)	50–500	50–150
Cost of steam (Rs/kg)	5–6	2–4
Monitoring requirements	High	Centralised
Maintenance costs	High	Shared
Safety	Low	High
Productivity	Lower	Higher
Cost of boiler installation (Rs)	7,00,000	0
Operation and maintenance cost (Rs/year)	1,00,000	0
APCD cost (Rs)	5,50,000	0
CEMS cost (Rs)	10,00,000	0
Regulatory inspections (visits/year)	4	0
Boiler permission requirement	Required	Not required

Source: CSE analysis and details as provided by the industry a single Continuous Emission Monitoring System (CEMS) installed at the common boiler facility.

A common boiler facility scores over a boiler with a capacity of 2 TPH on key economic, technical, regulatory and environmental aspects (*see Table 4: Comparative cost–benefit analysis of using a small boiler and a common boiler*).

However, the implementation of community boilers faces several challenges. These include securing adequate land—typically at least 5,000 square feet—developing a robust steam distribution network, and obtaining fast-tracked permissions for setting up centralised systems. Additionally, the cost of supplying steam over long distances can be high, potentially affecting the economic viability of the model.

State-level regulatory drivers

At the state level, Gujarat has taken the lead in implementing the common boiler policy. Successful implementation of community boilers is noted in industrial areas of Gujarat including Surat, Vapi, and Ankleshwar. Gujarat has demonstrated their effectiveness and potential for replication in other regions. Some of the latest examples of upcoming community boilers are Vapi GIDC (based on paper mill waste), Gabheni (RDF/textile waste to steam), Nandesari (RDF), and Ahmedabad Municipal Corporation (MSW/RDF) in Gujarat. These projects are at different stages of commissioning.

The potential for replication is steadily growing, as seen in the initiatives undertaken in MIDC-Patalganga (Maharashtra), Haldia (West Bengal), and Sonipat (Haryana). Gujarat is especially well-placed to take the lead, supported by the Gujarat Industrial Policy 2015, which promotes the development of common infrastructure that enables clean technologies, efficient resource use, and reduced environmental impact. The Gujarat Pollution Control Board has proactively encouraged the establishment of common boiler facilities within industrial estates—an initiative undertaken independently, without any central directive.

The common boiler system replaces hundreds of individual, inefficient, and often non-compliant boilers in small and medium-scale industries. By centralising steam generation and ensuring cleaner fuel use and advanced pollution control systems, GPCB has successfully reduced emissions and improved compliance across the board.

Upscaling common boiler uptake through NCAP programme: Way forward

Given this shift, the NCAP strategy can prioritise community boilers by setting clear targets and mandates, offering subsidies or financial aid to support adoption, educating industries on their economic and environmental benefits, and working with SPCBs to streamline regulatory approvals.

Scaling this model involves integrating community boiler systems into the planning of new industrial areas and retrofitting existing clusters. The governments and industry associations should conduct feasibility studies, provide financial incentives, and streamline the permissions required for setting up these facilities. Additionally, developing robust steam distribution networks and ensuring proper maintenance protocols will help deliver uninterrupted and cost-effective steam supply to all units.

To control pollution, community boilers should primarily run on cleaner fuels like natural gas. However, acquiring land for these centralised facilities poses a significant challenge. Governments and local authorities need to provide assistance in identifying and allocating suitable land for such projects. Professional management of these facilities is crucial to ensure regulatory compliance, enhance air quality, and maintain safer workplaces. With strategic planning, stakeholder collaboration, and adequate financial and administrative support, community boiler systems can transform steam generation for small industries, fostering sustainable industrial growth.

Awareness campaigns highlighting the economic, environmental, and operational benefits of such systems can encourage industries to adopt this model. Financial support, such as subsidies or low-interest loans for infrastructure development, will further boost adoption.

INDUSTRY GOOD PRACTICES

Surat

A common boiler facility in the Sachin industrial area of Surat, Gujarat, supplies steam to approximately 50 industries across an area of about 5 km✤. The steam is delivered at temperatures ranging between 170°C and 200°C.

The cost of steam varies based on the distance from the facility and the unit's consumption level. For example, if steam is supplied over a distance of 2 km and an industry consumes 2 TPH, the cost ranges from Rs 3.5–4 per kg. For consumption between 2 and 10 TPH, the cost decreases to Rs 3–3.35 per kg, and for consumption above 10 TPH, it further drops to Rs 2.6–2.85 per kg.

Table 5: Comparative analysis of steam cost for industry

S.No.	Location	In-house cost (Rs/kg)	Common boiler cost (Rs/kg)
1	Surat	2–2.5 (Coal/Lignite as fuel)	3.52–4 (Imported coal as fuel)
2	Ankleshwar	52–7 (PNG as fuel)	3.52–4 (Imported coal as fuel)

Source: CSE Survey

Economic feasibility: Community boilers offer significant economic advantages over individual boilers. With a thermal efficiency of 83 per cent, they consume approximately 28 per cent less fossil fuel, resulting in considerable savings on industrial fuel costs. While the initial capital investment for a community boiler may seem higher, the cost is shared among industries in a cluster, making it a financially viable option. Additionally, centralised systems are professionally managed, leading to reduced downtime and lower maintenance costs compared to individual boiler systems.

Environmental feasibility: Community boilers contribute significantly to environmental sustainability. They reduce emissions using RCC chimneys and advanced pollution control devices like Electrostatic Precipitators. By sourcing coal with a maximum ash content of 7–8 per cent, these systems minimise residue generation and maintain compliance with environmental regulations. Furthermore, community boilers can adopt cleaner fuels such as biomass, Refuse-Derived Fuel (RDF), and municipal solid waste, aligning with broader sustainability objectives.

Operational feasibility: The operational efficiency of community boilers is enhanced by their large capacity, ranging from 30 TPH to 60 TPH, which ensures optimal performance across multiple industries. These systems are managed by professionals, guaranteeing efficient operation while adhering to safety standards and emission norms. This professional oversight minimises operational risks and ensures consistent compliance.

Regulatory feasibility: Community boilers are well-aligned with government regulations concerning emissions and environmental policies. The centralised nature of these systems facilitates better control over emissions and simplifies adherence to environmental norms. This regulatory compliance makes community boilers a sustainable and lawful choice for industrial clusters.

Proactive Pharma, Ankleshwar

Proactive Pharma in Ankleshwar's GIDC struggled with its in-house boiler system powered by pipeline natural gas (PNG). High steam generation costs (Rs 5–7/kg), poor boiler efficiency, and wet steam output disrupted reactor performance and chemical processes. The setup also required expensive pollution control devices and a Continuous Emission Monitoring System (CEMS) to comply with environmental norms. Small-scale fuel procurement compounded costs, and despite efforts, the desired steam quality and efficiency remained unachievable, highlighting the need for a sustainable and cost-effective solution.

A shift was made to common boiler facility that provided a range of benefits.

Cost-efficient steam generation: One of the most significant benefits of using a common boiler system is the reduction in steam generation costs. Industries can produce steam at an economical rate of Rs 2–4 per kilogram, compared to the higher costs i.e., Rs 5–7 associated with in-house boilers. This cost efficiency allows industries to allocate their financial resources more effectively toward other critical areas of their operations.

Improved steam quality: The steam produced by common boiler systems is notably drier compared to that generated by in-house boilers. Dry steam is essential for achieving consistent production quality and maintaining the integrity of industrial processes. Almost 25 per cent quality is enhanced, this enhanced steam quality ensures that all reactors operate efficiently, leading to better product outcomes.

Elimination of environmental compliance burden: A centralised boiler system relieves individual industries from directly complying with strict environmental regulations,

Common boiler pipeline laying

Common boiler pressure decreasing system inside the industry

such as installing air pollution control devices and CEMS. Instead, the facility operator assumes responsibility for meeting emission norms, reducing regulatory burdens and allowing industries to focus on their core operations.

Freedom from fuel management: A common boiler facility eliminates the need for industries to manage fuel procurement and storage. This not only saves time and resources but also reduces risks associated with fuel handling and storage, such as safety hazards and logistical challenges.

Space optimisation: By outsourcing boiler operations, industries free up valuable space previously occupied by boilers and fuel storage. This reclaimed space can be utilised for other critical operations, improving overall plant layout and efficiency.

Consistent and seamless reactor operations: A reliable supply of high-quality steam ensures uninterrupted operation of reactors, which are vessels used for controlled chemical or industrial processes. Uninterrupted steam supply is essential for consistent production and timely delivery, as even short disruptions can halt operations. High-quality steam improves reactor efficiency, enhances product quality, and reduces waste. Additionally, the reduced risk of downtime not only saves time and resources but also enhances the overall reliability and stability of operations. This consistency allows industries to focus on scaling up production, meeting customer demands, and maintaining a competitive edge in the market. In the long run, a dependable steam supply contributes significantly to smoother operations, higher productivity, and better business performance.

Improved production quality and efficiency: The combined benefits of cost efficiency, high thermal efficiency, and superior steam quality contribute to enhanced production quality. Industries can achieve higher output rates with better consistency, meeting market demands effectively and improving their competitive edge. Adopting a common boiler facility is a strategic decision for small industries aiming to optimise operations and reduce costs. It provides a comprehensive solution that addresses energy efficiency, environmental compliance, and production challenges. By embracing this system, industries can enhance their operational performance, improve product quality, and align with sustainable practices, ensuring long-term growth and success.

FOUNDRY OPERATIONS

India's foundry sector is a vital contributor to the nation's economy and a significant source of environmental pollution. India is the second largest producer of castings in the world, with over 6,000 foundries across the country. Most of these foundries (85 per cent) are small-scale, while 10 per cent are medium-scale and five per cent are large-scale.[4] Together, they produce about 12 million metric tons of castings each year, generating a turnover of approximately USD 20 billion and exporting goods worth USD 3.54 billion.[5]

However, this sector also has significant impact on environment. Key foundry clusters in northern and eastern India include Jalandhar, Ludhiana, Rajkot, Kolhapur, Howrah, and Jaipur. A primary pollution source in these areas is the burning of fossil fuels in cupola furnaces. Transitioning to cleaner technologies, such as induction furnaces or natural gas-based systems, can significantly reduce emissions. Additionally, implementing advanced air pollution control measures like bag filters and wet scrubbers, along with efficient waste management practices, is essential for minimising environmental impact and promoting sustainable operations. Change in this direction is already underway. Metal castings in foundries involve melting metal into a liquid form for moulding purpose. The foundry industry produces a wide range of metal components for different industrial applications.

Regulatory good practices: Although electric furnaces for melting cast iron are more advanced and cleaner, cupolas have remained important in the MSME sector as they are affordable and easy to operate. There is considerable scope for regulatory interventions at the state level and the SPCBs can set the terms of change for the sector. There is emerging evidence of that.

The Rajasthan State Pollution Control Board (RSPCB) has taken important steps in controlling pollution from the foundry sector, which is known for its high emissions, especially from outdated furnace technologies (single blast cupola furnace).

In response to air pollution concerns, RSPCB has acted by directing foundry units to shift from single blast cupola furnaces to divided blast cupola (DBC) furnaces. The DBC technology is a significant improvement as it enables better combustion efficiency and reduces particulate matter emissions. The RSPCB's order came with technical guidelines help to ease the transition, showing its commitment to clean air while keeping industries running.

Leveraging convergence funding to build common infrastructure for industry cluster: In another unique effort, the Government of Uttar Pradesh has leveraged the Smart City Mission funds to create common furnace facility centre in Moradabad. This is a Piped Natural Gas (PNG)-based common furnace facility that was set up in Lakri Fazalpur Industrial Estate.

This initiative aims to offer artisans an alternative to coal-based furnaces used in household units across the city. The facility houses 20 PNG-based furnaces of varying capacities—300 kg, 100 kg, 50 kg, and 15 kg—and is equipped with proper air pollution control devices, unlike the unregulated household units. It also includes dedicated rooms for finishing activities post metal melting and casting.

This is a significant example of using urban infrastructure funding to upgrade industrial facilities.

Upscaling clean furnaces through NCAP programme: Way forward

Transitioning to cleaner fuels like Piped Natural Gas (PNG) is a crucial first step to ensure the scalability and replicability of cleaner furnace technologies in the foundry sector. Regions like Agra and Gurugram have already seen success, with PNG adoption leading to lower emissions and reduced operational costs.

Government support plays a vital role in scaling these practices. Financial incentives like low-interest loans, subsidies for technology upgrades, and policy reforms such as inclusion in Production Linked Incentive (PLI) schemes can accelerate adoption. Developing model foundry clusters, as demonstrated in VKIA, Jaipur, can showcase successful implementations, making it easier for other clusters to replicate these practices.

It is necessary to mandate installation of Air Pollution Control Devices (APCDs) such as bag filters and wet scrubbers, along with regular monitoring by State Pollution Control Boards (SPCBs). This will standardise compliance. Implementing a centralised waste management system for slag and sand reclamation can provide a scalable model that multiple units within a cluster can utilise, reducing costs and environmental impact.

Capacity building programmes and exposure visits to good practice foundries can help to replicate these models. Collaboration with research institutions can drive innovation, creating cost-effective solutions that are both scalable and replicable.

Real-time monitoring systems and regular energy audits can help foundries maintain compliance and optimise performance.

INDUSTRY GOOD PRACTICES

India Casting Company, Agra

Since 2001, Agra's foundry industry has operated on Piped Natural Gas (PNG), marking a major shift towards cleaner energy. Once home to over 100 units, around 80 foundries remain active today, collectively producing approximately 0.11 million tonnes annually and directly employing about 3,000 people.

PNG-based furnace

Casting products

Agra's foundries range widely in size and output: about 40 micro units produce 420 tonnes annually, 23 small units yield 900 tonnes, 15 medium units produce 3,000 tonnes, and 2 large units exceed 3,000 tonnes per year. The sector's energy use is divided between induction melting furnaces, used by 30 foundries contributing 65 per cent of total production (approximately 0.07 million tonnes annually), and natural gas-fired cupola furnaces, used by 50 foundries generating the remaining 35 per cent (approximately 0.04 million tonnes annually).

One of the leading foundries in Agra is India Casting Company, run by Puce and their partner. This company specialises in manufacturing machinery parts and has been operating on PNG since 2004. With a monthly production of 90–100 tonnes, the company incurs a PNG consumption cost of approximately Rs 1.5 lakhs and maintenance costs of Rs 20,000–30,000 per month. The adoption of PNG technology has significantly benefited the company by improving cost efficiency, with PNG costs amounting to Rs 2–3 per kg of metal melted and Rs 5–6 per kg after including carbon cost.

Additionally, PNG operations generate no slag, enhancing operational cleanliness and reducing waste. India Casting Company has implemented innovative manufacturing processes, including the use of advanced machinery for high-precision components catering to industries like automotive, heavy equipment, and general engineering.

To enhance efficiency and uphold quality, the company uses real-time energy monitoring, conducts regular staff training, implements waste heat recovery systems to cut energy use, and invests in ongoing R&D for high-performance alloys and customised solutions. Rigorous quality control ensures all products meet industry standards and client requirements.

To comply with environmental regulations, India Casting Company has installed an Air Pollution Control Device (APCD) using basic spray nozzles at the top of the stack. This system requires maintenance every two years, costing around Rs 4 lakhs.

Highlights of sensors and hood system

Modern energy solutions and strict environmental compliance are thus possible. These practices establish a benchmark for other foundries.

Sunbeam Light Weighting Solutions Pvt. Ltd, Gurugram

Sunbeam Light weighting Solutions Pvt. Ltd is a non-ferrous foundry situated in Gurugram, Haryana. They produce high-pressure die casting, gravity die casting, low-pressure die castings and pistons. They have installed 13 furnaces of different types within their industrial premises. The plant has a production capacity of around 60 to 80 tonnes per day.

Specific energy consumption: The foundry unit has installed an efficient hood system at all the furnaces. To measure the temperature of the molten metal, a sensor has been installed at all the furnaces. They have been using PNG as fuel for the last four years. This has replaced furnace oil as fuel. Their average specific fuel consumption is around 112–113 SCM. The natural gas is supplied by Haryana City Green Gas Limited, and the cost of PNG is around Rs 45 per SCM.

Slag and sand generation: Slag generation in this foundry is almost nil because they are using natural gas and 100 per cent combustion is ensured. Sand generated from the moulding section is sent to the municipal landfill site as it is non-hazardous.

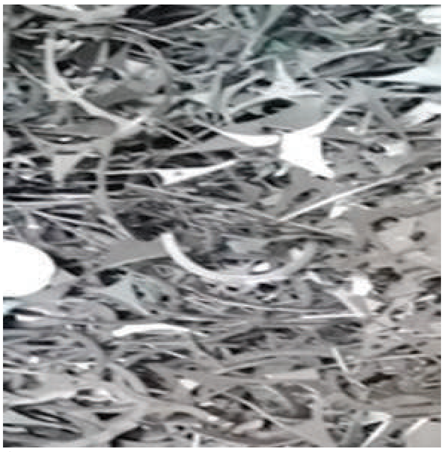
Air pollution control devices installed: They have adequate stack height (30 m). They claim that they do not require any air pollution control devices as 100 per cent combustion is possible with natural gas. They only reduce the temperature of emissions through adequate stack height and release the emissions. The foundry unit is meeting the emission norms laid down by the CPCB.

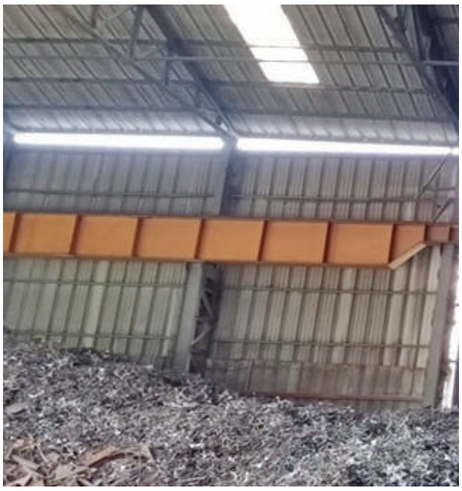
Shrinathji Ispat Ltd, Ghaziabad

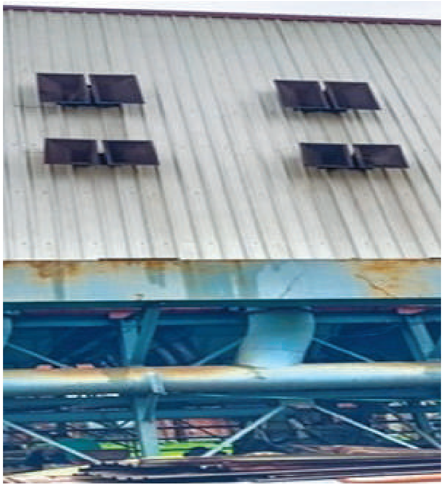
Srinathji Ispat Ltd is one of the leading manufacturers of alloy steel castings in India. The company was established in 1989 and has embraced expertise in producing sand castings for hydro power, steel, thermal power, sugar, cement, mining and heavy engineering industry sectors.

Production capacity: The production capacity of the Ghaziabad plant is around 375 tonnes per month and the foundry has single-shift operations of 12 to 14 hours per day. The


Hood installed at the furnace


Good quality scrap as raw material


Raw material stored in covered space


Bag house filter

foundry uses good-quality scrap, free from dust, oil, grease, paints and other impurities. This helps the foundry generate lesser pollution. Around 60 per cent of the raw material is imported, and the remaining 40 per cent of the scrap is indigenous.

Slag generation: Due to the use of high-quality scrap, slag generation is minimal—2–3 kg per tonne in steel-based foundries and 3–4 kg per tonne in iron-based foundries. The slag produced is sold to builders for use in construction activities.

Sand reclamation unit: The foundry unit has also installed a sand-reclamation unit and around 60–80 per cent of sand is re-used, while the remaining 20–40 per cent is discarded and sold for construction activities to nearby vendors.

Specific energy consumption: The specific energy consumption for melting 1 tonne of molten metal for all the products is less than or equal to 650 kWh. This clearly illustrates that foundry units are adopting good practices to reduce energy consumption.

Air pollution control devices installed: The unit has installed an efficient hood system to capture furnace emissions, along with bag filters in both steel and cast-iron units—comprising a total of 80 filter bags. Metals like lead and zinc are recovered from the sand and sold to vendors. The APCDs remain operational whenever the furnace is in use.

The preventive maintenance of APCDs is done every week and operational maintenance is done when there are any leakages in the bag filters.

Energy audits: Energy audits were conducted in the unit in the year 2020 by the Petroleum Conservation Research Association (PCRA). In addition to this, units have replaced all old motors with new motors that have better capacities.

Table 6: Major takeaways from case studies

Case studies	Major takeaways
Case study 1: India Casting Company, Agra	• The technology using is the cupola furnace. • Fuel source is PNG, which helps to comply with the environmental standards. • They have installed APCD. The unit is releasing emissions through adequate stack height and pass through the APCD which helps in achieving the emission norms laid down by CPCB.
Case study 2: Sunbeam Lightweighting Solutions Pvt. Ltd **Location:** Gurugram, Haryana	• Using natural gas as fuel and 100 per cent combustion is taking place, because of which no pollution is created. • The specific energy consumption is around 112–113 SCM. • They are not using any APCD. The unit is releasing emissions through adequate stack height and achieving the emission norms laid down by CPCB.
Case study 3: Shrinathji Ispat Ltd **Location:** Ghaziabad, Uttar Pradesh	• Using electricity as fuel and specific energy consumption is less than 650 kWh per tonne of molten metal. • Bag filters are installed as APCDs and they are extracting lead and zinc from the dust. Regular maintenance of APCDs is done. • Unit got an energy audit done in the year 2020 by PCRA and replaced all old and inefficient motors with the latest ones.

Source: CSE survey and analysis

FUGITIVE EMISSIONS

Sectoral challenges: Stone crushing units are significant contributors to air pollution due to the high levels of dust and particulate matter they generate. As per Central Pollution Control Board, there are about 17,000 stone crushers as of July, 2023. Stone crushing practices vary widely based on factors such as geographical location, demand for specific crushed products, type of raw material, and the local availability of plant and machinery.

Stone crushing units are classified as small, medium, or large-scale operations based on production capacity. While small crushers usually have a production capacity of 3–25 tonne per hour (TPH), the production capacity of medium-sized crushers is in the range of 25–100 TPH. The production capacity of large crushers is more than 100 TPH; they are generally owned by companies with their own or leased stone mines.

The process includes raw material transportation, primary and secondary crushing, screening, and storage. Dust emissions occur at every stage, particularly during material transfer, crushing, and screening. Fugitive emissions are generated from different processes in a stone-crushing industry. The major process in stone crusher units remains the same, with variations in the number of crushing and screening steps depending on the size of the unit and the requirement of the final product.

Screening is the process of separating groups of products of various sizes through several screens of different mesh sizes. The products from these units generally include fine dust and stones of sizes 6 mm, 10 mm, 20 mm and 40 mm. A different size of stone can also be produced as per the demand by changing only the size of the screen mesh. Large stones and boulders are crushed into stones of 100–140 mm.

During primary crushing, the finer dust particles enter the air and escape as fugitive emissions. The crushed stone are further transferred to secondary crusher through conveyor belts. Size reduction is done in the process of primary crushing. After primary crushing, stones are further crushed to sizes ranging from as large as 40–60 mm to 10 mm or even smaller. Stone-crushing units use different types of crushers for secondary crushing. Either granulators are used in units with basic design also called non-engineered units or cone crusher is used in engineered units.

After the first round of screening, stones are ground further to get fine dust. Large quantities of fugitive emissions are generated during this process. After tertiary crushing, materials are transferred via chutes, and directly depositing them onto stockpiles leads to significant fugitive dust emissions.

National-level action: The Central Pollution Control Board (CPCB) has issued the guidelines to minimise dust emissions from stone crushing units and encourage sustainable practices. Under the Environment (Protection) Rules, 1986, stone crushing units must secure permissions from State Pollution Control Boards (SPCBs) or Pollution Control Committees (PCCs). These include obtaining consent to establish (CTE) and consent to operate (CTO). Regular inspections, ambient air quality monitoring, and CCTV surveillance are required to ensure compliance. Health surveys for workers and restrictions on operating hours further mitigate the environmental and health impacts of these operations. New units must be established in designated zones, while existing units are encouraged to adopt updated practices for dust control.

The guidelines propose practical actions such as constructing wind-breaking walls, maintaining metaled roads, and recycling water through settling tanks. Proper handling of water resources and adherence to safety protocols during material transportation are also outlined. Units must document their compliance with these measures, including submitting photographs and videos, during permit applications or renewals. The guidelines also recommend water sprinklers, enclosed crushers and conveyors, and proper stockpile management. Maintaining roads, improving housekeeping, and planting greenbelts with tall trees are also emphasised to create cleaner and safer sites. By adopting these practices, the sector can enhance resource efficiency, protect worker health, and contribute to maintaining ambient air quality.

State-level action: At the state level, significant action has been spurred by directives from the National Green Tribunal (see *Box: National Green Tribunal on stone crusher sector*), prompting measures in states like Maharashtra, Haryana, Madhya Pradesh, and Jharkhand, among others.

At the same time SPCBs are also taking proactive initiative to improve implementation and monitoring. This is creating an important learning curve.

For instance, the Tamil Nadu Pollution Control Board (TNPCB) has regulated operation and management of stone crushing units in the state. TNPCB has enabled the siting and functioning of these units within designated zones, with all necessary infrastructure and environmental safeguards in place. This includes the installation of green belts, dust suppression systems, wind-breaking walls, and paved internal roads, all of which significantly reduce fugitive dust emissions, one of the major pollutants in this sector. Continuous inspections and strict adherence to environmental management practices have helped in maintaining compliance and ensuring that local air quality is not adversely affected.

TNPCB's role in ensuring operational efficiency of such clusters demonstrates how a pollution control board can go beyond enforcement to facilitate responsible industrial operations. This proactive involvement also includes working with local stakeholders and industry associations to ensure awareness, participation, and timely upgradation of technologies.

National Green Tribunal on stone crusher sector

Over the years, multiple NGT orders across various states have helped shape the regulatory roadmap for the stone crushing industry.

Jharkhand

In OA No. 23/2017 (EZ), the NGT order dated March 15, 2023, addressed violations of environmental norms in the operation of crushing units and quarrying activities in the ecologically sensitive Rajmahal hills of the Vindhya range, located in Sahebganj district. The case underscores the need for stricter enforcement in fragile hill ecosystems.

Maharashtra

An NGT order dated April 7, 2016, targeted unregulated stone crushing in Wagholi, Bhavadi, Perene, and Lonikand villages of Haveli Taluka, Pune district. The NGT sought a complete inventory of stone crushers and quarries in operation, including their consent-to-operate status. Subsequently, the Pune Bench, on September 26, 2016, directed the Maharashtra Pollution Control Board (MPCB) and CPCB to jointly inspect 56 units and submit a cumulative impact assessment report.

Haryana

In OA Nos. 667/2018, 679/2018, and 599/2019, the NGT ordered enforcement action against polluting units in Mahendragarh district. Of the 133 stone crushing units identified, seven were directed to deposit interim environmental compensation of Rs 20 lakh each, amounting to Rs 1.4 crore, as per the NGT's January 18, 2023, order. These funds were deposited with the Haryana State Pollution Control Board (HSPCB), and further action was initiated via show cause notices.

Madhya Pradesh

Following a joint inspection report, the NGT order dated February 21, 2019, found five stone crushers operating within a prohibited distance from the national highway in Satna district. These units, along with their captive mines, were ordered to shut down. Additionally, 14 units were issued show cause notices for failing to implement pollution control measures. The NGT criticised the lack of compensation recovery for environmental damage and directed the SPCB to assess and furnish a compensation report.

INDUSTRY GOOD PRACTICES

Salem Mines and Aggregates, Tamil Nadu

Salem Mines and Aggregates is a well-established stone crushing unit located in Kumarakkam village, Tiruvannamalai district, Tamil Nadu. The unit operates at a capacity of 200 tonne per day (TPD) and functions for 260 days annually. Operating hours span from 6:30 AM to 11:00 PM daily, with necessary breaks in between.

The unit specialises in producing various types of aggregates, including 30mm, 20mm, 12mm, and 6mm, along with manufactured sand (M-sand), plastering sand (P-sand), and dust. To ensure environmentally friendly operations, Salem Mines and Aggregates has implemented a range of measures aimed at controlling dust emissions, maintaining operational efficiency, and adhering to environmental regulations.

Sprinkling inside the premises

Fenced boundaries

Environmental measures during material handling and processing: To minimise dust emissions during the unloading of raw materials, water sprinkling systems are deployed, and proper access to roads and unloading points is provided. The raw material hopper is covered on three sides, equipped with water sprinklers to control airborne particles.

In the primary crushing stage, the jaw crusher is enclosed with galvanized iron (GI) sheets, with provisions for maintenance. Water sprinklers and mist systems further aid in reducing dust emissions. Secondary crushing operations follow similar measures, utilising GI sheet enclosures, dust extraction systems, and cyclones for effective dust control. Water mist systems are also applied to conveyor belts to minimise environmental impact.

Screening and tertiary crushing operations are fully enclosed with movable doors for maintenance. While dust extraction systems with water sprinklers are required, sprinklers on conveyor belts are primarily used. Semi-circular mild steel (MS) dome sheets cover the conveyor belts, ensuring dust control, and discharge points are managed with flexible telescopic chutes or closed elevated bunkers.

Road infrastructure and dust management: The premises have metalled roads, though the approach to the unloading area remains unmetalled. To control dust, regular road wetting and cleaning are carried out, supplemented by rotating water sprinklers and foggers that help clear accumulated dust and maintain a clean, safe working environment.

Information displayed clearly at entrance

Sprinkling in the conveyer belt

Covered conveyer belt

SOURCE: CSE

Maintainenance of M-type

Plantation and structural measures: The unit has developed a wide green belt around the periphery, using appropriate flora to act as a natural barrier against dust and noise pollution. While standard boundary walls are built to match the drop point height of chutes, wind-breaking walls, such as GI, MS, or brick walls, are not available. However, the presence of telescopic chutes compensates for this limitation.

Facilities and safety measures: The unit has a 75 kilolitre (KL) water storage tank, with a daily consumption of 30 KL. CCTV cameras are installed at the entrance and inside the processing area, though they are not yet linked to the Tamil Nadu Pollution Control Board (TNPCB). A signboard at the entrance displays the unit's name, contact information, and address for clear identification.

Salem Mines and Aggregates has implemented numerous measures to maintain compliance with environmental and safety standards. The adoption of dust suppression techniques, proper enclosures, and housekeeping practices showcases their commitment to sustainable operations. However, some areas, such as the construction of wind-breaking walls require improvement. With continued efforts, the unit can serve as a model for environmentally responsible practices in stone crushing operations.

Kakade Stone Crusher in Pune

In Mangrul village of Malwal Taluka, Pune district, the Kakade Stone Crusher stands out as a model unit adhering strictly to the Maharashtra Pollution Control Board (MPCB) guidelines. This exemplary unit operates three crushers with substantial capacities—two of 200 tonnes per hour (TPH) each and one of 300 TPH. Additionally, it includes a ready-mix concrete (RMC) plant with a capacity of 120 TPH, currently utilised for internal purposes. The crusher operates daily from 7–6 pm, with measures to control noise emissions and ensuring compliance with environmental standards. To enhance quality control, a storage plant is under construction to securely store final products in a closed space.

Adherence to MPCB guidelines: Kakade Stone Crusher strictly complies with MPCB's siting criteria, maintaining a distance of one kilometre from the national highway and 500 metres from state highways, schools, hospitals, and residential areas, thereby minimising disturbance to surrounding communities.

To effectively control air pollution, the company has implemented the following measures:

- Conveyor belts are covered with sheets to reduce fugitive emissions.
- Water sprinklers are installed at key locations, including loading, unloading, crushing points, conveyor belts, and entry points, to suppress dust.
- Crushing sections and screen classifiers are fully enclosed with galvanized iron (G.I.), equipped with proper maintenance doors.


Cleaning solar panels


Covered conveyor belts


Regular sprinkling done on the road


Covered screen with door arrangements


Thick foliage of plant along the periphery


Covered secondary crushing units

- All approach roads within the facility are metalled or cemented, significantly reducing dust emissions. These roads are also maintained and wetted regularly.
- A green belt of 20-metre-high trees, spanning 5 metres in width, encircles the unit, serving as a natural barrier against pollution.
- The facility is enclosed by a 10-foot-high boundary wall to ensure safety and contain dust emissions.
- Strict housekeeping practices, such as regular cleaning, reduce operational downtime and ensure smoother functioning.

Solar energy initiatives: One of the most notable achievements of the Kakade Stone Crusher is its commitment to energy conservation. The unit has installed two solar plants, each with a capacity of 1 Mega Watt (MW). The first plant, established in 2018, and the second, built in 2021, are both situated on reclaimed stone quarry sites. With a combined investment of around Rs 6 crore, they produce approximately 15 lakh electricity units annually.

Despite the challenges of maintaining solar panels in the dusty environment of crushers and quarries, the unit ensures regular cleaning and upkeep to maximise energy efficiency. During shutdowns or equipment breakdowns, surplus electricity is supplied to the Maharashtra State Electricity Board (MSEB), reinforcing the unit's commitment to sustainable operations.

By combining these measures, the Kakade Stone Crusher exemplifies sustainable and efficient practices in the stone-crushing industry, setting a benchmark for others. Documenting and sharing such case studies can inspire similar initiatives industry-wide.

PCS Industries Pvt. Ltd, Tamil Nadu

PCS Industries Pvt Ltd, located at 81, Punnamai Village, Chengalpattu District, operates with a production capacity of 450 TPH. The unit functions for 200–230 days a year, with operating between 10 pm to 6 am. The raw materials are sourced from self-owned mines, and the unit specialises in producing 20 mm, 12 mm, and 6 mm aggregates, along with M-sand and T-sand.

Dust suppression during raw material handling: PCS Industries Pvt. Ltd has implemented several measures to control dust during the unloading and storage of raw materials. Water sprinkling is used to suppress dust during the unloading process, ensuring minimal air pollution. When raw materials are unloaded into hoppers, the hopper is enclosed on three sides and semi-closed on the top, leaving one side open for vehicle movement. Water sprinklers are also installed on approach roads to minimise dust emissions during vehicle transit.

Dust control in crushing operations: Primary and secondary crushing operations are enclosed to reduce dust dispersal. The primary crusher is enclosed using GI sheets on three sides and the top, with a movable sheet or door for maintenance access. Water sprinklers and spray nozzles are utilised to further suppress dust. Similarly, secondary crushing involves the use of a dust extraction system equipped with a bag filter or a water mist system, followed by a cyclone, all within an enclosed shed. These measures help significantly reduce airborne particles during the crushing processes.

Screening and tertiary crushing measures: Screening and tertiary crushing are conducted with advanced dust control measures. An ID fan system vents into a closed chamber, and a water sprinkling system is installed to manage dust. The measures ensure compliance with environmental regulations while maintaining operational efficiency.

Dust extraction and transfer point management: The dust extraction system features a bag filter or ID fan housed within a closed chamber, complemented by a water sprinkling setup. All transfer points are fully enclosed and equipped with a water mist system to suppress dust during material handling, ensuring effective containment at critical operational stages.

Conveyor belt and discharge point management: Conveyor belts carrying aggregates and dust are covered with semi-circular MS dome sheets to prevent the escape of dust. Discharge points are equipped with flexible telescopic chutes or elevated closed bunkers to further control the spread of dust during material discharge. These measures ensure cleaner and safer working conditions.

Environmental enhancements: PCS Industries has taken several steps to enhance the surrounding environment. A 10-meter-wide green belt with indigenous, tall-growing

Updated technology for sand making

Covered conveyer belt

trees covers 33 per cent of the plant area, serving as a natural dust barrier and improving air quality. Boundary walls are erected as high as the drop points of chutes at conveyors, and wind-breaking walls made of GI/MS/brick are installed three feet higher than the crusher's highest nod to prevent the spread of dust.

Infrastructure and maintenance: To reduce dust dispersion and maintain cleanliness, metalled roads are provided within the premises, which are regularly cleaned and wetted. The crushing area is equipped with a rotating water sprinkling system or foggers for thorough coverage. Fine dust and bag filters are cleaned daily, and the collected dust is stored for further use, ensuring waste is managed effectively.

Additional measures for monitoring and safety: Signboards are placed at the entrance for proper identification, and the crusher is set up as a standalone unit to isolate its impact. An Ambient Air Quality Monitoring (AAQM) device is installed to monitor pollution levels in real-time. Surveillance is ensured through CCTV cameras installed at the entrance, though they are not connected to the Pollution Control Board (PCB).

Water management: Water availability and usage are meticulously managed. The plant has a five-kilolitre water storage tank, a 50-kiloliter underground reservoir, and a daily water consumption of 50 cubic meters. These measures ensure adequate water supply for sprinkling, cleaning, and operational needs. These efforts not only ensure regulatory compliance but also foster a sustainable and healthier environment.

Scalability and replicability in the stone crusher sector: Way forward

To ensure the scalability and replicability of sustainable practices in the stone-crushing sector, an integrated approach is crucial. This can be promoted through NCAP framework.

By fostering a culture of compliance through transparent monitoring mechanisms like real-time air quality sensors and CCTV surveillance linked to SPCBs, the sector can minimise environmental damage while maintaining productivity. Replicating successful models and promoting cross-learning between regions can drive systemic change, ultimately transforming the stone-crushing sector into a more sustainable and community-friendly industry. A key focus has to be on adoption of cost-effective pollution control measures, such as water sprinklers, enclosed crushing operations, and greenbelt development, which can be scaled according to the size of the unit.

Regulatory bodies like the Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCBs) need to prioritise capacity building among small and medium-scale units and dissemination of detailed best-practice guidelines tailored for different scales of operations.

Case studies demonstrate that advanced solutions such as solar energy installations, metalled roads, and closed conveyor systems are not only effective but also economically viable over time. Facilitating access to subsidies, low-interest loans, and shared technology platforms will encourage widespread adoption of these solutions.

CEMS

Smart, transparent monitoring of real-time emissions from industrial stacks is key to good governance. It enables preventive action, enhances emissions performance, provides feedback on technology efficacy, strengthens compliance strategies, and supports market-based mechanisms like emissions trading. Widespread adoption of CEMS can make this possible and reinforce industrial self-regulation.

National-level action

The CPCB, through its letter No. B-29016/04/06PCI-1/5401 dated 05.02.2014, mandated the installation of Continuous Emission Monitoring Systems (CEMS) under Section 18(1) of the Water and Air Acts. State Pollution Control Boards and Pollution Control Committees were directed to ensure that 17 categories of highly polluting industries, along with CETPs, STPs, common bio-medical waste incinerators, and hazardous waste incinerators, install online effluent and emission monitoring systems.

In 2017, the CPCB released the "CEMS Technical Guidelines" to assist industries and regulators with the deployment and operation of CEMS in India. However, implementation challenges remained due to the absence of a robust quality assurance framework—such as certification systems, functional testing, calibration protocols, and standards for operation, maintenance, and ongoing performance checks.

Recognising these challenges, the Ministry of Environment, Forest and Climate Change (MOEFCC) issued a notification in August 2019, designating the CSIR-NPL (Council of Scientific and Industrial Research–National Physical Laboratory) for establishing a standardised certification system to ensure accuracy and credibility of CEMS data.

The CSIR-NPL subsequently developed the CEMS certification in August 2024. However, the utilisation of CEMS data for regulatory and compliance purposes has been limited due to ongoing concerns about data accuracy and system reliability. Despite substantial investments in infrastructure and technology its practical usage has remained sub-optimal.

Nevertheless, a valuable learning curve is emerging from the proactive initiatives of some of the SPCBs that is important to capture.

State-level action

Odisha State Pollution Control Board: Leveraging CEMS data for monitoring and inspection

In Odisha, the State Pollution Control Board (SPCB) has mandated CEMS in 205 industries with 797 CEMS installation across 169 highly polluting industries (17 category) and other industries. The installed CEMS devices transmit data to the Central Real-Time Data Acquisition System (RT-DAS) server on a minute-by-minute average basis, where data analyst retrieves and reviews the data for compliance.

Enforcing compliance using IP cameras

As part of the state's 5T (Transparency, Teamwork, Technology, Transformation, and Time) charter, the Odisha State Pollution Control Board has outlined several action points to enhance environmental compliance. One key action point requires the installation of IP cameras at critical emission sources, such as stacks and fugitive emission points, and their connection to the SPCB server. All the large 17 category industries and mines with a capacity of 5 MTPA and above capacity are required to install these cameras in dust-prone areas and link them to the SPCB's sever. The installation of HD IP camera and its connection to the server of board within two months is also one of the consent conditions of the OSPCB board.

The mandated HD IP cameras are advanced digital video systems equipped with features like high resolution, night vision, motion detection, PTZ (pan-tilt-zoom) capability, and remote access. This provides the Odisha SPCB with real-time visual monitoring of emissions, augmenting the data provided by CEMS.

The Odisha State Pollution Control Board has set up a dedicated RT-DAS data Analysis Team focused specifically on CEMS. This team conducts fortnightly and monthly reviews of CEMS data. In cases of non-compliance—such as no data, constant readings, data availability below 85 per cent, or zero data—the team cross-verifies the reported OCEMS data with actual stack emissions observed through IP cameras. This comparison enhances transparency and provides a clearer picture of the emissions landscape at industrial sites.

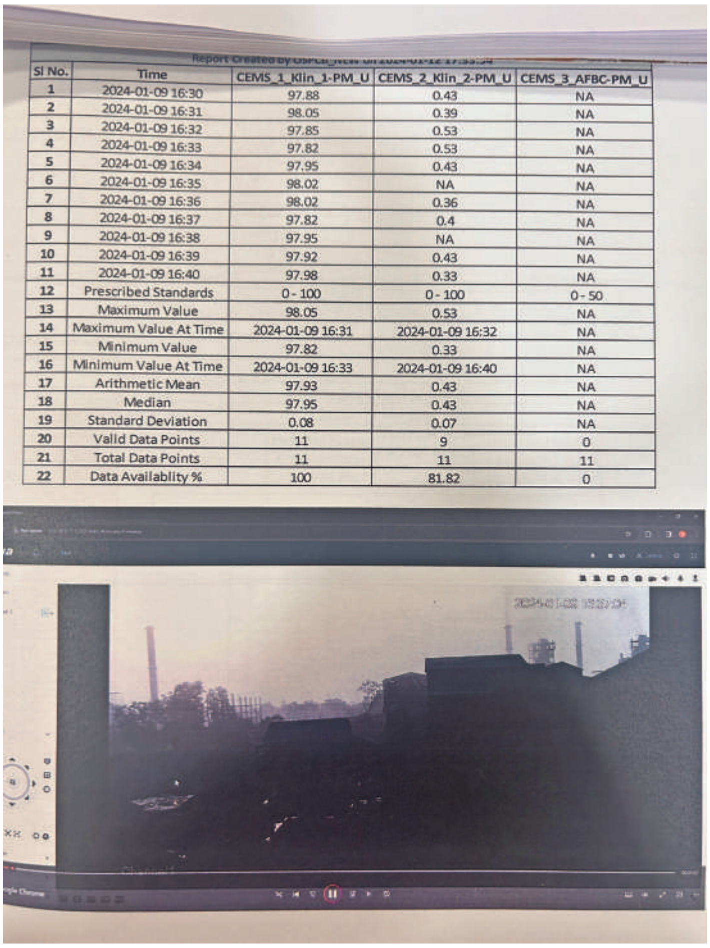
Comparing CEMS data with actual emission using IP cameras

There instances where IP camera footage clearly captures visible emissions from an industrial stack, while the data submitted to the Odisha SPCB indicate significantly lower or constant emission levels. The emissions observed via the IP camera and the data displayed on the RT-DAS server were recorded simultaneously, revealing discrepancies between what was reported and what was happening in real time.

Sometime an industry is found to be reporting constant emissions data while the IP camera footage captures show significant emissions. The captured emissions and the CEMS data displayed on the server are recorded at the same time. The near constant emission by the CEMS system further highlight the discrepancy between actual emissions and reported data.

In some cases, where industries claim to be in shutdown mode, the IP cameras can verify these claims. For instance, an industry reported a shutdown, and upon reviewing the IP camera footage, no emissions were observed, confirming that the plant was indeed inactive.

By integrating IP camera footage with CEMS data, the Odisha SPCB can more effectively monitor industrial compliance, cross-verifying reported data with real-time observations.



Sl No.	Time	CEMS_1_Klin_1-PM_U	CEMS_2_Klin_2-PM_U	CEMS_3_AFBC-PM_U
1	2024-01-09 16:30	97.88	0.43	NA
2	2024-01-09 16:31	98.05	0.39	NA
3	2024-01-09 16:32	97.85	0.53	NA
4	2024-01-09 16:33	97.82	0.53	NA
5	2024-01-09 16:34	97.95	0.43	NA
6	2024-01-09 16:35	98.02	NA	NA
7	2024-01-09 16:36	98.02	0.36	NA
8	2024-01-09 16:37	97.82	0.4	NA
9	2024-01-09 16:38	97.95	NA	NA
10	2024-01-09 16:39	97.92	0.43	NA
11	2024-01-09 16:40	97.98	0.33	NA
12	Prescribed Standards	0 - 100	0 - 100	0 - 50
13	Maximum Value	98.05	0.53	NA
14	Maximum Value At Time	2024-01-09 16:31	2024-01-09 16:32	NA
15	Minimum Value	97.82	0.33	NA
16	Minimum Value At Time	2024-01-09 16:33	2024-01-09 16:40	NA
17	Arithmetic Mean	97.93	0.43	NA
18	Median	97.95	0.43	NA
19	Standard Deviation	0.08	0.07	NA
20	Valid Data Points	11	9	0
21	Total Data Points	11	11	11
22	Data Availablity %	100	81.82	0

OSPCB records actual emission and reported data

This dual-layered approach improves transparency, accountability, and enforcement, ensuring that industries adhere to environmental regulations and accurately report their emissions.

The Odisha State Pollution Control Board (OSPCB) maintains detailed records for all industries and employs specialised software to analyse CEMS data. This data is cross-verified with real-time emissions footage from IP cameras. For instance, in one analysis, Stack 3 showed no data while Stack 2 reported emissions near baseline levels. Such reviews are conducted fortnightly and monthly, with records maintained and necessary actions taken. To support remote monitoring, the OSCB has also directed all industries to number their stacks for easy identification via IP cameras from the SPCB control room.

The OSPCB compiles a monthly list of industries, assessing the status of their operational IP cameras. This includes checks on the PTZ (pan-tilt-zoom) function, video clarity, availability of playback, and the accuracy of time and date stamps in the footage, as outlined in the following format.

Table 7: Monthly record of industries with functional IP cameras

IP camera status for the X -Month, 2024		
Industry name	**Status**	**Remarks**
ABC	Okay	No playback
ABC	Okay	No playback and PTZ not working
ABC	Okay	Not focused on stack
ABC	Okay	Poor visibility
XYZ	Okay	No date and time
XYZ	Okay	Okay

Source: CSE survey and analysis

The Odisha State Pollution Control Board also prepares a summary record of all industries, categorised by sector, along with details of their respective stack data types, as presented in the format below.

Table 8: Category-wise list of industries with data types

Industry Type	Exceedance	Contant	Baseline	Insufficient	Constant & baseline	No data
Iron & steel Large	1	27	24	20	10	30
Iron & steel medium	0	8	2	7	5	11
Aluminium	1	17	20	4	2	2
Power	1	14	3	1	2	5
Iron & steel small	6	24	4	9	4	21
Integrated steel	0	2	0	2	0	4
Other industry	2	13	4	0	0	1
Cement	0	2	6	3	9	4
Oil refinery	0	0	11	0	0	0
Total	11	107	74	46	32	78

Source: As provided by Odisha State Pollution Control Board

The OSPCB has further developed a Standard Operating Procedure (SOP) for IP cameras:

a) The real time visual data with visible video quality is to be captured by IP camera with date and time.

b) Each stack shall be numbered in the industry end to identify the stacks remotely through the IP camera from control room of SPCB.

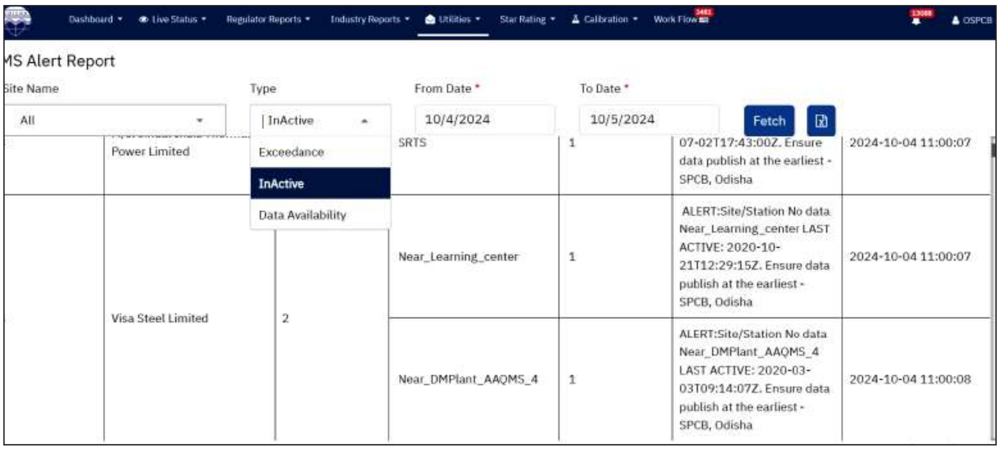
c) The PTZ and zoom option to be checked either data is coming directly from unit or from the recorded video

d) The visible emission level shall be cross checked with real time data for 15 minutes if it varies with real time monitoring data the report will be generated to the units with a copy to conformed branch head and Regional Officer of the Board.

e) In case high visible emission continues for 30 minutes a report will be generated to the units with a copy to conformed branch head and Regional Officer of the Board.
f) The unit shall ensure high-speed net connection and data transmission.

Action against non-compliant industries
The installation of HD IP cameras connected to the Board's server within two months, and uninterrupted CEMS data transfer to the RT-DAS server within one month, are mandatory consent conditions set by the Board. Non-compliance with these timelines will attract regulatory action against the industry.

Autogenerated SMS alerts to non-compliant industries
In case of non-compliance, SMS alert is sent to the industries every day at 6:00 pm, based on 24-hour data.



OSPCB SMS alert report

Categories of data anomalies based on which SMS alerts are sent:
Data availability: If less than 85 per cent of valid data (excluding zero or NA values) is received from any analyser, it is treated as data loss for the day. A daily 'No Data,' report is generated and shared with the unit.

If data is lost for more than 10 minutes within a 30-minute window, that half-hour value is considered lost. If more than five such half-hour values are lost in a day, it counts as a full day of data loss. Additionally, if over three hourly averages in a day are invalid due to equipment malfunction or maintenance, the day is marked as lost.

In all such cases, a daily report is sent to the unit and copied to the concerned branch head of the Board. If there are four such lost-data days in a month—either consecutively or separately—a report is escalated as per the workflow with a recommendation to issue a show cause notice to the concerned unit.

No data: 'No data' typically appears as blank readings. If no data is received continuously for 30 minutes, it is marked as 'no data' (NA). If this occurs four times in a single day, the entire day is considered a 'no data' day. A daily report is then generated and shared with both the unit and the concerned branch head of the Board.

If four such 'no data' days—whether consecutive or separate—are recorded within a month, a report is forwarded as per the workflow with a recommendation to issue a show cause notice to the unit.

Zero data: 'Zero data' typically refers to a continuous display of '0' readings. If such readings persist for 30 minutes, they are classified as 'zero data'. If this occurs four times in a day, the entire day is marked as a 'zero Data' day. A daily report is then generated and shared with the unit as a 'zero data' report.

If four such days—whether consecutive or separate—are recorded within a month, a report is forwarded to all concerned as per the workflow, with a recommendation to issue a show cause notice to the unit.

Constant data: 'Constant data' refers to readings with a variation of ffl1 per cent. If the same value is recorded continuously for 30 minutes or more, it is classified as constant data. Daily instances of such occurrences are tracked, and a report is generated and shared with the unit, with a copy sent to the concerned Branch Head of the SPCB as per the workflow.

Weekly and monthly summaries of constant data occurrences are also compiled. These reports are shared with the unit, the Branch Head, and the Regional Officer, who may be directed to conduct a physical verification of the online analysers and data transmission systems.

Data near baseline: If data values remain near zero—within the range of 0 to 5—for 30 minutes or if more than 500 such readings are recorded in a day, it is treated as potential data tampering. Each occurrence is documented, and a daily report is generated and shared with the unit, with a copy sent to the concerned Branch Head of the SPCB as per the workflow.

Weekly and monthly summaries of such near-base value data are also compiled. These are communicated to the unit, Branch Head, and Regional Officer, prompting physical verification of the online analysers and data transmission systems.

Data near standard: If data values remain within ffl2 per cent of the prescribed standard for over 30 minutes, or if more than 500 such readings are recorded in a day, it is considered potential data tampering. These occurrences are recorded, and a daily report is generated and shared with the unit, with intimation to the concerned Branch Head of the SPCB as per the workflow.

Weekly and monthly summaries of such near-standard value data are also compiled and communicated to the unit, the Branch Head, and the Regional Officer for physical verification of the online analysers and data transmission systems.

Exceedance of data: If data values for Particulate Matter (PM) exceed twice the prescribed standard continuously for 30 minutes, a report is forwarded to all concerned as per the workflow, along with a recommendation to issue a show cause notice to the unit.

Any exceedance of the prescribed standard for over 30 minutes is recorded as an exceedance event. If four such instances occur in a day, it is treated as a full-day exceedance. A daily exceedance report is generated and shared with the unit and the concerned Branch Head.

Additionally, if 85 per cent of the day's PM data shows exceedance—even in discrete intervals—a daily report is again generated and forwarded with a recommendation to issue a show cause notice to the concerned unit.

The OSPCB issues an intimation letter to industries found non-compliant, allowing up to 15 days for a response or corrective action from industry. If no action is taken, the Board conducts an inspection, which extends beyond CEMS compliance to include checks on other emission-related aspects such as Air Pollution Control Devices (APCDs). Based on the findings, a show cause notice is issued, detailing the CEMS-related and other compliance lapses.

Leveraging CEMS for Emissions Trading Scheme (ETS) for Particulate Matter (ETS-PM): Surat, Gujarat

An emission trading scheme (ETS) is a regulatory mechanism designed to reduce the total pollution load in a specific area while minimising the cost of compliance for industries. ETS operates as a market, where the commodity being traded is particulate matter (PM) emissions. The regulator puts a limit, or cap on the total PM emissions allowed from all industries under the scheme. Within this framework, industries can buy and sell the ability to emit PM, by trading permits under this cap.

The pilot ETS for particulate matter in Surat, Gujarat, is a progressive step towards tackling industrial air pollution. This initiative was developed through a collaboration between the Ministry of Environment, Forest and Climate Change (MOEFCC), the Central Pollution Control Board (CPCB), the Gujarat Pollution Control Board (GPCB), J-PAL South Asia, the University of Chicago, and Yale University. Notably, this is the world's first ETS aimed specifically at particulate matter from industrial sources.

In 2019, the ETS PM was introduced in Surat amongst 342 highly polluting solid fuel burning industries. The sample units were selected according to the criteria like units must belongs to red category industry of highly polluting industries, units with at least one stack and diameter >24 cm for CEMS installation, units using solid fuels and units from large and medium scale sectors (according to capital investment).

Improving CEMS data quality: To ensure high-quality CEMS data, all the industries under this programme, are mandated to enter into Annual Maintenance Contracts (AMC) and perform biannual calibration of their CEMS equipment. The GPCB regularly conducts regulatory spot checks, including iso-kinetic sampling, to detect any potential tampering with the data.

For effective operation and maintenance of CEMS, it is mandated by GPCB that every industry has a designated CEMS personnel. Each industry must appoint a nodal representative who is responsible for monitoring data availability from the CEMS. The designated CEMS personnel should be responsible for:

Monitoring site connectivity using the CEMS website or mobile application.
Co-ordinating with CEMS hardware vendors to ensure proper installation, calibration, and operation of the CEMS.

Represent the industry at CEMS-related meetings and events, and report to GPCB on data availability and PM performance as needed.

GPCB's best practices for ensuring data quality:
The Gujarat Pollution Control Board has introduced several best practices to maintain data quality:

Regular maintenance: Industry must carry out regular maintenance of the CEMS device as per the CPCB guidelines. All the industries are advised to enter into comprehensive maintenance contracts (CMCs) with their CEMS vendors.

Bi-annual calibration: Industry must re-calibrate the device every six months. Industries contact their CEMS vendor and follow CPCB guidelines for device calibration.

Maintenance of data quality: Conduct **yearly CEMS audit** by CEMS vendor and an accredited laboratory: A yearly audit of CEMS must be conducted by the CEMS vendor and an accredited laboratory.

Maintain the DAS at industry site: Ensure fast internet for the PC, enough PC storage to avoid data loss, and ensure CSVs are always generating at the local PC.

Improving CEMS data availability: Under the ETS programme, there is a rule for missing data. In case of missing data or invalid CEMS data, emissions are filled as per the rules cited in Table 9.

Any unit found knowingly reporting inaccurate or falsified data may incur penalties and be treated as non-complaint with the scheme. The imputation process for missing data enforces industries to ensure the continuous availability of CEMS data. Also, GPCB conducts regulatory spot checks of device who are suspected of under-reporting emissions. This programme makes use of CEMS and has established a record CEMS data availability of over 95 per cent.

Analysis of CEMS data to identify non-compliance: The Gujarat Pollution Control Board monitors and analyses CEMS data generated by industries in Surat on a monthly basis. This analysis helps GPCB assess whether industries are adhering to emission standards, for particulate matter (PM). By examining CEMS data trends, GPCB can identify patterns of compliance or non-compliance.

Table 9: Imputation for missing CEMS data

S. No	% Data available from CEMS during weekly reporting period	Load imputation for missing data values (Kg/hr)
1.	>95 %	Impute unit's mean operating emission load during the compliance period
2.	80-95%	Impute unit's 75th percentile emissions load during the compliance period
3.	50-80%	Impute unit's 90th percentile emissions load during the compliance period
4.	<50%	Impute unit's 90th percentile emissions load during the compliance period and prior three months of valid CEMS data, up to start of compliance period AND Notice sent to GPCB of unit's very poor data availability during the week
5.	<1%	Impute at flat rate of population 99th percentile emissions load during the compliance period and prior three months of valid CEMS data, up to start of compliance period AND Notice sent to GPCB of unit's very poor data availability during the week.

Source: CSE survey and Gujarat State Pollution Control Board

Industries that consistently exceed allowable emissions or frequently report incomplete or irregular data are flagged for further investigation. This systematic review of CEMS data allows GPCB to pinpoint industries that are not meeting their regulatory obligations, prompting necessary corrective actions such as inspections, warnings, or penalties. Ultimately, this continuous monitoring and analysis ensure that industries stay accountable for their emissions and comply with environmental regulations. The CEMS data generated by industries in Surat is monitored and analysed monthly by GPCB. This CEMS data analysis provides insights into the compliance status of industries and highlighting those that are frequently non-compliant.

Mandates by other State Pollution Control Boards

The Rajasthan State Pollution Control Board (RSPCB) has mandated that industries required to implement CEMS must also install IP/PTZ cameras to monitor emissions from their stacks. In its order dated May 23, 2023, RSPCB directed that these PTZ cameras be connected to the State Board's portal to enhance monitoring under the Continuous Emission Monitoring System (CEMS) and Continuous Effluent Quality Monitoring System (CEQMS). The cameras are intended to provide visual surveillance of emission and effluent discharge points.

To ensure effective CEMS implementation in the state, RSPCB has appointed nodal officers in all regional offices and laboratories. While the board initially had a dedicated team at its head office overseeing CEMS, the appointment of regional nodal officers helps enhance oversight and reduce the burden on the head office. Additionally, RSPCB is in the process of adopting Emission Trading Schemes (ETS) for PM, SOx, and NOx. RSPCB also issued orders to volunteer installation of OCEMS in units for self-surveillance purpose. RSPCB has also waived off the fee to be paid by industries for OCEMS connectivity.

Replicating and upscaling CEMS good practices through NCAP framework

The best practices of CEMS in India have highlighted how different Indian states like

Odisha and Gujarat have adopted Continuous Emission Monitoring Systems (CEMS) to manage industrial emissions and improve regulatory compliance. As the report highlights, the effective use of CEMS data has immense potential to reduce industrial air pollution while promoting transparency and accountability among industries. However, several challenges remain, especially concerning system reliability, data availability and accuracy across all states.

To further enhance the implementation of CEMS in India, recommend the following key actions:

Establish a dedicated team for CEMS at head office: For effective implementation of CEMS, it is important to establish a dedicated team at the head office, equipped with the necessary infrastructure for monitoring. Additionally, appointing nodal officers at regional offices will ensure more effective management of CEMS at the local level.

Disseminate best practices across States: While states like Odisha and Gujarat have introduced innovative methods such as IP cameras and emissions trading schemes (ETS), there is a need for nationwide dissemination of these best practices. Creating a centralised platform for exchanging successful strategies can enable states with less developed systems to adopt more efficient methods for utilising CEMS data.

Develop robust enforcement mechanisms: States like Odisha have demonstrated the importance of combining real-time visual monitoring with data analysis to identify discrepancies in reported emissions. More states should be encouraged to adopt such dual-layered approaches, integrating visual monitoring with CEMS data to ensure industries comply with environmental regulations.

Integration of IOT and advanced technologies: Promote the adoption of Internet of Things (IoT) technologies to ensure real-time, tamper-proof data transfer and improving the transparency of emissions data.

Implement strong measures against data irregularities: Take stringent action against industries showing irregularities such as no data, constant or near-baseline data, data near standards, zero data, exceedance of limits, or data availability below 85 per cent.

INDUSTRIAL ENTERPRISES AROUND CIRCULARITY

It is notable how new generation industrial enterprises are growing to recover material and energy from diverse waste streams in a circular economy. This not only helps to close the waste loop, but also builds new economic opportunities, earnings and jobs while reducing both local air pollution and greenhouse gases from open burning of biomass.

There is notable growth in the Compressed Biogas (CBG) enterprises. In 2016, the World Bank had estimated that India generates over 277 million tonnes of biomass annually that comes from agriculture residues, food scraps, animal dung, and municipal solid waste. These end up in unmanaged landfills, open fields, water bodies, or are burnt. But by converting biodegradable waste into energy (Compressed Biogas or CBG) and organic fertiliser (digestate), it can close the loop in the waste-to-energy cycle, support sustainable livelihoods, enhance energy security, foster integrated waste management systems and reduce emissions.

Regulatory drivers

The NCAP has an opportunity to align with and leverage the national Sustainable Alternative Towards Affordable Transportation (SATAT) initiative launched by the Ministry of Petroleum and Natural Gas (MoPNG) in 2018. SATAT aims to set up 5,000 CBG plants, with a target of producing 15 million tonnes of CBG annually. The initiative ensures fixed-price procurement by oil and gas marketing companies, offering market stability to investors. In parallel, the National Bioenergy Programme (NBP) under the Ministry of New and Renewable Energy (MNRE) provides Central Financial Assistance—up to Rs 4 crore per plant (with a 4,800 kg/day capacity)—for CBG facilities using urban, agricultural, or industrial waste.

Several additional national-level incentives have enhanced the financial and operational viability of CBG projects. These include Priority Sector Lending (PSL) status, which facilitates easier access to bank credit; the Agriculture Infrastructure Fund (AIF), which offers interest subvention for developing feedstock supply chains; and tax relaxations such as GST and excise duty exemptions. A newly introduced mandate for five per cent CBG blending in the natural gas grid further ensures consistent market demand.

These national-level policies have therefore created opportunities at the state level. Uttar Pradesh's Bioenergy Policy (2022) has a dedicated outlay of Rs 750 crore for 2022–2027. The policy provides capital subsidies (up to Rs 20 crore per plant), low-cost land leasing options, and single-window clearance mechanisms.

State-level initiatives

The Madhya Pradesh government has launched a new plan under its Renewable Energy Policy 2025 to set up at least one biofuel plant in every development block. The focus is on fuels like compressed biogas (CBG), biodiesel, and bio-coal, which help reduce farm waste and increase rural income. To support this, the government is offering big incentives—like capital subsidies of up to Rs 200 crore, land at lower prices, and tax waivers for up to ten years. Only one plant will be allowed in each block, and local committees will select the investors.

Similar bioenergy promotion frameworks in Bihar and Gujarat offer capital grants, tax breaks, and interest subsidies to support project development. Together, these policies encourage investment, foster innovation, and strengthen the ecosystem for CBG as a clean energy solution derived from waste.

CBG initiatives—utilisation of locally available feedstock

In Garhmukteshwar, Uttar Pradesh, a successful CBG project with a production capacity of 8 TPD has demonstrated the value of pressmud—a high-organic-content byproduct of sugar manufacturing—as a key feedstock. Western Uttar Pradesh, with its concentration of sugar mills, generates significant quantities of pressmud, which was previously discarded or incinerated. This waste is now being transformed into clean energy, providing a sustainable waste management solution and creating an additional revenue stream for sugar producers.

Indore in Madhya Pradesh has implemented an exemplary municipal solid waste (MSW) management system with a robust source segregation mechanism. With around 51 per cent organic content in its waste stream, Indore has ensured a steady and reliable supply of wet waste suitable for anaerobic digestion. The municipal corporation enforces strict compliance with waste segregation rules, ensuring the quality of feedstock. The city's strategy has helped transition from a landfill-reliant system to a circular waste-to-energy model. By prioritising source segregation and integrating waste collection with anaerobic digestion processes, Indore avoids contamination—one of the major challenges in MSW-based CBG plants (17–18 TPD CBG production capacity). This model significantly enhances plant efficiency and output.

In Garhmukteshwar, pressmud is the primary feedstock, while Indore utilises organic municipal solid waste (MSW), and Banaskantha in Gujarat relies on cattle dung (CBG production capacity: 0.8 TPD). These examples highlight the adaptability of CBG technology to local waste streams, enabling cost-effective operations and reducing transportation costs through region-specific solutions.


Overview of the Banaskantha CBG plant


Gas holder

Market linkages: In Indore, CBG is used to fuel city buses and is supplied to local gas distributors. This reduces reliance on uncertain markets. The SATAT scheme's procurement guarantee by oil marketing companies further mitigates investment risk, making CBG ventures bankable.

Byproduct monetisation is another area of innovation. The residual slurry from biogas plants, known as Fermented Organic Manure (FOM)/ Liquid Fermented Organic Manure (LFOM), is marketed as a biofertiliser. Not only does this reduce the use of chemical fertilisers, but it also offers an additional revenue stream. Uttar Pradesh's policy supports FOM branding and marketing to promote widespread use in agriculture.

Some projects also explore renewable energy integration by installing rooftop solar panels to power auxiliary systems in the CBG plant. This reduces operational costs and further aligns with low-carbon goals.

Policy and institutional support play a crucial role. For instance, Uttar Pradesh has appointed district-level CBG officers to coordinate feedstock aggregation and project implementation. The single-window clearance system minimises bureaucratic delays, enhancing investor confidence and project timelines.

Benefits and replicability of the CBG Model

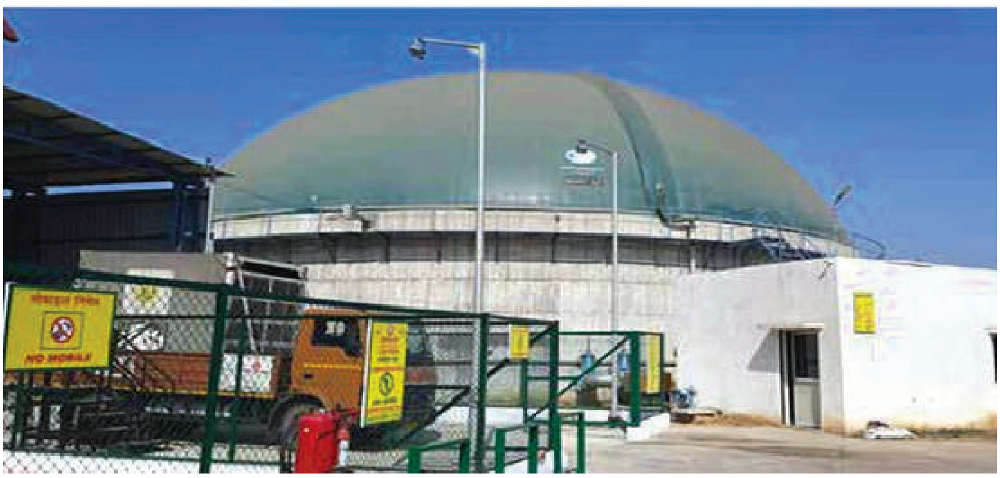
CBG initiatives offer a wide range of environmental, economic, and social benefits, making them highly suitable for replication across the country.

Environmental benefits: CBG plants help reduce methane emissions from decomposing organic waste in landfills, thereby mitigating climate change. They also lower fossil fuel dependency, supporting India's renewable energy targets. The use of biofertilisers derived from CBG plant residues improves soil health and reduces the need for chemical inputs, thus enhancing the quality of agricultural lands.

Economic benefits: The CBG value chain generates diverse income opportunities. Farmers benefit from selling crop residues; sugar mills and dairies profit from byproducts like pressmud and dung; municipalities gain from processing fees and tipping charges. The industry also supports employment generation in plant operations, waste logistics, and fertiliser marketing. Additional revenues come from carbon credits, CBG sales, and FOM/LFOM commercialisation.

Social benefits: Communities benefit from cleaner surroundings, reduced **waste-related pollution**, and lower health risks. Public awareness and participation in waste segregation also promote civic responsibility and environmental stewardship.

Replicability: The CBG models implemented in Indore, Garhmukteshwar, and Banaskantha are highly replicable, provided certain enabling conditions are met. These include effective waste segregation systems, especially for MSW-based plants; state-level policies that offer subsidies, land support, and single-window approvals;



Biogas digester with a total capacity of four tonnes per day (TPD) reliable feedstock supply chains, often enabled by partnerships with farmer cooperatives or industries; and secure offtake mechanisms, either through SATAT or tie-ups with local distribution networks.

Even decentralised models, such as the institutional CBG plant at IIT Delhi, demonstrate that smaller-scale plants (25m^3 of CBG production) can work effectively in universities, residential townships, and rural communities. These systems promote self-sufficiency and offer low-cost energy solutions in areas lacking centralised infrastructure.

The promotion of compressed biogas (CBG) a strategic convergence of India's environmental, energy, and waste management goals. Case studies from Indore, Garhmukteshwar, and Banaskantha reveal that successful implementation depends on localised solutions, robust waste management practices, institutional support, and secured market linkages.

MUNICIPAL SOLID WASTE

URBAN REFORMS FOR CLEANER AIR

The solid waste management has been driven more purposefully under the convergence framework, in which the sectoral performance linked funding programme of the Swachh Bharat Mission 2.0 (urban) and Swachh Survekshan have driven cities with targets and a strong compliance strategy.

A few cities have taken an ecosystem approach to addressing collection, segregation, processing and material recovery, along with remediation of legacy waste in a composite way, while others have focused on specific progressive strategies to attain good management practices.

Indore has closed the entire waste and material loop, which includes door-to-door collection covering all households, a 100 per cent source segregation, bio-remediation of legacy waste in its 100-acre Devguradia site, and all fresh wet waste (about 1,150–1,200 $t.d^{-1}$) is channelled to treatment plants rather than landfilled. It converts organic waste into transport-fuel-grade bio-CNG to run buses.

Pune has demonstrated an explicit equitable model that integrates informal workforce with the service delivery. Bhopal is consolidating gains won through rigorous source-segregation bylaws.

The once-notorious Bhanpur dump has been capped and partly landscaped, signalling a decisive break with the past.

Bengaluru has leveraged its tech DNA to tame a daunting 5,500-TPD waste stream.

Surat has achieved 100 per cent segregation that aids in improved material recovery.

The tiny coastal town Vengurla illustrates that scale is no barrier to advancing waste management and has achieved over 95 per cent segregation and 'zero landfill' status.

Ambikapur has adopted a systemic framework to waste management that is built on achieving 100 per cent collection and processing of waste, eliminating the need for landfill disposal. This initiative has involved Self-Help Groups (SHGs) and embeds social equity in waste management.

INTRODUCTION

Open burning of waste and spontaneous fire in landfills are sources of highly toxic emissions and exposures as well as emissions of heat trapping greenhouse gases. A robust waste management system can enable co-control of these emissions to maximise public health and climate benefits.

All city clean air action plans of non-attainment cities under the National Clean Air Programme (NCAP) have included mitigation strategies to eliminate or minimise waste burning.

To define the scope of these interventions, and for the purpose of reporting quarterly progress in implementation and compliance, the Central Pollution Control Board (CPCB) has provided a range of indicators to the cities that the state pollution control boards (SPCBs), and urban local bodies (ULBs) in cities need to include to define the scope of interventions (see *Box: Key indicators provided by the CPCB for waste management and control of waste burning*).

Key indicators provided by the CPCB for waste management and control of waste burning

Enforcement measures

- Regular check and control of burning of municipal solid waste
- Defaulters for open burning to be imposed fines
- Identify garbage burning locations
- Prohibition/complete ban on garbage burning
- Launch extensive drive against open burning of biomass, crop residue, garbage, leaves, etc.

Waste management and infrastructure development

- Regular collection of municipal solid waste
- Ensure segregation of waste at source
- Proper collection of horticulture waste and its disposal
- Infrastructure development for waste processing.
- Promote decentralised processing of waste and dry waste collection centres
- Construction of waste management sites
- Proper management of landfill sites to prevent spontaneous fires
- Adopt roadmap for zero landfill policy to promote decentralised waste segregation, reuse and recycling

Other measures

- Ambient air quality monitoring of municipal dumping sites and parks
- Awareness for controlling of burning of agricultural waste and crop residues

These indicators can be classified as:

a) Enforcement measures that require regular checks and collection, legal ban on open burning and penalty.
b) Infrastructure development and management, including construction of waste management facilities equipped with air quality monitoring.
c) Promoting decentralised collection and processing waste centres.
d) Mitigation strategies for landfill fire that require proper management of landfill sites.
e) Roadmap for zero landfill policy to promote decentralised waste segregation, reuse and recycling.

It is notable that, even though these indicators have been provided under the NCAP, the actual share of spending of the 15th Finance Commission funds on waste management is not substantial. Out of the total performance-linked funds released under the 15th Finance Commission for 49 cities and urban agglomerations, only about 11 per cent has been spent on waste management. Thus, out of the total allocation of Rs 11,211.13 crore for the period 2019–20 and 2023–24, only a little over Rs 1,200 crore has been spent for waste management.

Yet, the information available on the PRANA portal on NCAP-related sectoral action (which is not an exhaustive list and is limited) showed that most cities have reported comparatively more action on municipal solid waste (MSW) management than most other sectors, and is second after the reporting on the action on road dust. This, therefore, brings out the significance of the convergence with other sectoral funding and programmes in the sector.

The convergence framework and the national-level drivers: Notably, parallelly, the NCAP period (2019–2026), also coincides with yet another major Central government programme in waste management—the Swachh Bharat Mission Urban 2.0 (2021–2026)—and linked it with the Swachh Survekshan ranking of cities, based on their waste management performance. This mandates garbage-free cities with aims for 100 per cent source segregation, door-to-door collection of segregated waste and scientific processing and management of all fractions of waste, including its safe disposal in scientific landfills and remediation of legacy waste to convert dumpsites to green zones.

This, therefore, requires infrastructure for scientific treatment and management of MSW including material recovery facilities, waste-to-compost (WtC) plants, construction and demolition (C&D) waste processing plants, bio-mechanisation, waste-to-electricity (WtE) plants, etc. This has enormous potential to reclaim large parcels of lands.

The Ministry of Housing and Urban Affairs (MoHUA) provides financial assistance to States/UTs, offers technical protocols and standards, enhances capacity building of ULBs, and conducts information, education and communication (IEC) campaigns. To support this process, several initiatives have been implemented such as the annual sanitation survey of cities (Swachh Survekshan), the launch of Swachhatam portal and the Swachhata app, protocols like Star Rating of Garbage Free Cities (GFC), and protocols for Open Defecation Free Plus (ODF+) and ODF++ and Water+ protocol, etc.

The total budget allocation for Swachh Bharat Mission Urban 2.0 is Rs 1,41,600 crore (about USD 19 billion) for the period 2021–2026. This includes the Central government's share of Rs 36,465 crore, the State government's share of Rs 22,186 crore and private sector/funding agencies share of Rs 83,000 crore (this includes waste processing, wastewater treatment, etc.). Urban local bodies (ULBs) are funded to implement these measures. For cities on the plains, a total of 70 per cent central share comes from the Centre and 30 per cent from the State. For cities in the hills and Union Territories, 90 per cent is Central share, and 30 per cent is State share. However, city-wise data on disbursement of funds under SBM 2.0 (Urban) is not readily available.

The Swachh Survekshan is also carrying out an annual sanitation performance assessment survey that helps to generate key performance data that makes it an effective propeller of change in the waste sector.

The lesson here is that the performance-linked funding becomes a strong propeller if it is connected with binding targets for tangible on-ground action. The SBM 2.0 performance-linked funding is explicitly connected with well-defined targets and mandates for waste management.

Therefore, it will be an opportunity for the NCAP programme if its monitoring system builds effective synergy with other sectoral targets and performance indicators, to promote stronger convergence to deliver on clean air objectives. The dedicated umbrella grant like the 15th Finance Commission for multi-sector action under the NCAP remains critical to ensure reform-based action in which the NCAP fund works as a catalyst to mainstream clean air indicators, higher level of targets in the sectoral programmes and fund strategically to enable upscaling with speed.

State-level drivers: While national-level programmes such as the NCAP and SBM 2.0 (Urban) 2.0, have created conditions and opportunities for accelerated improvement in waste management to deliver on clean air objectives in states and cities, there are state-level regulatory drivers as well to catalyse local action to beyond the common minimum.

The state governments have created their respective SBM 2.0 mission directorates to propel local action. This has also created opportunities for additional measures to strengthen the state interventions. Additionally, the amendment of municipal bye-law in light of National Solid Waste Management Rules, 2016—have created more effective mandates at the city level, although with varying scope of action.

There are several instances where state-level policies have gone beyond the common minimum requirements.

The Maharashtra Swachh Bharat Mission Directorate focused on 100 per cent collection of waste to prevent any possible leakage into the environment. The state policy also prioritised zero landfill through maximum processing and treatment of collected waste to reduce pollution footprints. The state also focused heavily on banning single-use plastics following the national ban which was being littered, leaked into waterbodies and stormwater drainage systems, burnt and created garbage hotspots. The state also initiated the idea of pink toilets to provide safe and hygienic facilities for women. Cities like Pune, Nagpur, Nashik, Chhatrapati Sambhaji Nagar, Ahilyanagar, Vengurla etc. have emerged as models as a result of the push from the state policies.

Similarly, the Swachh Chhattisgarh Mission was created in 2014 with the objective of achieving 100 per cent source segregation and using segregated waste streams to create sustainable value chain through green jobs and provide safe sanitation to people. The state had particular focus on developing zero landfill cities through processing of biodegradable waste prioritising decentralised systems through its policy. Chhattisgarh prioritised bioremediation of legacy waste following the SBM 2.0 mandate to reclaim lands and reusing the same to gain economic purpose. The state encourages developing material recovery facilities to fuel recycling and reuse.

The *Mukhyamantri Swachhata Doot Yojana* was launched to strengthen waste management at the community level through *Swachhata doots* (Cleanliness Ambassadors) to promote and build capacities around waste segregation at source, home composting etc. The state also emphasised faecal sludge and septage management (FSSM) through decentralised plants leveraging support from the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) scheme. Cities like Ambikapur, Raipur etc. are among the top ranked cities in the country, as per the SS assessment. which has taken initiatives like reusing plastic waste, *swachhata* green leaf rating certificate for hotels, *swachh* school and college campaigns etc to promote sustainable waste management.

The Swachh Karnataka Mission prioritised bioremediation of dumpsites, leveraging the financial aid from the Swachh Bharat Mission co-financing mechanism, and it is among the first few states to initiate the process to reclaim the lost lands. In addition, the state focused heavily on segregation at source through inclusive behaviour change communication (BCC) campaign. The policy to ban mixed waste collection has been a leap forward to promote a circular economy value chain around processed and treated waste products with a provision to impose heavy penalties in the event of non-compliance. The state also promoted zero waste wards through encouraging dry waste collection centres in cities. Cities like Mysuru and Bengaluru are known for instituting robust waste management ecosystem.

Madhya Pradesh has been one of flag bearers of the sanitation movement through a set of robust policies. The Swachh Madhya Pradesh Mission introduced zero waste cities with a focus on 100 per cent waste collection and processing. Technologies like waste-to-compost and bio-CNG were promoted to deal with nearly half of the municipal solid waste that are biodegradable in nature. The state-wide campaign called "*my city my pride*" was instrumental to create public awareness which also included punitive measures for littering and burning. Urban local bodies were directed to get all the state priorities reflected through its byelaws for ease of enforcement. Biomining of existing legacy dumpsites was undertaken as soon as SBM 2.0 was launched. The reclaimed land has been used for greening or setting up waste processing facilities. Plastic collection centres were created in ULBs to recycle low value plastics into fuel or paving roads. The state also launched its own app to make the entire initiative more inclusive for real-time monitoring, institutional support for home composting and grievance management.

Gujarat's public-private-partnership driven approach to MSW management, plastic recycling innovations, and citizen engagement has made it a leader in implementation of the Swachh Bharat Mission. The Swachh Gujarat Mission focused heavily on 100 per cent segregation, segregated collection through a three-bin system. The strong mandate for setting up material recovery facilities was critical for secondary processing of collected dry waste streams. The state's emphasis on legacy waste remediation resulted in the removal of 1.2 million tonnes of garbage.

The state mission also paved the way to promotion of waste-to-energy, compressed biogas, construction and demolition (C&D) waste plants to particularly reduce emissions leading to air pollution. The state's policy to decentralise systems resulted in good models in many of its ULBs. Gujarat's inclusive policy prioritised citizens' engagement through *Swachhata raths* (mobile awareness vans), *Swachhata pakhwada*, etc. The state *swachhata* mission also introduced its own *Swachh Survekshan Excellence* ranking system to encourage innovation among its ULBs. Cities like Surat, Ahmedabad, Vadodara are some of the models which can be replicated in other States as well.

UNDERSTANDING EMERGING GOOD PRACTICES

Even though nearly all targeted cities under the SBM 2.0 and the NCAP have initiated action plans to accelerate waste management practices, some cities have emerged as the front runners, demonstrating a range of good practices in their respective implementation strategies.

It is necessary to capture the elements and design of these practices and interventions for cross-learning among cities and to inform the roadmap to maximise benefits from the current investments in the sector.

The case studies for review have been selected from two perspectives:

a) Cities that have taken a more cohesive and system-based approach in addressing diverse aspects of waste management, including collection, segregation, processing and material recovery, remediation of legacy waste, and building economic enterprises for circular economy.
b) Cities that have demonstrated progressive action in developing specific strategies including integration of information technology system (ITS) with waste management systems; management innovations in terms of segregation and collection; integration of informal and formal sectors; targeted reclamation of legacy waste to reclaim land for other productive uses; significant community outreach and engagement to change behaviour, among others.

All these progressive experiences reflect locally-appropriate solutions but that are also scalable across cities. These cases provide the understanding of the scope and nature of system design, infrastructure development for segregation, collection, transport, and processing, management and planning strategies, fiscal approach and community outreach. They need to add up for a comprehensive portfolio of solutions at the city level.

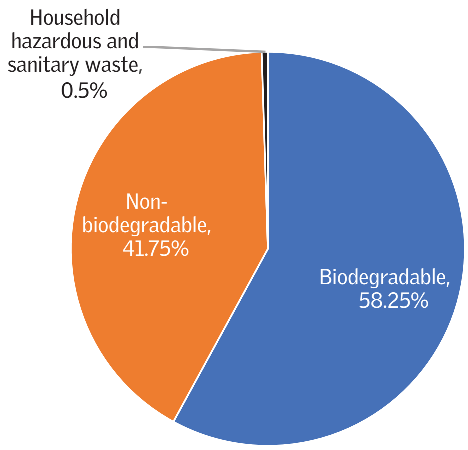
INDORE

Taking a cohesive approach

Indore, the commercial and educational hub of Madhya Pradesh, has an estimated population of 2.9 million and a floating population of 0.3 million daily. The city generates about 988 metric tonnes of waste each day. Once plagued by poor sanitation, littered streets, and over a thousand garbage vulnerable points, Indore has undergone a complete transformation. Since 2017, it has consistently ranked as the cleanest city in India, according to Swachh Survekshan surveys, achieving a seven-star garbage-free city status and becoming the first city to earn the Water Plus certification.

Before the reform, Indore faced numerous challenges typical of rapidly urbanising cities—open dumping, burning of waste, inadequate segregation, and unscientific landfilling. Nearly 1,000 garbage vulnerable points (GVPs) were scattered across the city, while collection and disposal remained erratic and largely unmonitored. Recognising the growing threat to public health and environmental quality, the Indore Municipal Corporation (IMC) launched a city-wide overhaul in collaboration with technical experts, civil society, and private partners.

Graph 1: Waste characterisation



Source: Smart City Indore

PROGRESSIVE INITIATIVES

Improvement in collection efficiency: A pivotal step in Indore's transformation was the pilot program for waste collection to cover 100 per cent door-to-door segregated waste collection across all 85 wards, covering nearly 600,000 establishments. Waste from the primary source is collected daily using over 850 GPS-fitted vehicles, including battery-operated e-rickshaws and compactors.

Table 1: The city—at a glance

Population (2011 Census)	1.9 million
Estimated current population (2025)	2.9 million
Estimated floating population	0.3 million
Area	276 Sq km
Number of Households	0.6 million
Number of wards	85
Number of zones	19
Municipal solid waste generation	988
Number of sanitation workers	8,000[1]
Number of community bins	0
Number of garbage vulnerable points	0
Sources covered under door-to-door collection	100%
Current rate of segregation of waste at source	100%

Source : Compiled from various sources

Improving transportation of waste: For secondary transportation, IMC has dedicated eight Garbage Transfer Stations (GTS) to handle logistics. Each vehicle is colour-coded and compartmentalised to keep wet and dry waste separated. Residents are trained and encouraged to segregate at the source into six streams—wet, dry, plastic, sanitary, hazardous, and domestic biomedical waste. This source-level segregation has achieved more than 100 per cent compliance, reinforced by community awareness programs and a digital citizen grievance redressal system.

Segregated collection of household waste

Compartmentalised waste collection vehicles

Innovative waste processing model: To reduce the centralised burden and logistics-related emissions, Indore adopted a combination of centralised and decentralised waste processing models. The city operates seven composting facilities, three bio-methanation facilities, and six material recovery facilities (MRFs), each handling dry and organic waste at zonal levels. Wet waste, comprising around 58.25 per cent of the city's total waste (about 575.50 TPD), is managed through composting and bio-methanation processes. Dry recyclables are sorted into over 14 categories and sold through registered vendors, while non-recyclables are converted into Refuse-Derived Fuel (RDF) to be incinerated.

The city's commitment to circular economy principles is visible in initiatives like the Green Ganesha campaign for eco-friendly immersions, using eco-friendly materials instead of single-use plastics for Ganesh idols and decorations, segregating dry and wet waste in all puja pandals and temples, plastic buyback schemes, garbage cafés for the homeless, and the remediation of legacy waste at the Devguradia dumpsite, converting it into green areas. About 15 lakh metric tonnes of legacy waste were bio-mined and reclaimed, freeing over 100 acres of land.

Adopting a financial model: From an economic perspective, the IMC has created a financially self-sustaining model. In the bylaws, they have provisions for user charges in the range of Rs 60–150, depending on the property type. Revenue from CNG, recyclables, compost, and carbon credits offset a large portion of the operational costs. To further encourage compliance, fines of Rs 1,000 for households and Rs 5,000 for commercial units are imposed for non-segregation, along with higher penalties of Rs 2,000 for large-scale violations such as dumping waste in water bodies and up to Rs 1 lakh for bulk dumping on public and private land. The IMC used a variety of financing mechanisms to fund the capital and operational costs of its new solid waste management system. Large infrastructure projects—such as transfer stations (Rs 60 crore), the bio-CNG plant (Rs 150 crore), and MRFs—were financed through Central, state, and local government funds, as well as corporate social responsibility contributions.

Monitoring, digitisation and public involvement: Indore's waste management approaches have been institutionalised through robust monitoring, digitalisation, and accountability frameworks. A centralised command control centre tracks vehicle movement, waste volumes, staff attendance, and citizen feedback in real-time. Ward-level audits, third-party verifications, and performance-linked incentives ensure continuous improvement.

IMC also launched multiple information, education, and communication campaigns to educate the public on waste segregation and household composting. They engaged over 800 self-help groups, made up of more than 8,000 women, to spread awareness about the importance of source segregation and cleanliness. To amplify the message, the IMC involved local celebrities and religious institutions through talk shows, radio, street plays, and other media outlets. Across the city, IMC displayed advertisements, flags, murals, and distributed pamphlets and infographics raising awareness about individual-level actions to manage waste. They held regular public meetings to share information regarding policy changes and solicit feedback from citizens.

Addressing open burning of waste to control air pollution: Prior to 2016, the city witnessed frequent incidents of open dumping and burning of municipal solid waste—including plastics, mixed garbage, and organic matter—at over 1,000 garbage vulnerable sites and an overburdened dumpsite in Devguradia. These practices were a major source of harmful pollutants such as PM2.5, PM10, volatile organic compounds (VOCs), as well as heat trapping greenhouse gas emissions including methane, carbon monoxide, and dioxins.

The city's comprehensive reform efforts have reduced emissions at source. Indore implemented 100 per cent door-to-door segregated collection, reaching every part of the city, which significantly curtailed waste accumulation in public spaces and discouraged informal burning. With the adoption of Garbage Transfer Stations GTS at various locations in the city, vehicle movement has been reduced. Previously, each vehicle had to travel 20–23 km which further increased emissions. All of the city's 988 TPD of waste is now either composted, recycled, or processed into alternative fuels, with zero open dumping. The legacy dumpsite at Devguradia—once a major emitter of leachate and GHG emissions—has been completely bio-mined and reclaimed, freeing over 100 acres of land and removing a chronic source of air and soil pollution.

The bio-CNG powered buses have replaced the previously-used diesel fleet. This transition has contributed to a substantial reduction in fuel-related air pollutants. Additionally, the implementation of GPS-based route optimisation has minimised unnecessary vehicle movement, further lowering emissions. Complementary measures such as the use of dust suppression systems, routine street washing, and the deployment of mechanical sweepers have also played a crucial role in reducing particulate matter and improving overall air quality.

The public health benefits indicate an improvement in air quality as well as reduction in vector-borne diseases that have dropped by 60 per cent since the implementation of the waste management system. This has also led to co-control of greenhouse emissions.

Waste processing in site

Bio-CNG Plant at Devguradia, Indore

Economic opportunity in circularity—bio-CNG generation: A cornerstone of Indore's air pollution mitigation is the city's large-scale adoption of aerobic composting and Bio-CNG generation. Wet organic waste—comprising 58.25 per cent of total municipal waste—is processed through home composting by bulk waste generator. This is done in Asia's largest 550 TPD bio-CNG plant at Devguradia or in composting facilities. The bio-CNG plant alone processes the majority of organic waste, particularly from bulk waste generators (BWGs), hotels, and vegetable markets, converting food and market waste into 17,000 kg of compressed gas daily. This gas is used to power over 150 city buses and municipal vehicles, replacing diesel and reducing tailpipe emissions of PM, NOx, and SOx. It is estimated that the bio-CNG plant runs in its full capacity and has potential to mitigate 130,000 tonnes of carbon dioxide equivalent per year, which is equivalent to taking 30,000 gasoline-powered passenger vehicles off the road for one year.

PHOTO: SMART CITY INDORE

Integrated command and control centre

Developing value chain around waste stream—Refuse- Derived Fuel from waste for industry: To manage non-recyclable dry waste and multilayer plastics, Indore produces Refuse-Derived Fuel (RDF), which is co-processed in cement kilns as a substitute for coal. This strategy not only diverts low-value plastics from incineration or landfilling but also contributes to reducing industrial emissions. High-value dry recyclables are sorted at material recovery facilities (MRFs) and sold to registered vendors, promoting circularity and minimising the need for virgin material extraction.

Public engagement and awareness building: Sanitation workers and SHG members continuously interact with residents, discouraging open burning and encouraging segregation at the source. This has led to a significant behavioural shift, where improper waste disposal practices are now socially stigmatised. Real-time monitoring via the city's Integrated Command Control Centre (ICCC) allows for swift intervention at any signs of non-compliance or pollution hotspots.

Indore's approach demonstrates integrated, inclusive, and intelligent urban waste management that has enabled transition towards zero-landfill approach.

EMISSION BENEFITS FROM WASTE MANAGEMENT

The city-wide comprehensive waste management system has led to substantial emissions benefits—both toxic particulate pollution and heat trapping warming gas methane. While open burning of waste in the absence of a good waste management system causes toxic particulate emissions, the rotting or decomposition of accumulated organic matter in landfills causes enormous methane emissions that are several times more warming than the carbon dioxide (CO_2). The warming potential of methane over the period of 20 years can be 84–87 times more potent than CO_2.

The comprehensive management of waste has enabled co-control of both toxic and warming pollutants and have contributed substantially towards reducing public health risk and warming risk.

Reducing particulate pollution: Indore now collects, segregates and processes virtually every kilogram of roadside piles that residents were previously torching on street corners. This has provided a substantial reduction in particulate pollution load.
Open burning studies in Indian and other Asian cities suggest that around 50 per cent of MSW in small towns were unaccounted for and of that, 10–20 per cent was typically burned in the open when collection is very inadequate.[2,3,4,5] This implies 5–10 per cent of total waste generated was burned in the open.

With open burning now reduced to near zero, those tonnes of particles are the annual benefit attributable solely to the 100 per cent segregation and the citywide ban on waste burning (see *Graph 1: PM emissions avoided due to banning open waste burning in Indore*). Thus, Indore's elimination of open waste burning reforms avoids about 240–260 tonnes of coarse particles (PM_{10}) and 180–200 tonnes of fine particles ($PM_{2.5}$) every year.

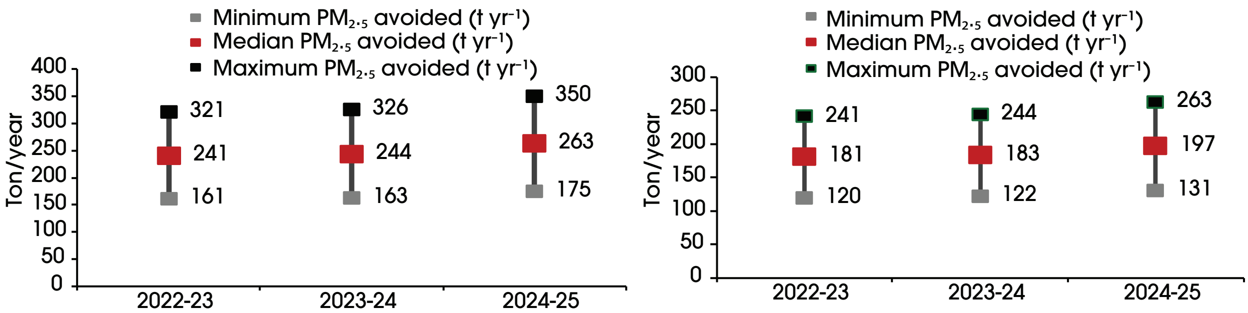
Methane emissions' reduction benefits: The emissions benefits emerge from the fact that Indore has succeeded in diverting a substantial part of daily fresh waste from landfills towards the 550 tonnes per day bio-CNG plant and another 300 tonnes per day towards composting. This indicates that the city has virtually eliminated almost all methane that the same tonnage would have released if it were still dumped at Devguradia.

Moreover, aggressive remediation of the legacy dump—1.5 million tonnes excavated, bioremediated and capped between 2018 and 2022—has cut the residual emissions from historic waste to a small fraction of what they would otherwise have been.

Graph 2: PM emissions avoided due to banning open waste burning in Indore

PM10 avoided from barring open waste burning in Indore

PM2.5 avoided from barring open waste burning in Indore



Note: ICLEI-South Asia's HEAT+ inventory tool adopts AP–42 factors of 8 kg PM10 t^{-1} and 6 kg PM2.5 t^{-1} for mixed-waste fires; those values are therefore used here.

Source: CSE analysis

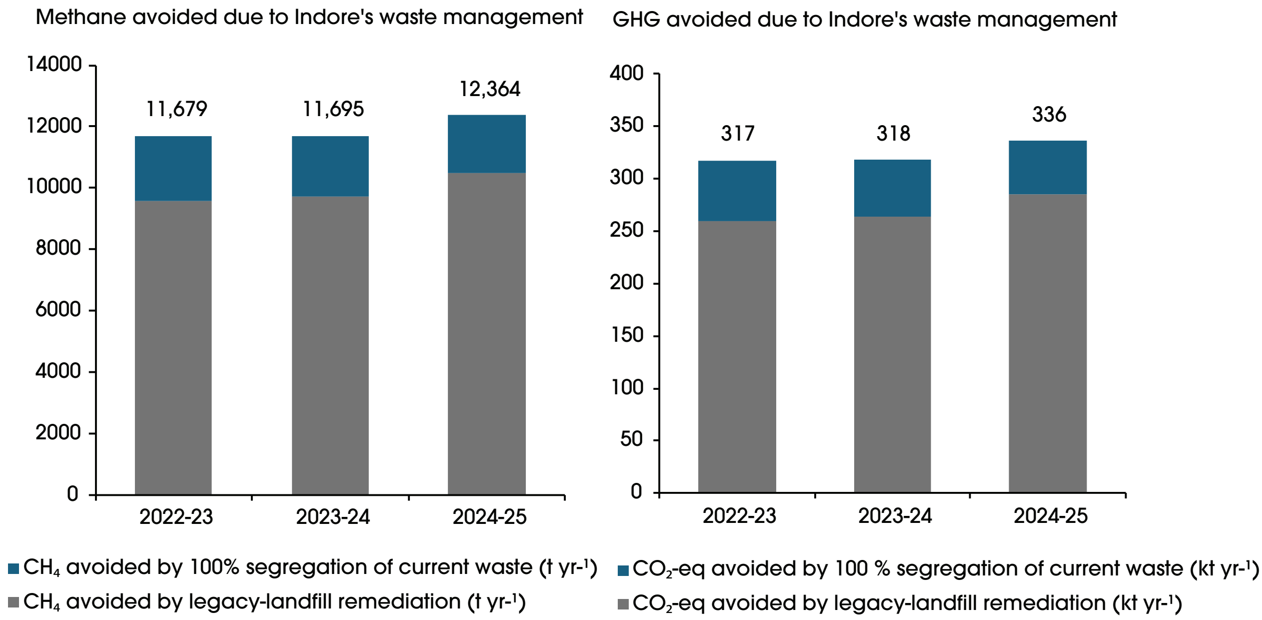
The segregation-and-diversion stream alone is responsible for roughly 80–85 per cent of annual methane savings, but landfill remediation still removes a solid 2 kilo tonnes of CH_4 each year—benefits that would otherwise persist for another decade. The combined programme now prevents around 0.32 million tonnes CO_4 -eq per year, of which one quarter comes from the reclaimed dump and three-quarters from keeping new waste out of it in the first place (see *Graph 2: Methane and GHG avoided due to Indore's MSW management*).

Energy benefits from the bio-CNG initiative: The 550-tonne per day anaerobic-digestion complex at Devguradia has become a second climate asset by converting segregated wet waste into transport-grade bio-CNG. Production averaged 15 tonnes per day in 2022–23 and 2023–24 and is now stabilising close to its design level of 17 tonnes per day in 2024–25.

At a lower-heating value of 53.6 MJ kg-*, that output delivers about 7,000 tonnes-of-oil-equivalent (TOE) of renewable energy each year, rising to almost 8,000 TOE in 2024–25. The fuel substitutes directly for fossil CNG or diesel; in energy terms, the 2024–25 yield is enough to replace roughly eight million litres of diesel to operate over 270 CNG city buses for an entire year, while also creating a revenue stream that helps fund solid waste operations (see *Graph 3: Energy benefits of Indore's bio-CNG plant*).

The methane-avoidance and the bio-CNG energy dividend underscores how Indore's integrated solid-waste strategy simultaneously cuts emissions at source and supplies a clean, locally-produced transport fuel.

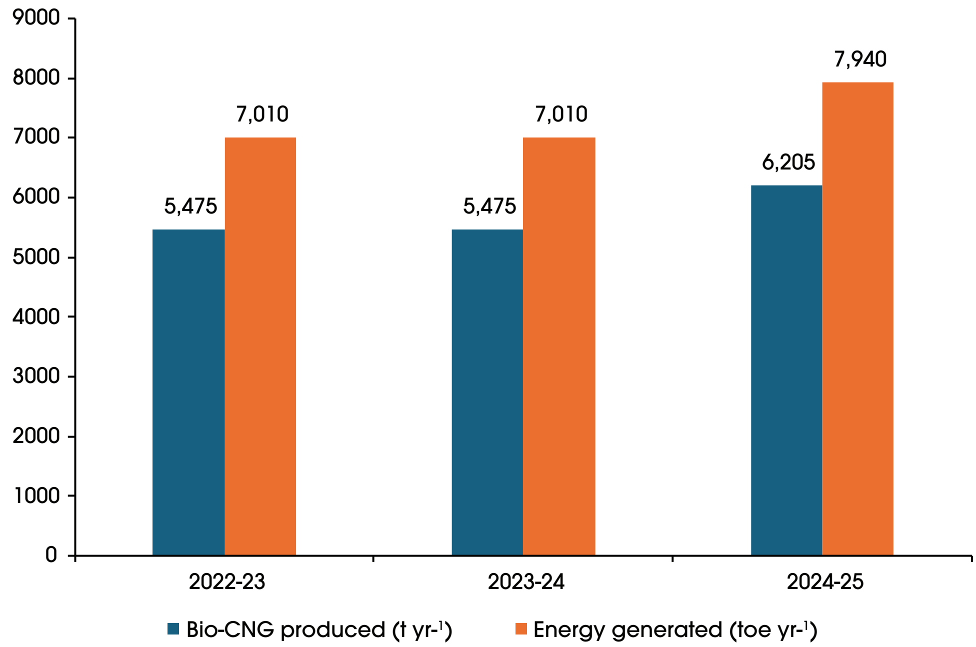
Graph 3: Methane and GHG avoided due to Indore’s MSW management



Note: (a) For the segregation measure the baseline is “all current-year waste land-dumped, unmanaged”; the project is “digestor-plus-compost leaks only”. (b) For landfill-remediation the baseline is a first-order-decay ($k \approx 0.06$ yr^{-1}) open-dump profile for the 2000-2016 deposits; the project assumes capping and aeration lower methane release by about 90 percent, an efficiency consistent with case studies of Indian biomining projects.

Source: CSE analysis

Graph 4: Energy benefits of Indore’s bio-CNG plant



Source: CSE analysis

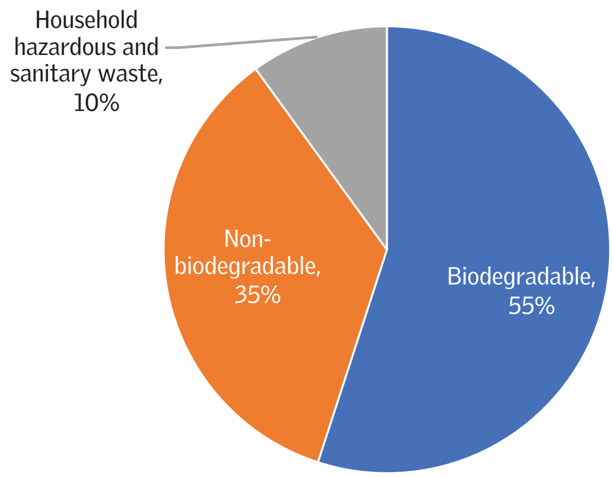
BENGALURU

Technological integration across the entire waste management chain

Bengaluru, widely recognised as India's primary IT hub, stands as the nation's third most populous city and fifth largest urban agglomeration. This dynamic metropolis generates a substantial amount of municipal solid waste daily, reflecting its large and growing population. In tackling this challenge, Bengaluru has characteristically leveraged its technological prowess, implementing innovative solutions to manage waste effectively.

Integration of ITS with waste management for comprehensive solutions: Bengaluru's approach to tackling its significant waste management challenges stands out due to its comprehensive and integrated use of Information, Communication, and Technology (ICT) solutions across the entire waste management chain.

Graph 5: Waste characterization



Source: Bruhat Bengaluru Mahanagara Palike (BBMP), Swachh Survekshan, 2023

Faced with typical urban issues like informal dumping, creating garbage vulnerable points (GVPs or 'black spots'), overburdened landfills—including the one at Mitganahalli which receives 2,750 TPD in addition to the seven million tonne of legacy waste—and operational difficulties in managing outsourced services (including coordination gaps, accountability issues, and payment disputes with concessionaires), the Bruhat Bengaluru Mahanagara Palike (BBMP) initiated a major technological transformation in 2020, shifting from manual oversight towards a data-driven, digitally monitored system,

Table 2: The city—at a glance

Population (2011 Census):	**8.4 million**
Estimated current population	**13 million**
Estimated floating population (daily)	**2 million**
Area	**713 sq. km**
Households	**3 million**
Administrative structure	**198 wards, 27 divisions, 8 zones**
Municipal solid waste generation	**Approx. 5,500 TPD (excluding C&D waste)**
Waste management fleet	**18,500 workers**
Door-to-door collection coverage	**97%**
Household waste segregation rate	**99%**
Waste processing rate	**81%**

Source: Bruhat Bengaluru Mahanagara Palike (BBMP), Swachh Survekshan, 2023

establishing transparency, accountability, and efficiency. The BBMP adopted a strategy of decentralised digitisation, implementing and refining the technology ward-wise rather than attempting a city-wide rollout of one component at a time, allowing for better monitoring of loopholes and iterative improvements within the management chain.

Implementation of a suite of inter-connected digital tools targeting specific operational bottlenecks: A primary focus was enhancing the efficiency and reliability of door-to-door waste collection. Manual attendance systems for the large workforce of *safai mitras* (sanitation workers) and collection vehicles were prone to discrepancies. The BBMP addressed this by introducing a Radio-Frequency Identification (RFID) based attendance


Segregated waste collection from the city


Waste sorting at a DWCC

PHOTOS: HASIRU DALA

system. Every door-to-door collection vehicle (auto-tipper) is equipped with an RFID tag. These vehicles are required to report to designated mustering points (587 points across the city) between 5:30 a.m. and 7:00 a.m. daily. The BBMP officials use scanners to record attendance by reading the RFID tags, ensuring punctuality and creating an accurate, tamper-proof record for payroll and performance monitoring. Vehicles arriving after 7:00 a.m. are marked absent for the day, enforcing discipline.

GPS-based fleet management system: Each of the nearly 5,000 auto-tippers involved in daily collection are equipped with GPS tracking devices. Junior Health Inspectors (JHIs) assign fixed routes and designate households to each vehicle. Post attendance, the movement of these vehicles is monitored in real-time throughout their collection shifts via a central dashboard. This allows BBMP supervisors to ensure that assigned routes are fully covered, guaranteeing service delivery to all designated areas and minimising missed collections. The system is designed to automatically generate detailed reports and alerts for various deviations, including driver over speeding, prolonged stoppages (over five minutes), missed houses or lanes, unusual delays, or reported mechanical issues. Payments are directly linked not only to the verified RFID attendance but also to the successful completion of the assigned routes as tracked by GPS, creating a strong financial incentive for service quality and adherence. This integrated system is instrumental for BBMP in achieving and maintaining high door-to-door collection coverage.

Back-end infrastructure of web and mobile applications ('ATR Apk' software) to support field technology: This software authenticates auto-tippers and assigns them to specific zones, divisions, and wards. Health Inspectors (HIs), Senior Health Inspectors (SHIs), and Executive Engineers (EEs) are required to use the app on their devices for monitoring and verification purposes, ensuring hierarchical oversight within the digital framework. Citizens are also provided with an app feature allowing them to check the real-time location of their area's collection vehicle.

When auto-tippers arrive at designated secondary transfer stations (locations defined and geo-fenced within the system) to unload their collected waste into larger compactors, their RFID cards are scanned again capturing the vehicle's identity, precise timestamp of arrival, its geo-location, and photographic evidence of the transfer, all of which are stored on a central server. The system tracks the number of trips made by each auto-tipper and automatically flags discrepancies if a vehicle recorded attendance at a mustering point but failed to register at the transfer station.

At the landfill, the compactor's RFID tag is scanned and data is recorded on the quantity of waste reaching the designated endpoint from each zone or transfer station, preventing unauthorised diversion and ensuring full accountability for final disposal or processing. Monthly performance analysis using Python-based algorithms evaluate the efficiency of individual vehicles and the overall collection and disposal process.

Controlling open burning of waste: Recognising the link between mismanaged waste and air pollution, the BBMP has implemented several measures, integrating them with its technology-driven Solid Waste Management System (SWM) system.

A significant challenge tackled through technology has been the persistent issue of garbage vulnerable points (GVPs) or 'black spots' resulting from informal dumping. The BBMP introduced the 'Ezetap' mobile application specifically for this purpose and for enforcing penalties. Field marshals use the Ezetap app to identify and geo-tag black spots, and upload images with precise location data. Alerts are sent to the responsible Junior Health Inspector (JHI) who is then required to ensure the spot is cleared and upload geo-tagged photographic evidence of the cleaned location as proof of action. To prevent the spot from reforming, a follow-up protocol is implemented—monitoring the spot for 21 days before the complaint is formally closed in the system. This systematic, app-based monitoring and follow-up process has proved highly effective, leading to the elimination of over 1,100 black spots across the city.

Burning garbage is prohibited under the BBMP's Solid Waste Management (SWM) Bye-laws, 2020 and Section 19(5) of the Air (Prevention and Control of Pollution) Act, 1981. The city's clean air action plan includes deploying BBMP marshals specifically to monitor and eradicate open burning of waste and implement punitive measures. However, reports suggest that challenges persist with enforcement and the effectiveness of marshals in penalising offenders for burning.

Penal action on waste burning: To discourage illegal dumping and burning, the BBMP has established and enforced a system of penalties, facilitated by digital tools. The Ezetap app, used in conjunction with Point of Sale (PoS) machines, allows JHIs and field marshals to levy fines digitally for littering, open dumping, and plastic ban violations. Over 6,300 penalties for littering/dumping and 1,400 for plastic ban violations were recorded through this system. The SWM Bye-laws, 2020 also specify penalties for the disposal of solid waste by burning—Rs 5,000 penalty for general waste generators and Rs 25,000 for bulk waste generators for the first offence, doubling for subsequent offences.

Efficient collection of waste: A fundamental aspect of preventing dumping and burning is ensuring that waste is collected efficiently from all sources. The BBMP reports high door-to-door collection coverage with GPS-monitored auto-tippers reaching almost every household. However, some external reports indicate that occasional irregularities or gaps in collection services still contribute to incidents of littering and open burning.

Developing processing capacity and circularity: The BBMP estimates total wet waste generation at 3,025 TPD. The current processing capacity utilization stands at 2,180 TPD. This processing is achieved through a combination of methods—1,350 TPD processed at seven composting plants (combined installed capacity of 1,620 TPD), 500 TPD processed at a private plant, 80 TPD processed in existing bio-methanization plants, and 250 TPD managed through mandated in-situ processing by Bulk Waste Generators (BWGs). However, this leaves a processing gap of 845 TPD.

Bio-methanation: To address this gap, the BBMP has initiated several projects—tenders invited for four large Integrated SWM Facilities with a total capacity of 6,666 TPD, and under this 2,844 TPD of new bio-methanation plants; construction underway for a 50

TPD bio-CNG plant; four small 5 TPD bio-methanization plants; and a large 500 TPD bio-CNG plant with GAIL. The total proposed additional capacity through these projects amounts to 3,414 TPD.

Waste-to-energy: The BBMP reports generating 1,925 TPD of dry waste, with existing infrastructure handling 1,200 TPD (600 TPD as RDF to a waste-to-energy plant at Bidadi and 600 TPD through dry waste collection centres (DWCCs)). To address the 725-TPD processing gap and further improve air quality by minimizing landfill burden, the BBMP has invited tenders for four large Integrated SWM facilities, which propose to include 1,767 TPD of waste-to-energy capacity and 696 TPD of dry waste management capacity. A material recovery facility (MRF) with a capacity of 1,686 TPD is also approved. The overall proposed additional capacity for dry waste management through these initiatives is 4,149 TPD.

Remediation of legacy waste: The BBMP has also prioritized the management of legacy waste for long-term air quality improvement. According to the BBMP, 9.78 MMT of total legacy waste is accumulated in nine dumpsites. The remediation plan was initiated with target completion timelines spanning from 2025 to 2027. Till date, 40 per cent (3.89 MMT) of the total legacy waste had been remediated. The overall system aims for high efficiency with over 80 per cent overall waste processing rate.

Developing waste management infrastructure: The city's waste management infrastructure has expanded considerably to include a fleet of over 4,500 vehicles, designated transfer stations, dry waste collection centres (DWCC) network, and the aforementioned wet and dry waste processing plants. The multi-layered digital monitoring system, including real-time monitoring provided by RFID and GPS systems, has played a vital role in ensuring the integrity of the entire value chain. This comprehensive, technology-driven approach with specific measures targeting GVP removal, open burning, and ensuring efficient collection and processing through digital monitoring, represents Bengaluru's concerted effort to minimize the adverse impact of air pollution, arising from mismanaged municipal solid waste.

Impact of technology integration with waste management: The cumulative impact of this technological integration across the entire waste management chain—from attendance and collection to transfer, transport, processing, and compliance monitoring—has been transformative for Bengaluru.

The system has established unprecedented levels of accountability for every stakeholder, from individual drivers and *safai mitras* to concessionaire and monitoring officials. The constant flow of real-time data enables data-driven management, and allows BBMP officials to analyse performance metrics, identify operational bottlenecks, optimize routes and resource allocation, and strategically plan interventions, including targeted IEC campaigns informed by penalty data patterns. The system has fostered discipline among the workforce, reduced instances of mismanagement and enhanced convenience and transparency to citizens.

PUNE

Source segregation and integration of informal sector

Pune, the largest municipal corporation in Maharashtra following its 2021 expansion, is a major urban centre as well as an IT and educational hub. This dynamic metropolis faces substantial waste management demands, and the Pune Municipal Corporation (PMC) has implemented several innovative strategies, particularly focusing on source segregation and integrating the informal sector.

Graph 6: Waste characterization

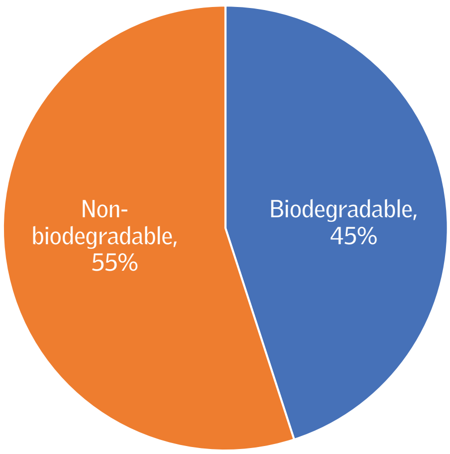


Table 3: The city—at a glance

Population (2011 Census):	3.12 million
Estimated current population	6.5-7.0 million
Estimated floating population (daily)	0.4 million
Area	516 sq. km
Households	1.2 million
Administrative structure	5 zones 42 wards, 23 villages
Municipal solid waste generation	Approx. 2,200 TPD
Waste management vehicle fleet	More than 850 (including compactors, refuse collectors, hook loaders, sweepers)
Door-to-door collection coverage	>95%
Household waste segregation rate	>95%
Waste processing rate	100%

Source: Pune Municipal Corporation (PMC)

Integration of informal sector: Pune pioneered the integration of informal waste pickers into the formal waste management system. This began with the formation of the Kagad Kach Patra Kashtakari Panchayat (KPKPK) trade union in 1993, which empowers waste pickers. Subsequently, SWaCH (Solid Waste Collection and Handling) was established in 2006 under KPKPK's umbrella. SWaCH, a cooperative wholly owned by waste pickers, partners with PMC to provide door-to-door waste collection service. Registered waste pickers receive identity cards from PMC, granting them formal recognition and improving public perception. This model provides dignified livelihoods, better income through access to segregated recyclables, and improved working conditions for the waste pickers, while improving the city's collection efficiency.

A significant element of PMC's approach involved a formal partnership with the waste picker cooperative SWaCH. PMC actively worked to identify and eliminate GVPs. These points were typically chronic dumping spots found in locations such as vacant lots, roadsides, near drainage channels, and other neglected public spaces, which frequently became sites for open waste burning.

Segregation of waste: PMC has promoted waste segregation at the source into four waste streams—biodegradable, non-biodegradable, sanitary and domestic hazard, improving the quality of recyclable materials recovered by waste pickers, and reducing the burden on landfills. The success of segregation (over 95 per cent) is closely linked to the efforts of SWaCH members who also conduct citizen awareness programs.


Door-to-door collection of segregated waste

Addressing occupational hazards: Recognizing the occupational hazards faced by waste pickers handling mixed waste including sanitary items (pads, diapers), the SWaCH leadership (which includes waste picker representatives) advocated for a solution. In response, PMC and SWaCH launched the innovative 'Red Dot Campaign' in 2016. This targeted IEC programme trained waste pickers and educated citizens to wrap sanitary waste separately in paper marked with a red dot before handing it over. This practice aimed to ensure safer handling for workers, maintain the quality of other dry recyclables, and facilitate potentially separate processing streams for sanitary waste, demonstrating a unique, collaborative approach to managing a challenging waste fraction.

Building capacity: Continuous training programmes are conducted for both SWaCH members and PMC field staff, focusing on source segregation principles, safe handling of specific waste types like sanitary waste, and citizen interaction. This collaborative capacity building was essential for the successful implementation of initiatives like the Red Dot Campaign and maintaining high door-to-door collection and segregation efficiency.

Legal action to address open burning of waste and air pollution: The PMC has directly addressed the issue of open waste burning through prevention and enforcement. This practice was explicitly prohibited under existing regulations, including the PMC Solid Waste Management (SWM) Bye-laws, 2020 and the Air (Prevention and Control of Pollution) Act, 1981. The PMC developed and implemented an action plan specifically targeting waste burning.

This strategy encompassed several key operational areas—systematic identification and remediation of GVPs, enforcement of prohibitions against waste burning through preventative actions and penalties, establishment of comprehensive waste collection systems designed to reach all areas, including informal settlements, development of waste processing infrastructure to divert waste, particularly organic fractions from landfills, and the utilization of technology for monitoring and managing the entire system.

Improving waste collection efficiency: A core component of this plan was preventative action focused on enhancing waste collection efficiency to minimize the amount of waste left unattended. The prevention of dumping and burning is fundamentally supported by achieving comprehensive waste collection coverage across the city. The PMC has reported achieving over 95 per cent door-to-door collection coverage. This high rate is largely facilitated through the operational partnership with SWaCH. SWaCH's nearly 3,800 member waste pickers provide regular doorstep collection services to 980,000 properties.

The operational model involves waste pickers collecting user fees directly from households and supplementing their income through the sale of sorted recyclables. The strategic addition of 81 smaller collection vehicles by the PMC is intended to further strengthen this network, particularly aiming to improve service reliability and reach within the 23 villages added to PMC limits in 2021 and other hard-to-reach areas. This ensures equitable service and minimizes uncollected waste. These have the ability to navigate narrow lanes and improve service frequency in densely populated and newly incorporated areas, thus, reducing the accumulation of waste susceptible to burning.

Monitoring and surveillance: According to the PMC, monitoring of these locations involved a combination of regular field surveillance by municipal sanitation staff (such as ward sanitary inspectors) and the use of digital tools. These tools included applications aligned with the national Swachh Bharat Mission's GVP App framework, enabling geotagging, photographic documentation of site conditions, and tracking of cleaning and remediation efforts.

Citizen's involvement: Citizen reporting through the PMC CARE mobile application also served as an important source of information for identifying and addressing these spots. Significant progress was reported in these efforts. For instance, as per the *Action Plan by Pune Municipal Corporation on Open Burning*, data from 15 ward offices indicated a reduction in the number of identified chronic (garbage) spots from 928 to 209 by 6 December, 2024. Remediation actions went beyond simple clearing and included beautification efforts such as planting local flora, cleaning drives involving community participation, painting walls with social messages, and installing physical barriers to prevent future dumping.

Public outreach and awareness: The PMC conducts public awareness campaigns using methods like distributing pamphlets, public announcements and ward meetings to inform citizens about the health hazards and laws associated with waste burning. A system for rapid response to burning incidents was supported by citizen reporting mechanisms, primarily through the PMC CARE app, which allowed users to select specific complaint categories ('Garbage Depot Complaint' 4 'Burning of Garbage') and upload photographic evidence. Official records indicate that 44 complaints regarding open burning were received and formally addressed by PMC officials between June and December 2024.

Penal action: According to the PMC, enforcement of SWM regulations is backed by a system of spot fines, intended as a deterrent against violations. These fines are levied by designated PMC officials (such as Health Inspectors or Assistant Engineers) based on the provisions of the SWM Rules, 2016 and city bylaws. The established penalty structure specified distinct fines for various offences, with amounts typically doubling for subsequent violations.

For instance, Rs 500 for first offence/Rs 1,000 for subsequent littering or dumping waste in public places; a significant Rs 5,000 for first offence/Rs 10,000 for subsequent open burning of waste; Rs 500 for first offence/Rs 1,000 (subsequent) for failure by domestic generators to segregate waste as required (wet, dry, domestic hazardous, sanitary); Rs 300 for first offence/Rs 500 (subsequent) for spitting in public spaces; and fines ranging from Rs 200 to Rs 1,000 for open urination or defecation. This framework provided the legal basis for punitive action against violators, although specific aggregated data on the number of challans issued was not available in the reviewed sources.

Promoting decentralized processing systems: Significant resources are placed on the treatment of segregated wet waste (approximately 1,100 TPD) to divert it from landfills. According to the PMC, Pune processes 100 per cent of its segregated wet waste. Treatment infrastructure for wet waste includes: composting facilities (two plants with a combined capacity of 300 TPD), one bio-CNG plant utilizing anaerobic digestion technology (processing 150 TPD out of a 300 TPD capacity) to generate compressed biogas suitable for use as vehicle fuel, along with nutrient-rich liquid slurry usable as fertilizer, a network of ten smaller community/decentralized biogas plants contributing an additional 50

TPD of processing capacity, mandated and encouraged on-site processing by bulk waste generators, promotion of home composting techniques among residents, and supplying compost to farmers in surrounding areas.

The overall collection and processing system maintained high performance levels, with reported rates exceeding 95 per cent for both door-to-door collection coverage and waste segregation at source. The city aimed for 100 per cent processing of the collected, segregated waste. This is supported by extensive infrastructure, including a large and varied vehicle fleet of over 850 units (comprising primary collection vehicles, compactors, small and big bell trucks, dumper placer, tippers, tractors, and hook loader).

Transfer stations are equipped with technologies like static compaction machines. Seven Material Recovery Facilities (MRFs) with combined capacity of 400 MTPD are part of the infrastructure designed for sorting and pre-processing dry waste for recycling.

SWaCH plays a direct role in dry waste management, handling about 200 TPD through its network, including initiatives for recycling challenging materials like multi-layered plastics (MLP, with 150 MT/month processed via an ITC-supported facility) and Thermocole (polystyrene) through partnerships with 'KK Nag Thermocole Plant'.

Comprehensive monitoring system: According to the PMC, the entire waste management operation is overseen and managed using an Integrated Solid Waste Management (ISWM) system that incorporates various monitoring technologies. GPS devices are installed across the vehicle fleet (over 850 vehicles), enabling real-time tracking of vehicle location, monitoring of route adherence, speed, stoppages, and generation of operational reports for performance analysis and route optimization.

The Radio-Frequency Identification (RFID) readers are utilized for automated vehicle identification, potentially used at entry/exit points of transfer stations or processing facilities to log vehicle movement and link vehicles to specific waste loads. There are also plans for deploying IoT (Internet of Things) sensors in public or community bins (smart bins) to monitor waste fill levels, which would enable more efficient collection scheduling based on actual need rather than fixed routes. Automation at key facilities, such as weighbridges integrated with the monitoring system, is aimed at ensuring accurate recording of waste quantities received and processed. Citizen interaction is facilitated through the PMC CARE app, which serves as a channel for lodging complaints, providing feedback, and tracking the status of submitted grievances.

This comprehensive monitoring system provides data for enhancing operational accountability, optimizing logistics, supporting data-driven decision-making, and improving overall service delivery within the waste management chain. Collectively, these integrated measures represent PMC's strategic efforts during that period to manage the city's solid waste in a more sustainable manner and specifically to minimize the contribution of mismanaged waste to local air pollution.

SURAT

Model of community ownership and innovation

Surat, located in the western state of Gujarat, is one of India's most dynamic and rapidly growing cities, largely driven by migration from different parts of Gujarat and other states. Surat's journey from a plague-stricken city in 1994 to one of India's cleanest and most efficiently managed urban centres is a remarkable example of administrative reform, citizen engagement, and decentralized solid waste management (SWM). The 1994 plague outbreak exposed critical gaps in waste collection, drainage, and sanitation. At the time,

Graph 7: Waste characterization

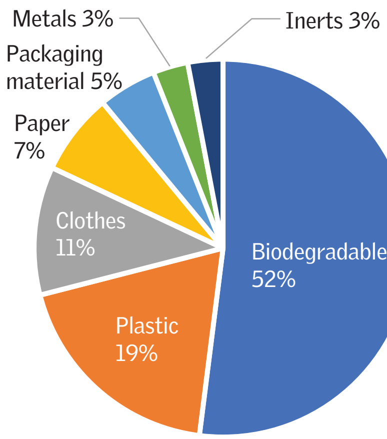


Table 4: The city—at a glance

Population (2011 Census):	4.46 million (as per 2011 census)
Estimated current population	approx. 5.73 million
Estimated floating population	0.15 million
Area	461.60 sq. km
Households	1.43 million
Administrative structure	8 zones 89 wards
Municipal solid waste generation	2,485 TPD
Number of sanitation workers	10,000
Number of community bins	0
Number of garbage vulnerable points	0
Waste management vehicle fleet	684
Percentage of households covered under door-to-door collection	**100**
Percentage of waste processed	100
Waste processing rate	100%

Source: Surat Municipal Corporation

Surat had less than 40 per cent collection efficiency, with garbage openly dumped into drains and water bodies. This not only caused health crises but also led to urban flooding.

In response, the Surat Municipal Corporation (SMC) launched an urgent citywide clean-up campaign. Administrative divisions were realigned, decentralized ward-level monitoring was introduced, and public health was prioritized in urban governance. Within six months, the city had undergone a dramatic transformation, setting the stage for long-term reforms in sanitation and waste management.

This situation has changed substantially today with Surat as one of the front runners. The city has emerged as a national leader in solid waste management and is ranked 1st as the cleanest city in India, along with Indore, as per the Swachh Survekshan 2023 results. It has also received a seven-star rating under the Garbage Free City (GFC) and Water+ city in ODF certification.[6]

Improvement in waste collection efficiency: Surat city is divided into eight zones and 89 sanitary wards. A 100 per cent door-to-door waste is collected using mechanical and electric vehicles with five compartments for dry waste, wet waste, e-waste, sanitary waste, and plastic waste. Daily municipal solid waste generation is 2,485 tonnes per day which is collected through 623 GPS-enabled vehicles, each operated by a driver and two *safai mitras*.

Universal access to collection services: To prevent unmanaged waste from accumulating in under-served areas, Surat ensures universal access to collection services. The system involves 623 GPS-tracked vehicles, each with a trained *safai mitra* team, covering even informal or migrant settlements. This last-mile connectivity prevents waste buildup in low-income neighbourhoods, where open burning could otherwise become common. The inclusion of over 15,000 informal workers, supported by NGOs, ensures that dry waste, especially plastic, is recovered before it can be burned. Households' door-to-door collection starts at 07:30 a.m. to 12:30 p.m. while restaurants and hotels are serviced between 5 p.m. and 11 p.m.

Involving community and informal sector: Out of these, 350 are e-vehicle used for door-to-door waste collection supported by NGOs and informal sector workers. The waste management system also empowers the informal sector. Nearly 15,000 individuals, including ragpickers, sorters, and recyclers, are indirectly employed through various stages of waste value chain and recycling. These livelihoods are supported through NGO partnerships and city-led integration programs, ensuring income stability and social inclusion.

Along with municipal services, the SMC has joined hands with NGOs to collect flower waste from temples, carefully segregated and handpicked. The flower waste is then dried and converted into powdered form. This powder is then handcrafted into incense sticks (dhoop). The sticks are infused with organic essential oils, resulting in long-lasting fragrances.

PHOTO: SURAT MUNICIPAL CORPORATION

Briquettes from waste recovered from the dumpsite

Systems and infrastructure for processing: Collected waste is sent to eight semi-mechanized Material Recovery Facility (MRF) within the premises of transfer stations with a total processing capacity of 200 TPD. These stations are designed with closed containers, leachate systems, and no animal access, ensuring hygiene and environmental safety. Surat operates 80 decentralized organic waste composting centres and a central composting plant with a cumulative capacity of 2,500 TPD (1,500 TPD for centralized windrow composting and 1,000 MT for dry waste management).

In May 2023, the MoHUA established RRR centres under the “Meri LiFE, Mera Swachh Shehar” initiative. The SMC went a step further and opened 5R (Refuse, Reduce, Reuse, Recycle and Repair) centres. Currently, there are 31 5R centres with more than 100 collection points where people can give their excess resources which are repaired, or distributed to the ones in need or recycled.

PHOTO: SURAT MUNICIPAL CORPORATION

GVP was transformed into selfie points because people are less likely to litter in areas that are already clean

PHOTO: SURAT MUNICIPAL CORPORATION

Plastic Waste processing facility at Bhatar

There are 80 decentralized organic waste composting centres. Surat operates a central composting plant with a cumulative capacity of 2,500 TPD of which 1,500 TPD is centralized windrow composting facility and 1,000 MT is for dry waste management. Produced compost is being sold to Krishak Bharati Cooperative Limited (KRIBHCO) and dry waste is being converted to refuse-derived fuel (RDF). The SMC has an MoU signed with cement industries for the complete utilization of RDF as raw material in their plant. Last year, in 2024, revenue generated from the sale of compost and RDF was Rs 8 crore and Rs 1 crore, respectively, with the sale of 25,000 MT of compost and 300,000 MT of RDF.

Remediation of legacy waste and reclamation of land: The SMC has successfully remediated over 25 lakh tonnes of legacy waste at the Khajod dumpsite using bio-mining. The SMC is planning to convert this reclaimed land into a biodiversity or ecological park which will be open for public for walking and cycling. In absence of potential for biomining and bioremediation of the old dumpsite, as mentioned in clause (zk) of SWM Rules 2016, capping of the open dumpsite at Khajod was adopted. Biocapping work has been completed in Jan 2020, and now the SMC is planning to convert this recovered land into an ecological park.

Ward-wise decentralized waste management: Surat has declared Ward no. 22 as an Atmanirbhar Ward. In this self-reliant ward, 100 per cent of the wet waste is managed through home or community composting within the ward or its Resident Welfare Associations (RWAs), ensuring efficient and localized waste processing. Additionally, all dry waste is sent to nearby MRFs or other processing centres for further treatment. This comprehensive waste management system not only promotes environmental sustainability but also fosters community responsibility and participation in maintaining cleanliness and reducing waste.

Plastic waste processing: One of Surat's flagship initiatives is its plastic waste processing facility in Bhatar. With a capacity of 200 tonnes per day (TPD), this plant receives plastic waste collected via 15 dedicated vehicles and drop-offs by NGOs, ragpickers, and citizens. The facility segregates, shreds, and converts plastic into pellets, which are then used to manufacture benches, tiles and chairs. It operates on a self-sustaining PPP model—no tipping fee or royalty is involved. The plant generates 30 tonnes of plastic pellets daily, which are supplied to industries, including plastic PET bottles which are used in the textile industry for weaving process.

Through a tie-up with Sumul Dairy, the city collects over 1.6 lakh milk pouches daily for recycling. Surat's approach aligns with Extended Producer Responsibility (EPR) policies and significantly reduces plastic going to landfills. Additionally, plastic waste is being utilized in road making, and about 32.56 km of road has been constructed using plastic waste material in the past year.

Public campaigns: Surat's success in waste management stems from both robust infrastructure and active public engagement. The 'Surat Khubsurat' campaign fostered civic pride and encouraged responsible behaviour through targeted communication in schools, RWAs, and NGOs. Regular street plays, workshops, and cleanliness drives has sustained citizen involvement and promoted waste segregation, along with anti-littering habits.

Addressing open burning of waste to control air pollution: Surat's zonal and ward-level structure (eight zones, 89 wards), coupled with regular street sweeping and collection systems, ensures early identification and elimination of waste hotspots. This systematic approach prevents garbage accumulation in public spaces, thereby reducing chances of spontaneous or intentional waste burning. Surat has a 100 per cent door-to-door waste collection, integrated segregation at source, and covered transport infrastructure, a five-bin segregation system and a fleet of monitored vehicles.

Enforcement measures: The enforcement system in Surat includes spot fines and monitoring squads in all 89 wards. A total of Rs 2.6 crore was recovered through penalties and enforcement actions. Surat's enforcement squads also play a deterrent role in discouraging illegal dumping and open burning, reducing instances of air pollution from such sources. To prevent public spitting in Surat city, CCTV monitoring at Integrated Command Control Centre (ICCC) identifies offenders by their vehicle number and issues an E-Challan. From October 2023 to June 2024, a total penalty of Rs 6,96,300 has been collected.

Monitoring system for enforcement: The city maintains strong monitoring through GPS-enabled tracking, decentralized reporting from ward offices, and NGO involvement. Enforcement teams track compliance with waste collection schedules, segregation norms, and plastic bans. Secondary handling is minimized, and all eight transfer stations are designed to avoid open waste exposure. This closed-loop monitoring significantly curtails open exposure and mismanagement of waste.

More than a technical solution, Surat's approach is a holistic model of governance, community ownership, and innovation. What began as a response to a public health crisis has evolved into a national benchmark—proving that clean, liveable cities is attainable through collaboration between citizens and institutions.

The Surat model stands out as a scalable and replicable model in urban waste management. It adheres to the Solid Waste Management Rules, 2016, and supports global sustainability goals. Key strengths include strong citizen participation, integration of informal waste workers, low municipal capital investment, effective public-private partnerships, and stringent monitoring systems. Its decentralized and self-sustaining framework makes it adaptable for cities of all sizes.

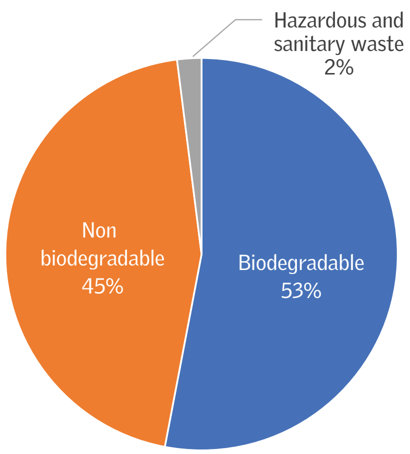
BHOPAL

Reclaiming land from legacy waste

Bhopal, the capital of Madhya Pradesh, has a current estimated population of 2.6 million and a daily floating population of about 1.5 million in an area of 413 sq. km. It is divided into 85 wards and 19 zones. The city generates about 850–900 tonnes of municipal solid waste (MSW) per day.

Bhopal has undergone notable transformation in how it handles solid waste evolving from a system once marked by open dumping and poor waste processing to one that now boasts 100 per cent collection and 95 per cent processing of MSW—supported by a fleet of over

Graph 8: Waste characterization



Source: Bhopal Municipal Corporation

Table 5: The city—at a glance

Population (2011 Census)	1.8 million
Estimated current population (2025)	2.6 million
Estimated floating population	1.5 million
Area	413 Sq. km
Number of wards	85
Number of zones	19
Municipal solid waste generation	850-900
Number of sanitation workers	7,800+
Number of garbage vulnerable points	0
Sources covered under door-to-door collection	100%
Current rate of segregation of waste at source	95%

Source: Bhopal Municipal Corporation

780 waste management vehicles and nearly 8,000 sanitation workers. This shift is the result of a well-rounded strategy that emphasizes innovation, inclusivity, and efficient execution.

Dramatic improvement in waste collection: Bhopal's success is due to its commitment to source segregation. Every household and commercial establishment is required to separate waste into four categories—biodegradable, non-biodegradable, sanitary, and domestic hazardous waste. This is made possible by a fleet of 469 specially-designed auto-tippers that collect waste door-to-door in all 85 wards. The city's 19 zones follow structured route plans, and the system is closely monitored by zonal officers and ward inspectors. Even the sanitation workers are held accountable through facial recognition attendance systems, which has improved punctuality and minimized absenteeism.

Infrastructure for waste processing and material recovery: To support this system, the city has set up 11 Material Transfer Stations, each linked to a Material Recovery Facility (MRF). This setup has cut down the distance collection vehicles required to travel, saving time and fuel. At these MRFs, waste is sorted into various recyclable categories, and importantly, informal workers like rag-pickers are given formal roles. They're paid fairly based on how much and what type of waste they process, with payments managed through mobile apps, making the system both transparent and inclusive.

On the biodegradable side, Bhopal treats its organic waste at three windrow composting units with a combined capacity of 410 tonnes per day, two biogas plants handling another 105 tonnes per day, and one 5 TPD bio-CNG plant. A small, decentralized unit at AIIMS adds further capacity. Additionally, many large waste generators, bulk institutions, housing societies, and public parks now treat their waste on-site, reducing the load on city facilities.

Waste collection vehicle

Digital monitoring of waste transfers: Technology has played a critical role in streamlining operations. Every waste collection vehicle is tracked and linked to Bhopal's ICCC, allowing for real-time monitoring. RFID-enabled weighbridges at transfer stations record waste volumes automatically, reducing human error and enhancing transparency.

Bio-CNG generation and circularity: Bhopal is also looking ahead with two large-scale projects—a 400-TPD bio-CNG plant supported by the UNIDO and a 400-TPD torrefied charcoal plant in partnership with the NTPC. They are both expected to be functional in the next few months. Community involvement has made this possible. The Bhopal Municipal Corporation (BMC) has run robust awareness campaigns and partnered with RWAs and local business groups. Combined with strict enforcement of waste management bylaws including fines for non-compliance, these efforts have fostered a culture of civic responsibility.

Addressing open burning and air pollution: Bhopal has implemented a multi-faceted strategy to curb air pollution from mismanaged waste, combining strict enforcement, technological oversight, and public engagement. In April 2025, the BMC intensified penalties for open waste burning, issuing on-the-spot fines in areas like Neelbad and Suraj Nagar Bishankhedi Road, with health officials mandated to take immediate

PHOTO: SBM URBAN

Waste transfer station in the city

action against violators. This aligns with municipal bylaws that impose challans (penalty tickets) for littering and waste burning, supported by ward-level awareness campaigns highlighting the environmental and health risks of these practices.

The city's five-star Garbage-Free City rating (Swachh Survekshan 2023) reflects its success in eliminating all GVPs and community bins through a 100 per cent door-to-door segregated collection.

Remediation of legacy waste and land reclamation: Bhopal's environmental commitment is also evident in how it tackled the infamous Bhanpur dumpsite. The site has been scientifically remediated, bio-capped, and partially converted into a public green space, thus, removing a major health hazard and transforming a long-standing eyesore into a community asset.

To prevent landfill emissions, Bhopal processes 412 TPD of biodegradable waste at its three centralized windrow composting and biogas plants. A 400-TPD bio-CNG plant is nearing completion, designed to convert wet waste into fuel, cutting down on the gases released from decomposing organic matter. Recent initiatives include night cleaning drives, event waste management protocols for religious gatherings, and partnerships with NTPC for a 400-TPD torrefied charcoal plant to process non-recyclables, expected to start soon in a few months.

AMBIKAPUR

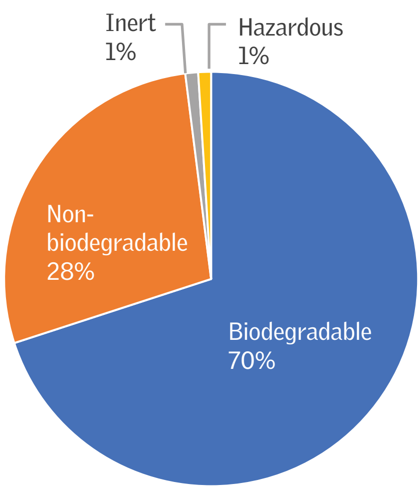
India's first zero-dumpsite city with an inclusive approach

Ambikapur, the administrative headquarters of the Surguja district in Chhattisgarh, has an estimated population of over 200,000 and encompassing 48 municipal wards. The city was once emblematic of widespread urban waste mismanagement characterized by overflowing bins, indiscriminate street dumping, frequent open burning, and an overburdened dumpsite situated along the highway to Raipur, the state capital.

In 2015, in response to an escalating waste management crisis, the Ambikapur Municipal Corporation (AMC), in collaboration with the district administration, undertook a comprehensive overhaul of its waste system. Today, Ambikapur is celebrated as India's first zero-dumpsite city and is consistently ranked among one of the top cleanest small cities in India.

Adopting systemic framework to waste management: Prior to intervention, the city housed nearly 600 community waste bins and over 1,000 GVPs. Waste collection was managed by contractors who could service only 20–25 bins per day, leaving vast areas unattended. The principal dumpsite, spanning 15 acres near the national highway, was severely filled over capacity and posed significant public health risks. This included frequent fires, uncontrolled leachate, and persistent emissions. Rather than approving a new landfill, the district administration advocated for a systemic transformation.

Graph 9: Waste characterization



Source: Ambikapur Municipal Corporation

Table 6: The city—at a glance

Population (2011 Census)	0.121 Million
Estimated Current Population (2025)	0.225 Million
Estimated Floating Population	5,000 (Daily)
Area	36 Sq.km
Number of sources generating waste	(a) 32,000 households (b) 500 commercial and other sources
Number of wards	48
Daily waste generation	70 TPD
Number of Sanitation workers	480
Number of community bins	0
Number of garbage vulnerable points	0
Sources covered under door to door collection	99%
Current rate of segregation of waste at source	95% +

Source: Ambikapur Municipal Corporation

On 1 March, 2015, a multi-stakeholder roundtable comprising AMC officials, political leaders, and local residents resulted in the adoption of a city-wide action plan grounded in a decentralized waste management approach. This strategy was inspired by the Solid and Liquid Resource Management (SLRM) framework developed by environmentalist C. Srinivasan.

Under this model, Ambikapur transitioned away from the ineffective contractor-led system. Supported by public and private investments, the city established 20 SLRM centres over the years.

Each SLRM is designed to handle about 5 tonnes of waste per day and collectively capable of managing about 100 tonnes of waste daily.

The model is built on achieving 100 per cent collection and processing of waste, eliminating the need for landfill disposal. Waste is collected daily from all 32,000 sources and nearly 500 commercial units via manual carts and electric rickshaws. Households segregate waste at source into wet and dry categories—a behavioural shift facilitated by sustained community-led awareness initiatives.

Participatory model—involvement of women Self-Help Groups: A distinctive feature of Ambikapur's approach is the empowerment of women through Self-Help Groups (SHGs). Following a Widow, Divorcee, Separated (WDS) survey conducted in 2014, the AMC identified vulnerable urban women and provided them with training and employment opportunities.

Waste sorting area, DC Road SLRM

Currently, a total of 62 SHGs employ around 480 women, commonly referred to as 'didis', who are responsible for waste collection, sorting, user fee collection, and household sensitization. These workers receive a minimum state-prescribed wage and bonuses during festive seasons and are also enrolled in various government welfare schemes, including health insurance and pensions.

During the Covid-19 pandemic, SHG members demonstrated remarkable adaptability by initiating the local production of face masks and hand sanitizers, showcasing both community resilience and institutional strength.

Sorting and segregation of waste: Collected waste is transported to SLRM centres where it is subjected to a three-stage sorting process, dividing it into different material categories such as paper, plastics, glass, textile, metal and e-waste. High-value recyclables are sold to seven empanelled vendors, while low-value residuals are compacted into fuel cubes and sent to cement factories for use as an alternative energy source. Organic wet waste is composted either on-site or at the common processing facility, producing high-quality organic manure available for sale.

Promoting a circular economy through revenue from user fees, and the sale of dry waste and compost: From an economic standpoint, the Ambikapur model is not only sustainable but also revenue-generating. User charges of Rs.50 per household and Rs.100 per commercial unit - cover the majority of operational expenses. Revenue from the sale of dry recyclables and compost further enhances the city's financial efficiency. Several area federations have accumulated fixed deposits of Rs.2 lakh each from surplus earnings, indicating long-term economic resilience. The governance of the system is further strengthened by the Swachh Ambikapur Mission City Level Federation (SAMCLAF), established in 2019. Comprising representatives from 15 area-level federations, SAMCLAF oversees financial management, workforce deployment, performance evaluation, and grievance redressal. This federated model promotes participatory governance, enhances transparency, and facilitates the replication of successful innovations, including community cutlery banks and waste-based enterprises. During the COVID-19 pandemic, SHG members demonstrated remarkable adaptability by initiating the local production of face masks and hand sanitizers, showcasing both community resilience and institutional strength.

Driving behavioural change to prevent open burning and illegal dumping: The city's transformation is underpinned by a significant behavioural shift. Ongoing engagement between SHG workers and residents has led to near-universal compliance with waste segregation protocols. Practices such as open dumping and burning have become socially unacceptable. Furthermore, the former 15-acre dumpsite has been remediated and converted into a sanitation park. This facility now features green space, educational displays, and public amenities, symbolizing the tangible benefits of sustainable waste management.

Implementing decentralized waste management systems: The Ambikapur model is now recognized as a highly effective and replicable approach, particularly for small and medium-sized urban local bodies (ULBs). Its success was rooted in low capital investment, decentralized operations, community-managed approach and sustained citizen participation. Building on this success, the Government of Chhattisgarh launched the Mission Clean City initiative to replicate the model in 166 of the state's 168 urban centres. Raipur and Bilaspur, which already had established landfill facilities, were excluded. The remaining cities were piloted to adopt decentralized waste management systems aimed at reducing dependency on large disposal sites. The model also drew interest from states like Uttar Pradesh, Kerala, Haryana, and Andhra Pradesh, as well as from various organizations, with many sending official delegations to observe and learn from Ambikapur's experience. The city's achievements demonstrate that modern waste management need not depend on expensive technologies or complex administrative mechanisms. Instead, success can be achieved through a citizen-centric inclusive approach, institutional reform, and the creation of dignified livelihoods for marginalized communities. Ambikapur's model delivers environmental, social, and economic benefits paving the way for a cleaner, more equitable, and resilient urban future.

Eliminating dumpsites to improve urban air quality: Ambikapur's transformation into a zero-dumpsite city has yielded substantial environmental dividends, particularly in terms of improved air quality. Prior to 2015, the open burning of municipal solid waste - especially plastics and other combustible materials was widespread. Waste was frequently burnt at overloaded dumpsites or by residents in the absence of timely collection. These practices released harmful pollutants, including fine particulate matter (PM2.5 and PM10), dioxins, carbon monoxide, and methane, posing serious risks to public health and climate stability. The Ambikapur Municipal Corporation adopted byelaws in line with the Solid Waste Management Rules, 2016, to impose penalties for littering. The byelaw was strictly enforced, effectively preventing the open burning of waste.

Segregated collection of waste from households

Leveraging Solid and Liquid Resource Management (SLRM) to address urban waste challenges: The introduction of the SLRM model effectively eliminated open dumping and burning. The closure and rehabilitation of the 15-acre dumpsite removed a major source of urban air pollution. All municipal waste, approximately 70 tonnes per day, is now processed at 20 decentralized SLRM units. Daily waste collection prevents accumulation and discourages burning in public spaces. Organic (wet) waste, which constitutes nearly 70% of the total municipal solid waste, is aerobically composted under controlled environment, thereby avoiding methane emissions and foul odours associated with anaerobic decomposition. This composting process is energy-efficient and non-polluting. The high-quality compost is then utilized by local farmers, reducing reliance on chemical fertilizers and reinforcing a circular economy. Dry residual waste, rather than being incinerated or landfilled, is converted into fuel cubes made of multilayer plastics and other non-recyclables with high calorific value (approximately 4,000–5,000 kcal/kg). These fuel cubes are sold to nearby cement industries as an alternative to coal, thereby reducing the harmful emissions associated with uncontrolled plastic burning and contributing to reductions in industrial carbon emissions.

Ensuring sustainable and efficient waste transportation: Ambikapur has taken deliberate steps to cut down emissions from waste transportation. The shift from diesel-powered vehicles to electric rickshaws and manual pushcarts has notably reduced particulate emissions and fossil fuel consumption, particularly in residential neighborhoods, while ensuring comprehensive coverage. Consistent last-mile waste collection has prevented the formation of garbage vulnerable points (GVPs), and rigorous oversight by the waste management operations cell has ensured that all waste is systematically collected and sent for processing. Finally the strong community engagement strategy has played a vital role in reducing air pollution. Self-Help Group (SHG) workers maintain regular interaction with households, consistently reinforcing messages against open burning and encouraging waste segregation at the source. The city is also well-prepared to meet future demands, as its waste processing capacity exceeds the current levels of waste generation.

Ambikapur's integrated approach has substantially reduced air pollution arising from solid waste mismanagement. By embedding air quality goals into everyday operational practices - such as segregation, composting, resource recovery, and low-emission transport - the city has established a replicable model that aligns environmental sustainability with social inclusion and economic viability. This case offers valuable lessons for other small urban centres seeking to mitigate pollution while building resilient waste systems.

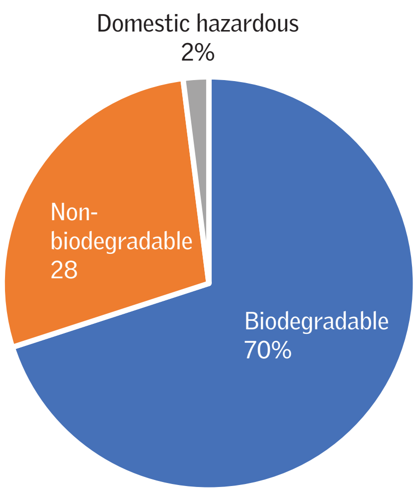
VENGURLA

Near complete segregation at source

Vengurla is a coastal town in the Sindhudurg district of Maharashtra, governed by one of the state's oldest municipal councils. Until a few years ago, the Vengurla Municipal Council (VMC) used to collect all types of waste together and dispose of it at a dumping ground in Parabwada. This practice not only degraded air quality, due to harmful emissions and contaminated groundwater through leachate, but also played a role in polluting the nearby marine environment.

Vengurla generates around 3.3 tonnes per day (TPD) of municipal solid waste, of which 84.4 per cent is biodegradable. Waste collection and segregation used to be the major hurdle for a small town like Vengurla, which was further leading to the creation of dumpsite and creating a potential source of air pollution.

Graph 10: Waste characterization



Source: Vengurla Municipal Council

Table 7: The city—at a glance

Population (2011)	12,392
Estimated current population	17,900 (estimated)
Estimated floating population	700
Area	13 sq. km
Number of wards	17
Daily waste generation	3 TPD
Number of sanitation workers	55
Number of community bins	0
Number of garbage vulnerable points	0
Current rate of segregation of waste at source	More than 95%

Source: Vengurla Municipal Council

Vengurla's solid waste management system boasts full door-to-door collection coverage and complete segregation at source. It operates a fleet of 11 waste management vehicles and employs 55 sanitation workers. With zero GVPs and no community bins, Vengurla has been recognized under the Swachh Survekshan ranking system for its efficient and decentralized waste management practices.

The waste collected is processed through a combination of centralized bio-methanization, vermicomposting, and decentralized composting units. The town proudly claims 'zero landfill' status, processing 100 per cent of its biodegradable waste. The town's unique participatory approach, including the appointment of *Swachhata doots* (cleanliness ambassadors) and *Swachhata sacheevs* (administrative liaisons), has ensured strong public engagement, leading to 100 per cent household-level waste segregation and effective monitoring.

Vengurla's transformation journey began in 2013 with the approval of a bio-methanization and a composting plant. It moved from mixed waste dumping to a model of source segregation and local processing. Major highlights include:

a) **Community engagement and two-bin, two-bag system**: *Swachhata doots* were assigned to each electoral ward to raise awareness, resolve waste issues, and monitor segregation. *Swachhata sacheevs* from the municipal office supported implementation. A colour-coded bin system for wet and dry waste was rolled out with strict enforcement measures.

b) **Waste collection and monitoring**: A two-shift collection system with GPS-enabled vehicles was implemented. Radio-Frequency Identification (RFID) tags at households and shops allow real-time tracking through the Swachhata Netra system.

c) **Decentralized and centralized processing**: The town processes 2.7 TPD of organic waste, with around 274 households participating in backyard composting.

Central facilities include biogas plants, a vermicomposting unit, an OWC unit, and a briquetting plant.

d) **Biogas generation from waste**: The biogas unit powers on-site operations, supplemented by a 18 kW solar plant.

e) **Fiscal incentives**: Property tax rebates encourage decentralized composting; revenues are also generated from compost and recyclables.

Enhanced source segregated collection: Since 2016, the residents of Vengurla have been actively practicing source separation of waste. Initially, Vengurla citizens started with three waste categories, and they now successfully sort their waste into 27 distinct types. This has ensured that the waste leakages in the environment is minimized and hence, the precondition for GVPs creation is minimized. Through consistent IEC efforts—particularly door-to-door training and regular monitoring—a strong, efficient system has been established between the VMC and the community, supported by *Swachhata doots* and the dedicated team.

Each day, a team member is stationed at the designated ward to oversee the waste collection process, ensuring it runs smoothly. Collection vehicles are also accompanied by *Swachhata sacheevs* to support the operation. For secondary collection, there is a tractor which is deployed to collect road sweeps and horticultural waste, apart from a backhoe loader to assist the horticultural waste loading. To ensure maximum reachability in door-to-door collection, eight mini tippers are deployed. Lastly, one tipper is also allocated to deal with C&D waste.

Measures to curb air pollution from mismanaged waste: Vengurla has identified and eliminated all garbage vulnerable points (GVPs). Continuous community engagement and rigorous monitoring has been done to ensure that cleanliness is maintained town-wide. This has been made possible after ensuring the waste is collected in fully segregated manner from household levels, eliminating the scope of leakage to the surroundings and potential creation of the GVPs. Around 2016, the chief officer of Vengurla municipality has strictly emphasized on increasing the efficiency of waste collection from the households.

The VMC has scheduled two rounds of waste collection each day. The first round runs from 9:00 a.m. to 12:00 noon, while the second round, held from 2:00 p.m. to 5:00 p.m., is intended to cover any households or individuals missed during the morning collection. Each waste collection vehicle is staffed by a driver and two collectors, with a balanced representation of genders among the collectors. Special care is taken to ensure safety, particularly when handling sanitary waste.

The municipal council conducted targeted IEC campaigns, warning residents of the environmental and health impacts of burning. Offenders were penalized and persistently followed up by *Swachhata doots*. Vengurla initiated full remediation of their dumpsites which used to be the menace for emissions through accidental waste burning. The VMC recognized that accidental burning at dumpsite is a critical challenge and prioritized to resolve the same for clean air quality in the region. Therefore, they have decided to convert the dumpsite land after remediation into a centralized waste processing centre.

The initial step in transforming the dumpsite into a processing centre involved removing over 300 tonnes of legacy waste. This cleanup process took three years to complete. During this time, recyclable materials were sorted and sent for recycling, non-recyclables were directed to cement kilns, and the remaining residue was used to level the site. In 2016, efforts of the VMC were acknowledged by the state for the first time—the council received a Rs 2.5-crore incentive from the state government and through CSR funds. Since then, the VMC's work has garnered around Rs 12 crore as incentives, grants and awards.

Penal action includes disconnection of municipal services and issuance of challans. Monitoring was done using CCTVs. However, a malpractice was detected—*Swachhata doots* and local volunteers observed that defaulters were bypassing the surveillance by switching off the camera and putting mixed waste in the bins. A few defaulters were nabbed, but the VMC realized that this form of monitoring is tedious and thus, a long-term solution is required for ensuring compliance of waste laws,

For open waste burning, offenders are fined and publicly corrected through peer pressure and council action. While specific numbers are not cited, enforcement is noted as active and effective. The waste collection system covers 100 per cent of households, including informal and migrant settlements, with *Swachhata doots* ensuring compliance and engagement. Dedicated rounds in underserved areas ensure comprehensive coverage. The VMC identified this technology as the first to be implemented at the processing centre, with the goal of making the facility self-reliant in terms of energy and enabling the production of its own liquid fertiliser. The plant has a daily capacity of 1.5 tonnes and currently processes about 1.2 tonnes of biodegradable waste each day.

This operation generates about 100 cubic metres of biogas and produces 50–60 units of electricity daily. Additionally, the plant yields about 800–1,000 litres of liquid fertilizer. This fertilizer is first sent to a settling tank where the solid compost settles as sludge at the bottom while the liquid remains at the top. The liquid is then collected and used

Dry waste collection drive by the residents for gardening within the facility. Any surplus is sold to local farmers at Re. 1 per litre. Bulk waste processing by large generators is significantly reducing the risk of methane emissions from landfilling mixed waste.

RFID tagging and real-time monitoring through Swachhata Netra, along with the absence of community bins and open dumping sites, reinforce the robustness of the waste management infrastructure. Fortnightly review meetings are conducted to evaluate challenges and devise solutions.

Compost Testing: Regular testing of compost is done at the Fertilizer Control Laboratory in Kolhapur. Vengurla is a small coastal town and it is characterized by reverse population—as people over the years emigrate towards larger cities for livelihood.

Although the city is quite densely-populated during festive times, its overall waste burden owing to city population is not concerning. However, there have been well-settled households which require guidance for managing their household waste the correct way. The municipality has provided IEC activities for segregation methodologies and awareness of wet waste utilization at the site. The city has remediated most of its waste at the dumpsite and has established a well-integrated waste value chain which has minimized any possibility of open waste burning, creating a challenge of degrading air quality due to waste burning emissions.

CONSTRUCTION AND DEMOLITION (C&D) WASTE

ADDRESSING DUST POLLUTION AND CIRCULARITY

Construction and demolition (C&D) waste and its management has emerged as a key aspect of clean air action in India. With a construction market slated to become the world's third largest by 2025, India is looking at a potential explosion in this waste stream.

The sector must opt for a circular policy to address its problem of toxic fugitive dust emissions, and to enable recycling and reuse of its waste material. The latter can help manage the galloping demand for new virgin construction material.

CSE's review of C&D waste management in over 15 cities shows that in most of them, management is ad-hoc and there are several systemic gaps.

This section focuses on five major cities as case studies — the National Capital Territory of Delhi, Chandigarh, Hyderabad and Noida.

Delhi has the most mature and well-rounded ecosystem among the selected cities, incorporating on-site management at construction sites, collection and transport systems, extensive infrastructure, capacity for recycling, and a policy for uptake of the recycled material.

Chandigarh's strategy focuses on collection and transportation, use of the recycled material, and a strong communication and public outreach programme. Hyderabad, on its part, has set up a decentralised model for recycling and integration of the informal sector; Noida showcases stringent application of dust control measures in its C&D waste recycling plants; and Pimpri-Chinchwad has opted for third-party enforcement to stop illegal dumping.

INTRODUCTION

Management of construction and demolition (C&D) waste and dust control at construction sites has drawn considerable attention within the ambit of clean air action. This assumes significance from the perspective of the prolific growth of the construction industry and massive expansion of built spaces, which is further expected to more than double by 2040.[1] India's construction market is set to become the third largest globally by 2025[2] as per Invest India — the national investment promotion and facilitation agency set up under the Department for Promotion of Industry and Internal Trade.

It is critical for the sector, therefore, to opt for a circular policy for two reasons: to address its problem of toxic fugitive dust emissions, and to enable recycling and reuse of its waste material. The latter can help manage the galloping demand for new virgin construction material, which leaves behind significant environmental footprints.

The construction sector is beginning to show up among the important sources in pollution source assessment in cities. The Central Pollution Control Board (CPCB) has provided 13 indicators to define the scope and nature of interventions needed in the sector. Cities are required to report on these indicators periodically on the 'Portal for Regulation of Air Pollution in Non-attainment Cities' (PRANA) of the NCAP to indicate their progress. An overview of the clean air action plans of cities shows that a range of these measures have been included (see Box: *Scope of key interventions as defined by indicators in PRANA*).

Scope of key interventions as defined by indicators in PRANA

- Identification and designation of waste collection points
- Spaces for processing C&D waste
- Tracking of waste generation
- Notification of policy and by-laws on C&D waste and dust
- Transportation of construction material
- Segregation of C&D waste and decentralised collection centres
- Enforcement of C&D waste rules
- Setting up of recycling plants
- Use of recycled material
- Dust mitigation practices in construction sites as per CPCB guidelines
- Restrictions on construction activities within the urban airshed during high pollution periods

THE BEGINNINGS

The mandate for C&D waste management had first emerged with the notification of the C&D Waste Management Rules of 2016 and the Environment Protection (Amendment) Rules of 2018. These provide for C&D waste and dust management and have laid down the roles and responsibilities of different actors and empowered cities to take action on littering and illegal dumping; these have also given a deadline for setting up the recycling infrastructure. However, the Rules by themselves could not drive change adequately.

The bigger catalyst has been — as is evident in the case of municipal solid waste as well — the Swachh Bharat Mission 2.0, which was launched in 2019. This came with clear operational guidelines, time-bound targets and substantial fiscal support for capital-intensive infrastructure. This instrument of sectoral funding and policy mandate for waste management from the Central government created an opportunity to implement on-ground strategies. Linked to the SBM 2.0 is the Swachh Survekshan initiative of ranking cities. This — based on a city's performance in waste management within a competitive framework to evaluate and encourage improvements in waste management practices — provided a stronger boost.

In fact, the 2023 revision of Swachh Survekshan assigned higher points to C&D waste management for ranking purposes: as much as 120 points.[3] The points are awarded based on the provision of facilities such as on-call C&D waste collection services, designated geo-tagged collection points within reasonable distances for waste generators to deposit materials, notification of applicable charges, and campaigns to promote the collection of C&D waste from households or construction sites for processing. This approach of policy mandates, incentives and dedicated funding streams have opened up avenues and opportunities for efficient circularity.

Therefore, when NCAP and the 15th Finance Commission funding came into force in 2019, conditions and the mandate for C&D waste management were already in place for the million-plus cities. This created better opportunities for building an interface between NCAP and SBM 2.0 in cities for leveraging the convergence funding. This is now evident in the reporting pattern in PRANA, where cities are being able to capture action on waste streams relatively more cohesively than in other sectors.

More recently, stronger opportunities for compliance have been created with the new Environment (Construction and Demolition) Waste Management Rules, 2025, which has established an accountability framework for the real estate industry. This will be operated and monitored by CPCB and state pollution control boards after it comes into effect in April 2026. This has introduced extended producer responsibility (EPR) to recycle and utilise the generated C&D waste in all projects with equal or larger than 20,000 sq m of built-up area.

THE CSE REVIEW: WHAT IT INDICATES IN A NUTSHELL

Efforts to select representative case studies to demonstrate good practices in cities have also revealed some of the challenges associated with C&D waste management. In most cities, the approach is still fragmented and limited in scope; not all cities display a composite framework to address all aspects including segregation, collection and transportation of construction material and C&D waste and assessment of waste generation in order to design the systems and recycling capacity, recycling plants and a policy mandate for market uptake of the recycled material.

To identify the case studies, CSE has reviewed C&D waste management ecosystems of more than 15 cities, including non-attainment and million-plus cities. The exercise has assessed the information from quarterly progress available on the PRANA portal and from the ULBs, plant operators and other stakeholders.

The review shows that in most cities, the system of management is *ad-hoc* and that there are several systemic gaps. Cities do not have the capacity to quantify their C&D waste generation to be able to design systems and recycling capacity adequately. Plant operators follow a thumb rule of 80 kg per capita, which is an underestimation according to the field investigations done by CSE. Most cities estimate their processing needs based on the waste volume collected; but there is considerable leakage through informal collection of C&D waste.

Moreover, even with fiscal support under SBM 2.0 and the 15th Finance Commission, cities do not have much clarity about the scope of action to decide the utilisation of these funds. Thus, spending gets skewed towards short-term enforcement measures including mechanical sweepers, smog guns, etc that are also expensive to maintain and operate — as a result, usage remains sub-optimal. Long-term systemic and infrastructure-level solutions do not get adequate attention.

Similarly, absence of or delays in legislative support slows down action. For instance, operational recycling plants need C&D waste by-laws to ensure sustainable feedstock to the plants as well as a mandate for uptake of the recycled products. This is needed to enforce rules with respect to bulk waste generators. Intra-departmental coordination, communication and public outreach are the other key gap areas. Cities also need to build adequate resources including infrastructure, human resource and financing to address the entire chain of collection, segregation, transportation and processing.

It is also evident that bigger cities are better equipped to plan and execute action than the smaller cities that have inadequate capacity for assessment, data collection and planning for requisite infrastructure for collection, segregation and recycling.

Urban construction also includes construction of infrastructure — roads, bridges, flyovers, metro systems etc — which generate enormous amounts of debris. While some agencies like the metro systems have adopted their own institutional guidelines for disposal and processing, the municipalities need to adopt a comprehensive approach towards addressing waste generation from this infrastructure.

CRITERIA FOR THE CASE STUDIES

The ideal benchmark that the cities need to adhere to for a robust management approach include *in-situ* management of material and dust control in all construction sites, segregation of waste as per the notified categories, a well-defined collection system, geo-tagged transportation of waste, reuse and processing of all waste material, adequate processing capacity to reutilise the waste, systems for uptake of all recycled material, enforcement of obligations of bulk waste generators and ERP for the industry. This system needs to target nearly the 100 per cent waste from all construction sites.

None of the cities have implemented these criteria by taking an ecosystem approach. As C&D waste management is an emerging sector, it appears to be work-in-progress in most cities. Among those that have undertaken C&D waste management, only a few display good practices — that too, in just a few aspects.

Yet, it is important to capture the notable changes of any scale in the key areas of C&D waste management to build an adequate guidance framework for all other cities in the country. From this perspective, a few case studies have been selected to represent the different aspects.

- **DELHI** has the most matured and well-rounded ecosystem among the selected cities — it includes on-site management in construction sites, collection and transport systems, extensive infrastructure, capacity for recycling, and a policy for uptake of the recycled material.
- **CHANDIGARH** has adopted a framework for C&D recycling with a strategy for uptake and application of the recycled material in construction and municipal infrastructure. This is combined with a robust collection and transportation system and strong communication and public outreach programme.
- **HYDERABAD** has demonstrated a decentralised model for C&D waste recycling and integration of the informal sector.
- **NOIDA**, in Uttar Pradesh, demonstrates stringent application of dust control measures in its C&D waste recycling plant.
- **NATIONAL CAPITAL REGION TRANSPORT CORPORATION and DELHI METRO RAIL CORPORATION** illustrate good practices in dust and waste management in linear infrastructure projects — something that several cities have been unable to address.
- **PIMPRI CHINCHWAD** has incorporated third-party enforcement to arrest illegal dumping of C&D waste.

DELHI

An ecosystem approach to C&D waste management

TOWARDS FUGITIVE DUST CONTROL AT CONSTRUCTION SITES

In 2014, the Environment Pollution (Prevention and Control) Authority (EPCA) — as part of an ongoing public interest litigation (PIL) in the Supreme Court of India — took on board an order by the National Green Tribunal (NGT), dated 10.04.2015 in OA No 95 of 2014. The order pointed out that the dust pollution from construction and other allied activities was one among the several problems the city was facing.

These directions were circulated vide orders dated November 26, 2014 and December 4, 2014, which laid down the steps to be taken by anyone responsible for construction, carrying construction material and dealing with debris. Failure to comply with these directions would lead to immediate stoppage of construction activity in all the identified sites/projects in the state of Uttar Pradesh, the Noida and Greater Noida Authority, the Haryana Urban Development Authority and the state of Haryana, and the NCT of Delhi.

A Supreme Court order (dated 16.12.2015) followed, with a checklist of measures recommended by CPCB for mitigating dust pollution. This strengthened the norms for dust control from construction and related activities. Violation of these norms would fetch heavy penalties for those involved in the construction activity.

Graded Response Action Plan (GRAP) and construction activities: In November 2016, Delhi was struck by pollution at an emergency scale: 14 times the standard, higher than what was recorded during the infamous London smog incident and certainly the highest ever in Delhi. The EPCA responded by putting together priority actions like wet suppression of dust from construction activities. It also developed an accountability mechanism to identify the agency and actions that had been taken to check pollution from construction activities. A guidance note was prepared for inspection of such sites; the EPCA demanded close monitoring by the Supreme Court and stringent enforcement. On February 9, 2016, the Authority notified a 12-point checklist titled '*Guidance on measures to be adopted to control dust emissions from construction activities larger than 20,000 sq m of built-up area*'.

In 2017, the Union Ministry of Environment, Forest and Climate Change (MoEFCC) notified the Graded Response Action Plan (GRAP) in Delhi. The Plan called for dust control measures at construction sites and stoppage of all construction activities when the air quality index hit 'very severe' or 'emergency' levels. To strengthen enforcement, the EPCA called for the following:

- Action to be taken by development authorities and municipal corporations in the case of construction projects with areas between 20,000 sq m to 1,50,000 sq m

- Action to be taken by state pollution control boards (SPCBs) for construction projects with areas greater than 1,50,000 sq m, which were not complying with environmental clearance guidelines

- Listing by the SPCBs of all construction projects in NCR having an area greater than 1,50,000 sq m

Dust control from road construction: The EPCA also called for the SPCBs to immediately impose fines on road construction agencies which were not following dust control measures adequately; a fine of Rs 50,000 was to be imposed as penalty per day per stretch. The CPCB released two documents which included guidelines to curb dust emissions during the handling of construction material and C&D waste.

In 2018, with the notification of the Environment (Protection) Amendment Rules, dust control measures were firmed up as mandatory practices for dust-free construction activities. These measures comprise installation of wind breaks and water sprinkling systems and covering of material and C&D waste stockpiles and vehicles carrying construction material, among others.

In 2021, these Rules, as well as the 12-point checklist for guidance on dust control measures, were adopted by the Delhi government as 'Dust Mitigation Measures for Construction and Demolition Activities'. Two points were added to them: one, installation of anti-smog gun/s and paving and blacktopping of roads leading to construction sites for sites with built-up area more than 20,000 sq m.[4]

Delhi's anti-dust drive: To implement the mandate of dust control measures in a stringent manner, the Delhi Pollution Control Committee (DPCC) launched an anti-dust drive in 2021. Under this, all projects involving construction or demolition with a plot area of 500 sq m or more were asked to register on the DPCC's designated web portal. The project proponents were directed to carry out dust self-assessments/audits every fortnight and upload the reports on the portal. To support this, the DPCC has also released a guidebook on dust mitigation measures. It incorporates visuals and illustrations from real-world construction and demolition sites, allowing implementers to better grasp the practical application of the measures.

It has been mandated that while all projects must install PM2.5 and PM10 sensors at their sites, these must be linked to a live dashboard on the DPCC's portal to provide real-time air quality data at and around those sites. There is a graphical guideline on the website that explains this entire process of self-assessment and uploading of information on the portal. This system is still in place and is being monitored today by the Commission for Air Quality Management (CAQM) in Delhi NCR and Adjoining Areas, which was set up in 2022.

DELHI'S INITIATIVE TO TACKLE DUST POLLUTION FROM CONSTRUCTION AND DEMOLITION ACTIVITIES

A TIMELINE

2014

- NGT directs Delhi and neighbouring cities to stop construction at sites that violate NGT order and MoEFCC's Environment Impact Assessment (EIA) guidelines of 2010.5

2015

- Delhi government authorises its revenue department and municipalities to enforce NGT's dust control guidelines.6 By May 2016, fines and notices had resulted in a total collection of Rs 11,850,000.7
- Supreme Court's 16.12.2015 order directs Delhi government to enforce CPCB rules and regulations to curb pollution from construction activities.8

2016

- In February, EPCA issues 12-point dust control checklist for construction sites over 20,000 sq m.9
- In April, NGT raises the fine amounts for dust pollution violations.10
- In November, Delhi witnesses a spike in pollution levels.
- EPCA, in collaboration with municipal bodies and state departments, develops a mobile app11 for tracking pollution complaints, including from construction dust, along with an accountability mechanism and inspection guidelines to monitor agencies and enhance enforcement.12

2017

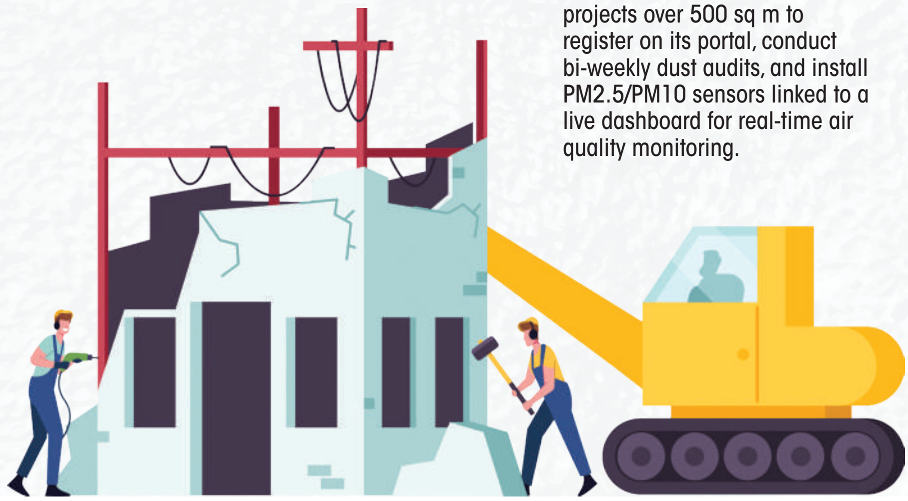
- MoEFCC notifies GRAP in January and entrusts EPCA with the task of overseeing its implementation.
- In November, EPCA meets stakeholders, ordering construction halts and fines for poor dust control on road projects.
- CPCB releases two documents that lay out guidelines regarding dust mitigation measures while handling construction material and C&D waste.

2018

- MoEFCC comes out with the Environment (Protection) Amendment Rules that provide dust mitigation compliance measures applicable for C&D activities

2021

- DPCC's 2021 anti-dust drive mandates all construction projects over 500 sq m to register on its portal, conduct bi-weekly dust audits, and install PM2.5/PM10 sensors linked to a live dashboard for real-time air quality monitoring.



DUST CONTROL IN LINEAR INFRASTRUCTURE PROJECTS

Dust control guidelines notified so far address measures to be taken on construction sites and during transportation of materials in the city. They do not address the specific and functional challenges faced by linear infrastructure projects. Instead of a confined polygonal area, these projects span long distances involving highways, railways and viaducts. In case of elevated construction, measures like wind barriers and dust covers become ineffective. There is a lot of movement of heavy vehicles too as they carry prefabricated components of bridges and highways. In the process, these projects cross city boundaries or even state boundaries, thus changing jurisdictions. All these factors make dust management in linear projects practically challenging.

A few agencies responsible for such projects are addressing the tricky problem of dust management innovatively. The Delhi Metro Rail Corporation (DMRC) and the National Capital Region Transport Corporation (NCRTC) are two such agencies which are demonstrating best practices of dust control in linear projects.

A CSE survey team visited several project sites of both the agencies and compiled information on how they are arresting dust dispersal and building a learning curve. In linear projects, there are usually three sections for dust control: first is the batching plant, second is the active construction area, and third is the C&D waste recycling plant.

The DMRC, for instance, has its own C&D waste recycling plant of 150 tonne per day (TPD) capacity located in Mundka. The plant processes C&D waste generated in the course of metro rail construction only. Each section demonstrates good and replicable dust control practices.

Use of vehicle-mounted and elevated stationary anti-smog guns: Both DMRC and NCRTC have deployed vehicle-mounted and stationary anti-smog guns at active construction sites. Anti-smog guns spray a fine mist of water into the air to capture and settle airborne dust and particulate matter. Using high-pressure nozzles, they break water into ultra-fine droplets that bind with pollutants. This makes them heavier and causes them to fall to the ground. These guns, when mounted on vehicles, can enable coverage of wider areas for longer periods for dust suppression. Placing anti-smog guns at higher points facilitates improved mist dispersion with wider coverage. This is particularly useful when the project has elevated structures.

CREDIT

Anti-smog guns kept at high elevation of buildings

Paving of roads and wheel washing at entry-exit points: Hard-paving or black-topping of roads that lead to a construction site can reduce the amount of dust that gets dispersed with every vehicle that comes in and leaves the site. Washing of wheels of the vehicles at entry and exit points can further reduce dust from leaving the site and dispersing in the city. It keeps the roads clean as well. The DMRC has used both the methods at a few metro stations that are being constructed, as well as at their concrete-mixing plant.

Blacktopping or hard-paving entry and exit points across the linear stretch


Wheel washing stations at a DMRC site entrance

Mechanical sweeping: The NCRTC has employed mechanical sweeping machines at some of its large station construction sites. These machines efficiently remove dust and debris from expansive areas, ensuring consistent cleaning while reducing reliance on manual labour. Additionally, they aid in waste management by preventing debris build-up, and keeping the site organised.


Mechanical sweeping machine at NCRTC stations

Enclosed storage and wet suppression of materials: The DMRC has installed a system within its batching plant where the loading and unloading of material takes place within an enclosed space. The material is sprayed with water with the help of a nozzle to avoid emissions of fugitive dust during its handling.


Material handling taking place within enclosure

THE C&D WASTE MANAGEMENT ECOSYSTEM

Highest C&D waste recycling capacity: Delhi has the highest C&D waste processing capacity in India, with the maximum number of operational recycling plants. It now has a well-rounded ecosystem for collection, transportation, processing and uptake of recycled products — that too, in a sprawled and space-constrained geography that offers abundant ridge areas and river plains which can attract indiscriminate disposal. Delhi's success has been the result of almost two decades of efforts, and was accomplished with the help of timely decisions and relevant mandates, all the while learning from its own experiences and mistakes.

Like many other cities in India, Delhi too used to face the problem of illegal dumping of C&D waste into and on its waterbodies, ridge areas, parks, open lands, railway lands, roads and highways. To tackle this, in 2004 and 2005, surveys of C&D waste in Delhi were conducted by the Municipal Corporation of Delhi (MCD) and IL&FS Environmental Infrastructure & Services Ltd (IEISL), a city-based company which partners with ULBs to set up and operate C&D waste recycling plants.[13] Based on this, the first C&D recycling plant in India was established in Burari in Delhi in 2009, with a processing capacity of 500 TPD.

However, far from being a solution, it ended up raising more questions. This is because a plant does not just work in isolation — it needs an entire ecosystem support to function viably. While attempting to solve these questions and fitting parts of the puzzle together, Delhi began developing its own ecosystem which became a benchmark for many other cities in the country.

Initially, the plant faced challenges due to insufficient quantity and quality of the waste received. The 2010 Commonwealth Games was a significant catalyst for clearing the city's debris — preparations for the Games had resulted in the generation of enormous amounts of C&D waste that had started to clog the city by 2008.[14] The Delhi government set an August 10, 2010 deadline for its municipalities to remove all the debris.[15] This redirected more waste to the plant, effectively addressing the common challenge faced by many recycling facilities in the country today — that of insufficient raw materials.

Regulatory action to enable use of recycled products: The recycling plant also needed to sell the recycled products that it produces to become financially viable. A roadblock was brought to light by a CSE investigation around 2013 — it found that IS:383-1970, the Indian standard for concrete aggregates set by the Bureau of Indian Standards (BIS), allowed only 'naturally accessed material' for concrete production. Concerned about potential non-compliance, construction agencies refrained from using recycled C&D waste. Recognising this issue, BIS established a fast-track panel in early 2014 to include aggregates from non-natural sources in Indian standards; the results of this initiative were, however, not visible immediately.

Mandate for market uptake of recycled products: In the meantime, the plant faced difficulties in generating demand for its recycled products. The situation began to improve in 2015-16 when the Department of Urban Development of the government of NCT of Delhi made it mandatory for all municipal and local government bodies in Delhi — including the Public Works Department (PWD), Department of Irrigation and Flood Control, DSIIDC, and the Delhi Jal Board — to use recycled C&D waste products for construction and maintenance projects. In the meantime, in 2016, the BIS updated IS 383: *Coarse and Fine Aggregate for Concrete Specification*, officially acknowledging recycled C&D waste as a legitimate alternative to natural aggregates in concrete mixes.[16] These developments helped increase the demand for recycled C&D waste products within the market.

By now, several pieces of the waste management puzzle had started falling into place. But one concern remained: the waste being collected still came largely from bulk waste generators and not from smaller generators. The C&D Waste Management Rules came in 2016 and clearly defined the roles of the waste generator and the service provider. The Rules required the waste generator to deposit the waste at collection centres identified by the local body, or hand it over to an authorised C&D waste processing facility. This called for a collection system in the city so that the waste generators could dispose of their waste only in the formal manner.

A well-distributed and user-convenient collection system: Delhi's C&D waste management system is structured to ensure extensive coverage through a widespread network of 132 collection points[17] distributed across the city's three ULBs and 272 wards/circles, providing easy access to waste disposal facilities for residents, contractors and construction personnel. The MCD, encompassing 250 wards, has 106 designated collection centres with 61 more planned in future.[18] The New Delhi Municipal Council (NDMC), which oversees 14 circles, has 25 collection centres. The Delhi Cantonment Board (DCB) has eight circles with one designated collection centre.

This ensures that nearly every two wards have a designated point for C&D waste collection — this demonstrates a deliberate effort to ensure convenience and accessibility city-wide. When collection points are strategically placed within two-three km of waste generators, as recommended by the Building Materials and Technology Promotion Council (BMTPC)[19], it minimises the need for long-distance transportation, cutting down vehicular emissions and fuel consumption caused by waste-carrying vehicles. When waste is collected closer to its source, it also brings down the number of times it is handled — this, in turn, reduces incidences of spillage during transit and decreases exposure to wind. By enabling quicker,

C&D waste collection points within Municipal Corporation of Delhi area localised disposal, multiple collection points create a more sustainable and efficient waste management system, contributing less to the urban air quality and reducing health hazards for city residents.

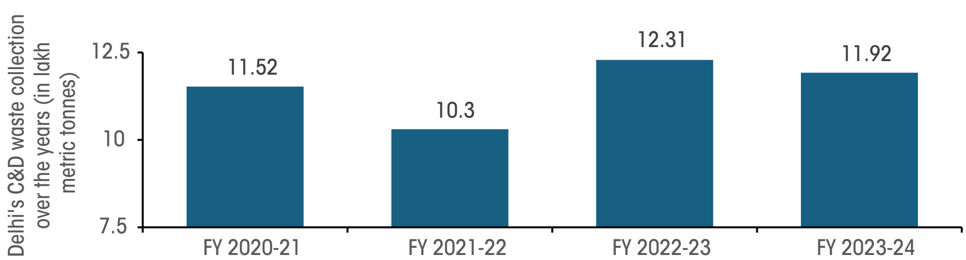
The MCD has smartly utilised the existing space in wards in a space-constrained city. MCD junior engineers have a ward office with some storage space within the premises. These storage spaces have been converted into C&D waste collection points with clear demarcations and signages. Each space has its own collection vehicle and logbooks to keep track of the waste deposition. When these points get full, the junior engineer calls the plant operator to take the waste for processing. This is the secondary collection leg of the process. This process is done during early morning hours to avoid troubling nearby residents and activities.

Delhi has steadily progressed towards this widespread network, with more collection points being added regularly. The increase in collection points has yielded positive results, with the MCD having reported a 38 per cent reduction in illegal dumping from October to November 2023.[20] On the other hand, MCD has achieved a steady collection of about 12 lakh metric tonne as of 2024, as per to the annual report submitted to DPCC (*see Graph 1: Delhi's C&D waste collection over the years*).

With the city largely expanding northward and westward, new waste collection points are also being set up in places like Narela, Shahdara (North), Shahdara (South) and Rohini zones to meet the increasing demand for proper waste disposal.[21] These additional collection points will not only improve waste management efficiency, but also help reduce air pollution by minimising the distances that waste transport vehicles need to travel. Shorter trips mean lesser fugitive dust from the C&D hauling vehicles, lower fuel consumption and fewer emissions.

Improved transportation system — skip-hauler system: Skips — metal bins — curb dust emanating from handling of waste and support enforcement. The NDMC has introduced color-coded skips and vehicles for C&D waste collection and transportation. The red coloured skips can be distinguished from other street elements and easily identified by small waste generators. The colour coding also extends to C&D waste hauling vehicles,

Graph 1: Delhi's C&D waste collection over the years



Source: Compiled from annual reports submitted to DPCC

C&D waste collection points within New Delhi Municipal Council area (left); color-coded C&D waste carrying vehicles of NDMC (right)

which enables quick recognition of authorised transporters. Against the colour-coded vehicles, it becomes easier for the enforcers to distinguish illegal hauling and dumping of C&D waste. By combining accessibility with clear visual cues, the NDMC's system simplifies waste disposal for citizens while improving regulatory oversight.

Another benefit of this system is control of dust pollution and better adherence to dust control norms. Storage, loading and unloading of debris is a significant source of fugitive dust emissions and safety concerns, particularly when handled manually. These emissions not only contribute to local air quality but also pose health risks to workers and residents in the vicinity. Moreover, manual handling has several safety risks for the workers while they deal with heavy and sometimes sharp rubble. When the debris lies on the roadside without confinement it not only acts as an obstruction for pedestrians and vehicles, but also stirs up dust with every passer-by.

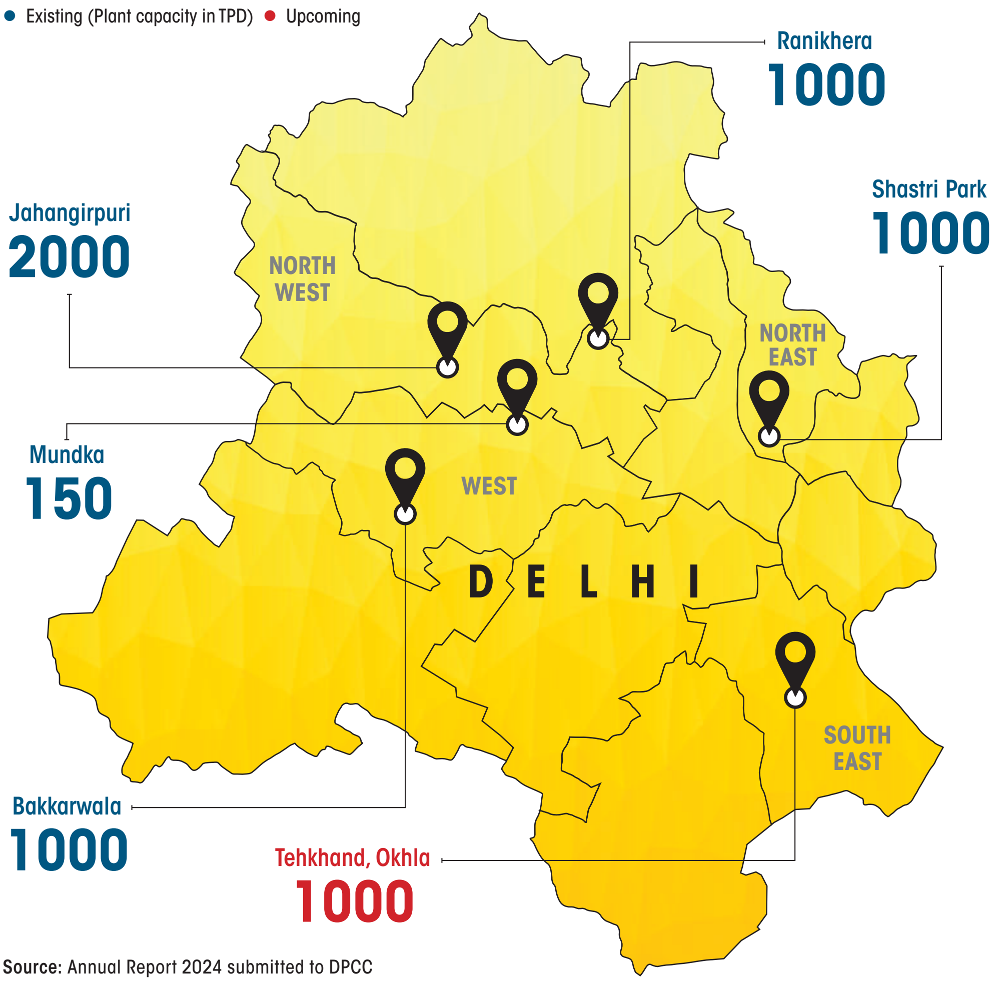
The NDMC's skip-hauler system addresses these concerns. The skips keep the C&D waste confined, reducing fugitive dust and eliminating the risk of injuries to passers-by. In this system, the hauling trucks are equipped with a special hook that xattaches to metal skips. The cranes in these trucks lift the filled skips and place them securely on the vehicle; they can also replace them with an empty skip. The skips have hooks to fasten covers to prevent dust emissions both while being used for collection and for transporting waste to the transfer station. With minimum disturbance, this system significantly curbs the release of dust into the atmosphere. In addition to its environmental benefits, the mechanism improves operational efficiency, reduces manual labour, and speeds up the waste collection process, creating a cleaner and safer urban environment.

Decentralised recycling reduces transportation distances: As Delhi has steadily expanded, so has its waste processing capacity to over 11 times from where it started initially. There are five recycling plants in the city with a combined processing capacity of 5,150 TPD,[22] which is the highest in the country. Instead of one large plant, this decentralised approach offers several advantages. Firstly, it reduces the distance for transporting the waste. This cuts costs as well as carbon emissions while minimising particulate pollution. This also eases traffic congestion by lowering the number of heavy vehicles on roads; optimises vehicle utilisation which reduces capital investment; strategically places plants near construction hotspots to improve efficiency; and fosters healthy competition by providing waste generators with multiple convenient options for disposal and processing.

Delhi's journey in C&D waste recycling began in 2009 with its first 500-TPD facility at Jahangirpuri in the northern part of the city. This was soon followed by a plant at Shastri Park (1,000 TPD) in the east. Over time, additional facilities were established in the western regions, including Bakkarwala (1,000 TPD) and Ranikhera (1,000 TPD). In addition, a recycling plant at Mundka has a processing capacity of 150 TPD and particularly caters to the C&D waste coming out of projects handled by the Delhi Metro. The Jahangirpuri plant has since then expanded its capacity to 2,000 TPD, making it the largest such facility in the country (*see Table 1: C&D recycling plants in Delhi*).

The city has also attempted decentralised waste recycling through mobile recycling plants. In 2014, the NBCC — the Indian government's civil engineering enterprise — piloted *in situ* recycling of demolition waste for the East Kidwai Nagar redevelopment project. A temporary 150-TPD C&D waste recycling plant was set up under a PPP model, with NBCC ensuring 100 per cent buyback. The project involved demolishing 2,444 houses, and the recycled waste was used to produce aggregates, manufactured soil, and downstream products like RMC, bricks, blocks, and tiles.[23]

Map 1: C&D waste recycling plants in Delhi



Source: Annual Report 2024 submitted to DPCC

However, the city's decentralisation aspect remains partially unfulfilled as it still does not have a permanent C&D recycling plant to cater to its southern parts. The municipality initially planned setting up a C&D recycling facility in Maidangarhi; however, this faced hurdles. In 2024, the municipality floated a tender for a recycling facility to be set up on a seven-acre plot in Tehkhand, Okhla. The plant will cater to the south and central zones of Delhi cutting down travel distances of debris further within the city. It will initially be of 1,000 TPD, but will be expanded to 2,000 TPD within two years of its establishment.[24]

Reducing transportation distances has a direct effect on lowering overall costs, as is reflected in the average tipping fee of Rs 210 per tonne charged to municipalities in Delhi. This fee is significantly lower than those charged by other plants, demonstrating the cost-efficiency of decentralised recycling facilities.[25]

Mandatory reuse to generate demand for recycled products: The uptake of C&D recycled materials is a crucial factor in achieving a circular economy. Creating a sustainable business model for C&D recycling plants hinges on ensuring that revenue from the sale of recycled products becomes the dominant source of income. As per the 2016 C&D Waste Management Rules, use of materials made from C&D waste is to be mandated by the state government/Union territory administration. The Rules suggest up to 20 per cent use of C&D waste products in municipal and government contacts.

Delhi has taken strategic steps and policy initiatives to cultivate a mature market for C&D waste recycled products. The city began this effort in 2015, predating the 2016 Rules. The GNCTD issued an advisory on July 27, 2015, mandating the use of recycled C&D waste products in Delhi. Another advisory was also issued on September 14, 2015 by the deputy secretary (PWD/UD).[26] In July 2016, the Department of Urban Development, GNCTD, mandated all municipal bodies and the departments of GNCTD to use recycled C&D waste products. According to the order, all departments are to use minimum 2 per cent of recycled products in building works and 10 per cent in road works. Further, all ULBs are to mandate 5 per cent use of recycled products for non-structural applications by everyone. The order also laid down provisions for enforcement and compliance.

The Supreme Court Annexe building used 1.8 million recycled C&D waste blocks

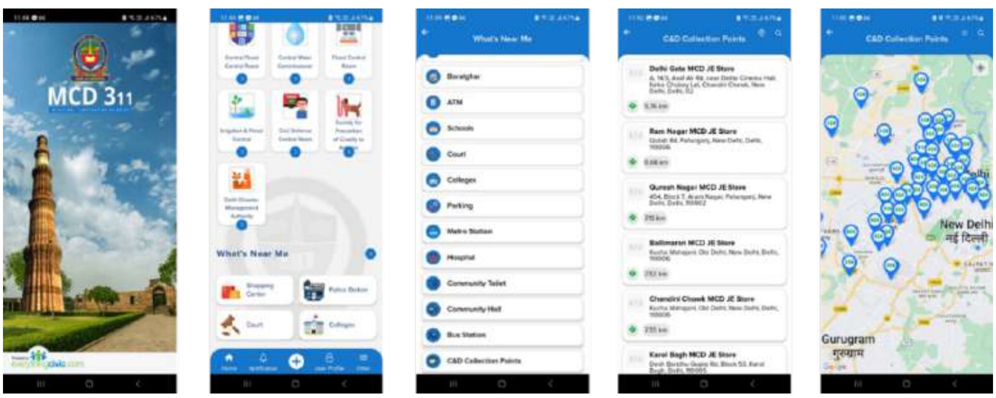
Such mandates, along with demonstration by iconic projects, improved awareness and acceptance of recycled products. For instance, the Supreme Court Annexe building in New Delhi used 1.8 million blocks made of recycled aggregates, conserving nearly 25,000 tonne of fertile soil. Such efforts pushed utilisation of recycled products to 2.5 lakh metric tonne (MT) in 2018-19 from just 60,000 MT in 2017-18.[27]

The DPCC also called on all agencies such as NHAI, NBCC, CPWD, etc to increase the reuse of recycled materials as per directions notified under Section 5 of the Environment (Protection) Act, 1986. This was done on January 14, 2020 to further these agencies' uptake in line with the annual targets set by MoHUA.[28] For the financial year 2023-2024, MoHUA set a target of 16.015 lakh MT of recycled products.[29] In response, Delhi's C&D waste facilities saw a total offtake of 7.423 lakh MT.[30] Of this, government departments utilised 2.517 lakh MT, accounting for 33.9 per cent, while private parties took up a larger share of 4.906 lakh MT, contributing 66.1 per cent.[31]

This private sector involvement highlights its critical role in sustaining the demand for recycled materials. Meanwhile, the government's steady uptake ensures consistent utilisation of recycled products, supporting the city's efforts towards sustainable waste management and a circular economy. The CPWD Schedule of Rates (SOR) 2023 for Delhi has also played its part by incorporating materials derived from C&D waste into this widely used document. This has provided a big endorsement, instilling confidence among builders and contractors about the quality and reliability of these materials.

Tools to enable public outreach: Over the years, the city has developed tools to enhance awareness among waste generators through digital platforms to inform and engage citizens: this includes introduction of a mobile app and a website which provide access to the MCD helpline for requesting C&D waste collection services and informing users about C&D waste collection points in their vicinity. This is a crucial component of a successful and efficient C&D waste collection system.

The MCD 311 app is the official mobile phone app for several municipal services. The app has incorporated C&D waste management by listing down the waste collection points within the municipal area. This list can be accessed by:



Interface of MCD 311 app to find C&D waste collection points

- Clicking on the ‘what’s near me’ tab
- Selecting ‘C&D collection points’ option
- Selecting the nearest collection point as guided by the options and the distance to them, and the map that shows all the designated C&D collection points

The NDMC has a similar app by the name ‘NDMC Citizen’ that enables placing collection request. The MCD website also lists down the designated sites in each ward for disposing of C&D waste. To strengthen the collection system further, regular training of citizens and transporters is essential. Civic departments are actively conducting citizen awareness drives and sensitisation programmes to ensure proper debris collection and to prevent illegal roadside dumping.[32]

CHANDIGARH

Comprehensive approach towards recycling and uptake of recycled products

A STATE-MANAGED SYSTEM

Chandigarh’s C&D waste management system is designed and operated solely by the Municipal Corporation of Chandigarh (MCC) without involvement of any private party. It is the only government-run C&D waste management system in the country and has a recycling plant with a capacity of 150 TPD, operationalised in 2019. This system is able to collect most of the waste generated in the city, process it, deter illegal dumping and make profits by sale of recycled material. A key factor behind this success is its strong focus on information, education and communication (IEC).

The Waste Management Rules, 2016 place the major onus of managing waste on its generator. This requires tremendous efforts by the city — it has to familiarise the public about the several processes involved in waste management; and about their responsibilities and the consequences of failing to fulfil them. Recognising this, the MCC engaged KPMG Consultants to develop a comprehensive IEC strategy for city’s waste management systems, including the C&D waste stream. This strategy involves engaging the public through various mediums of communication — digital, print, audio-visual and physical (events and interactions).

INNOVATIVE REGULATORY INSTRUMENTS TO ENSURE MARKET UPTAKE OF RECYCLED PRODUCTS

Chandigarh's Waste Management Policy of 2019 provides for mandatory reuse of recycled C&D waste in an innovative way. There are two parts to this process.

Firstly, the policy includes a provision for waste generators who have paid processing charges at the time of building plan approval — they are entitled to receive processed material free of cost, amounting to 50 per cent of the charges paid, within one year.

Secondly, to buy materials from the plant, developers and waste generators need to place a demand request specifying the types of products and their quantities needed — the plant must respond to this. In case it is not able to meet the demands placed by buyers, it will have to issue a non-availability certificate.

These two provisions push the developer and waste generator to use recycled waste as much as possible and bridge the gap between policy and practice towards increased use of recycled materials.

PRODUCT DIVERSITY

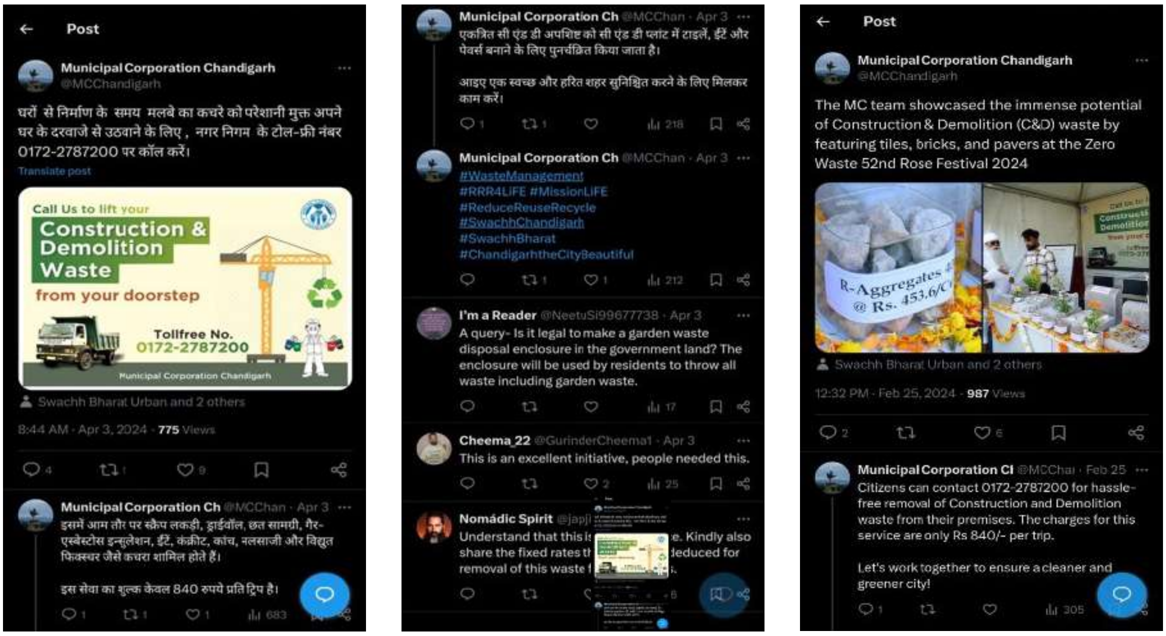
Chandigarh has also demonstrated wider diversity of the products that are made from recycled aggregates. In addition to the usual paver blocks and aggregates that most recycling plants produce, the Chandigarh plant also manufactures a variety of material that can be utilised by municipalities for different applications — street furniture and amenities, coverings of sewer drains etc. This leads to much higher value addition and increases the revenue potential

PUBLIC OUTREACH TO STRENGTHEN IMPLEMENTATION

Digital communication: The MCC regularly posts information on its website and social media platforms such as X, Youtube, Facebook and Instagram. Approximately 10 per cent of the content is dedicated to C&D waste management, as per the MCC's IEC experts.

Printed communication: The MCC disseminates information related to C&D waste through newspapers, magazines and advertisements. It also uses outdoor media outreach platforms like hoardings, banners and posters that are placed at public spaces.

C&D waste stall featuring tiles, bricks and pavers at the Zero Waste 52nd Rose Festival, 2024



Posts covering toll-free number for C&D waste collection and events, on the social media platform, X

Audio-visual communication: The municipality runs ads and public messages on radio and television. This is complemented by dedicated Residents Welfare Association (RWA) and Market Welfare Association WhatsApp groups to ensure targeted messaging for specific wards.

Public events: The MCC strategically utilises major annual public events, such as the Rose Festival, Teej Mahotsav and the Swachhta hi Sewa campaign, to set up informational stalls and booths. These stalls showcase recycled C&D waste products, highlighting their benefits and applications, and provide information on the toll-free number for door-to-door collection services.

The outreach strategy also includes guided tours of the C&D waste management plant for visiting delegations and student groups from outside Chandigarh. These tours provide insights into the plant's operations, the broader waste recycling ecosystem, and real-world examples of public spaces constructed with C&D waste recycled materials such as Chandigarh's Waste to Wonder park located at sector 32. This park utilises recycled materials to make benches, picnic tables, kerbstones and interactive play spaces. Expansion plans include collaboration with the community and social media influencers to spread the word on the city's C&D waste management system.

HYDERABAD

Innovative decentralised recycling

Hyderabad has developed the largest C&D waste management system in southern India, with four decentralised recycling facilities strategically distributed across the city. While this is largely in response to the city's rapid growth — a population that has nearly doubled from 1991 (43.4 lakh) to 2011 (76.8 lakh) — fuelling demand for housing and infrastructure and a rise in C&D waste, Hyderabad is reaping multiple benefits from its C&D waste management system.

The primary advantage of multiple C&D waste recycling facilities is that it reduces travel distances and the linked user charges. Transportation is the most dynamic part of the recycling cost and can form its major proportion in a large city. Hyderabad ULB pays a tipping fee of Rs 450 per tonne for transport and processing. In case a generator brings waste directly to the plant, they pay only 25 per cent of this fee this fee to the plant operator.

Further, shorter trips due to decentralised plants reduce the need for vehicles to be owned and operated by the ULB, and bring down the capital costs. Short trips also cut down fuel consumption tremendously as Hyderabad is a sprawled city. Lesser tail-pipe emissions support better air quality. Limited movement of heavy debris-laden trucks across the city reduces fugitive dust and particulate matter, which benefits both public health and the environment.

Decentralised plants enable recycling strategically near the construction hotspots of the city. This not only makes it easier for the generators to recycle and reuse C&D waste, but also reduces illegal dumping. Short trips support enforcement by providing a closer eye on the operations involving waste handling and movement of vehicles. Additionally, shorter transport routes reduce congestion on city roads, enhancing overall urban mobility and related emissions.

Greater Hyderabad Municipal Corporation (GHMC) spans four districts — Hyderabad, Rangareddy, Medchal and Sangareddy — across 650 sq km. The first of the four plants was set up in 2020 in Jeedimetla and caters to the northern part of the municipal area. It was followed by the Fathullaguda plant in 2021, located in the east. Both the plants are operated by the city-based RE Sustainability Ltd and provide a processing capacity of 1,000 TPD.

In 2021-22, the GHMC sought to establish two more plants but lacked the land needed for them. The commissioner proposed a PPP model where the concessionaire provided the land — but the proposal did not gain traction due to no precedence of this model. Later, an interested concessionaire, the Hyderabad-based SSREC, set up recycling plants in Shamsabad and Thumakunta to cater to the southern and the expanding new north-eastern outskirts of the city.[33]

As of September 2024, a total of 2,950,378.57 metric tonne (MT) of C&D waste had been deposited at the four recycling plants. Of this, approximately 769,221.1 MT, which accounts for about 26 per cent, had been successfully processed into recycled products.

Map 2: C&D waste recycling plants in Hyderabad

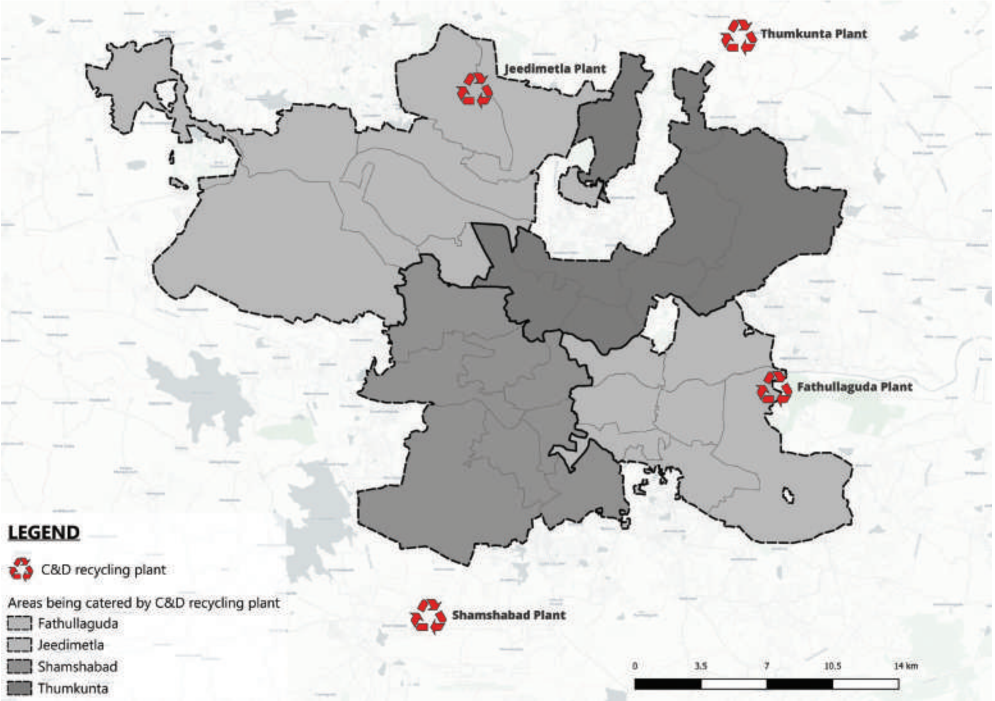


Table 1: Capacities of C&D waste recycling plants in Hyderabad

Plant location	Processing capacity (TPD)	Caters to circles (number)	Waste quantity collected at the plant till September 2024 (metric tonne)
Jeedimetla	500	8 Circles	1,598,208.49
Fathullaguda	500	7 Circles	261,432.11
Shamshabad	500	8 Circles	143,849.51
Thumakunta	750	7 Circles	189,862.24
Total	2250		2,193,352.35

Source: 'Debris Deliberations', CSE's national conference, November 11, 2024

INTEGRATION OF THE INFORMAL SECTOR

Hyderabad has deployed a door-to-door waste collection model that utilises the strength of the informal sector. This improves collection efficiency, reduces municipal costs and at the same time prevents job loss for informal workers as they transition into a formal ecosystem.

To enhance transparency and compliance, QR tags have been added to waste collection trucks/vehicles. The codes scanned at collection points help track vehicles and verify authorisation; they also assist the police in identifying official waste collectors. This system prevents illegal dumping and enhances accountability. Capacity building of the workers helps bring down fugitive emissions during handling as well.

PIMPRI-CHINCHWAD

Innovation in the collection system

Developing the C&D waste collection system: Pimpri-Chinchwad is a rapidly developing city in the Pune urban area. The Pimpri-Chinchwad Municipal Corporation (PCMC) began dedicated C&D waste management in 2019 and set up a C&D waste recycling plant in 2020. The Corporation identified the need to improve the collection of C&D waste and curb illegal disposal after observing numerous incidents of illegal dumping across the municipal area. However, being short-staffed, it planned to hire a private agency to look after city's enforcement needs.

Figure 1: Key aspects of PCMC's third party engagement for surveillance

ILLEGAL DUMPING AFFECTING COLLECTION EFFICIENCY IN PIMPRI-CHINCHWAD

THIRD PARTY ENGAGEMENT FOR SURVEILLANCE

Regulation and Enforcement

- Ensures compliance with PCMC's C&D waste disposal and collection protocols
- Focus on curbing illegal dumping in public spaces

Surveillance and Monitoring

- Deployment of 39 personnel, including field staff, supervisors, and a project manager
- Continuous surveillance through dedicated squads covering eight collection points
- Use of patrolling and vigilance teams to track and report violations
- Integration of technology for monitoring and reporting (GPS, cameras)
- Imposing on-the-spot challans on defaulters and impounding unauthorized vehicles

Penalties and Fines

60% of the fines collected are to be kept by the agency while the rest goes to PCMC

Rs 4,000 per ton fine for illegal dumping in public areas

Rs 5,000 fine for transportation of C&D waste without proper covering

Fines are registered through an online portal, ensuring transparency

This outsourcing of surveillance and enforcement brought personnel, technology and equipment to PCMC through which it seeks to strengthen compliance. This initiative commenced in 2024 and brought into play a more accountable and efficient waste management system by ensuring the C&D waste reached the plant, while mitigating the environmental hazards of open dumping, such as dust pollution and contamination of waterbodies.

The PCMC has looked at the engagement in detail to prevent role overlaps and gaps. While the third party brings to the table several resources, their primary duty is to ensure compliance with the PCMC's C&D waste-related protocols and cracking down on illegal dumping. The third party is to be paid to compensate for the humanpower it brings and with 60 per cent of the fines collected, according to the agreement. This approach incentivises the agency to impose fines diligently, ensuring no defaulters are overlooked. The PCMC has also defined penalties for specific offense and created an online portal to enter details of the imposed fines to maintain transparency.

NOIDA

Controlling fugitive dust from the recycling plant

As a number of cities set up their C&D waste recycling facilities, their need to comply with dust control norms and demonstrate good dust mitigation practices has also increased. With a direct bearing on the health of the workers at the plant and of nearby citizens, these practices have become paramount. The C&D waste recycling plant at Noida demonstrates these practices clearly and strongly. To check the air quality at the plant, a test is carried out every three months in which the concentration of various pollutants including heavy metals (lead, arsenic, etc) is assessed.

According to an estimation based on US Environment Protection Agency benchmarks, three broad dust control measures from CPCB guidelines on environmental management of C&D wastes can bring down PM10 emissions drastically:

- **Proper management of unpaved roads**: Measures such as limiting vehicle speed, applying water or dust suppressants, and paving the surface can bring down fugitive dust emissions by 57 to 73 per cent.

- **Material handling:** Measures such as covering stockpiles during high wind, implementing wet dust suppression measures and erecting three walls around stockpiles can lead to a reduction from 72 to 85 per cent.

- **Installation of wind barriers**: Installing wind barriers around the site can lead to a reduction scenario ranging from 4 to 88 per cent.

Covered transportation (left), wetting of debris (middle) and covered storage (right)

Cumulatively, the three measures have the potential to reduce dust emissions by up to 93 per cent. Noida has taken dust control measures beyond these categories.

SECURED BOUNDARY

The entire site has seven-metre high wind barriers made of metal sheets running along the boundary of around 500 m. As per the plant operator, this boundary was erected in 2020 at a cost of about Rs 30 lakh.

The site also has a vegetative buffer running along the wind barriers. The buffer varies from 3 to 6 m in thickness. Nearly 13-15 tree species, including Chukrasia, Kanner, Banana, Bamboo, Jamun, and Neem have been planted. Trees act as natural dust barriers as they trap particulate matter on their leaves. Over time, dust build-up reduces their effectiveness, so they are periodically washed to maintain their role as filters. Regular cleaning also supports tree health and helps reduce dust in the area.

MATERIAL HANDLING

Material handling is required at different stages of C&D waste processing at the plant. It involves loading, unloading, storage, transportation and processing of materials — all of which require specific attention and handling to arrest fugitive dust.

Covered transportation: At the first step, trucks carrying C&D waste to the plant are covered with a green net. Before unloading, a worker sprinkles a generous amount of water on the waste to control the dust. Once dumped in the storage area, the waste is kept under cover to prevent dust dispersion caused by wind movement.

Processing takes place within a covered area; there is also a vegetative barrier outside the recycling shed

Wetting of roads, wind barrier, and low drop height at the collection centre

Processing in enclosures: The processing of C&D waste, including activities like sorting, crushing and screening, takes place inside an enclosed structure approximately 80 m x 25 m in size; the enclosure is made up of metal sheets. Additionally, a vegetative barrier of trees has been established around the outer periphery of the shed. An anti-fogging machine, connected to a water tank on a vehicle, discharges fine mist to control dust during the first crushing phase.

Paved base and an extensive drainage system: Debris falling from conveyor belts dries into dust and impacts air quality. Regular cleaning is challenging on unpaved surfaces, so the plant is paving areas under equipment for easier maintenance and dust reduction. Additionally, stormwater drains prevent stagnation, which can create mud that dries into airborne dust and also damages surfaces. An extensive drainage system helps minimise this and maintains surface integrity.

Management of roads: The waste carrying trucks travel to the dumping point at the plant, with high-pressure sprinklers keeping the path wet. Initially, the system was automatic in which the sprinklers activated once dust was detected at the site. This system was found to be too water-intensive and was replaced with a manual system. A staff member monitors the wetness levels of the road and turns on the sprinklers based on requirement. Wherever the sprinklers are not present, the wetting is carried out manually by a vehicle.

Recently, the plant paved a dedicated pedestrian path, separate from the vehicular route, to reduce dust. The new surface minimises dust and maintenance issues.

Cleaning of fallen debris: The plant regularly cleans the places where mud and debris accumulate, especially after the rain. If not removed, this could dry into dust or spread via vehicle tires, worsening the air quality.

BEYOND THE PLANT

Noida has 14 collection points for depositing C&D waste. Dust mitigation measures have been implemented at these collection points to minimise fugitive dust generated during the loading, unloading, and handling of the waste. The ground at the collection points is regularly sprinkled with water, and a 4-5 meter wind barrier wall helps contain dust during loading and unloading. Vehicles transporting C&D waste remain covered with a cloth, removed only during loading and unloading. The drop height while unloading the waste is kept minimum to avoid fugitive dust from escaping.

ANNEXURE

CITY-WISE FUNDING STATUS AND UTILIZATION UNDER NATIONAL CLEAN AIR PROGRAMME (NCAP)

City-wise detailed information on the financial status and utilization of funds for 127 cities is provided under NCAP and XV-FC for the FY 2019-20 to 2024–25 (till date, as on 7 May 2025). This is linked to the funds released to 82 cities under NCAP from 2019–25 and to 48 cities under the XV-FC programme from 2020–25 totaling Rs 12368.63 crores (for 130 cities). (till 7 May 2025) (see *Table 1: City-wise status of fund utilization under NCAP, FY 2019–20 to 2024–25*).

Index	
Fund utilization (%)	
Above 100%	
80-100%	
60-80%	
40-60%	
20-40%	
below 20%	

Table 1: City-wise status of fund utilization under NCAP, FY 2019–20 to 2024–25 (till 7 May 2025)

Note- Fund details for three cities—Patna, Thane, and Sangareddy—are not available on the PRANA portal.

- Total fund released for 127 cities-12072.46 Cr
- Total fund utilized by 127 cities-8277.31 (68.56%)

S.no	City name	Fund released (in Crores)	Fund utilized (in Crores)	Fund utilization (%)
1	Ulhasnagar	2.1	22.52	>100.00
2	Badlapur	2	8.91	>100.00
3	Navi Mumbai	9.45	52.92	>100.00
4	Rajahmundry	7.87	8.23	>100.00
5	Angul	1.61	1.66	>100.00
6	Chandigarh	32.81	33.63	>100.00
7	Howrah	5	5.11	>100.00
8	Jhansi	11.08	11.27	>100.00
9	Gorakhpur	66.87	67.06	>100.00

S.no	City name	Fund released (in Crores)	Fund utilized (in Crores)	Fund utilization (%)
10	Kala Amb	3.9	3.9	100.00
11	Cuttack	20.93	20.93	100.00
12	Talcher	3.07	3.07	100.00
13	Barrackpore	2	2	100.00
14	Bhubaneswar	26.68	26.65	99.89
15	Ongole	7.87	7.86	99.87
16	Akola	9.61	9.51	98.96
17	Vasai-Virar	72.35	71.38	98.66
18	Solapur	40.35	39.8	98.64
19	Rourkela	13.26	13.07	98.57
20	Thoothukudi	13.4	13.08	97.61
21	Jaipur	344.7	335.82	97.42
22	Chandrapur	6.99	6.74	96.42
23	Kohima	9.8	9.41	96.02
24	Allahabad	240.32	230.31	95.83
25	Vizianagaram	5.31	5.04	94.92
26	Amravati	34.64	32.83	94.77
27	Moradabad	79.09	74.64	94.37
28	Dhanbad	69.09	65.01	94.09
29	Dewas	7.95	7.43	93.46
30	Kashipur	7.29	6.76	92.73
31	Jalna	6.35	5.88	92.60
32	Nellore	21.4	19.8	92.52
33	Firozabad	47.78	44.01	92.11
34	Kadapa	8.48	7.81	92.10
35	Nalgonda	5.29	4.87	92.06
36	Vadodara	154.76	142.43	92.03
37	Balasore	3.95	3.56	90.13
38	Silchar	7.81	7.03	90.01
39	Gwalior	102.64	91.83	89.47
40	Anpara	2.41	2.14	88.80
41	Gajraula	4.41	3.91	88.66
42	Meerut	174.62	152.78	87.49
43	Madurai	85.94	75.11	87.40

S.no	City name	Fund released (in Crores)	Fund utilized (in Crores)	Fund utilization (%)
44	Sunder Nagar	2.3	2.01	87.39
45	Eluru	5.21	4.55	87.33
46	Udaipur	17.5	15.19	86.80
47	Parwanoo	1.96	1.7	86.73
48	Paonta Sahib	2.06	1.78	86.41
49	Guntur	17.34	14.98	86.39
50	Gobindgarh	5.64	4.84	85.82
51	Baddi	3.11	2.66	85.53
52	Srikakulam	3.96	3.38	85.35
53	Bareily	73.35	62.46	85.15
54	Bhopal	232.04	195.01	84.04
55	Kurnool	6.33	5.28	83.41
56	Surat	318.93	265.88	83.37
57	Chitoor	6.14	5.08	82.74
58	Indore	236.2	194.38	82.29
59	Chennai	467.22	384.33	82.26
60	Ludhiana	97.75	80.24	82.09
61	Pune	271.3	222.57	82.04
62	Rishikesh	9.78	7.94	81.19
63	Sangli	11.65	9.45	81.12
64	Amritsar	89.75	72.46	80.74
65	Jabalpur	153.08	123.48	80.66
66	Guwahati	39.23	31.52	80.35
67	Nalagarh	2.26	1.81	80.09
68	Lucknow	467.32	373.36	79.89
69	Aurangabad	68.3	54.44	79.71
70	Trichy	75.35	59.75	79.30
71	Korba	4.69	3.68	78.46
72	Khanna	7	5.49	78.43
73	Raebareli	15.62	11.99	76.76
74	Kota	131.47	100.68	76.58
75	Dehradun	51.2	38.7	75.59
76	Khurja	18.37	13.71	74.63
77	Jammu	25.08	18.53	73.88

S.no	City name	Fund released (in Crores)	Fund utilized (in Crores)	Fund utilization (%)
78	Kolhapur	24.11	17.57	72.87
79	Haldia	10.33	7.42	71.83
80	Muzzafarpur	17.06	12.22	71.63
81	Byrnihat	7.95	5.45	68.55
82	Damtal	1.91	1.29	67.54
83	Dera Bassi	1.34	0.89	66.42
84	Kolkata	1129.02	749.15	66.35
85	Kalinga Nagar	5.1	3.38	66.27
86	Ghaziabad	224.42	148.3	66.08
87	Asansol	87.6	57.44	65.57
88	Patiala	21.18	13.8	65.16
89	Kanpur	462.49	299.64	64.79
90	Agra	323.89	208.66	64.42
91	Naya Nangal	3.37	2.17	64.39
92	Dimapur	10.2	6.56	64.31
93	Latur	17.37	11.03	63.50
94	Alwar	21.89	13.74	62.77
95	Ahmedabad	650.79	404.44	62.15
96	Ranchi	93.5	57.39	61.38
97	Mumbai	938.59	574.64	61.22
98	Hyderabad	717.57	435.11	60.64
99	Bhilai	141.6	85.79	60.59
100	Durgapur	44.58	26.78	60.07
101	Raipur	149.35	89.49	59.92
102	Rajkot	137.94	79.31	57.50
103	Jodhpur	145.69	80.46	55.23
104	Nashik	91.55	50.43	55.08
105	Sagar	14.92	7.87	52.75
106	Varanasi	348.84	181.47	52.02
107	Gaya	12.45	6.47	51.97
108	Nagpur	142.05	69.59	48.99
109	Nagaon	8.8	4.27	48.52
110	Hubli-Dharwad	19.15	8.96	46.79
111	Jalgaon	5.64	2.59	45.92

S.no	City name	Fund released (in Crores)	Fund utilized (in Crores)	Fund utilization (%)
112	Jamshedpur	116.85	51.69	44.24
113	Nalbari	6.81	2.9	42.58
114	Jalandhar	45.44	17.64	38.82
115	Delhi	42.69	16.44	38.51
116	Gulburga	23.48	8.98	38.25
117	Sibsagar	8.03	3.04	37.86
118	Pathankot/Dera Baba	6.73	2.48	36.85
119	Vijayawada	130.35	40.88	31.36
120	Srinagar	90.87	28.45	31.31
121	Bangalore	541.1	166.79	30.82
122	Faridabad	94.53	28.61	30.27
123	Ujjain	20.23	6	29.66
124	Anantapur	11.46	2.33	20.33
125	Devanagere	19.79	3.58	18.09
126	Vishakhapatnam	129.25	19.27	14.91
127	Noida	30.89	3.44	11.14
	Total	**12072.46**	**8277.31**	**68.56%**

Source- PRANA Portal, as on 7 May 2025

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India's National Clean Air Programme (NCAP) has helped establish the national air quality management framework in the country. For the first time, non-attainment cities have been identified, given clean air targets, and made accountable for meeting them, and a performance-linked funding strategy has been adopted for air quality management.

This assessment report attempts to understand how this framework has catalysed good practices in the key sectors of pollution: vehicles, industry, solid waste and construction and demolition waste. It finds that the convergence of several other programmes and funding strategies in each sector has played a bigger role in driving action. This alignment will be important in the future.

This review is not a report card on what all cities have done, but an assessment of selected case studies from these sectors. The aim is to present a learning curve, and to understand how NCAP can be made more purposeful to drive implementation.

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