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GOVERNANCE FRAMEWORK FOR AIRSHED-LEVEL AIR QUALITY MANAGEMENT IN SOUTH INDIA

Governance Framework for Airshed-Level Air Quality Management in South India

Shivani Sharma

Dr Nirav L Lekinwala

Dr Nidhi Malik

Faiza Khalil

Harshitha KM

Dr Piyush Bhardwaj

Swagata Dey

Center for Study of Science, Technology and Policy (CSTEP)

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Bengaluru
No. 18, 10th Cross, Mayura Street
Papanna Layout, Nagashettyhalli
RMV Stage 2, Bengaluru 560094
Karnataka (India)

Noida
1st Floor, Tower-A
Smartworks Corporate Park
Sector 125, Noida 201303
Uttar Pradesh (India)

Tel.: +91 (80) 6690 2500
Email: cpe@cstep.in

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Executive Summary

Air pollution in South India typically receives less attention than other polluted regions in India. Except for national-level regulations, focused policy efforts on emission mitigation have largely been concentrated in Delhi-NCR and states in the Indo-Gangetic Plain (IGP), where higher levels of pollution are observed. The South Indian region, however, still includes about 25 of the 131 non-attainment (NA) cities listed under the National Clean Air Programme (NCAP). For the major urban regions in southern India, the Central Pollution Control Board (CPCB) monitoring data from 2021 to 2025 indicate that the annual average PM_{10} levels exceed the annual National Ambient Air Quality Standards, while $PM_{2.5}$ remains below the annual standard in all cities, except Visakhapatnam. However, these numbers have been increasing in some cities, indicating the need for a proactive management approach to curb the rising air pollution.

NCAP has allocated about INR 2,862 crore to NA cities since 2019–2020. The XVth Finance Commission provides an additional INR 13,561 crore to million-plus urban agglomerations. However, only 9 of the 131 funded cities have met the 40% reduction target for PM_{10} under NCAP, and most cities remain above the limit of 60 $\mu g/m^3$. The challenge is structural, stemming partly from NCAP's initial city-level focus. Cities can regulate only the emissions within their own boundaries, but a share of the observed pollution originates outside. Thus, air quality management efforts must extend beyond city jurisdictions to achieve effective improvement. To draw attention to the rising air pollution levels in South India and promote regional coordination among the states for air quality action, this study proposes a modelling-based policy framework for tackling cross-border air pollution in South India.

Chemical transport modelling-based estimates were used to quantify the contribution of five South Indian states to each other's pollution levels. Between the southern Indian states, at an annual average level, 38%–65% of the pollution originates from the region, while the remaining is transported. The local contribution in all South Indian states is lowest in Telangana (38%), Andhra Pradesh (44%), and Karnataka (47%) and highest in Tamil Nadu (61%) and Kerala (65%). The results also indicate that unlike Delhi-NCR or IGP, the transboundary contribution in South Indian states varies depending on prevailing meteorological conditions and their geographic locations. While the major emission sources are still the same, their strengths and relative contributions vary between states. Based on the modelling results, a regional cooperation framework can be built, in which these states work in sync to develop aligned policies and achieve clean air.

The regional coordination framework for states has a precedent in India. The establishment and operation of the Commission for Air Quality Management in National Capital Region and Adjoining Areas (CAQM) demonstrate how a statutory body with jurisdiction over several states is functional within India's federal structure and can deliver results. As per reports by the CAQM, paddy stubble burning dropped by 90% in 2025 compared with 2022. Industrial coal use in the National Capital Region has been almost entirely phased out. Delhi's annual particulate matter levels have declined gradually since 2016 until 2019 and remained steady in the past few years. There are limitations too. Directions do not translate

automatically into action because delivery rests with the states. Further, CAQM also has no financing mechanism of its own.

The National Green Tribunal has made regional coordination a formal requirement. In its order dated 28 April 2026, it notes that air pollution crosses administrative boundaries and requires a regional or airshed perspective. It directed the Ministry of Environment, Forest and Climate Change and CPCB to establish institutional arrangements for coordination among the southern states. This report is aligned with that direction. It combines the modelling evidence with institutional design to set out a phased pathway for the five states to work together.

This report proposes building that coordination in two stages. The first stage involves voluntary cooperation. The states agree to a common regional goal, and each state then chooses its own measures based on the modelling results and the policy instruments available to it. This stage is easier to begin and builds the shared inventory and monitoring and financing arrangements that any binding authority would need.

The second stage involves establishing a statutory body for the five states, termed the Peninsular Air Quality Regional Coordination (PARC), by consent under Article 252 of the Constitution—the route used to enact the Water Act of 1974 and the Air Act of 1981. PARC would set binding regional targets and hold member states accountable, with implementation resting with the states. This stage offers legal force and a single point of accountability, but an enforcement-first design is difficult to establish without the shared evidence base and coordination habits developed in the first stage.

Both stages need the same three instruments: a harmonised Peninsular Region Emission Inventory, a shared monitoring dashboard, and a seasonal Peninsular Air Quality Response Protocol (PAQRP).

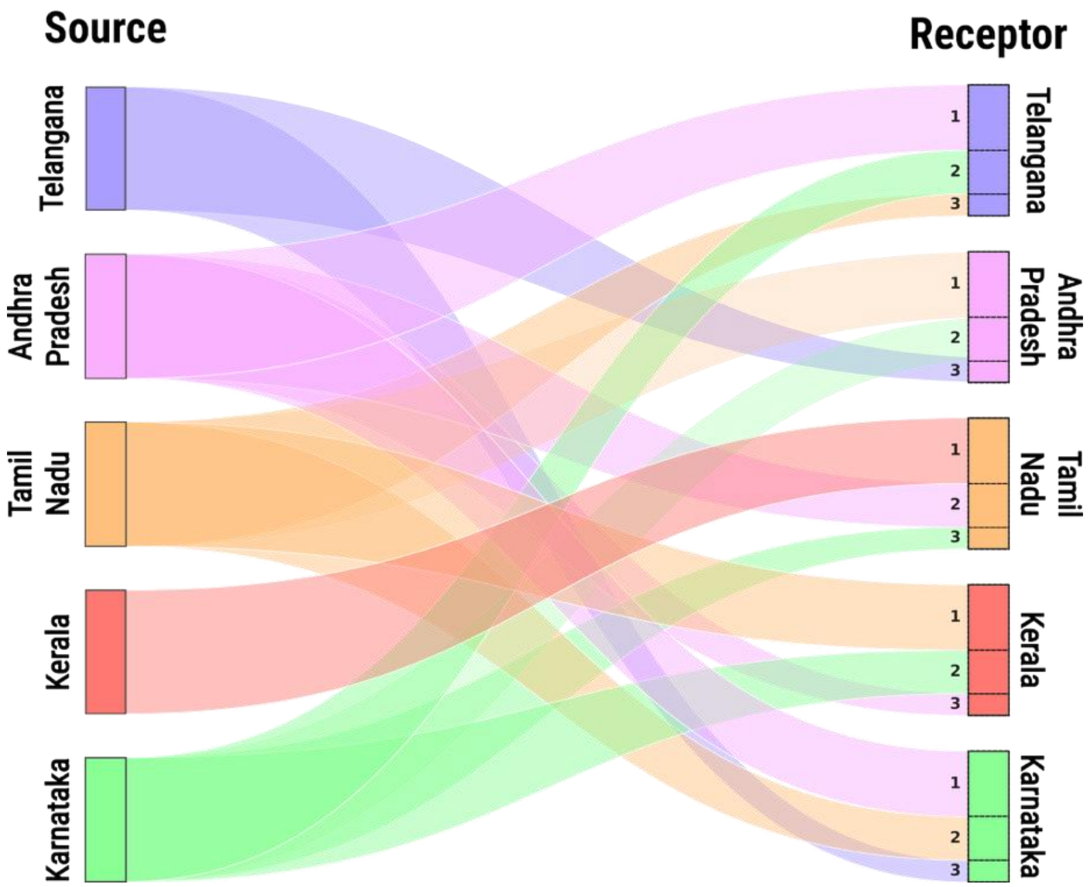
Regarding the various sectors that affect air quality in the region, the report recommends a varying degree of action. The domestic sector needs subsidised refill access, induction cooking, and bio-CNG. Industry needs an approved fuel framework, which has yet to be notified in the five states. Energy needs enforcement of norms that already exist. Transport needs uniform targets for electric vehicle adoption and phasing out of older vehicles.

Further, the report does not recommend establishing a new fund. The Clean Air Financing Convergence (CAFC) mechanism would instead align flows that already exist, from Finance Commission grants to largely unspent environmental compensation, towards these priorities.

Three sets of limitations qualify these findings. First, the model runs at a 25-km resolution with 2019 as the base year. This suits state and regional analysis but not city-level attribution. The model establishes source–receptor relationships. However, it does not project air quality under alternative policy scenarios. Rather, it identifies priority sectors for intervention and state-specific vulnerabilities to transboundary pollution. Limited $PM_{2.5}$ speciation data also restrict validation against ground measurements. The second limitation concerns the emission inventory. India has no comprehensive national emission inventory, so the study relies on global datasets, which are based on gross activity data, lack systematic ground-level validation, and do not capture the sub-monthly variation in emissions. Emission estimates, therefore, remain the largest source of uncertainty in this work. The third limitation concerns the governance structure proposed. Both roadmaps depend on sustained political will and robust institutional capacity and preparedness.

However, these considerations need not be a reason to defer action. Instead, it would be recommended that the process be initiated now by developing and adopting an approach suited to the South Indian context, while allowing the framework to evolve over time as more data become available, understanding improves, and institutional capacity is strengthened.

Graphical Abstract



The figure shows the top three non-local contributions to $PM_{2.5}$ over five South Indian states. The source state is shown on the left, and the receptor state is shown on the right.

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Abbreviations

AQI	Air Quality Index
ASEAN	Association of Southeast Asian Nations
BS	Bharat Stage
CAAQMS	Continuous Ambient Air Quality Monitoring Stations
CAFC	Clean Air Financing Convergence
CAMx	Comprehensive Air Quality Model with Extensions
CAQM	Commission for Air Quality Management in National Capital Region and Adjoining Areas
CEDS	Community Earth-Atmospheric Data Systems
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CNG	Compressed Natural Gas
CPCB	Central Pollution Control Board
CSR	Corporate Social Responsibility
DG	Diesel generator
DPF	Diesel Particulate Filter
EDGAR	Emissions Database for Global Atmospheric Research
EU	European Union
EV	Electric vehicle
GFED	Global Fire Emission Database
GRAP	Graded Response Action Plan
LPG	Liquefied Petroleum Gas
MEL	Monitoring, Evaluation and Learning
MoEFCC	Ministry of Environment, Forest and Climate Change
NA	Non-attainment
NAAQS	National Ambient Air Quality Standards
NCAP	National Clean Air Programme
NCR	National Capital Region
NGT	National Green Tribunal
Nox	Nitrogen oxides
PM	Particulate matter
$PM_{2.5}$	Particulate matter with a diameter of 2.5 μm or less
PM_{10}	Particulate matter with a diameter of 10 μm or less

PAQRP	Peninsular Air Quality Response Protocol
PARC	Peninsular Air Quality Regional Coordination
PNG	Piped Natural Gas
PSAT	Particulate Source Apportionment Technology
RTO	Regional Transport Office
SATAT	Sustainable Alternative Towards Affordable Transportation
SIP	State Implementation Plan
SPCB	State Pollution Control Board
STU	State Transport Undertaking
ULB	Urban Local Body
USEPA	United States Environmental Protection Agency
WRF	Weather Research and Forecasting

1. Air quality in South India

Air pollution in South India often receives far less attention than the severe pollution levels in northern and central India. Yet, concentrations of PM_{10} and, in some cases, $PM_{2.5}$ continue to exceed the National Ambient Air Quality Standards (NAAQS) in major cities across the region. Annual average PM_{10} and $PM_{2.5}$ concentrations calculated from the Continuous Ambient Air Quality Monitoring Station (CAAQMS) in Bengaluru, Kochi, Chennai, Visakhapatnam, and Hyderabad during 2021–2025 indicate PM_{10} levels mostly exceeding the NAAQS, despite interannual variability (Figure 1). In contrast, $PM_{2.5}$ levels remain below the annual NAAQS in all cities except Visakhapatnam, with a slight year-on-year increase observed in the CAAQMS data for the selected cities (Figure 2). Overall, these findings indicate that while PM_{10} remains a persistent air quality concern in South India, the increasing trend in $PM_{2.5}$ should not be neglected, given its impacts on public health.

Figure 1: Annual average PM_{10} concentrations in major South Indian cities (2021–2025) based on CAAQMS data

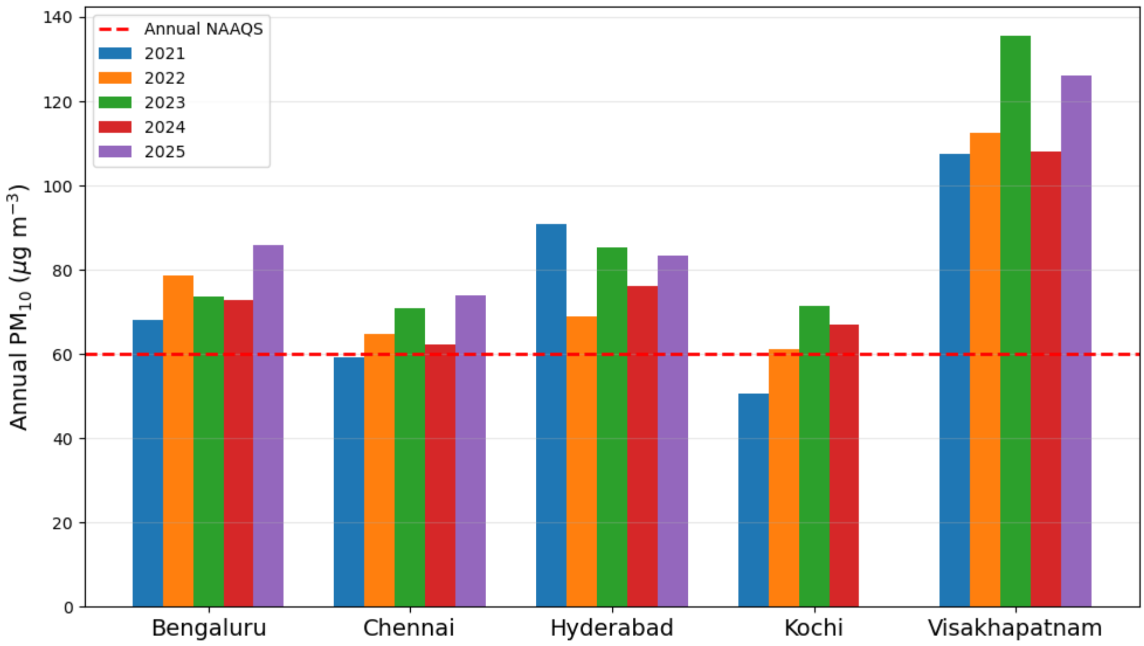
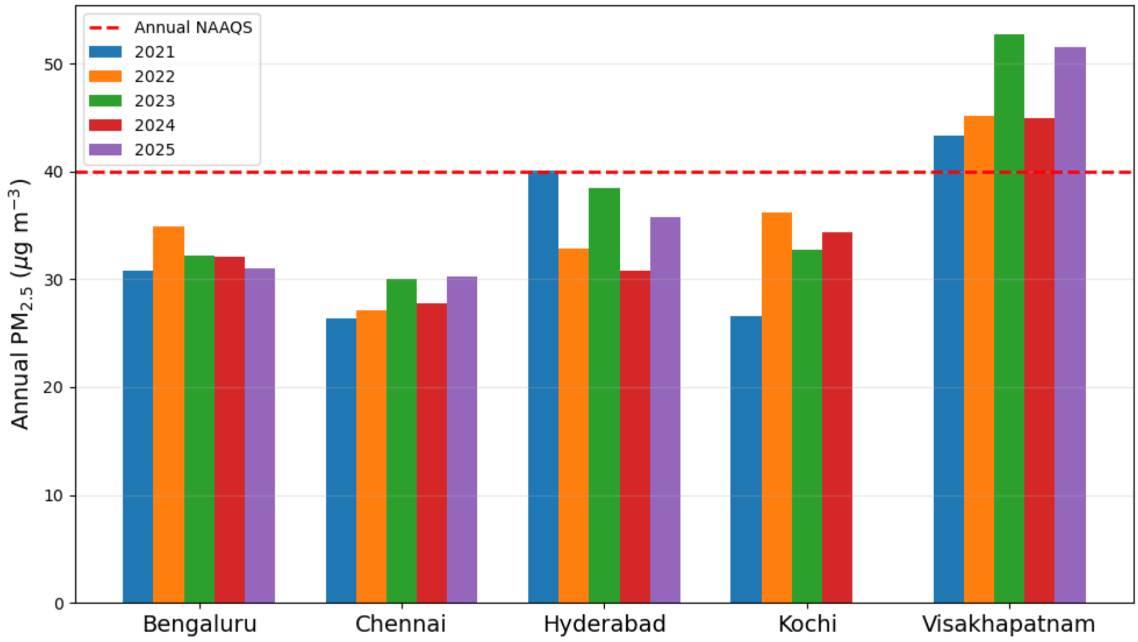


Figure 2: Annual average $PM_{2.5}$ concentrations in major South Indian cities (2021–2025) based on CAAQMS data



In recent years, substantial resources have been diverted to pollution control through the National Clean Air Programme (NCAP), and most cities in the region have also implemented measures to reduce local emissions. However, despite these efforts, the improvements in air quality have been limited.

Currently, a major gap in air quality management is the control of non-local pollution sources in these cities. As a result, a city implementing rigorous vehicular emission controls or waste management practices will continue to face severe air pollution if industrial clusters, power plants, and agricultural burning in neighbouring states or regions contribute the bulk of ambient concentrations. Thus, air quality over a city and state is not determined solely by sources located within its own boundaries but is also substantially influenced by upwind sources. A region can be upwind (a source of pollution) or downwind (a recipient of pollution) depending on prevailing geographical conditions and wind patterns. In South India, where transboundary pollution transport is substantial and varies by season, air quality action must shift from a city-level to an airshed-level approach.

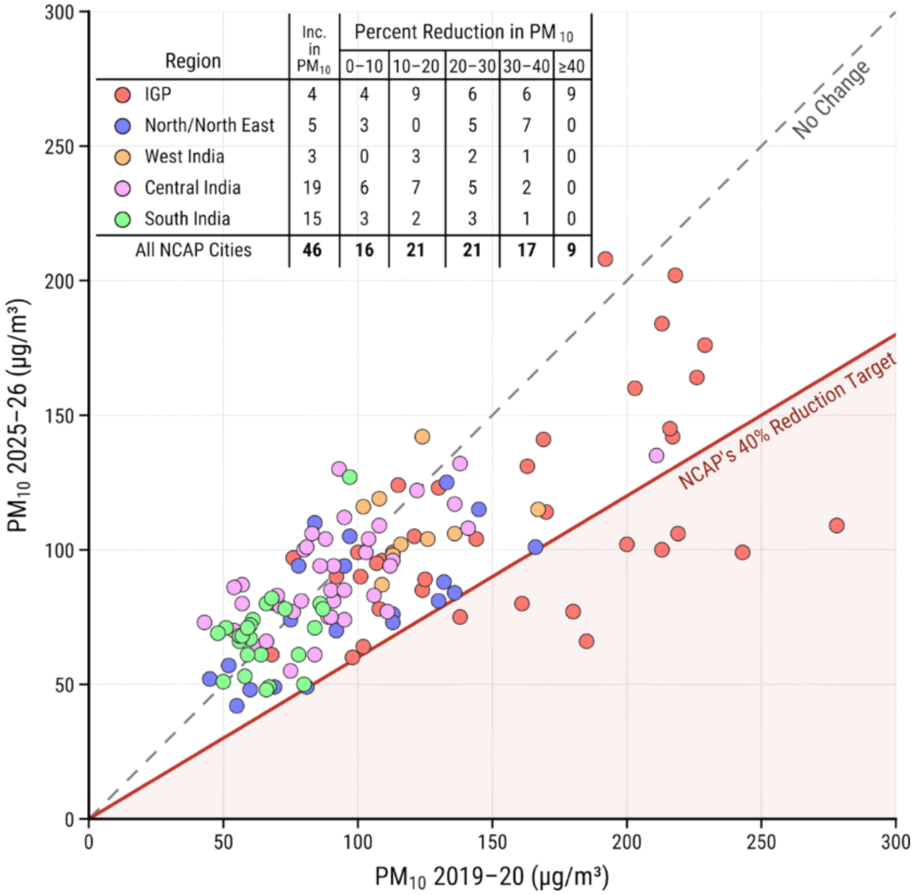
An airshed is a geographic area where pollutants are transported and accumulate, often resulting in similar air quality across the region. Its boundaries are shaped by meteorology and topography rather than political boundaries and can therefore extend across multiple districts and states. Specific to the South Indian region, several studies have attempted to define the airshed based on meteorology (Zaid and Sahu, 2025), agro-climatic zones (Guttikunda, 2024), and dominant source contributions (Brauer et al., 2019). While parts of all five states (Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, and Telangana) are included in the same airshed, none of these studies define the airshed's geographical boundaries. Regional cooperation to improve air quality can be developed based on geography, meteorological similarities, and shared pollution issues, whether seasonal or year-round.

However, when an airshed extends across regions or districts in another state, coordination moves beyond a single state's jurisdiction and becomes more complex owing to differences in rules and regulations across states. Therefore, a framework that brings multiple states together is needed to address shared air quality challenges in all five South Indian states. Such cooperation can form the basis for a multi-jurisdictional air quality management plan.

1.1. Current air pollution management under the National Clean Air Programme

The NCAP was launched in 2019 by the Ministry of Environment, Forest and Climate Change (MoEFCC), with a focus on implementing sectoral policies, strengthening monitoring, and enhancing public participation in about 131 non-attainment (NA) and million-plus cities across the country. The goal of the programme was to achieve a 40% reduction in PM_{10} concentrations or meet the ambient air quality standards for PM_{10} of 60 μg/m³ by 2025–2026, relative to levels in 2019–2020. Comparison of PM_{10} concentrations between 2019–2020 and 2025–2026 shows that only nine cities have achieved the intended 40% reduction, and most cities remain above the national standard of 60 μg/m³ (Figure 3).

Figure 3: Change in PM_{10} concentrations over 130 non-attainment and million-plus cities under NCAP (Source: NCAP Tracker, PRANA Portal).



Region	Inc. in PM_{10}	Percent Reduction in PM_{10} 0–10	10–20	20–30	30–40	≥40
IGP	4	4	9	6	6	9
North/North East	5	3	0	5	7	0
West India	3	0	3	2	1	0
Central India	19	6	7	5	2	0
South India	15	3	2	3	1	0
All NCAP Cities	**46**	**16**	**21**	**21**	**17**	**9**

Note: The table in the top-left corner shows the number of cities in a region where PM_{10} concentrations have changed.

Under NCAP, about INR 2,862 crore was allocated to NA cities from 2019 to 2020, while INR 13,561 crore was made available through the 15th Finance Commission grant from 2020 to 2021 to 42 million-plus urban agglomerates. The funds are made available to various urban local bodies (ULBs) to control PM_{10}-emitting sources within their jurisdictions; however, a recent air quality modelling study (Lal et al. 2025) suggested that on an average, about 85% (range: 17%–98%) of the modelled $PM_{2.5}$ concentration over 143 cities (including 122 NCAP NA cities and additional million-plus population cities) is transboundary or non-local in nature. While a city or urban agglomeration can be affected by local sources, such as transport, residential fuel use, industrial activity, construction, demolition, and open burning, these are often supplemented by emissions from rural households, coal-fired power plants and industries, agricultural waste burning, and informal industries such as brick kilns. Although more studies are needed to understand the transboundary nature of pollution, clean air action plans that focus only on local emission sources might not be sufficient to improve air quality and meet NCAP targets. Extending the scope of NCAP to an airshed-level, multi-jurisdictional approach for all NA cities could strengthen its impact and deliver greater reductions in particulate matter (PM) levels.

1.2. Governing air pollution beyond state boundaries

From an implementation perspective, India's current federal structure allows each state to formulate its own policies. One state's environmental policy is independent of another's, even when they affect shared air. Thus, a state cannot impose standards on another or enforce emission controls across borders. This dichotomy between the geography of air pollution and the geography of regulatory powers defines air pollution management in India.

However, this challenge is not unique to India, and several countries have attempted to mitigate transboundary pollution through different mechanisms. The United States Environmental Protection Agency (USEPA) requires upwind states to limit emissions that affect air quality in downwind states and mandates that states prepare a State Implementation Plan (SIP). SIPs set out how each state will meet and maintain the national air quality standards, and USEPA can impose a federal plan if a state's plan is not approvable (United States Environmental Protection Agency, 2026). Further, Europe has established binding regional protocols through the Convention on Long-Range Transboundary Air Pollution (United Nations Economic Commission for Europe, 1979).

India also has set a precedent in transboundary air quality management by establishing the Commission for Air Quality Management in National Capital Region (NCR) and Adjoining Areas (CAQM) in 2021. CAQM is a supra-institutional body that governs a multi-jurisdictional region encompassing parts of three states (Haryana, Rajasthan, and Uttar Pradesh) and the entire Delhi. Created via an ordinance in the parliament, the CAQM issues binding directions to these states and enforces compliance. It has achieved measurable results, including a 90% reduction in stubble-burning incidents and a gradual improvement in Delhi's annual $PM_{2.5}$ levels. This demonstrates that federal coordination on transboundary air pollution is possible within India's constitutional framework. However, CAQM's model addresses a geographically concentrated pollution hotspot in the NCR (with directional pollution transport). The NCR comprises multiple polluted cities located close to one another. This is starkly different from peninsular India, wherein multiple pollution centres are distributed across states. This distributed geography requires a coordination mechanism that works across five states with varying emission profiles and institutional capacities. The mechanism should enable states to address shared problems while accounting for their unique challenges.

Further, recent National Green Tribunal (NGT) orders on air quality management in the southern region have explicitly recognised this need. The NGT has emphasised that 'air pollution transcends administrative boundaries and therefore requires a broader regional or airshed-based perspective'. Most significantly, the NGT has issued a specific direction that 'the Ministry of Environment, Forest and Climate Change (MoEF&CC) and the Central Pollution Control Board (CPCB) establish appropriate institutional arrangements to ensure effective regional coordination and cooperative action among the Southern States'. This judicial mandate recognises that independent state action has reached its limits and that the region requires a governance framework enabling coordinated action (National Green Tribunal, 2026).

Supporting the NGT mandate, this study proposes a framework for regional air quality governance grounded in air quality modelling and observations and shaped by existing governance arrangements, recent NGT orders on regional coordination, and India's federal constitutional structure. The framework rests on one central insight from the modelling: improving air quality in South India requires coordinated action but with flexibility for states in how they address their contributions to regional pollution.

Section 2 of this report presents the modelling methodology and results indicating transboundary pollution and sectoral contributions, highlighting the need for regional coordination. Sections 3–5 provide guidance through the CAQM experience, map existing governance arrangements and policy gaps across the five states, and review international approaches to transboundary air pollution. Section 6 presents a two-stage governance model, identifies sectoral and state-specific priorities based on scientific evidence rather than arbitrary spending patterns, and proposes a funding mechanism aligned with regional needs. The final section addresses limitations and describes future directions.

2. Air Quality Modelling

This section discusses the air quality modelling approach used in this study to assess pollution transported across state borders, the contributing sectors, and variations by season and geography.

2.1. Methodology

This study undertook a comprehensive assessment of regional air pollution transport and source contributions across the five South Indian states, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, and Telangana, using the Weather Research and Forecasting (WRF) model coupled with the Comprehensive Air Quality Model with Extensions (CAMx). The CAMx model is a multi-scale photochemical modelling system for gas- and particulate-phase air pollution and has been approved by the USEPA for developing state-level SIPs. It obtains meteorological and other inputs generated by the WRF model, as well as emissions from various anthropogenic and natural sources. The Particulate Source Apportionment Technology (PSAT) module in CAMx is used to quantify the regional and sectoral contributions of $PM_{2.5}$ from one region to another. The modelling framework uses a global emission inventory that provides emissions of air pollutants classified into six major sources. These results establish baseline source–receptor relationships identifying where emissions originate, where they impact, and to what extent, indicating the most vulnerable states and the sectors contributing to the pollution burden in each state. This dual insight enables state-specific and sector-specific recommendations. For example, if domestic energy use in state A degrades air quality in state B, the governance framework must ensure that state A prioritises energy transition as a regional responsibility. The governance framework, described in Section 6, ensures that sectoral priorities and recommendations are grounded in actual pollution patterns.

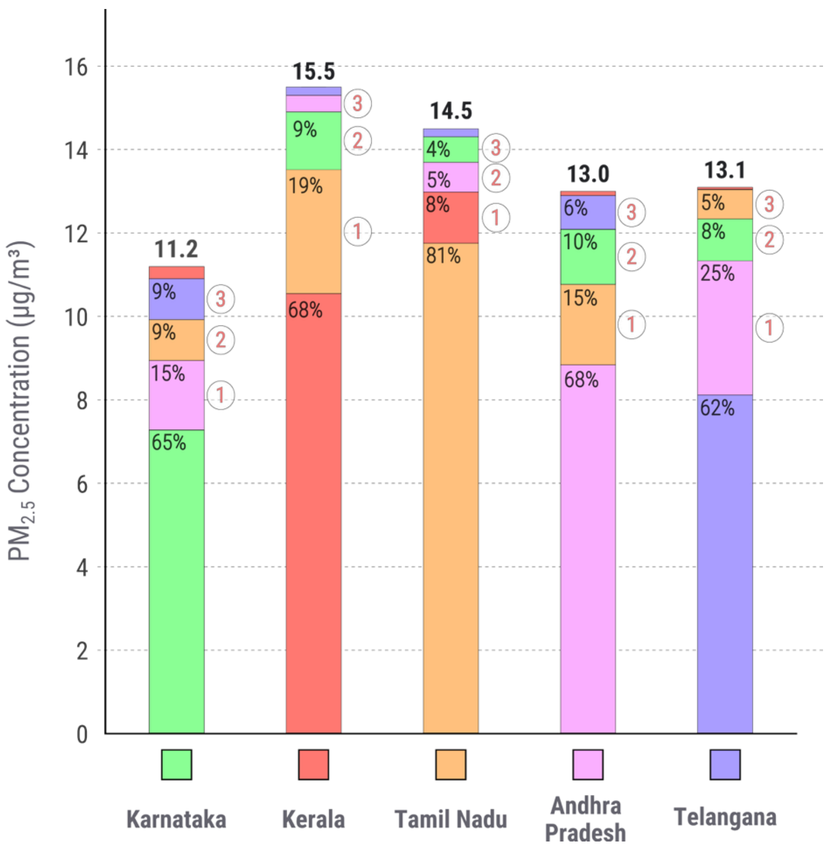
For this work, the model is run for the base year of 2019 at a 25-km spatial resolution. The emission data include a combination of multiple emission inventories: Community Earth-Atmospheric Data Systems (CEDS, McDuffie et al., 2020) for major anthropogenic emission sources, Global Fire Emissions Database (GFED v4.1, Randerson et al., 2017) for crop-residue burning and forest fire-related emissions, Emissions Database for Global Atmospheric Research (EDGAR v6.1, Crippa et al., 2022) for emissions from the aviation sector, WRF-Chem simulations for natural dust emissions (Singh et al., 2021), Copernicus Atmosphere Monitoring Service. Global Biogenic VOC emissions (CAMS-GLOB-BIO version 3.1, Sindelarova et al., 2022) and a CAMx utility to calculate emissions from oceanic sources. The initial and boundary conditions needed for the model are obtained from the Whole Atmosphere Community Climate Model. To identify the contribution of any region or source to a receptor, the PSAT tool in CAMx was used. Results for the regional and sectoral PSAT for the five South Indian states are discussed in the next subsection.

2.2. Results

2.2.1. Interstate transport pathways and source–receptor relationships

The five South Indian states exhibit distinct source–receptor relationships, with local emissions remaining the dominant contributor to $PM_{2.5}$ concentrations in every state. The regional contribution from one state/region to other states in South India, as simulated with CAMx-PSAT, is presented in Figure A1. Except for Telangana, the regional contribution from just the five South Indian states accounts for more than 40% of the seasonal/annual average $PM_{2.5}$ concentration in the state under consideration. The local contribution is high in Kerala and Tamil Nadu and decreases in the north, as they share borders with more states in peninsular India. Coordinated action among the five South Indian states can lead to a significant reduction in their overall $PM_{2.5}$ concentrations. Figure 4 shows the absolute contributions of different South Indian states to one another, after excluding contributions from other regions. In contrast, local contributions play a major role, and transported contributions are significant during the highly polluted post-monsoon and winter seasons. An example of regional and sectoral contribution to Karnataka is given in the Appendix (Figure A2).

Figure 4: Absolute contributions from and to different states in South India



Note: The x-axis indicates the state under consideration. The numbers in the circle denote the top three ranking states as per South India's contribution to air pollution for the states under consideration, except the state itself.

Annually, Andhra Pradesh is the largest external contributor to Karnataka and Telangana, accounting for about 15% and 25%, respectively, of the contributions from South Indian states after excluding pollution originating outside the region. Tamil Nadu is the dominant external contributor to Kerala (19%), while Kerala contributes about 9% to Tamil Nadu. Karnataka also contributes to Andhra Pradesh (15%), Telangana (9%), and Kerala (9%). In contrast, Kerala contributes less than 5% to Andhra Pradesh and Telangana. Overall, the results show that interstate pollution transport within South India is strongly influenced by geographical proximity, although the magnitude and direction of transport vary among states.

Tamil Nadu maintains a consistently high local contribution throughout the year, indicating that seasonal changes have a comparatively smaller influence on interstate transport of pollution. However, for all other South Indian states, seasonal meteorology modulates the interstate transport patterns. Andhra Pradesh and Telangana are also affected by pollution transported from central and northern India, given their geographical proximity along the northern boundary of the proposed South India Regional Cooperation (see Figure A1). The source–receptor relationships among South Indian states are presented in Table 1.

Table 1. Seasonal relative contribution (in %) from source states (row) to receptor states (column) in South India

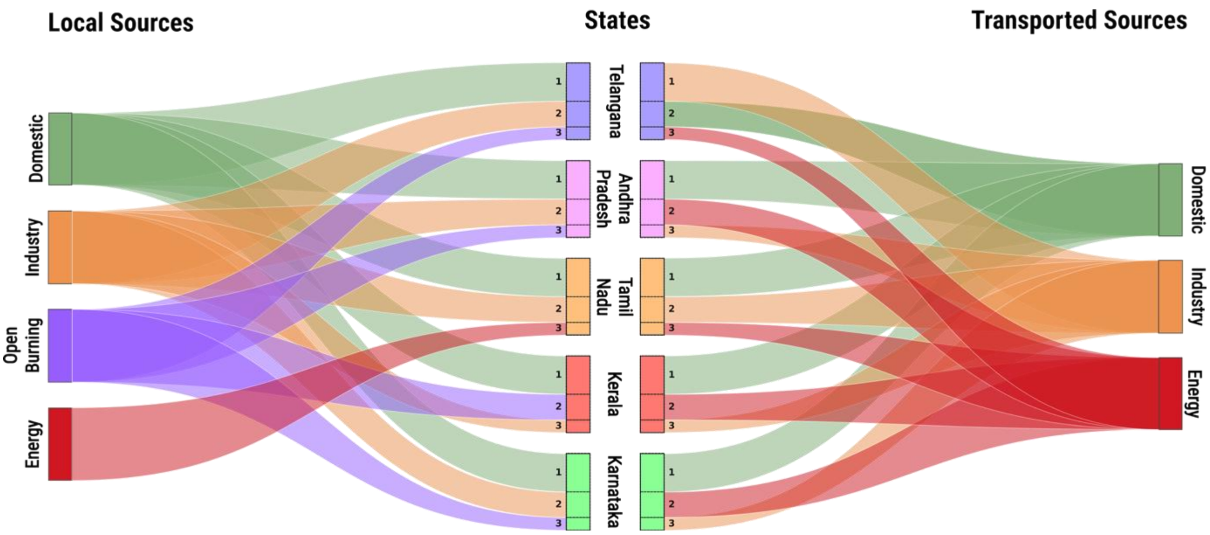
Winter Season (Dec to Feb)						Pre-Monsoon (Mar to May)					
	KA	KL	TN	AP	TS		KA	KL	TN	AP	TS
KA	57.3	1.4	9.2	21.4	10.7	KA	67.1	3.0	13.1	10.3	6.5
KL	9.8	55.3	30.0	4.1	0.8	KL	10.0	69.8	16.5	2.4	1.3
TN	1.8	2.9	86.1	7.7	1.5	TN	4.7	11.5	79.6	2.9	1.4
AP	3.7	0.1	6.1	84.0	6.1	AP	9.3	1.6	26.5	58.8	3.8
TS	2.6	0.0	1.4	28.8	67.3	TS	6.9	0.7	11.8	27.8	52.8
Monsoon (Jun to Sep)						**Post-monsoon (Oct and Nov)**					
	KA	KL	TN	AP	TS		KA	KL	TN	AP	TS
KA	86.0	6.4	2.4	2.6	2.6	KA	66.1	3.0	5.2	15.1	10.6
KL	3.1	94.5	1.4	0.5	0.5	KL	10.8	68.3	16.0	3.1	1.8
TN	7.6	14.3	75.8	1.7	0.6	TN	3.6	6.9	81.3	6.7	1.4
AP	19.7	1.3	13.3	57.7	8.1	AP	7.6	0.6	7.6	76.8	7.4
TS	23.5	0.4	5.0	12.3	58.8	TS	4.3	0.1	0.7	23.7	71.3

Sample interpretation for Karnataka in Winter season: 57.3 % pollution is from Karnataka itself, 21.4% from Andhra Pradesh, 10.7% from Telangana, 9.2% from Tamil Nadu, and 1.4% from Kerala

Unlike the Indo-Gangetic Plain, where severe wintertime pollution in cities such as New Delhi often shapes the regional air quality narrative, South India lacks a single dominant pollution hotspot. Instead, air quality is governed by a network of interacting source and receptor states, with the relative importance of local and transported pollution varying across space and time. This makes regional cooperation particularly important, as improving air quality requires coordinated action across multiple states rather than interventions focused on a single geographic area.

Across all interstate transport pathways, the exchanged $PM_{2.5}$ is predominantly associated with emissions from domestic, industrial, and energy sectors, although the relative importance of these sectors varies between source states. These three sectors account for the majority of pollution transported between South Indian states, highlighting them as the main sectors for coordinated regional emission-control strategies. The sectoral source–receptor relations are presented in Figure 5. Based on this plot, domestic sector, industries, and open burning are the major emission sources at the local level across all five states (except Tamil Nadu, where energy sector is also a major contributor), whereas domestic sector, industries, and energy sector are three major emission sources contributing to transported pollution in all five states.

Figure 5: Sankey diagram showing the top three local and transported emission sources for the five South Indian states

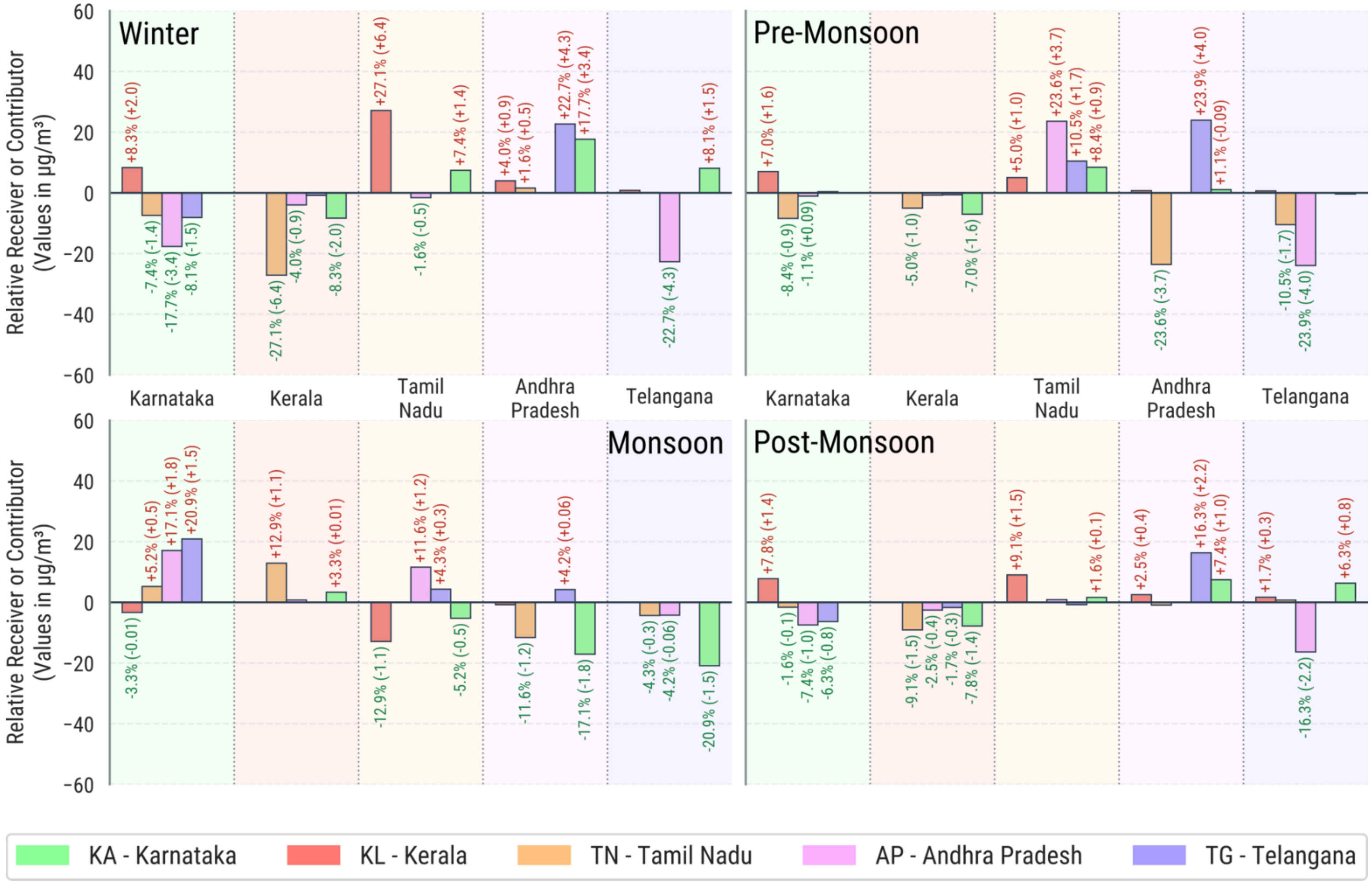


2.2.2. Net contributors and net receivers: Implications for regional coordination

The previous subsection established that interstate pollution transport follows geographical proximity and seasonal patterns. However, this transport is not evenly apportioned; some states export more pollution than they receive, while others absorb more than they contribute to the region. This section examines these disparities and identifies each state's role in the regional pollution system. Understanding these differences is critical for governance design, as they highlight why a uniform approach cannot work: states with different vulnerabilities and responsibilities require different priorities in coordinated action.

These modelling results show that while local emissions remain the dominant contributor to $PM_{2.5}$ concentrations in all five states, the magnitude of interstate transport and the balance between pollution received and exported vary considerably. Tamil Nadu and Andhra Pradesh are net contributors, exporting more to neighbouring states than they receive. Kerala and Telangana are net receivers, whereas Karnataka both receives and exports moderate amounts owing to its central location within the region (Figure 6).

Figure 6: Seasonal and regional contribution (receivers and contributors) to different states in South India



Note: A state is a receiver in a season if the difference in the contribution between two states is negative, whereas a state is a contributor if the difference is positive.

These results highlight that effective regional cooperation should recognise the different roles each state plays as a source, a receptor, or both, rather than assuming that all states contribute equally to the regional pollution burden. Hence, this study recommends establishing a dedicated forum to enable states to jointly plan, review, and monitor regional air quality actions, without equally distributing the burden of transported pollution or altering their existing statutory responsibilities (discussed in detail in Section 6).

2.2.3. Sectoral priorities by state: Quantifying required reductions

Based on the results presented above and the regional and sectoral ranking shown in Figure 6, the domestic sector is the largest contributor to local $PM_{2.5}$ concentrations in all five South Indian states and is also the dominant source of transported pollution within the region. Domestic emissions account for approximately 33% of transported $PM_{2.5}$ in Karnataka, 40% in Kerala, 36% in Tamil Nadu, 30% in Andhra Pradesh, and 37% in Telangana. These emissions are primarily associated with the combustion of solid fuel for cooking and heating. Consequently, policies promoting cleaner technologies and fuels for cooking would simultaneously reduce locally generated and transported pollution across state boundaries. If the emissions from domestic sources were completely eliminated in all South Indian states (a theoretical maximum scenario), it would lead to a theoretical reduction in $PM_{2.5}$ concentrations by approximately 33% in Karnataka, 40% in Kerala, 36% in Tamil Nadu, 30% in Andhra Pradesh, and 37% in Telangana, demonstrating the substantial regional benefits of coordinated action on this sector.

While complete elimination of domestic emissions is not practically achievable, given the scale of the population dependent on solid fuels for cooking and heating, this theoretical 100% reduction scenario establishes an upper limit on the potential air quality improvements achievable through $PM_{2.5}$ emission reductions in the domestic sector. Achieving even partial reductions through a transition to cleaner fuels could still deliver substantial air quality benefits across the region and in neighbouring states.

The industrial sector is the second-largest contributor to transported $PM_{2.5}$ in most states, accounting for approximately 18% in Karnataka, 14% in Kerala, 20% in Tamil Nadu, 22% in Andhra Pradesh, and 19% in Telangana. These emissions originate from industrial clusters and often influence neighbouring states, highlighting the need for harmonised industrial emission standards, cleaner production technologies, and improved compliance across South India. In addition, fuel standards and retrofitting can help deliver significant reductions while supporting long-term economic activity.

The energy sector is the third major contributor to interstate pollution transport, contributing approximately 11% of transported $PM_{2.5}$ in Karnataka, 7% in Kerala, 11% in Tamil Nadu, 14% in Andhra Pradesh, and 13% in Telangana. Because these emissions primarily arise from large stationary sources, such as thermal power plants, coordinated implementation (via Central Government directives) of emission-control technologies, including flue-gas desulphurisation systems and low-nitrogen oxide (NO_x) burners, and stricter emission standards could provide air quality benefits extending well beyond the source state.

The transport sector contributes a comparatively smaller fraction of interstate $PM_{2.5}$, accounting for approximately 9% of transported pollution in Karnataka, 9% in Kerala, 8% in Tamil Nadu, 5% in Andhra Pradesh, and 4% in Telangana. Although this sector contributes less to regional pollution transport than the domestic, industrial, and energy sectors, it remains a major source of urban air pollution. Regional cooperation through harmonised vehicle emission standards, accelerated fleet electrification, improved public transport, and cleaner interstate freight movement could, therefore, complement efforts to reduce emissions from other major sectors.

3. CAQM as a Model for Regional Air Quality Governance

CAQM is a statutory body with multi-state jurisdiction under Section 2(1)(a) of the CAQM Act, 2021, exclusive authority under Section 3(6), and overriding effect under Section 28 over directions issued by other authorities. These features make it a useful model for designing regional air quality governance in India, particularly with respect to institutional design, enforcement mechanisms, and coordination frameworks.

3.1. Evolution of the CAQM Act

CAQM was formally established in 2021, following the recognition that Delhi’s air pollution conundrum was not driven by local sources alone. Because pollution sources spanned multiple administrative boundaries, a supra-institutional governance mechanism was needed to coordinate action across jurisdictions. The Act came into force following amendments to India's constitutional framework under Article 252, which enables the Parliament to extend cooperation among multiple states on matters of national interest. The enactment timeline demonstrates the legal pathway through which India formalised regional air quality governance, a precedent directly relevant to South India (Figure 7).

Figure 7: Evolution of the CAQM Act, India (1998–2021)

INSTITUTIONAL EVOLUTION

1998

EPCA constituted
Environmental Pollution (Prevention and Control) Authority (EPCA) was constituted with the objective of protecting and improving environmental quality and preventing and controlling environmental pollution in the National Capital Region (NCR).

JUDICIAL INTERVENTIONS

16 October 2020

Supreme Court constitutes Lokur Committee
The Supreme Court constituted a one-member committee, headed by retired Supreme Court Justice Madan Lokur, to monitor and oversee stubble burning management.

LEGISLATIVE MILESTONES

28 October 2020

CAQM established through Ordinance
The government promulgated the Commission for Air Quality Management (CAQM) Ordinance, replacing the Lokur Committee and dissolving the Environmental Pollution (Prevention and Control) Authority (EPCA).

12 March 2021

First Ordinance lapses
The Ordinance ceased to operate as no replacement legislation was introduced in the Parliament within the stipulated constitutional time period.

13 April 2021

Re-promulgation of CAQM Ordinance
A revised Ordinance was promulgated introducing important policy changes, including the removal of criminal penalties for farmers involved in stubble burning. Instead, CAQM was empowered to impose environmental compensation where appropriate.

30 July 2021

CAQM Bill introduced
The Commission for Air Quality Management Bill, 2021, was introduced in the Lok Sabha to replace the Ordinance through legislation.

13 August 2021

CAQM Act comes into force
The Commission for Air Quality Management in National Capital Region and Adjoining Areas Act, 2021, came into force, establishing CAQM as the statutory authority for regional air quality management.

Source: Compiled from Supreme Court Orders, Government of India Ordinances (2020 & 2021), and the Commission for Air Quality Management Act, 2021.

3.2. Current role and institutional design

CAQM's jurisdiction extends to Delhi, 8 districts of Uttar Pradesh, 14 districts of Haryana, 2 districts of Rajasthan, with authority over Punjab on matters related to stubble burning. It combines three key functions:

(i) Policy and strategic coordination—setting air quality parameters and emission standards across the region.

(ii) Regulatory and enforcement authority—issuing binding directions to industries, states, and individuals, with powers to restrict activities or impose penalties up to INR 1 crore.

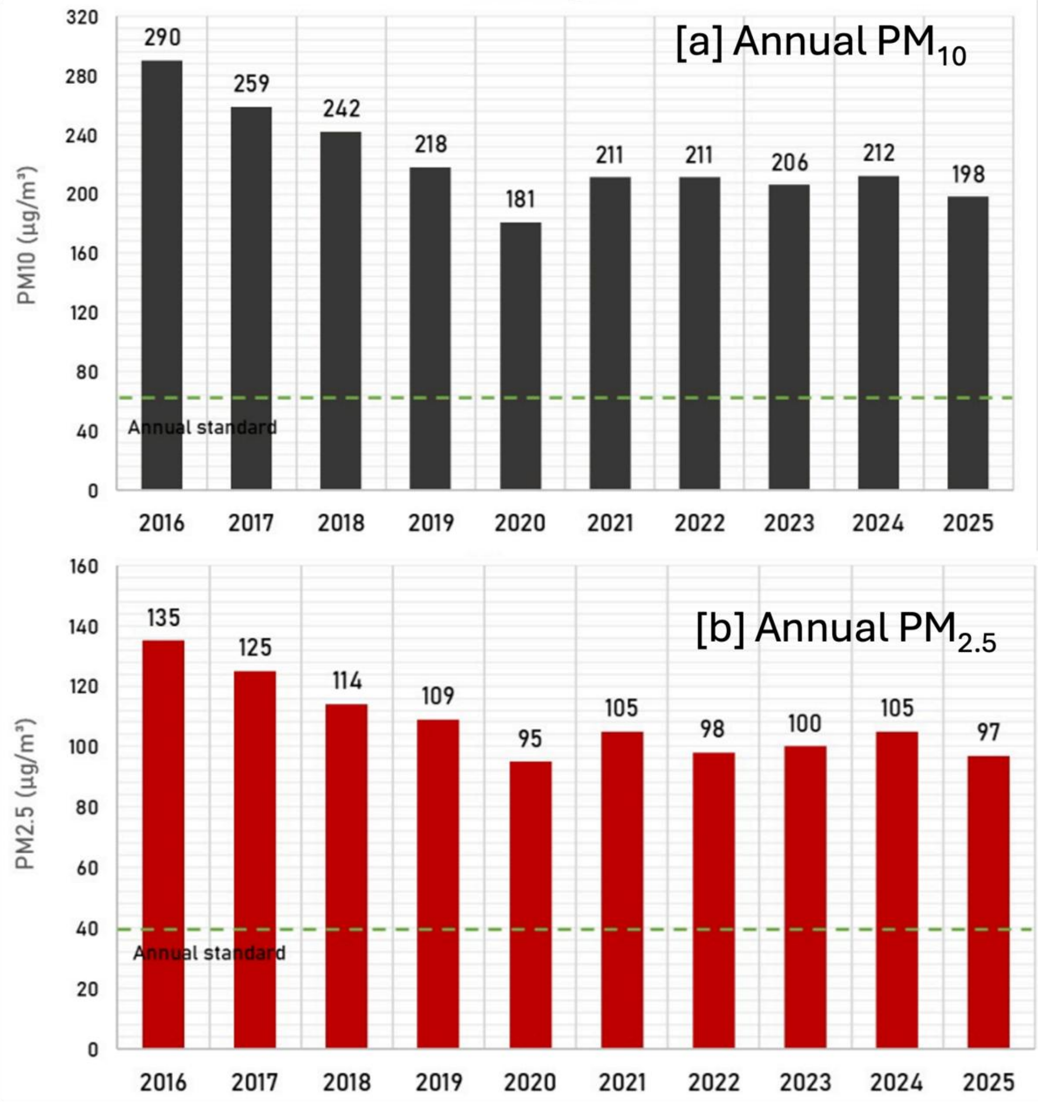
(iii) Monitoring and implementation—tracking compliance, conducting source identification, and coordinating emergency responses (Graded Response Action Plan [GRAP]) based on real-time air quality data.

Institutionally, CAQM operates through three mandatory sub-committees: Monitoring and Identification, Safeguarding and Enforcement, and Research and Development. The Commission is accountable to Parliament through annual reporting and audit by the Comptroller and Auditor General of India. While it operates with a degree of autonomy, it is bound by general directions from the Central Government, and its actions are subject to appeal before the NGT. This institutional design, combining binding authority with democratic accountability, offers a blueprint for establishing an air quality governance framework in South India.

3.3. CAQM in action: Sectoral and institutional approach

Air quality improvements: Despite population growth and urban expansion, annual $PM_{2.5}$ and PM_{10} concentrations in Delhi have remained stable in the post-COVID years. The annual average PM_{10} and $PM_{2.5}$ levels during 2016–2025 are presented in Figure 8. Good-to-Moderate Air Quality Index (AQI) days increased from 159 in 2018 to approximately 200 in 2025, and Poor-to-Very Poor days declined from 186 to 157. Most significantly, the number of Severe and Severe+ AQI days decreased substantially from 20 in 2018 to 8 in 2025. These improvements, although modest, demonstrate that coordinated regional action can deliver measurable benefits over time, even under persistently challenging meteorological conditions.

Figure 8: Annual trends of (a) PM_{10} and (b) $PM_{2.5}$ concentrations in Delhi during 2016–2025



Source: Commission for Air Quality Management in NCR and Adjoining Areas, 2026

Sectoral effectiveness: CAQM has reported specific wins in key emission sectors. First, CAQM's coordinated enforcement, incentives, and monitoring in Punjab, Haryana, and Uttar Pradesh resulted in a 90% reduction in recorded paddy stubble burning incidents in 2025 compared to 2022, demonstrating that multi-state enforcement mechanisms can address agricultural emissions (Commission for Air Quality Management in NCR and Adjoining Areas, 2025). Second, a series of statutory directions (Direction Numbers 30, 31, 42, and 65), issued between September 2021 and June 2022, led to a near-complete phase-out of coal use in industries in the NCR, with cleaner fuels, such as piped natural gas (PNG), liquefied petroleum gas (LPG), and biofuels, made mandatory. Enforcement actions, including fines, have been levied on non-compliant facilities. By 2026, all major industrial clusters in Delhi had shifted to cleaner fuels, and 11 identified thermal power plants (within 300 km of Delhi) had moved towards 10% biomass co-firing (Commission for Air Quality Management in NCR and Adjoining Areas, 2026). Third, CAQM regularly activates and revokes GRAP stages based on real-time AQI and meteorological forecasts, thereby dynamically managing peak pollution.

These outcomes are largely drawn from official reporting and should be interpreted in light of complementary evidence. Studies indicate that the sharp fall in recorded fire counts partly reflects a shift in burning to the late afternoon, outside the overpass window of the polar-orbiting sensors used for official counts, while burnt-area mapping shows a real but considerably slower decline (International Forum for Environment, Sustainability and Technology, 2025; Singh et al., 2025). These findings highlight two important considerations for regional institutional design: binding authority, combined with regular monitoring, can deliver measurable change, while robust monitoring systems are essential for accurately tracking progress and compliance.

Institutional coordination: CAQM established robust inter-state coordination mechanisms that translate policy into action through high-level annual reviews of state-level Annual Action Plans; the issuance of statutory directions (issuing a total of 98 such directions as of February 2026); and targeted sectoral advisories addressing vehicular emissions, construction dust, and waste management (Commission for Air Quality Management in NCR and Adjoining Areas, 2026a). CAQM has also taken steps to strengthen the evidence base for this coordination. In its status report to the Supreme Court, CAQM proposed developing a high-resolution emission inventory and source apportionment framework for the entire NCR on a 500 m × 500 m grid, combining updated activity data, improved emission factors, and dispersion modelling (Commission for Air Quality Management in NCR and Adjoining Areas, 2026b). The proposal followed findings that existing studies in Delhi-NCR diverged sharply because of inconsistent emission factors and outdated activity data. Further, in March 2026, CAQM issued a framework directing NCR states and the Government of the National Capital Territory of Delhi to prepare State-Level Information, Education, and Communication Action Plans and run year-round, source-specific awareness campaigns, with nodal departments designated for coordination. Taken together, these mechanisms suggest that institutional preparedness and regular interstate engagement can support implementation at state and local levels, provided high-quality emission data are available to effectively target action (Commission for Air Quality Management in NCR and Adjoining Areas, 2026c).

3.4. Key lessons from the CAQM experience

Monitoring data indicates that air quality in Delhi NCR has remained largely stable over the past few years. The absence of a consistent annual increase in measured concentrations suggests that current interventions are helping prevent further deterioration. However, NCR continues to experience ‘Severe’ air quality episodes during winter, when transboundary pollution contributions and stable meteorological conditions can limit pollutant dispersion.

Data gaps and uncertainties: Variations in emission inventories, source apportionment methodologies, and monitoring data across states and research institutions hinder precise sectoral targeting. This inconsistency makes it difficult to fairly align regional responsibilities or track progress against specific baselines. CAQM is currently developing an emission inventory using a consistent methodology that may help address part of the challenge. However, a similar inventory at the national scale, and specifically for South India, is needed to accurately assess regional impacts.

Funding for implementation: Although CAQM has the authority to issue binding directions to state governments and industries, implementation is supported through state governments and sectoral departments, which draw on their own resources and relevant national funding schemes.

Strengthening outcome evaluation and accountability: CAQM documents its actions and advisories through meeting minutes, directions, and state compliance reports. Further strengthening systematic evaluation could help assess how specific directions translate into measurable emission reductions and air quality improvements, with clearer accountability mechanisms supporting implementation.

Strengthening long-term transitions and structural measures: CAQM's regulatory framework has focused significantly on operational measures, such as GRAP and emergency responses. There is an opportunity to further strengthen long-term structural approaches, including industrial relocation, power plant decommissioning, and large-scale fuel shifts, and to develop roadmaps with clear timelines, targets, and enforcement mechanisms.

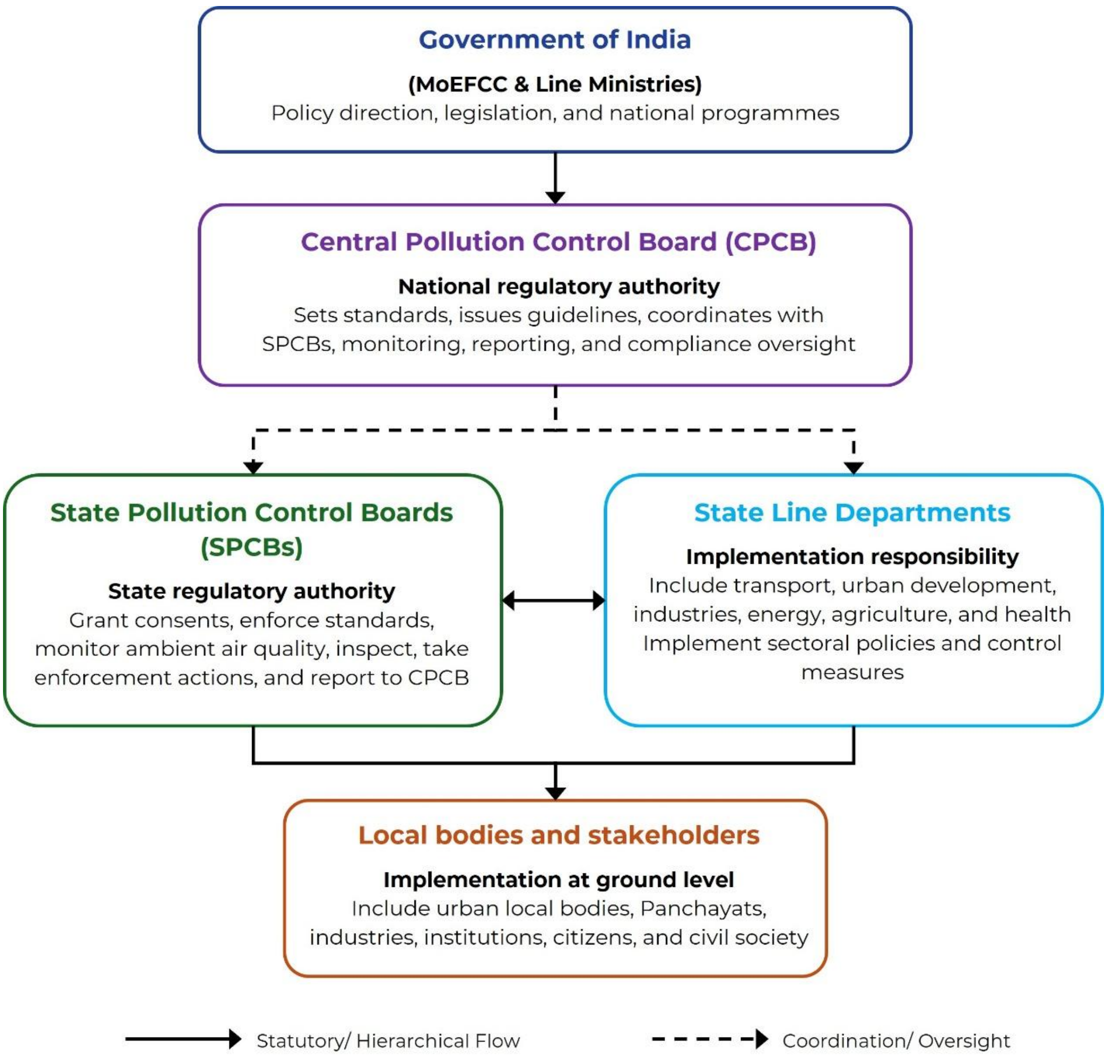
4. Institutional and Governance Framework for Air Quality in South India

4.1. Existing policy and governance structure in South India

This section examines the current policy and governance landscape across the five states to identify (i) the institutions and actors managing air quality, (ii) current policies and their level of convergence, and (iii) gaps in regional coordination.

Air quality management in India operates within a multi-level legal and institutional framework defined by central legislation and state-level implementation. The governance structure reflects a combination of hierarchical regulatory authority and distributed sectoral responsibilities, with distinct but interdependent roles across national, state, and local levels. This multi-level framework, shown in Figure 9, presents the institutional structure and functional linkages among key actors involved in air quality management.

Figure 9: Institutional framework for air quality governance



As shown in the figure above, air quality governance operates through parallel regulatory and implementation pathways, necessitating coordination across multiple institutions. At the apex, the MoEFCC is responsible for policy formulation, legislative frameworks, and national initiatives such as NCAP.

The Central Government is empowered under the Environment (Protection) Act, 1986, to set environmental standards, regulate industrial activity, and issue directions for pollution control, including closure or restriction of polluting activities.

The Central Pollution Control Board (CPCB) functions as the national regulatory authority for air pollution control, with statutory powers under the Air (Prevention and Control of Pollution) Act, 1981. Its primary functions include (i) establishing NAAQS and emission norms, (ii) coordinating activities of State Pollution Control Boards (SPCBs), (iii) providing technical guidance and support to states, (iv) conducting national-level monitoring and data dissemination, and (v) planning and executing nationwide programmes for pollution control. CPCB also acts as an advisory body to the Central Government and plays a critical role in ensuring uniformity in regulatory approaches across states.

At the state level, SPCBs serve as the primary regulatory bodies responsible for implementing air pollution control legislation. Their main functions include granting consent to establish and operate industrial units, inspecting industrial facilities, enforcing emission standards and regulatory norms, and conducting ambient air quality monitoring. SPCBs operate within the framework of standards and guidance provided by CPCB, but their jurisdiction is limited to the respective states. Importantly, their role is largely regulatory and supervisory, with limited direct control over sectoral implementation. SPCBs also serve as the key interface between central regulatory frameworks and state-level implementation, reporting to the CPCB and responding to directives from judicial and quasi-judicial bodies such as the NGT.

Air pollution control measures are implemented by multiple state line departments, each with its own sectoral mandate and responsibilities for specific emission sources. These departments include

- Transportation: vehicular emissions, fuel quality, and mobility systems
- Urban development and local bodies: waste management, construction dust, and urban planning
- Industries: industrial compliance and operations
- Energy: power plants and diesel generator (DG) sets
- Agriculture: crop residue management
- Health: public health advisories and exposure response

While institutional roles are clearly defined across regulatory and sectoral departments, the governance framework exhibits a structural gap between regulation and implementation, which shapes accountability outcomes. Regulatory bodies such as SPCBs are responsible for enforcing emission standards and ensuring compliance, while relying on sectoral departments and local bodies for actual implementation.

At the ground level, ULBs, Panchayati Raj Institutions, and industries are responsible for day-to-day implementation and compliance. ULBs are primarily involved in waste collection and management, local enforcement of construction and dust regulations, implementation of local mobility and planning measures, and community awareness and behavioural change. Table 2 summarises the roles of various stakeholders across sectors involved in air quality management.

Table 2: State- and sector-wise stakeholder mapping

Transport Sector	
Regulatory Actors	SPCBs, Transport Departments
Implementation Actors	Regional Transport Office (RTOs), Traffic Police, State Transport Undertakings (STUs), Urban Development Agencies, ULBs
Coordination Complexity	High - multiple agencies involved in vehicular regulation, enforcement, mobility planning, and public transport
Accountability Structure	Shared across SPCBs, transport departments, traffic police, and urban authorities
Key State-level Variation	Karnataka has specialised urban mobility planning through the Directorate of Urban Land Transport; Tamil Nadu exhibits relatively stronger RTO-based enforcement systems
Industry Sector	
Regulatory Actors	SPCBs, MoEFCC
Implementation Actors	Industries Departments, Industrial Development Corporations, Industrial Units, Manufacturing industries
Coordination Complexity	Moderate to High - compliance depends on both regulatory enforcement and industrial facilitation systems
Accountability Structure	Primarily SPCB-led regulation with implementation by industrial operators
Key State-level Variation	Tamil Nadu and Karnataka demonstrate stronger industrial cluster governance and industrial infrastructure systems
Energy Sector	
Regulatory Actors	SPCBs, CPCB, MoEFCC
Implementation Actors	Energy Departments, Distribution Companies, Thermal Power Utilities
Coordination Complexity	Moderate - regulatory standards centrally defined, implementation through utilities and state energy agencies
Accountability Structure	Shared between utilities and regulatory agencies

Key State-level Variation	Andhra Pradesh and Tamil Nadu have relatively higher thermal power dependence compared to Kerala
Residential Sector	
Regulatory Actors	SPCBs (indirect advisory role), Energy Departments
Implementation Actors	Civil Supplies Departments, Local Bodies, Self-Help Groups (SHGs), households
Coordination Complexity	Moderate - implementation depends heavily on behavioural transition and local outreach systems
Accountability Structure	Diffused across local institutions and households
Key State-level Variation	Kerala exhibits relatively stronger decentralised implementation through local governments and community-based institutions
Waste Sector	
Regulatory Actors	SPCBs, Urban Development Departments
Implementation Actors	ULBs, Municipal Corporations, Sanitation Departments, Waste Processing Operators
Coordination Complexity	High - waste collection, segregation, processing, and enforcement distributed across agencies
Accountability Structure	Shared between local bodies and regulatory agencies
Key State-level Variation	Kerala demonstrates relatively stronger decentralised waste governance and ULB participation
DG Set Sector	
Regulatory Actors	SPCBs, CPCB
Implementation Actors	Industries, Commercial Establishments, Energy Departments
Coordination Complexity	Moderate - compliance monitoring distributed across commercial and industrial users
Accountability Structure	Primarily compliance-based accountability
Key State-level Variation	Higher prevalence in rapidly urbanising and commercial regions
Agriculture and Biomass Burning Sector	
Regulatory Actors	SPCBs (monitoring role), Agriculture Departments
Implementation actors	Panchayats, Rural Development Departments, farmers and local institutions
Coordination Complexity	Moderate - coordination required between agriculture, rural development, and local governance institutions

Accountability Structure	Shared and locally distributed
Key State-level Variation	Biomass burning is relatively less dominant than that in North India, although localised seasonal burning persists
Crematoria Sector	
Regulatory Actors	SPCBs, Urban Development Departments
Implementation Actors	ULBs, Municipal Corporations, crematoria operators
Coordination Complexity	Low to Moderate - implementation primarily localised
Accountability Structure	Local body-led implementation with SPCB oversight
Key State-level Variation	Urban centres have seen relatively greater adoption of modernised and electrified crematoria

Mechanisms such as state action plans and inter-agency committees are intended to facilitate alignment across sectors. However, improving inter-departmental coordination mechanisms could further support more consistent action across departments. Given the distributed nature of responsibilities, establishing a clearly defined nodal authority with cross-sectoral enforcement powers is crucial for effective air pollution management across all five states.

The following section examines policy differences across state boundaries to provide a clearer picture of the areas where greater alignment could strengthen coordination.

4.2. Mapping of relevant policies

While institutional actors operate across state boundaries, the policies they implement often vary significantly from state to state. This section maps the air quality measures and policies implemented or proposed by each of the five states across six major emission sectors: domestic and clean cooking, industry, energy, transport, open and waste burning, and agriculture. The mapping is based on official state documents, state action plans submitted to the MoEFCC under NCAP, and Pollution Control Board notifications issued through 2025.

Table 3 shows a comparative coverage of air quality mitigation measures across the five states. The table identifies (i) policy measures adopted by the states, (ii) sectors or measures with limited action or policies under formulation, (iii) important synergies where interventions in one sector generate benefits in another (e.g. electric vehicle [EV] policies affecting both transport and power demand), and (iv) critical gaps where the absence of coordinated approaches creates risks or inefficiencies. The analysis that follows examines these patterns to identify opportunities for harmonisation and cooperation across states.

Table 3: Policy matrix for the five South Indian states

S. No.	Sector	Measures	Tamil Nadu	Kerala	Karnataka	Andhra Pradesh	Telangana
1	**Residential**	Increasing the penetration rate of liquefied petroleum gas [LPG]					
2		Adoption of advanced chulhas					
3		Ban on solid fuel burning					
4		Restrict easy access to coal, reduce use of coal in commercial eateries/ tandoors					
5	**Industries**	Incentivising industries to shift to advanced technologies and clean fuel					
6		Installation of pollution control devices in polluting micro, small, and medium industries					
7		Installation of electrostatic precipitators in cement industries					
8		Adopting Zigzag technologies in brick kilns					
9		Use of clean fuel and advanced tech in sponge iron industries					
10		Switching to clean fuels in the cement industry					
11		Switching to clean fuels in chemical industries					
12		Adoption of advanced techniques (Like newer furnaces, electric arc furnaces) in iron and steel plants					
13		Restrict usage of coal/wood as fuel in pharma industries and switch to clean fuels					
14		Industries shifting to clean fuel from coal (steel industries)					
15	**Power plants**	Adoption of pollution control devices in thermal power plants as per MoEFCC norms					
16		Adopting MoEFCC norms in thermal power plants					
17	**Transport**	Installation of diesel particulate filters (DPFs) in Bharat Stage (BS) IV trucks					
18		Phasing out of older trucks for BS VI trucks (with in-built DPF)					
19		Electrification of autos					
20		Electrification of light commercial vehicles					

S. No.	Sector	Measures	Tamil Nadu	Kerala	Karnataka	Andhra Pradesh	Telangana
21		Electrification of passenger cars					
22		Electrification of public transportation systems (buses)					
23		Electrification of two-wheelers					
24		Scrappage of 15-year-old buses/ BS III or older buses					
25		Scrappage of older passenger vehicles					
26		Scrappage of 15-year-old trucks / BS III or older trucks					
27		Removing 50% of super-emitters* from roads by remote-sensing measurements followed by challans					
28		Replacement of two-stroke autos with cleaner fuel (compressed natural gas [CNG] / LPG)					
29		Restrict entry of goods transport vehicles in metro cities					
30	**Waste**	Reduction in open waste burning (through punitive action, bans, or fines)					
31		Improving solid waste management infrastructure (collection and segregation)					
32		Establishment of bio-CNG plants					
33	**DG Sets**	Elimination of DG set usage by provision of 24x7 electricity					
34		Stricter emission norms for DG sets					
35		Use of retrofitted emission control equipment having a minimum specified PM-capturing efficiency of at least 70% and its type approved by one of the five CPCB-recognised labs					
36		Shifting to gas-based generators by employing new gas-based generators or retrofitting the existing DG sets for partial gas usage					
37	**Agricultural waste burning**	Crop diversification (shift from paddy/wheat cycle to millets, seeds, and nuts)					
38		In-situ management practices					
39		Ex-situ management practices					
40	**Crematorium**	Convert at least 50% of crematoria spots to electric ones					

Note: Green = explicitly addressed by an existing policy; Orange = indirectly addressed through broader policy provisions; Blank = no identified policy.

**Their mean emission factor is estimated to be 4–11 times higher than that of non-super-emitters.*

The policy mapping across the five states indicates that air pollution management is currently addressed through a combination of sector-specific policies, regulatory measures, and energy-transition initiatives. However, the policy landscape exhibits varying degrees of convergence.

Overall, the highest level of policy convergence is observed in the transport and industrial sectors across the five states. Almost all states have adopted interventions promoting vehicle electrification, implementing BS-VI emission standards, replacing older vehicles, expanding public transport, and adopting cleaner fuel technologies. Collectively, these measures indicate that transport policies have moved beyond emission control alone towards a broader clean mobility transition.

In the industrial sector, multiple states have adopted measures to improve emission controls and promote cleaner production practices. Common interventions include installing pollution control devices, adopting cleaner fuels, transitioning to advanced industrial technologies, implementing Continuous Emissions Monitoring Systems, and enforcing stricter compliance mechanisms for thermal power plants and industrial units. These interventions indicate a common regulatory emphasis on improving emission performance in industries.

The available policy instruments for transition to clean fuels vary considerably across states. The Andhra Pradesh State Action Plan proposed replacing heavy oil with cleaner fuels such as compressed natural gas (CNG), PNG, and electricity. However, the NGT observed that there is no record of this proposed fuel transition policy being formally notified, even though the notification deadline expired in December 2023. Telangana has adopted a different approach by restricting the use of pet coke in selected industrial sectors, whereas Tamil Nadu has focused on promoting PNG adoption and sector-specific fuel substitution measures.

Importantly, South India needs a comprehensive, approved fuel list, similar to the framework developed by CAQM through its airshed-oriented regulatory approach. The framework identifies permitted and prohibited fuels, along with sector-specific exemptions, across multiple jurisdictions. This is important because fuel type and quality significantly influence industrial emissions, particularly PM, SO_2, NO_x, and other toxic pollutants. Recent analysis of fuel governance in India (Tyagi and Hegde, 2025) highlights the growing use of approved fuel lists to phase out more polluting fuels, such as pet coke and furnace oil, while promoting cleaner alternatives, including LPG, PNG, biomass pellets, and low-sulphur fuels.

Beyond the transport and industrial sectors, the policy matrix also reveals important gaps in other sectors, such as agricultural waste burning, DG set emissions, and waste burning. Although some states have introduced measures on crop diversification, ex-situ residue management, waste collection systems, and restrictions on open burning, overall policy coverage remains uneven. Similarly, policies addressing retrofitting of DG sets, cleaner backup power systems, and bio-CNG integration remain limited across the region despite increasing dependence on decentralised power generation.

The policy matrix also highlights several important cross-sectoral synergies, where interventions introduced in one sector may generate benefits or influence outcomes in another. Some examples are discussed below:

- EV policies extend beyond the transport sector by increasing electricity demand while creating the need for coordination in transport planning, charging infrastructure, and the power sector.
- Improving the reliability of grid electricity can reduce dependence on DG sets across residential and commercial sectors, linking power sector planning with emission reduction strategies.
- Industrial fuel transition policies, including the proposed shift towards cleaner fuels and the adoption of an approved fuel list, require close coordination among industries, energy suppliers, and regulatory agencies to ensure the availability, accessibility, and adoption of cleaner fuels.
- Crop residue management policies promoting biomass utilisation create linkages between the agriculture and energy sectors by diverting agricultural residues for bioenergy and industrial fuel applications.

These examples demonstrate that effective air quality management increasingly depends on integrated planning across sectors rather than isolated sector-specific interventions.

Overall, the policy assessment suggests that while considerable progress has been made in adopting sector-specific interventions, strengthening policy coherence across sectors and states can further build on this progress and support a more coordinated and integrated approach to air quality management in South India. This is especially true for policies that are not governed by the Central Government.

4.3. State-specific sectoral priorities

Although the magnitudes of individual sectoral contributions vary across the five South Indian states, their ordering is almost invariant. Domestic emissions rank first in every state, industrial emissions rank second, and energy ranks third in four of the five states; the only exception is Kerala, where the contribution of the energy sector falls slightly below that of the transport sector. Together, these four sectors account for roughly 70%–75% of transported $PM_{2.5}$ in each state. This consistency implies that the South Indian states do not require fundamentally different mitigation strategies. What differs between them is not which sectors to target, but how much weightage each should carry.

First, the domestic share spans a relatively narrow band (30%–40%). It leads in every state, making household energy transition the one intervention whose benefits are unambiguous regionwide and that acts on locally generated and transported pollution simultaneously. It is therefore the natural anchor of any coordinated programme and the sector for which joint, commonly binding targets are most defensible.

Second, the balance between distributed and large point sources varies considerably. Kerala sits at one extreme, with the highest domestic share and the lowest combined industrial-plus-energy contribution (21%); Andhra Pradesh sits at the other end and is the only state in which industrial and energy emissions combined (36%) exceed the domestic contribution (30%). Telangana (32%) and Tamil Nadu (31%) resemble Andhra Pradesh in this respect, with Karnataka being intermediate (29%). Point-source controls are justified regionwide, but they carry disproportionate leverage in Andhra Pradesh, Telangana, and Tamil Nadu. In contrast, in Kerala, the same measures would yield modest reductions relative to household interventions.

The transport sector requires a different reading. Its 4%–9% share should not be interpreted as low importance. Vehicular emissions are released in urban areas with the highest population density, so their contribution to population exposure is disproportionate to their contribution to interstate transport. Transport measures are therefore best positioned as instruments of urban air quality management, coordinated regionally where interstate freight and vehicle standards are concerned but evaluated against city-scale exposure rather than against regional transport metrics.

Taken together, these results support the need for a single regional framework with differentiated emphasis: a common household–energy commitment applying to all states, industrial and energy sector controls weighted towards the states where point sources dominate the transported burden, and transport interventions devolved to the urban scale. The consistent sectoral rankings across the five states, despite their markedly different economic structures and energy profiles, strengthen the case for airshed-level coordination and indicate that a common regional framework can accommodate differences in the relative contribution of individual sectors across states.

5. Global Approaches to Airshed Governance

5.1. International treaties and tenets

Air pollution moves across administrative and national boundaries through atmospheric transport. This is recognised internationally, and in the past five decades, there have been several principles and treaties that address this transboundary harm and promote regional cooperation. These offer useful lessons for designing an airshed governance mechanism for South India. This section reviews the most relevant declarations, treaties, and regional initiatives. A comprehensive comparison is provided in the Appendix (Table A1).

5.1.1. Stockholm Declaration on the Human Environment, 1972

The Stockholm Declaration (1972) was the first major international statement of state responsibility for the environment. Two principles matter for transboundary air pollution. Principle 21 affirms that states may use their own resources but must ensure that activities within their jurisdiction do not harm the environment of other states. Principle 22 calls for cooperation on liability and compensation for such harm. Together, these established the 'no-harm rule' that remains a cornerstone of international environmental law. The declaration is non-binding and offers normative guidance rather than enforceable obligations. For India, this principle could offer a guiding framework for ensuring that activities in one state do not adversely affect the air quality of neighbouring states. However, existing laws do not currently establish such cross-border considerations as a legally binding requirement.

5.1.2. Convention on Long-Range Transboundary Air Pollution (1979, Geneva)

The Convention on Long-Range Transboundary Air Pollution (CLRTAP) was adopted in Geneva in 1979 under the United Nations Economic Commission for Europe. It was the first legally binding treaty on transboundary air pollution. The convention has a few key features. It set up regional cooperation mechanisms to reduce air pollution and created monitoring and scientific assessment networks, such as the European Monitoring and Evaluation Programme. It also promoted emission reduction commitments through protocols, which targeted pollutants such as sulphur dioxide, nitrogen oxides, volatile organic compounds, heavy metals, and persistent organic pollutants. Over time, the convention evolved through several protocols. One of these was the 1999 Gothenburg Protocol, which introduced multi-pollutant and multi-effect strategies. The CLRTAP framework shows several governance innovations, including regional institutional coordination, shared scientific monitoring systems, progressive emission reduction targets, and cooperative policymaking among sovereign states. The model illustrates how regional governance can address pollution that crosses political boundaries. In the Indian context, CLRTAP highlights the importance of creating scientifically informed regional institutions that can set coordinated emission targets across states.

5.1.3. Rio Declaration on Environment and Development, 1992

The Rio Declaration (1992) reaffirmed and broadened the principles of the Stockholm Declaration. Principle 2 of the statement restates the no-harm rule, Principle 7 introduces common but differentiated responsibilities, Principle 10 provides for public access to environmental information and participation in decisions, and Principle 15 sets out the precautionary principle. Although non-binding, it shaped much of the international environmental law and the multilateral agreements that followed. For India, these principles support cooperative governance across states, transparency in emission monitoring, and shared but differentiated responsibility within a federal structure.

5.1.4. Malé Declaration on Control and Prevention of Air Pollution and Its Likely Transboundary Effects for South Asia, 1998

The Malé Declaration (1998) is one of the few regional initiatives addressing transboundary air pollution in South Asia. Its signatories include India, Bangladesh, Pakistan, Sri Lanka, Nepal, Bhutan, and the Maldives. It aims to improve regional monitoring, strengthen scientific understanding, build regional emissions inventories, and promote policy dialogue. Unlike CLRTAP, it is non-binding and focuses on capacity building and research rather than enforceable reduction commitments. Its policy impact has therefore been limited despite its scientific value. For India, the experience shows that voluntary cooperation builds scientific and institutional capacity but reaches its limits without enforceable commitments and that stronger institutional mechanisms are needed as cooperation matures.

5.1.5. USEPA's 'Good Neighbour' Plan

The United States manages interstate air pollution through the Good Neighbour Plan under Section 110(a)(2)(D) of the Clean Air Act. It requires states to ensure that their emissions do not significantly worsen air quality in downwind states, with federal authority to issue an implementation plan when a state's own plan is found inadequate. The provision demonstrates the benefit of binding reduction requirements across jurisdictions within a federal system, although the specific federal plans issued under it have been revised over time.

5.1.6. Additional treaties in the European Union

The European Union (EU) operates one of the most well-developed regional air quality systems. Its Ambient Air Quality Directive (2008/50/EC) sets binding air quality standards, and its National Emission Ceilings Directive (2016/2284) sets country-specific reduction targets. Both are supported by coordinated monitoring and reporting and are enforced through the European Commission and the Court of Justice. The EU model demonstrates how supranational institutions can ensure compliance across multiple jurisdictions through shared standards and credible enforcement. For South India, the relevance lies in the fact that shared standards are effective only when enforced by an institutional authority, which forms the basis of the statutory stage proposed here.

5.1.7. Case studies from China and Southeast Asia

China provides the most relevant case study among large developing economies. Its regional air pollution control zones in the Beijing-Tianjin-Hebei region, the Yangtze River Delta, and the Pearl River Delta allow the State Council to set common targets, run joint monitoring, and enforce regionwide pollution reductions across provinces. This demonstrates the effectiveness of strong central coordination. In Southeast Asia, the Association of Southeast Asian Nations (ASEAN) Agreement on Transboundary Haze Pollution (2002) addresses cross-border haze from forest fires. Although binding in form, its enforcement is weak because of limited compliance mechanisms and national sovereignty concerns.

5.2. Lessons for South India: Requirements for an Effective Regional Framework

The review of international frameworks reveals several key governance principles relevant to addressing transboundary air pollution:

- Recognition of cross-jurisdictional environmental harm
- Institutional mechanisms for regional cooperation
- Scientific monitoring and emission inventories
- Binding emission reduction commitments
- Coordinated supervision and enforcement mechanisms

These international experiences offer valuable lessons for designing an effective air quality governance framework for South India. Regional coordination alone cannot overcome meteorological and long-range transboundary factors. Policies must target multiple sectors simultaneously and set realistic goals for seasonal air quality, particularly during winter or post-monsoon periods when meteorological conditions are unfavourable, as winter baselines may not achieve annual NAAQS even with aggressive sectoral controls.

A standardised emission methodology and dedicated South India inventory should be established before setting binding reduction targets or allocating sectoral responsibilities, with their development mandated in the regional governance framework.

The framework must also include a dedicated financing mechanism that aligns national funding (from NCAP, climate finance, and renewable energy budgets) with regional priorities. This will boost implementation capacity.

Long-term structural changes, such as the coal phase-out, relocation of large industrial clusters, and energy transition, require dedicated governance arrangements separate from operational regulations. Accordingly, sector-specific roadmaps for coal-fired power plants (phase-out timeline, capacity replacement strategy), brick kilns (fuel transition, technology upgrade), and large industrial clusters (fuel standardisation, relocation possibilities) with explicit financing mechanisms and enforcement pathways should be developed in South India.

Many international agreements rely primarily on voluntary cooperation or diplomatic engagement, which often limits their effectiveness. In India, the challenge is further complicated by its federal governance structure, in which environmental regulation is primarily implemented at the state level. While national policies such as the NCAP provide strategic direction, implementation remains fragmented across jurisdictions. Further, global examples suggest that credible enforcement backed by a binding authority is what distinguishes effective frameworks from declaratory ones.

Together, these lessons inform the governance framework presented in Section 6, which sets out a voluntary cooperation framework as the first step and a statutory body as the second, alongside dedicated financing and sectoral implementation roadmaps. The principles of no-harm, differentiated responsibility, and shared monitoring that underpin successful international frameworks also reinforce the proposed governance model for South India, which could operationalise these principles within India's federal structure.

6. Policy Recommendations

The modelling results presented earlier in this report show how $PM_{2.5}$ moves between the five peninsular states, and which sectors drive both local and transported pollution. This section translates those results into policy recommendations for the region. It sets out the key findings in brief and delineates the recommendations based on them.

6.1. Evidence in brief

The air quality of peninsular states is interdependent. Across all five states, a substantial share of the $PM_{2.5}$ originates from neighbouring states, and the magnitude of interstate contribution varies seasonally, increasing during winter when air quality is at its worst. The relationship is not one-directional; each state acts as both a contributor and a receiver of transported pollution, although to varying degrees. Karnataka, for example, receives over one-third of the region-sourced $PM_{2.5}$ from the other four states across the year, and this rises to more than two-fifths in winter. Similar two-way interactions are observed across the remaining states, as shown in Table 4. These findings indicate that improvements in air quality within one state can generate benefits beyond its borders, while actions taken by neighbouring states also influence local air quality. Consequently, effective air quality management of regional $PM_{2.5}$ requires coordinated action rather than isolated city or state-level interventions.

Table 4: Local vs outside contributors to $PM_{2.5}$ between South Indian states

State	Local contribution (%, annual)	Outside contribution (%, annual)	Outside contribution (% winter, Dec–Feb)	Outside contribution (% post-monsoon, Oct and Nov)	Top outside contributor (%)
Karnataka	65%	35%	43%	34%	Andhra Pradesh (15%)
Kerala	68%	32%	45%	32%	Tamil Nadu (19%)
Tamil Nadu	81%	19%	14%	19%	Kerala (9%)
Andhra Pradesh	68%	32%	16%	23%	Tamil Nadu (15%)
Telangana	62%	38%	33%	29%	Andhra Pradesh (25%)

The dominant sectors are similar across the region. Domestic, industry, and open burning are the three largest local sources across all five states. Domestic, energy, and industry are the three largest sources of transported $PM_{2.5}$. Because the priorities align, a coordinated and sector-aware strategy is feasible. The states need to align on shared solutions to a shared problem.

There is no single nucleus of pollution. Unlike the Delhi airshed, the peninsula has no single pollution hotspot. Different states encounter their peaks at different times and for different reasons. Consequently, each state acts as both a contributor to and a receptor of transported $PM_{2.5}$ over the course of a year. Thus, no single state has the onus of the problem alone, as none can solve it independently, highlighting the need for regional coordination.

6.2. Phased governance pathway for South India

The evidence supports one central need—coordinated air quality action across the five states. Collectively, the modelling results reinforce the recent recommendations of the NGT recognising the need for a broader regional or airshed-based approach to achieve sustained improvements in air quality.

This study recommends a two-stage approach that is sequential, but not alternative: first, building shared capacity through voluntary cooperation, and second, establishing a binding authority once the foundation is in place or if pollution levels warrant it.

Stage 1: A voluntary regional cooperation framework

India is already working across state boundaries on air quality. CAQM coordinates the states around Delhi, and the NGT requires every state to prepare and implement state-level air quality action plans. Building on this direction, the first stage emphasises building voluntary cooperation among the five southern states. This non-binding mechanism would rest on a shared understanding of priorities and regional cooperation.

With the objective of convergence, this framework combines the existing resources and programmes (such as NCAP and city and state action plans) and aligns them through mutual cooperation, reducing fragmentation and strengthening regional planning. Rather than prescribing identical actions, collective progress can be achieved by allowing each state to select measures that best address its own emission profile while contributing towards shared regional objectives. States are more likely to act on measures they have chosen themselves. The framework works on a simple principle: modelling studies identify how much each state contributes to regional pollution and which sectors drive those contributions. This provides an indication of the relative scale of each state's responsibility without assigning fixed reduction targets or prescribing uniform policy measures. States can then determine which sectors and sources to prioritise and select their best-suited combinations. This allows flexibility in state-level implementation while supporting coordinated regional outcomes. The policy analysis in Section 4 provides states with options to address policy gaps, particularly with respect to their highest-emitting sectors.

The framework borrows its logic from emission trading. The total quantum of pollution to be reduced across the region is fixed (like a cap). Within that cap, the states trade off how much each reduces and how much each pays. A state can take on a larger share of the reduction in sectors where it can act more cost-effectively or easily, while another state takes on more in sectors better suited to it. The design is incentive-based, not punitive.

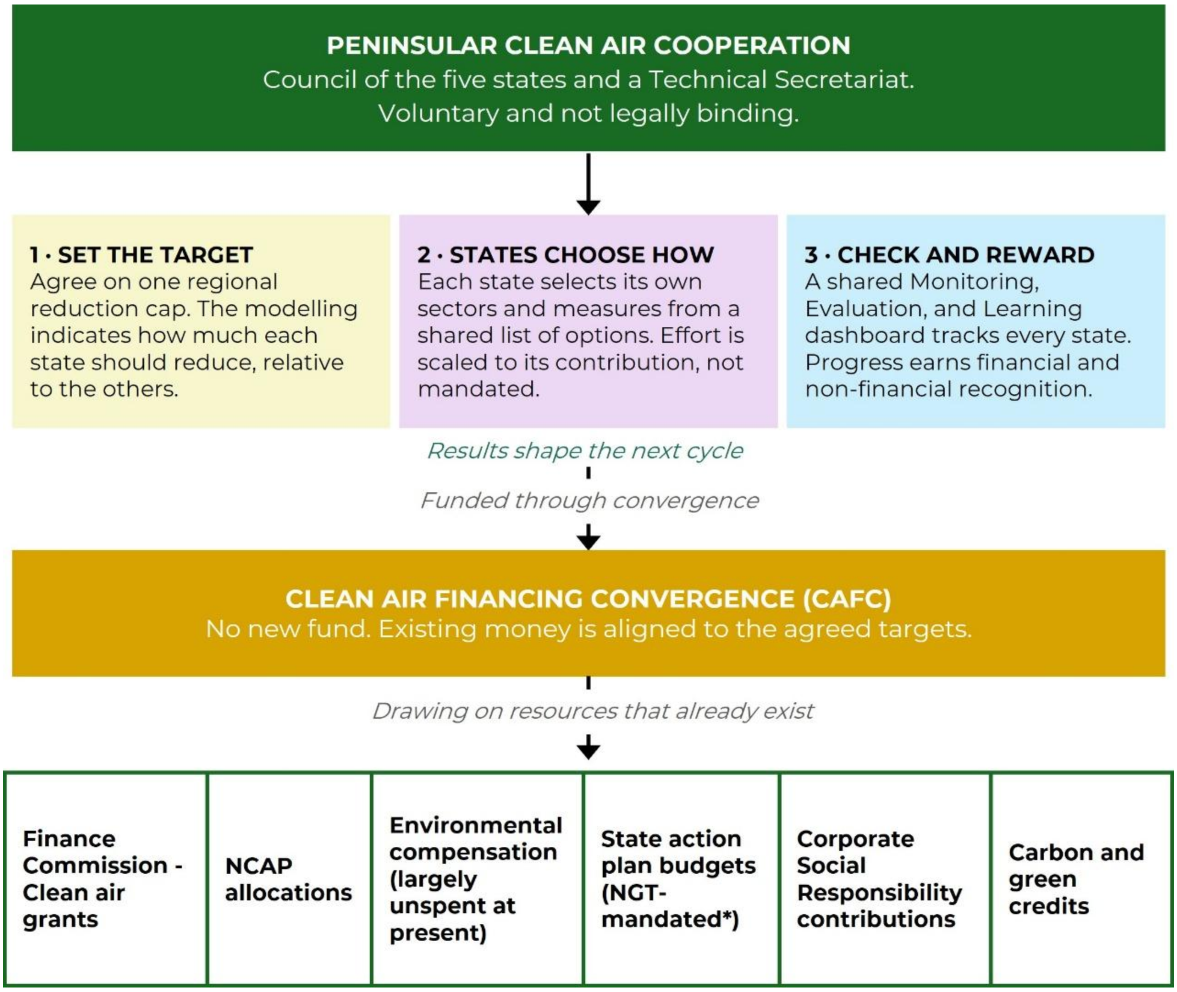
To incentivise various actors, the framework also proposes non-financial levers, such as public recognition, regional rankings, shared technical support, and a visible record of progress. For instance, recognition can place a city commissioner at the front of an effort, lend legitimacy to the work, and motivate a municipal corporation to act. The framework attaches these levers to the targets, so that actions are rewarded.

A state with a larger industrial share may have a stronger emphasis on industrial fuel policy, directed at that state, rather than a blanket mandate for all five states. The same logic applies to other sectors. States, therefore, work towards common regional goals but through differentiated implementation pathways that reflect their respective contribution profiles and capacities.

The framework also draws on established principles of cooperation between neighbours, set out in Section 5. The ‘good neighbour’ principle holds that a state should not allow activities within its borders that harm a neighbour and that it should cooperate to prevent such harm. The knowledge-sharing tradition holds that shared science and open information are the basis of joint action. The proposed peninsular framework adapts both approaches. It asks each state to account for the pollution it transports across its borders and builds a common evidence base, supported by a shared inventory and a seasonal Peninsular Air Quality Response Protocol (PAQRP), which all five states can access and execute.

Figure 10 illustrates how the proposed voluntary cooperation framework translates the NGT’s call for greater regional coordination into an operational model based on shared regional goals, differentiated implementation, and collective accountability.

Figure 10: Illustrative voluntary regional cooperation framework for coordinated air quality management in South India



**Anchored on the NGT mandate (OA 681/2018; NGT Southern Zone, 2021): the states are already required to prepare, fund, and spend on air quality action plans.*

A voluntary framework can deliver shared monitoring, a common emission inventory, agreed sectoral priorities, and collaborative practices. However, it cannot compel a state that chooses not to act. As transported contributions grow, this becomes a binding constraint, highlighting the need for a statutory body.

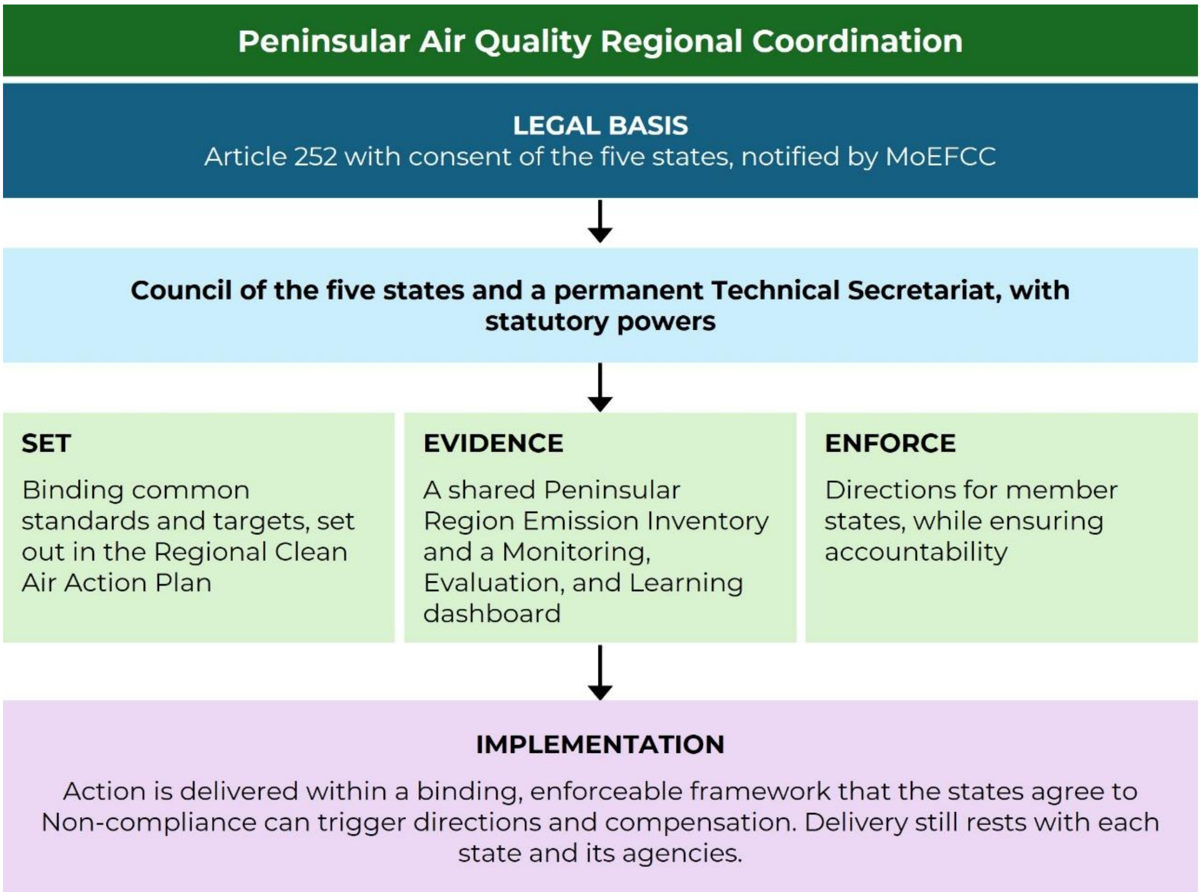
Stage 2: A statutory regional body: Peninsular Air Quality Regional Coordination (PARC)

Where voluntary cooperation reaches its limits, the proposed Peninsular Air Quality Regional Coordination (PARC) forum would function as a dedicated platform for interstate coordination, enabling the five states to jointly plan, review, and monitor regional air quality actions while retaining their existing statutory responsibilities (Figure 11).

PARC may be established with legal power routed through the MoEFCC, with representation from the CPCB, southern SPCBs, relevant line departments, technical institutions, and domain experts. It could be modelled on the lines of CAQM and created with the consent of the five states under Article 252 of the Constitution. This is the same route used for the Water (Prevention and Control of Pollution) Act, 1974, and the Air (Prevention and Control of Pollution) Act, 1981. Comprising a council of the five states and a permanent technical secretariat, its primary role could be to facilitate regional coordination by setting binding common standards and targets. This could involve preparing a Regional Clean Air Action Plan; maintaining a shared Peninsular Region Emission Inventory; running a Monitoring, Evaluation, and Learning (MEL) dashboard; and maintaining accountability of member states. States would retain the responsibility for implementing agreed actions while operating within a collectively agreed and enforceable framework.

This model has a clear strength: legal force and a single point of accountability. It also has a clear cost. A CAQM-style body places most of its weight on enforcement and directions. CAQM was created for an acute, nationally visible crisis centred on a single metropolitan hotspot, with sustained judicial pressure behind it. South India does not present those conditions today, which is why PARC is proposed as the second stage rather than an immediate step. Pollution in this region is also distributed across several urban and industrial centres, rather than one core, so PARC would need to set up offices across the region to work directly with the state agencies, instead of operating as a single commission in one city. The CAQM experience shows that directions do not convert automatically into action on the ground because implementation still rests with each state and its agencies. PARC should therefore be empowered by the member states to decide actions in line with each state's capacity, while each state remains responsible for reducing its own emissions and accountable to PARC for doing so.

Figure 11: Statutory regional body model for air quality coordination across South India



The shared inventory, monitoring arrangements, and financing convergence established under Stage 1 are the operational prerequisites for a statutory body. Where these are absent, the statutory body should build a common evidence base and act on it simultaneously, as the CAQM case indicates.

6.3. Sectoral priorities: A shared list of options

In the regional cooperation model, sectoral priorities are designed based on the results from air quality models. Domestic emissions, the largest source of both local and transported $PM_{2.5}$, should be prioritised.

Domestic (transboundary priority)

Domestic biomass burning is the largest local source of pollution in all five states and accounts for a major share of the transported pollution from each state. This sector is also the most manageable, given its contribution to pollution, the reach of the Pradhan Mantri Ujjwala Yojana (PMUY), and existing infrastructure. Refill affordability and fuel stacking are the persistent barriers. Following are some of the options for a state:

- End fuel stacking among existing PMUY beneficiaries through subsidised refill access. Himachal Pradesh reached near-universal LPG coverage through its state scheme, and Telangana provides a subsidised refill under the Mahalakshmi scheme. Each state could allocate additional subsidies beyond those under PMUY.
- Promote induction cooking in electrified households, beginning with states with a continuous power supply in remote areas.
- Replace coal and wood tandoors in eateries with cleaner alternatives, along the model of municipal orders in Mumbai, Indore, and Lucknow.
- Scale bio-CNG and biogas under the Galvanizing Organic Bio-Agro Resources Dhan (GOBARdhan) initiative and the Sustainable Alternative Towards Affordable Transportation (SATAT) scheme using crop residue and wet waste for community-level cooking fuel.

Industry (transboundary priority)

Industry is a leading source of transported $PM_{2.5}$ within the region and a dominant transported source into some states. None of the five states has notified an approved fuel list, which has been the single most effective industrial emission tool demonstrated in India. Following are some of the solutions applicable across the five states:

- Adopt an Approved Industrial Fuel Framework. A state must prohibit the most polluting fuels, such as pet coke, high-sulphur coal, and furnace oil and permit cleaner ones, such as PNG, biomass pellets, and electricity. If states adopt compatible lists, the regional benefit is larger.
- Shift brick kilns to Zigzag or vertical-shaft technologies, following the Alwar (Rajasthan) model.

- Support clean-fuel transition in micro, small, and medium enterprises through a capital subsidy for boiler and furnace conversion, in line with similar schemes in Haryana and Tamil Nadu.
- Install continuous emission monitoring in red- and orange-category industries, irrespective of size, and mandate reporting through a shared portal for all five states.

Energy

The energy sector is a significant source of transported $PM_{2.5}$ into the northern peninsular states and a leading local source where coal generation is concentrated. Most cross-state energy pollution comes from coal-fired plants that have delayed compliance with the 2015 emission norms. Options include the following:

- Enforce time-bound installation of flue-gas desulphurisation and particulate and NO_x controls in coal plants, with escalating compensation for delay. While the norms are already in force, stricter enforcement is needed.
- Mandate biomass co-firing in coal plants, which creates demand for crop residue and reduces coal use.
- Develop a shared renewable integration plan to displace coal generation during peak pollution seasons. The five states share significant renewable potential, so coordination avoids redundant grid investments.
- Phase out the use of DG sets through a reliable power supply and retrofit emission control devices, following the model of orders in Karnataka, Tamil Nadu, and Odisha.
- Adoption of solar power across institutions for power backup, considering the high solar potential of these states.

Transport (urban air quality priority)

Vehicular emissions contribute 4%–9% to regional $PM_{2.5}$, a share that appears modest but masks disproportionate urban impact. Additionally, global emission inventories underestimate transport emissions. Because transport emissions are released in densely populated areas, population exposure to these emissions is high. Transport measures are therefore fundamental tools for managing urban air quality. Yet, regional coordination remains essential owing to the movement of vehicles across state boundaries and freight corridors.

- Harmonise management of on-road emissions across the five states with uniform testing, compliance verification, and enforcement protocols, reducing regulatory arbitrage and supporting common standards for inter-state vehicle movement.
- Develop a regional EV charging infrastructure plan, coordinating placement and connectivity across state borders to support vehicle electrification and alleviate range anxiety while travelling on highways.
- Coordinate heavy-duty vehicle (truck and bus) standards and enforcement across state boundaries, including harmonised penalties, inspection protocols, and

scrappage incentives for older vehicles. Create a network of vehicle scrappage and automated testing centers to issue fitness certificates.

- Establish common fuel quality standards for petrol and diesel (sulphur content, heavy metals, and additives) across the region, working with fuel suppliers to prevent fuel quality variations across state borders.
- Harmonise public transport modernisation (bus fleet age, emission norms, and fuel type) across all urban centres to achieve consistent fleet renewal and modal shift towards buses and intermediate public transport, including on interstate routes.

Open and waste burning

Open and waste burning are among the two largest local sources in most peninsular states. The regional profile is more varied than that in the north. It covers municipal waste burning, localised crop residue burning, and forest fires in the Western Ghats. The cross-boundary fraction is substantial, with one state's open burning emissions reaching its neighbours. Options include the following:

- Invest in solid waste management infrastructure, including scaling up segregated collection, bio-CNG processing, and scientific disposal.
- Harmonise open-burning penalties across states to prevent selective enforcement and seasonal spillover.
- Establish a joint fire-response protocol with early warning systems for the Western Ghats.
- Coordinate crop residue management methods, including procurement from non-paddy crops and the infrastructure and supply chains needed to produce biomass pellets for co-firing in power plants.

Table 5 summarises the sectoral options discussed above.

Table 5: Sectoral actions within the framework of regional cooperation

Sector	What the states agree on	What each state chooses and delivers	What shared monitoring checks
Domestic and clean cooking	A shared clean-cooking goal in the regional plan	Each state's chosen mix of subsidised refills, induction and bio-CNG, delivered by civil supplies and energy departments, urban local bodies and panchayats	Adoption tracked on the shared dashboard
Industry	A compatible approved fuel approach	Notification and enforcement by state boards and industry departments	Emissions tracked through the shared monitoring portal

Sector	What the states agree on	What each state chooses and delivers	What shared monitoring checks
Energy	Co-firing and renewable energy integration goals	Delivery by energy departments, generators, and distribution companies	Plant compliance tracked across state borders
Transport	Regional vehicle emission standards (Bharat Stage-VI), electric vehicle (EV) charging coordination, harmonisation of heavy-duty vehicle standards, and fuel quality alignment	Implementation by transport departments, RTOs, traffic police, and ULBs, with coordination through shared testing and inspection standards	Vehicle compliance tracked through an inter-state portal; EV charging network expansion monitored; fuel quality verified at state entry points
Open and waste burning	Shared protocols to tackle waste burning and comparable penalties	Delivery by state boards, urban local bodies, and forest departments	Seasonal burning tracked through the response protocol

6.4. Possible funding mechanism: Clean Air Financing Convergence

The framework does not propose a new dedicated fund. The money to address air quality issues is already allocated across schemes and may often be underutilised. A compliance report filed by CPCB before the NGT in March 2024 showed that only about a fifth of the environment protection charge and environmental compensation collected by the Board had been disbursed, leaving the larger part unused. The framework therefore suggests converging existing resources through a proposed mechanism called the Clean Air Financing Convergence. It could align funds that already flow to the states and direct them towards measures identified through modelling studies. The existing funding sources include

- Finance Commission - clean air grants,
- NCAP allocations,
- Environmental compensation collected from polluters (largely unspent),
- State action plan budgets (which states are already required to fund),
- Corporate Social Responsibility contributions, and
- Carbon and green credits.

Convergence rests on an existing mandate for states—the NGT requires every state to prepare and implement air quality action plans, with timelines to spend and consequences for default, and it has directed that the southern states, in particular, account for their plans

(OA 681/2018; NGT Southern Zone, 2021). States may fund themselves through the above sources. The role of the framework is to align spending across the region and direct it to the prioritised sectors while delivering visible results. Two principles could help guide spending. First, funding should follow the sectoral ranking from the modelling, with the domestic and industrial sectors being prioritised, rather than based on the visibility of their pollution impacts alone. Second, future recognition and support should be linked to demonstrated progress to ensure effective use of funds.

7. Limitations and Future Directions

This section identifies the key sources of uncertainty in the modelling framework and policy recommendations and outlines priorities for future work.

7.1. Modelling and emission inventory limitations

Although this study uses a WRF-CAMx chemical transport modelling setup, which is also widely used in regulatory air quality assessments in the United States, its outputs remain subject to several sources of uncertainty. In the absence of a comprehensive national emission inventory for India, this study relies on global inventories, which are only available for certain base year(s). Such inventories are based on gross country-specific activity data; however, they lack systematic ground-level validation. Emission estimates may therefore represent a major source of uncertainty in the existing modelling framework. Apart from ground validation of sectoral totals and spatial distribution, global inventories do not provide emission variability at sub-monthly scales and may not adequately capture emission sources that vary diurnally/weekly.

The choice of spatial resolution can also influence the magnitude of the relative contributions from high-emission regions (urban agglomerations) to nearby areas. The 25-km spatial resolution is appropriate for regional/state-level analysis but may not provide accurate estimates at the city level. The accuracy of the model outputs also depends on detailed validation against ground measurements. While the model setup performed well on the available CAAQMS data, it is also limited by the data quality. In addition, the lack of $PM_{2.5}$ speciation and other detailed gas-phase measurement data makes it difficult to validate whether the underlying biases are attributable to the model's representation of atmospheric chemistry and/or emissions.

7.2. Policy framework limitations

The phased governance pathway proposed in Section 6 addresses the institutional fragmentation issue documented in this report, but its effectiveness depends on several conditions.

First, regional coordination requires sustained political commitment. State-level changes in government, shifting political priorities, or conflicts over sectoral distribution of efforts can destabilise the coordination mechanism. The first stage is easier to initiate but harder to sustain through political transitions, which is itself part of the case for progressing to a statutory arrangement. The second stage has clearer enforcement tools but faces higher political barriers to establishment.

Second, implementation on the ground depends on state and local capacity. In practice, states face competing demands on budgets and institutional bandwidth, so coordinated regional targets may not translate into coordinated action if states lack the technical expertise, financial resources, or administrative capacity to deliver. The CAQM experience in the NCR demonstrates this challenge. While coordination is set at the regional level, final implementation rests with state and local agencies, each operating under its own constraints.

Third, the policy recommendations assume that sectors can be decoupled. For example, industrial fuel transitions assume that fuel suppliers can deliver cleaner fuels at scale. Power generation decoupling assumes that renewable capacity can be added to phase-out coal on the required timeline. Transport electrification assumes that charging infrastructure can be built regionally. These assumptions may not hold if supply-chain constraints, investment shortfalls, or technology delays intervene. The framework does not account for possible trade-offs between sectors or the economic feasibility of simultaneous sectoral transitions across the region.

Fourth, the policy framework does not quantify enforcement mechanisms or financial penalties for non-compliance. A state that fails to meet agreed targets or implement agreed measures faces unclear consequences under the first stage and potentially court-imposed directions under the second. However, the pathway from non-compliance to enforcement to remedial action remains undefined.

7.3. Geographic and temporal scope

This study focuses on the five South Indian peninsular states (Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, and Telangana) and uses modelling outputs with 2019 emission data. The findings are therefore time- and region-specific: the transboundary percentages reported here reflect the emission profiles and meteorological conditions of that year. Air quality patterns can shift with changes in emissions, economic structure, climate variability, or atmospheric chemistry, so the relative contributions may differ in later years. Specifically, the impact of several interventions in the transport and residential sector that have been implemented after 2021 may not be captured. The analysis also does not account for contributions from North India or from beyond the country's borders, which may become important under certain seasonal conditions.

7.4. Future work

First, the recommendations in this report should be refined through stakeholder consultations. The governance models and sectoral options must be tested against the practical constraints, priorities, and capacities of state governments, industry forums, and city administrations. The consultation will also clarify which sectors and measures are most acceptable to states, thereby improving the likelihood of adoption.

Second, the findings should be updated once India's national emission inventory becomes available. Rather than relying on global inventories, this inventory could provide country-, sector-, and state-specific emission data. Once available, the modelling data can be re-run using India-specific activity data, improving the precision of transboundary contributions and sectoral rankings. Updated findings may alter policy priorities, particularly in sectors or states where global inventory estimates diverged significantly from ground reality.

Third, ongoing collaboration with CPCB and SPCBs should establish a protocol for long-term monitoring of transboundary transport. The proposed seasonal PAQRP could track actual transboundary contributions as monitoring networks improve and emissions change. This will allow the framework to be adaptive and evidence-based.

Fourth, if the governance models proceed to implementation, monitoring and evaluation must be built in from the start. A shared MEL dashboard should track progress against agreed targets, flag implementation gaps, and inform mid-course corrections. This will also generate evidence on which sectoral measures prove most effective under field conditions.

Finally, the framework should be designed to scale geographically, if successful. Transboundary air pollution is not confined to South India. Similar regional coordination mechanisms may be needed across other airsheds in India, including the broader Indo-Gangetic Plain, the eastern seaboard, and other multi-state regions. The experience of implementing the peninsular framework can inform the design and operationalisation of regional coordination elsewhere in the country.

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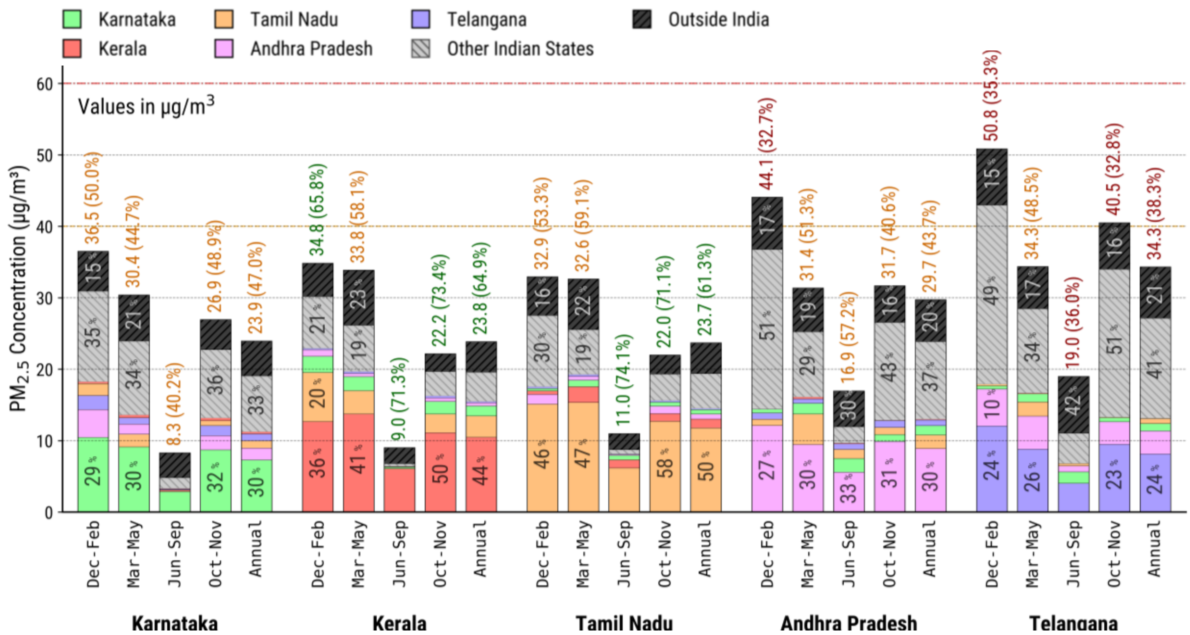
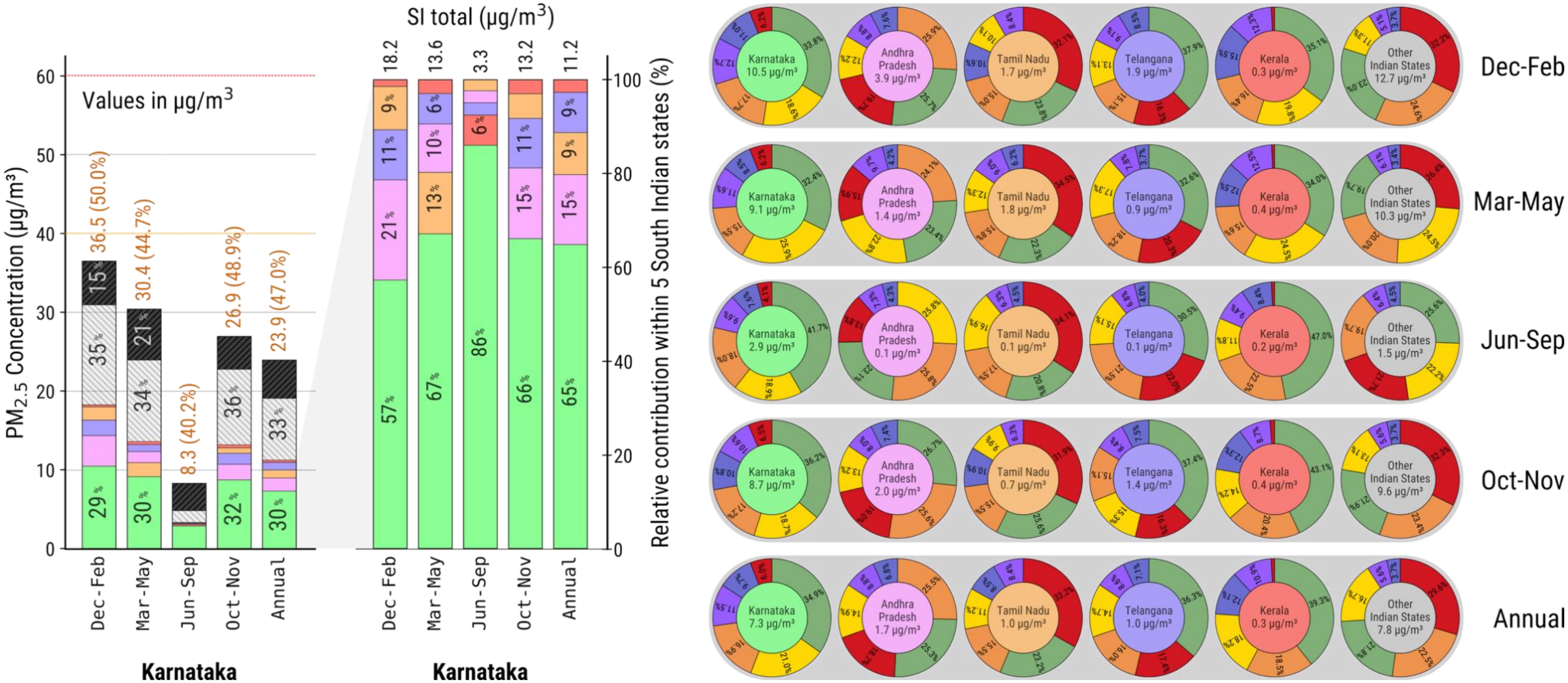
9. Appendix

Figure A1: Regional contributions to and from different states in South India



Note: The numbers at the top of the bar show the seasonal average $PM_{2.5}$ concentration, with numbers in the brackets indicating the contribution from the five South Indian states alone.

Figure A2: Annual and seasonal $PM_{2.5}$ source attribution for Karnataka



Note: The left panel shows the absolute $PM_{2.5}$ contributions to Karnataka from South Indian states, other Indian states, and outside India. The centre panel shows the relative share of each South Indian state.

Table A1: Key international frameworks addressing transboundary air pollution

Framework	Year	Region	Type	Key principle	Relevance for India
Trail Smelter arbitration	1938 & 1941	US–Canada	Binding (arbitral award)	Established that a state may not permit activities causing environmental harm to another state.	Legal origin of the no-harm principle that underpins interstate responsibility.
Stockholm Declaration	1972	Global	Non-binding	Principle 21 sets state responsibility to prevent transboundary harm; Principle 22 promotes cooperation on liability and compensation.	Normative basis for limiting cross-border pollution between Indian states.
Convention on Long-Range Transboundary Air Pollution (CLRTAP)	1979	Europe & North America	Binding	Regional monitoring network (European Monitoring and Evaluation Programme) and protocols set progressively stricter pollutant-specific emission limits.	Shows that binding regional agreements with shared monitoring can reduce cross-border pollution.
Rio Declaration	1992	Global	Non-binding	Reaffirms the no-harm rule (Principle 2) and adds the precautionary principle (Principle 15), common but differentiated responsibilities (Principle 7), and public access to information (Principle 10).	Supports cooperative governance, transparency, and shared responsibility across states.
US Clean Air Act – Good Neighbor Provision	§110(a)(2)(D); strengthened 1990	United States	Binding	Requires upwind states to limit emissions affecting downwind states; enforced through the Cross-State Air Pollution Rule.	Strong example of central authority managing interstate pollution within a federal system.
Malé Declaration	1998	South Asia	Non-binding	Regional cooperation on monitoring, emissions inventories, and research, with no binding targets.	Early regional effort with limited policy impact due to the absence of enforcement.
ASEAN Agreement on Transboundary Haze Pollution	2002	Southeast Asia	Binding in form; weak enforcement	Regional treaty addressing cross-border haze from forest fires.	It illustrates that a binding form without strong compliance mechanisms achieves little.

Framework	Year	Region	Type	Key principle	Relevance for India
China – regional air pollution control zones	from 2013	China	Binding (national policy)	Central Government sets common targets and coordinates measures across provinces in Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta.	Most relevant large-economy model for strong central coordination across sub-national units.
EU Ambient Air Quality Directive (2008/50/EC)	2008	European Union	Binding	Binding air quality standards and coordinated monitoring across member states are enforced by the Commission and the Court of Justice.	Shows how a supranational body coordinates environmental governance with enforcement.
EU National Emission Ceilings Directive (2016/2284)	2016	European Union	Binding	Country-specific emission reduction commitments for key pollutants.	Example of region-wide emission caps with accountability.

10. The Authors

Shivani Sharma

Shivani Sharma is a Consultant at CSTEP, with expertise in emission inventory development and policy assessments. She led the report writing, mainly focussing on policy recommendations including areas for funding and tenets from international treaties.

Dr Nirav Lekinwala

Dr Nirav Lekinwala is a Senior Associate at CSTEP, specialising in air quality modelling, data analysis, and machine learning. He conducted the WRF–CAMx model simulations, processed and analysed the model outputs, and developed the visualisations presented in this report. He also contributed to interpreting the modelling results and drafting the sections describing them.

Dr Nidhi Malik

Dr Nidhi Malik is a Senior Associate at CSTEP, with expertise in air quality assessment, techno-economic analysis, and policy-oriented applied research. She contributed to report writing, with a particular focus on policy analysis, including assessing the existing policy and governance landscape and mapping policy synergies and gaps across the five South Indian states.

Harshitha KM

Harshitha K M is a Senior Analyst at CSTEP, specialising in emission inventory development and quantitative air quality assessment. She assisted in stakeholder mapping for the South Indian states.

Faiza Khalil

Faiza Khalil is a Senior Associate at CSTEP, with experience in air quality research and field-based data collection. She contributed to the desk research, including the review of existing supra-institutional bodies such as CAQM.

Dr Piyush Bhardwaj

Dr Piyush Bhardwaj is a Research Scientist at CSTEP. He contributed to model domain setup, interpretation of modelling results, and report review.

Swagata Dey

Swagata Dey is a Policy Specialist at CSTEP, leading air quality policy research and programme design. As the Principal Investigator of this study, she was involved in conceptualising this report, developing the governance framework, providing policy insights, and reviewing the report.

CENTER FOR STUDY OF SCIENCE, TECHNOLOGY AND POLICY

Bengaluru
No. 18, 10th Cross, Mayura Street, Papanna Layout,
Nagashettyhalli (RMV II Stage), Bengaluru-560094
Karnataka, India

Noida
1st Floor, Tower-A, Smartworks Corporate Park, Sector-125,
Noida-201303, Uttar Pradesh, India

www.cstep.in

+91-8066902500

cpe@cstep.in