40 by 2040:
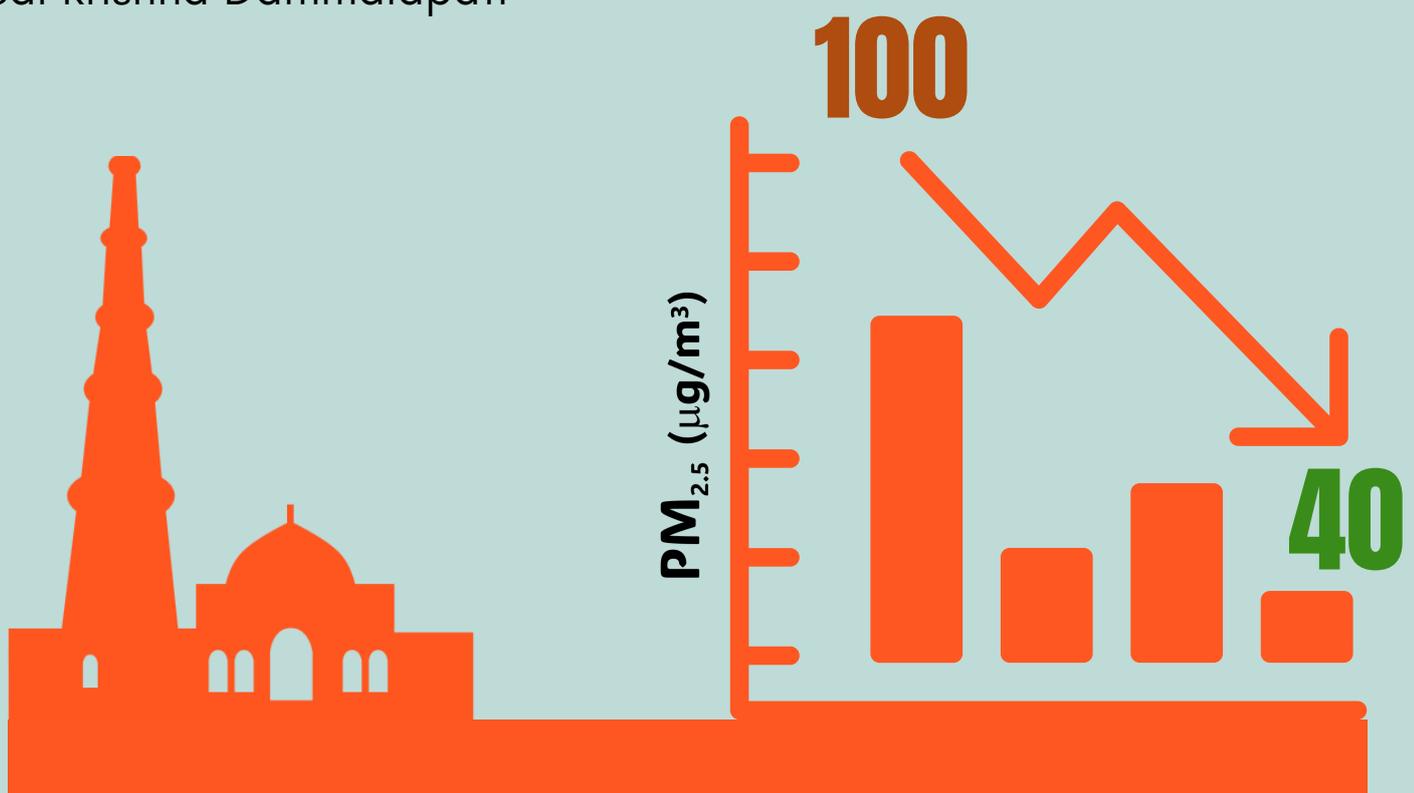# Cost of Inaction and Delays in Reaching Delhi's Air Quality Target

Sarath Guttikunda
Sai Krishna Dammalapati

100

PM$_{2.5}$ (μg/m³)

40

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About UrbanEmissions.Info

UrbanEmissions.info (UEinfo) was founded in 2007 with the vision to be a repository of information, research, and analysis related to air pollution and focusing on four key objectives:

- Sharing knowledge on air pollution
- Providing science-based air quality analysis
- Promoting advocacy and raising awareness on air quality management
- Building partnerships among local, national, and international airheads

About SIM-air Working Papers

The working-papers describe case studies where we applied the SIM-air family of tools, document general notes on emissions and pollution modeling, and present our reviews on topics related to air pollution analysis @ https://urbanemissions.info/publications

Last 5 working papers

Suggested Citation

Guttikunda, S. K., and S. Dammalapati, S. (2025) "40 by 2040: Cost of inaction and delays in reaching Delhi's air quality target". SIM-air working paper series #63-2025. Published by UrbanEmissions.Info, New Delhi, India

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1. Can Delhi's $PM_{2.5}$ levels reach 40 $\mu g/m^3$?

History and the lessons from across the world say, yes, it is an achievable target [1-6].

The history of **London's air quality** crisis is defined by two major policy eras: first, addressing coal smoke, and second, addressing vehicle emissions. London's air crisis peaked with the Great Smog of 1952, a deadly period caused primarily by the combustion of soft, high-sulfur coal for domestic heating and industry. The city initially cleaned itself through the Clean Air Act of 1956, which banned the burning of smoke-producing fuels in designated "Smoke Control Areas," forcing residents to switch to smokeless alternatives like gas or electricity. The subsequent long-term economic transition away from coal provided the sustained solution. More recently, London recognized that vehicle emissions were causing persistent pollution issues, particularly NO_2 and $PM_{2.5}$. To tackle this, the city introduced market mechanisms and strict regulations, offering crucial lessons in urban mobility management. This involved introducing the Congestion Charge (2003) to reduce traffic and, most importantly, implementing the Ultra Low Emission Zone (ULEZ) (established in 2019 and expanded in 2023). ULEZ imposes a daily charge on older, high-polluting vehicles that do not meet strict emissions standards, actively forcing a switch to cleaner vehicle fleets across the entire metropolitan area [7-9].

Infamous **Los Angeles (LA) smog**, a thick and brown photochemical haze, was first noticed in the 1940s. Unlike London's SO_2-based fog, LA's smog was primarily generated by sunlight reacting with VOCs and NO_x emissions, from the rapidly expanding use of gasoline vehicles. Its cleanup focused intensely on mobile sources. California first required smog control devices on new vehicles, pioneering the effort. This initial need for stricter control led to the creation of the California Air Resources Board (CARB), which has since developed rules and regulations that are historically more advanced and stringent than the U.S. federal standards. This pioneering state action was reinforced by the Federal Clean Air Acts (1970 & 1990), which mandated the national adoption of catalytic converters to drastically reduce the VOCs and NO_x emissions that were precursors to smog formation.

Beijing faced some of the worst $PM_{2.5}$ pollution levels in the world in the early 2010s, with annual averages frequently exceeding 100 $\mu g/m^3$. Following the 2013 launch of the Action Plan for Air Pollution Prevention and Control, the city achieved a dramatic reduction, cutting $PM_{2.5}$ by over 50% in ten years. This rapid success was built on large-scale and uncompromising measures starting from 2008 Olympic games: a program that switched residential and industrial heating from coal to cleaner natural gas or electricity; the closure, upgrade, or relocation of high-polluting industries across the surrounding region; the implementation of highly aggressive vehicle

emission standards; expansion of the public transport network in buses and subways; expansion of the walking and cycling infrastructure; and strict, consistent, top-down enforcement of all new regulations [10].

2. Delhi's PM$_{2.5}$ levels 1989 to 2025

Delhi has 40 operational monitoring stations consistently reporting data for the past six to seven years. This sample size and the data availability trend between 2019 and 2025, suggests that the city's annual average PM$_{2.5}$ concentration is hovering around 100 μg/m^3 consistently during this period (except for the covid 2020, which had a 10% dip in the year-to-year annual averages). This level is twenty times larger than the WHO health guideline 5 μg/m^3 and 2.5 times the national annual ambient standard of 40 μg/m^3 [11-14].
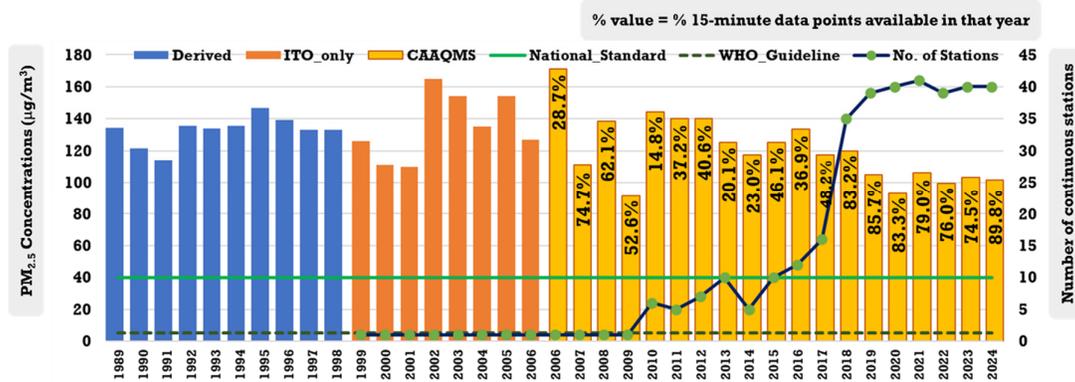
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
2015	179	124	96	101	120	97	67	58	90	153	243	177	**125**
2016	249	151	126	120	92	73	56	42	61	152	258	217	**133**
2017	164	134	96	96	122	60	36	37	58	135	268	200	**117**
2018	205	143	104	94	95	86	42	43	45	139	209	236	**120**
2019	190	123	83	81	88	63	46	34	39	114	187	203	**105**
2020	148	120	57	44	54	46	34	24	47	132	199	190	**93**
2021	187	150	96	86	53	53	39	41	32	74	230	191	**106**
2022	150	103	98	106	78	62	35	32	40	106	178	171	**100**
2023	175	114	78	66	65	46	34	38	43	105	242	200	**103**
2024	203	104	78	70	89	59	40	27	43	110	225	164	**102**
2025	162	97	70	77	66	50	30	33	36	103	220		

Figure 1: Annual average PM$_{2.5}$ concentrations from 1989 to 2024 and monthly average concentrations from 2015 to 2025. Raw data is sources from the Central Pollution Control Board's online portal; Cleaned data is sourced from https://www.earthmetry.com; and detailed discussion on the data is presented here [13].
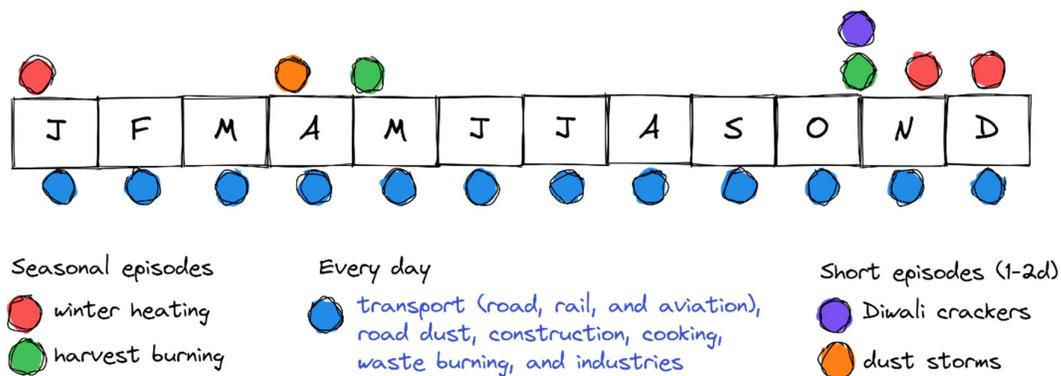
Seasonality in Delhi's pollution is very strong, as the region experiences dramatic swings in air quality driven by meteorological conditions and seasonal emission sources [11,13,15,16]. The most severe pollution events occur during the winter

months, typically starting in late October and intensifying through December and January. This deterioration often begins with two major events: the Diwali festival emissions and the onset of stubble burning (crop residue burning) in the neighboring states [17-19]. As temperatures drop significantly, energy demand for residential heating increases, contributing further to the local pollutant load. Onset of winter meteorological phenomena, particularly the mixing layer inversion, traps pollutants close to the surface and prevents vertical mixing, leading to extreme concentration levels.

Pollution levels are significantly lower during the summer months due to a higher mixing layer height and better dispersion, while regular rainfall during the monsoon season provides a powerful cleansing mechanism. These extreme concentration levels above 200 μg/m^3 recorded during the roughly three-month winter period heavily dominate Delhi's annual air quality picture, disproportionately raising the yearly average concentration to 100 μg/m^3 and making it nearly impossible for Delhi to meet the national standard and stricter WHO guidelines.

3. Source contributions to PM$_{2.5}$ (2019-2025 average)

While the winter season is meteorologically dominated by heating emissions, it is crucial to understand that all other regular sources are omnipresent and contribute significantly to the problem year-round, with their impact becoming magnified during periods of poor dispersion [13], including vehicle exhaust, industries, cooking, dust, and open waste burning. Important to note that these sources are not limited to the administrative boundary of Delhi – emissions from these sources immediately outside Delhi and farther away are also contributing to Delhi's air quality problem (a contribution technically termed as "long-range transport" and commonly referred to as "boundary").

| J | F | M | A | M | J | J | A | S | O | N | D |

Seasonal episodes
🔴 winter heating
🟢 harvest burning

Every day
🔵 transport (road, rail, and aviation), road dust, construction, cooking, waste burning, and industries

Short episodes (1-2d)
🟣 Diwali crackers
🟠 dust storms

Using a summary of the existing source apportionment studies, starting from 1990 [13] and the seasonal trends from the recent ambient monitoring data (**Figure 1**), a net annual source apportionment pie was reconstructed.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
assumed heating	40%	25%									25%	40%
assumed stubble				8%	15%					8%	15%	
Of the remaining ==>												
assumed transport	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%
assumed dust	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%
assumed cooking	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
assumed industries	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
assumed waste	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%
assumed others	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%

The proportions in **Table 1** were applied to the average concentrations observed between 2019 and 2025, to re-construct seasonal PM$_{2.5}$ absolute values and percent contributions. The calculator for these estimates, along with some reference notes is available @ https://www.urbanemissions.info. The noticeable difference is the absence of the stubble burning and heating contributions during the summer months, which dominate (more than 40%) during the winter months.
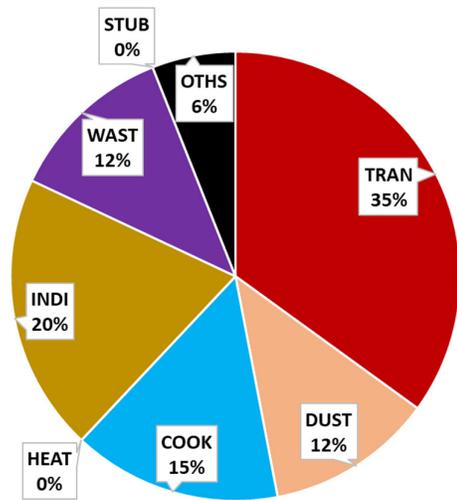
The annual reconstructed source apportionment incorporates contributions from all the major sources reported in source apportionment studies. In terms of proportions, this reconstruction resembles the wintertime source apportionment profile, primarily because of the inclusion of heating and stubble burning. This is also an indication of how the high wintertime concentrations and their source contributions dominate the overall story of PM$_{2.5}$ pollution in Delhi.

This is an average estimate of what is contributing to Delhi's PM$_{2.5}$ pollution problem. This doesn't differentiate the contributions from sources within the Delhi administrative boundary and those outside the administrative boundary, but the sources are the same everywhere – crisscrossing the region. These average source apportionment numbers are also used for the entire analysis through 2040. There will be changes in these numbers going forward, but there is limited understanding of future activities, and these uncertainties are not included in the current analysis. These estimates should be taken with *a pinch of salt* and used for open policy dialogue, rather than getting stuck on technicalities like whether these estimates should be plus or minus 2-5% here and there.
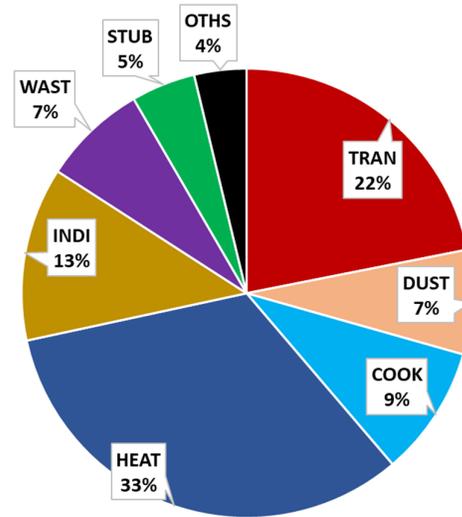
The summary presented in **Figure 2** is a consolidated number based on source apportionment studies conducted between 1990 and 2025, which include a range of methods, spatial and temporal spreads, and models [13,19,20].

Summer (JJAS) average = 41 μg/m³

STUB 0% · OTHS 6% · WAST 12% · INDI 20% · HEAT 0% · COOK 15% · DUST 12% · TRAN 35%

Winter (NDJF) average = 172 μg/m³

OTHS 4% · STUB 5% · WAST 7% · INDI 13% · HEAT 33% · COOK 9% · DUST 7% · TRAN 22%

Annual average = 100 μg/m³

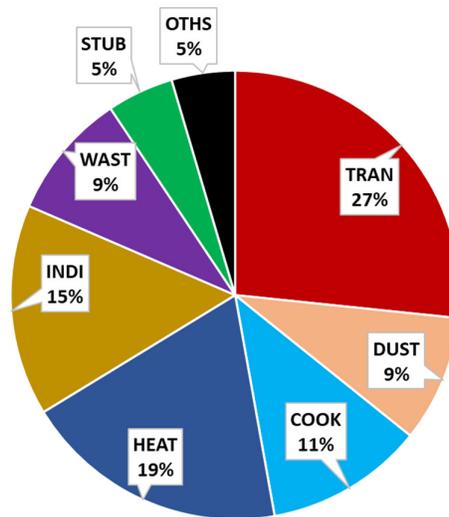OTHS 5% · STUB 5% · WAST 9% · INDI 15% · HEAT 19% · COOK 11% · DUST 9% · TRAN 27%

Figure 2: Reconstructed seasonal and annual source apportionment pies for PM₂.₅ pollution in Delhi. JJAS is months from June to September, representing the summer and monsoon months. NDJF is months from November to February, representing the winter months. TRAN includes contributions from road, railways, and aviation emissions; DUST includes contributions from resuspension on the roads, construction activities, and wind-blown erosion; COOK includes residential and commercial cooking emissions; HEAT includes primarily winter months space heating emissions; INDI is all the industrial emissions including power plants away from the city airshed via long-range transport, brick-kilns in the outskirts, and other industrial estate emissions; WAST includes emissions from open waste burning and any burning emissions at the known landfills; STUB is the contribution of emissions from post-harvest agricultural residue burning; and OTHS is the contribution from random sources like Diwali, cemeteries, temples, and others sources often listed as unaccounted in the source apportionment studies.

4. PM$_{2.5}$ projections 2026 to 2040

Predicting Delhi's air quality for the next 15 years is tricky. We face significant unknowns regarding activities, consumption levels, or even technology pathways to rely on. We only have some explanations of what has happened in the last 5 to 10 years, and we can only assume that the same trend will continue over the coming 15 years under a business-as-usual scenario, with some uncertainty.

With this assumption in mind, if you look at the concentrations between 2019 and 2025, the annual averages have remained around 100 μg/m^3. This is an indication of a combination of local activities, long-range transport contributions, and the result of interventions implemented over the last six years.
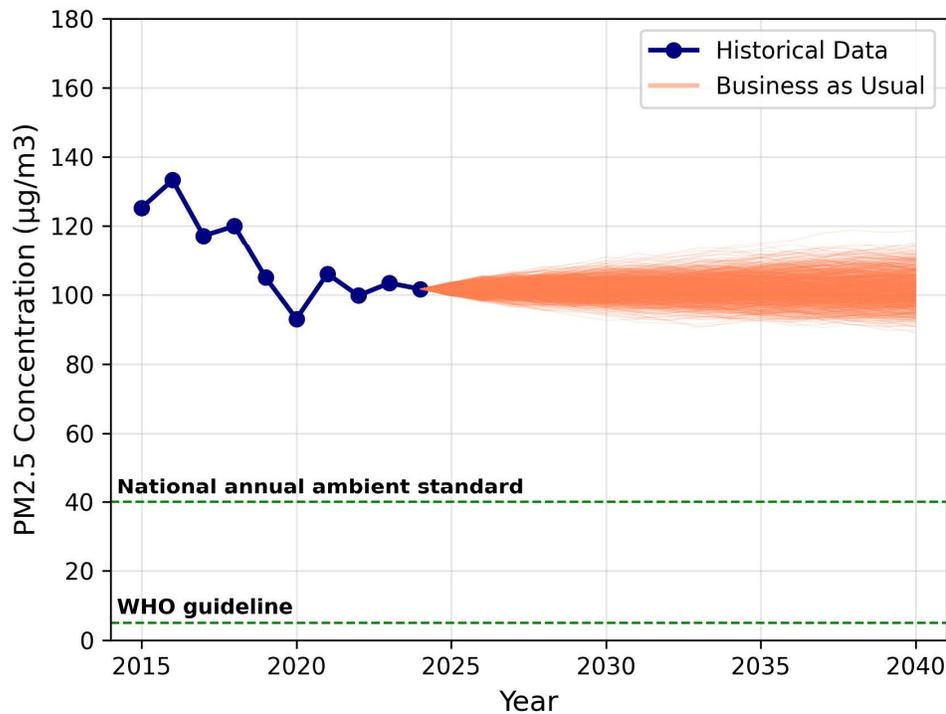

Figure 3: Annual average PM$_{2.5}$ concentrations from CPCB monitoring network (for the period covering 2015 and 2025) and projections (in orange for the period covering 2026 and 2040) simulated using 1000 Monte-Carlo simulations, considered as business as usual baseline.

These interventions include efforts across all sectors: introduction of the National Clean Air Programme (NCAP), implementation of the Graded Response Action Plan (GRAP), the introduction of Electric Vehicles (EVs) which has taken a central role managing vehicle exhaust emissions, the completion of large-scale construction activities like flyovers and metro construction (especially in South Delhi districts), a large increase in LPG consumption through piped gas, and various residential and municipal-level interventions for waste management [21-26]. All these factors have played some role in keeping the average annual concentration numbers at their

current 100 $\mu g/m^3$. Under business as usual, we can hope that the same level of awareness and cooperation will continue to keep the trend over the next 15 years.

To account for the uncertainty in future concentrations from 2026 to 2040, we looked at the variation in annual PM$_{2.5}$ concentrations (**Figure 1** and **Figure 3**) during a six-year period between 2019 and 2025. The variation during this period is approximately 2-3 $\mu g/m^3$. Using this observed variation, we projected the concentrations to 2040, using 1000 Monte-Carlo simulations with randomly varying the concentrations year-on-year. This approach places the annual average PM$_{2.5}$ concentration marker for 2040 in the range of 90 to 115 $\mu g/m^3$.

This business-as-usual analysis with uncertainty, establishes the baseline for concentrations and assumes the current trajectory of interventions will be sustained. While growth in sectoral activities (residential, transport, commercial, and industrial) is projected to increase the emission burden, the benefits accrued from existing and planned interventions are concurrently expected to somewhat mitigate this growth, as observed during of period of 2019-2025, thereby maintaining the average concentrations within a defined range. However, this definition of the baseline inherently encompasses significant uncertainty, projected optimistically as the net effect -- whether concentrations naturally decline or continue to rise due to unmitigated sectoral expansion -- remains statistically ambiguous.

5. Delhi's PM$_{2.5}$ pathways to 40 $\mu g/m^3$

Delhi's air pollution problem is not solvable overnight [16]. The year 2025 is over[1], and even if a new plan is put on the table right now, it is not going to address the problem this winter. If we could address and make an annual average of 60 $\mu g/m^3$ of PM$_{2.5}$ pollution vanish over a week, or a month, or even a season, then it would truly be a miracle.

Looking back four decades, what's seen in the review is that policy reforms have existed, and a laundry list of actions to address this problem has existed [11,13]. We have full awareness of the depth of the pollution problem, the breadth of all the sources that contribute to it (e.g., vehicles, industry, waste burning), and generally what it will take to get air quality under control [15,19,26-31].

If every single line item mentioned in the policy document submitted under the NCAP (National Clean Air Programme) in 2019 were implemented, Delhi will meet the national annual ambient standard by 2040 or even before that [22-24,26]. However,

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[1] This publication was published in November 2025

despite that document being prepared in 2019, the concentration continued to hover around 100 $\mu g/m^3$.

Two hypothetical emission reduction pathways are presented in **Figure 4**: one reaching the target of 40 $\mu g/m^3$ by 2040, and another reaching the same target by 2035. The pathway for 2035 is aggressive, requiring more action starting from 2026 and gradually picking up, reaching the target within 10 years and then continuing that path with the ambition of working toward the WHO guideline.
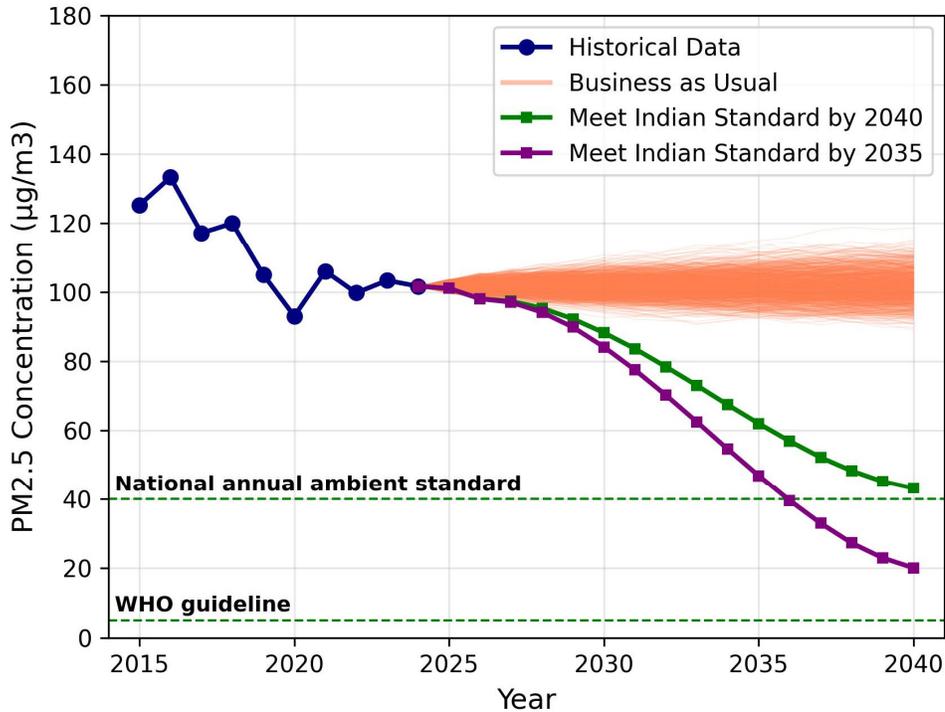

Figure 4: Annual average PM$_{2.5}$ concentrations from CPCB monitoring network (for the period 2015 and 2025); projections (in orange for the period covering 2026 and 2040) simulated using 1000 Monte-Carlo simulations, considered as business as usual baseline; and two hypothetical concentration pathways to reach the target of 40 $\mu g/m^3$ by either 2040 or 2035.

The WHO guideline of 5 $\mu g/m^3$ is an ambitious target, given Delhi's background concentrations can never be under 20 $\mu g/m^3$ unless it rains heavily for a large part of the day, all year round. Therefore, achieving the national standard of 40 $\mu g/m^3$ and simultaneously trying to move toward WHO's interim targets is already an ambitious path[2]. These two pathways are hypothetical; and many more such pathways can be programmed to optimize the resource allocation and institutional capabilities. Nevertheless, they represent the ambition to achieve clean air and ensure that ambient levels meet a standard that is not severe for the entire year.

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[2] WHO interim targets for annual PM$_{2.5}$ concentrations are 35, 25, 15, and 10 $\mu g/m^3$ respectively for IT-1, IT-2, IT-3, and IT-4.

6. Using COVID scenario as basis for reaching 40

The COVID-19 pandemic served as a truly valuable natural experiment, giving us a platform to understand the role of anthropogenic emissions on air quality. While the restrictions were severe, they also provided a window into the possibilities of how much reduction is feasible in each sector. This unprecedented drop in pollution resulted in remarkably clear air, most famously leading to the Himalayas becoming visible from parts of northern Punjab for the first time in decades. This showed us the possibility of achieving "blue skies" and clean air that could potentially last not just for a week or two months, but throughout the entire year.

During the lockdowns, several major shifts in human activity directly contributed to significantly cleaner air. The most impactful change was in the transport sector (passenger and freight movement), where the near-total cessation of road, rail, and air traffic drastically reduced tailpipe emissions. And for the vehicles which were allowed on the roads, an increase in speed also meant that the engines were running more efficiently with less exhaust emissions. Lesser vehicles on the roads also resulted in less road dust resuspension. A complete ban on the construction meant a lesser dust source. Simultaneously, industrial activity sharply declined due to operational restrictions and reduced demand, leading to a substantial drop in emissions from factories. A drop is also observed in the power generation rates, with lower industrial activity in the initial periods of the restrictions. While the use of biomass and LPG for cooking remained relatively stable or even increased slightly due to people staying home, the widespread reduction in major commercial and mobile (delivery) sources dominated the overall emission picture. Restricted movement on the roads also resulted in limited open waste burning. This collective drop revealed the high contribution of these anthropogenic sources to India's (and Delhi's) chronic air pollution problem. Forced reduction in activity levels is never a desired approach; we would like to see a more sustained policy in place that can result in similar emission drops from all the known sectors going forward.

Table 2: Comparison of long-term (2019-2025) PM$_{2.5}$ monthly averages with those observed during the COVID-19 lockdown periods in 2020

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	**Annual**
2019-2025 average		174	116	80	76	70	54	37	33	40	106	212	187	**99**
2020		148	120	57	44	54	46	34	24	47	132	199	190	**93**
%covid drop				29%	42%	23%								

Comparing, monthly concentrations during the period of 2019-25 (**Table 2**), when concentrations were consistently hovering over 100 units, and with the concentrations observed during the COVID-19 period, specifically for the months of March, April, and May, when restrictions were fully in place, the difference in concentrations was as high as 50-60% lower on some days and on average, the

monthly concentrations were lower by as much as 42% in April. This provides a great example of how much reduction is possible, if similar policies were in place to drop the overall emissions from all the major sectors. Hypothetically, we could use this 50-60% drop as the peak possible reduction in overall emissions.
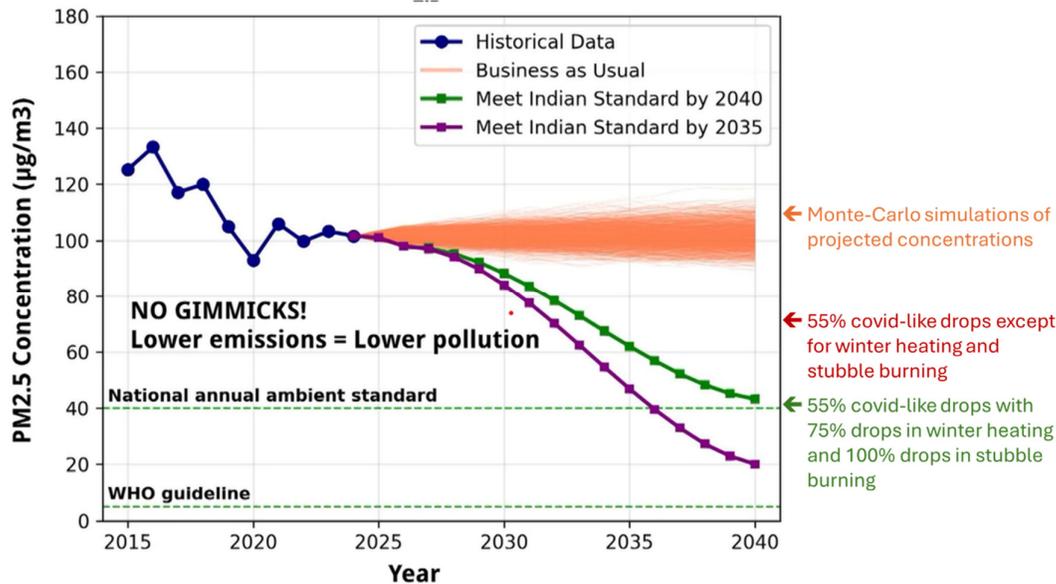

Figure 5: Annual average PM$_{2.5}$ concentrations from CPCB monitoring network (for the period 2015 and 2025); projections (in orange for the period covering 2026 and 2040) simulated using 1000 Monte-Carlo simulations, considered as business as usual baseline; and two hypothetical concentration pathways to reach the target of 40 μg/m^3 by either 2040 or 2035; with possible reductions in the concentrations from covid-like restrictions sustained as a policy through 2040 and additional reductions in heating emissions and complete elimination of stubble burning activities.

The two sectors that were unaffected during the lockdown restrictions were heating, which is a phenomenon limited to the winter months (and thus irrelevant during March, April, and May), and stubble burning of post-harvest agricultural residue, which also had very limited influence during those spring months. Therefore, we can fairly assume that all the drop in pollution (50-60% peak for some days) observed during those lockdown months derived strictly from the reduction in anthropogenic emission sources like transport, industries, cooking, open waste burning, and dust.

A combination of emission reductions -- specifically, up to 55% from all anthropogenic sources, a 75% drop in winter heating emissions, and a 100% drop in stubble burning emissions -- can help the city reach the Indian national ambient standard of 40 by 2040.

7. Cost of inaction

For the source apportionment numbers presented in **Table 2** and **Figure 2**, we constructed a scenario player, which allows the user to estimate the cost of inaction. For the selected implementation path, if the reduction percentage is less than the targets described in the previous section, means missing the national annual ambient standard for PM$_{2.5}$ in 2040.

Download the file here -- https://urbanemissions.info/whats-polluting-delhis-air
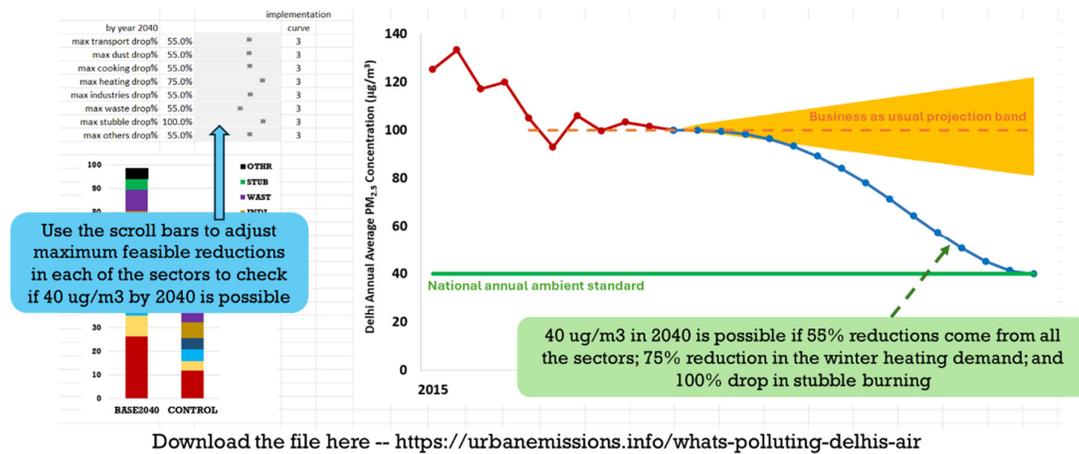
Figure 6: A scenario player for estimating the cost of inaction (based on MS Excel)

Table 3: Cost of in-action at the sectoral level, if the intended target of 40 μg/m^3 is not reached in 2040. The percentage is a proxy for additional health burden as mortality or morbidity the city will have to incur is the intended target is not reached in 2040. **This should be read as – for example, if the target concentration in 2040 reaches only 60 μg/m^3, then the city will experience 11.6% more exposure cases than if the target of 40 μg/m^3 was reached; if the concentrations don't change and remain at 100 μg/m^3, then the city will experience 35 more mortality cases for every 100 cases estimated if the target of 40 μg/m^3 was reached (for the assumed implementation plan)**.

Target achieved	Additional cost of inaction (% change in area from full implementation)
40 μg/m^3	0.0 %
50 μg/m^3	5.7 %
60 μg/m^3	11.6 %
70 μg/m^3	17.7%
80 μg/m^3	23.4 %
90 μg/m^3	29.5 %
100 μg/m^3	35.3 %

We estimated the cost of inaction as the area under the curve, which can be used as a proxy for exposure rates. The difference in the area when the target is achieved and not achieved is designated as "cost of inaction". This is a subjective assessment and entirely dependent on the pre-designed implementation plan (curve). In the

example presented in **Figure 6**, the implementation plan includes a lean period for up to 4 years, then picking up momentum to do more to reduce emissions from all the sectors and finally reaching the target of 40 μg/m³ in 2040[3].

The calculator is designed to give an indication of what percentage reduction is required in each of the sectors to achieve a certain target, or what the possible final concentration could be in 2040 given the maximum feasible reduction achievable in each of these sectors. This is done by setting a number less than the maximum reduction described in the previous section -- for example, 55% for all anthropogenic sources, 75% for the heating sector, and a complete 100% cut for stubble burning.

What this calculator does not do is provide the breakdown of how these percentage reductions are going to be achieved. For example, if the final calculation shows that only 30% reduction is possible in the transport sector by 2040, the calculator will not tell you how that reduction is possible. Is that reduction coming from aggressive promotion of public transportation, aggressive promotion of walking and cycling infrastructure and usage, or is it primarily coming from changes in vehicle technology? Similarly, this applies to the other sectors as well. This is an area where the dialogues need to happen and expand the possibilities of emissions management in all the sectors.

8. Cost of delays in implementation

The cost of air quality management is calculated in two parts. The first is the cost of inaction, where no action is taken on the emission loads from various sectors, which directly affects the pollution levels in the atmosphere (section 7). The second part is the cost incurred when we have the intent to act, but that action is delayed for some implementation reason. The same calculator used for estimating the cost of inaction can also be used for creating an estimate for the cost of delay, especially when that delay originates from the implementation strategy itself.

While plans are prepared for all sectors (or a particular sector) detailing how an intervention can result in a reduction in emissions and subsequently air pollution, there is always a timeline with various milestones for that implementation. These established timelines can also be used as operational targets for accountability.

We mathematically represented three hypothetical pathways in the calculator. One of them was used for demonstrating the cost of inaction pathway, and all three are presented in the table below with timeline from 2026 to 2040. The first strategy

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[3] The example curve is represented in the calculations as (-0.0459*t^3 + 0.9333*t^2 + 3*t)/100 to achieve 100% reductions of the selected feasible controls in each of the sectors by 2040 (in 15 years). See the worksheet names "drops" for more details on the equation. This is a subjective assessment, and the curve will (and can be) change depending on the local constraints – total change anticipated and the timeline (for example, more than 15 years or less).

involves starting with a slow implementation for the first four years, then gradually picking up speed and reaching the target. The second is a medium pace strategy, where implementation is slightly faster than the first. The third is an aggressive path, where substantial reductions are anticipated, and actions are taken immediately starting from 2026.

Table 4: Hypothetical (and conservative) implementation pathways for Delhi's PM2.5 to reach 40 $\mu g/m^3$ target in 2040. The % changes every year is the anticipated cumulative reduction in the concentrations year on year to reach the target.

Year	Pathway 1	Pathway 2	Pathway 3
2026	0.0%	0.0%	0.0%
2027	3.9%	1.3%	0.1%
2028	9.4%	4.9%	0.9%
2029	16.2%	10.4%	2.7%
2030	24.0%	17.5%	6.1%
2031	32.6%	25.9%	11.1%
2032	51.0%	45.0%	26.4%
2033	60.2%	55.0%	36.4%
2034	69.1%	64.8%	47.6%
2035	77.4%	74.1%	59.3%
2036	84.8%	82.5%	71.0%
2037	91.1%	89.6%	82.0%
2038	95.9%	95.1%	91.2%
2039	99.0%	98.7%	97.6%
2040	100 %	100 %	100 %

These three pathways are hypothetical in nature, and there is no set way of knowing if actual implementation is possible along this exact manner. The pathways only aim to have measurable results by the end of 15 years, specifically targeting the achievement of India's national ambient standard. If, by some miracle, these targets are achieved in a much more aggressive manner over the next five or ten years, that would be a bonus. However, given the history of how cities like London, Los Angeles, and Beijing have taken at least 10 to 15 years to reach cleaner, manageable air quality numbers, it is realistic to assume that Delhi will also take at least 15 years if a cohesive strategy and implementation plan are set into motion.

These three curves thus present three different implementation pathways that can be evaluated for what is possible. Crucially, any delay in implementing these pathways will come with a cost, not only in terms of bad air quality but also in terms of increased exposure rates. Like the cost of inaction calculations, the area under the curves is used as a proxy for exposure rates and the difference between the pathways is the additional cost of delay.

Figure 7 provides a glimpse of what the cost of implementation delay is between pathway 1 and pathway 3. Pathway 1 is the aggressive one, and pathway 3 is the one

that involves a slow start and only catches up at the end, reaching the target of 40 by 2040. The difference between these two curves provides us with the cost of delays: the longer the delay, the larger the cost will be. We consider the estimates provided in **Table 4** to represent conservative pathways, as in reality, the delays could be even longer than a slow start of four years. Any delay in implementation presented in **Figure 7** will result in up to 15% additional exposure rates (and estimated mortality cases) in Delhi.
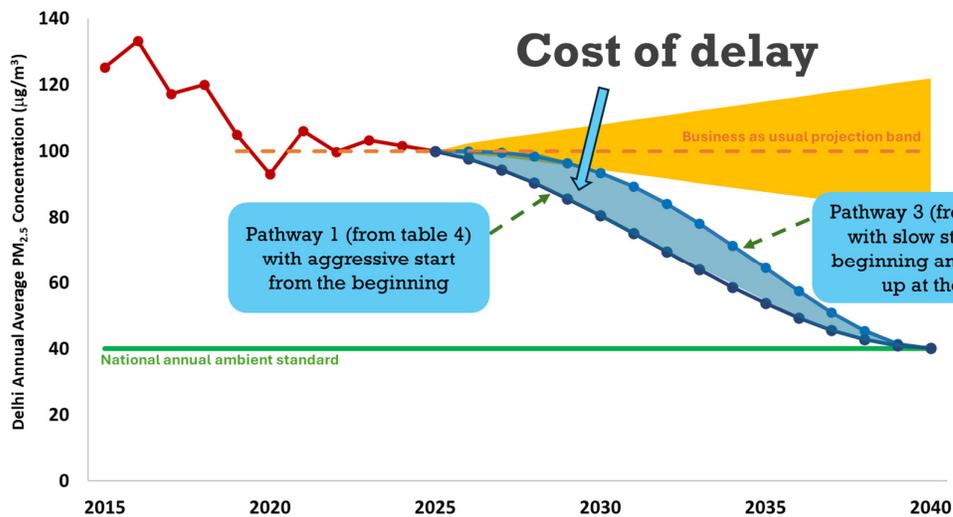

Figure 7: A scenario player for estimating the cost of delay for implementing interventions to reach the target of 40 $\mu g/m^3$ by 2040 (based on MS Excel)

The cost of delays can be minimized with immediate action in all the sectors. The calculator allows the user to select different implementation pathways for individual sectors as well, as not all sectors need to follow the same path. For example, managing stubble burning takes time to put the interventions in place, and perhaps two or three years of social and institutional negotiations will delay the actual implementation before it effectively takes off. Similarly, for the public transportation system, it will take some time to procure the buses and get the whole system in place before the overall reduction efforts commence. Whereas for addressing open waste burning emissions, one can start immediately with large cuts in the waste generation rates and big bumps in the waste management rates.

9. Additional cost of delays in implementation since NCAP 2019

The cost of delays has at least doubled since the start of the NCAP period, with nothing to little change in the concentrations between 2019 and 2025 (**Figure 8**). Using the same calculator, we extended the analysis to hypothetically project implementation, which could have resulted in a systematic reduction in the PM$_{2.5}$

concentrations from 100 $\mu g/m^3$, starting in 2019, through 2025, and resulting in 40 $\mu g/m^3$ in 2040. The difference between the NCAP curve and the slow implementation pathway curve starting in 2026 is 23% -- which means, with little action against cutting the emissions at all the known sources, the exposure rates and the estimated mortality cases are (conservatively) at least 23% more.
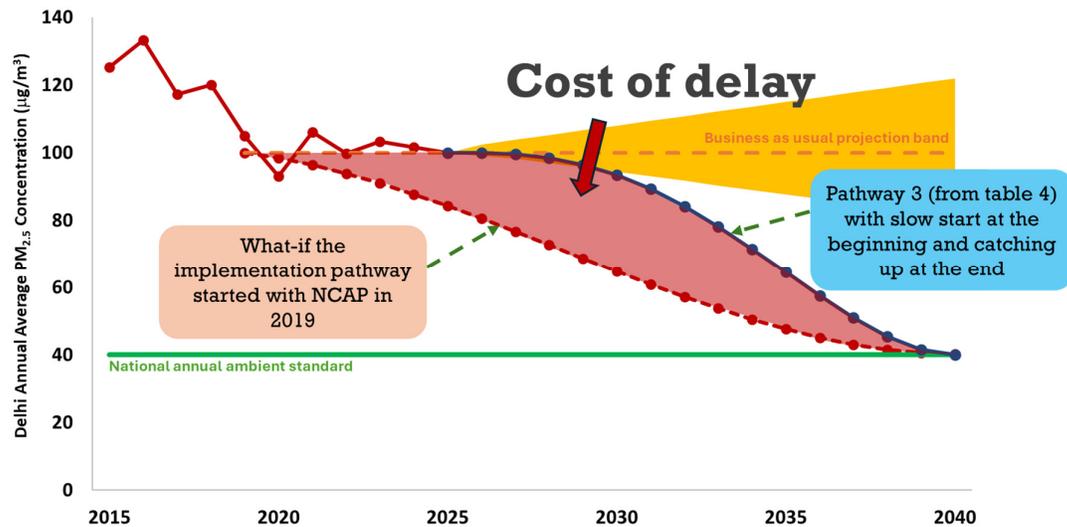

Figure 8: A scenario assessment for estimating the cost of delay for implementing interventions to reach the target of 40 $\mu g/m^3$ by 2040 (based on MS Excel)

10. In conclusion

Delhi can improve its $PM_{2.5}$ concentrations, but it will take at least 10 to 15 years of systematic implementation of a series of interventions, spanning all the sectors, at regional scale.

The necessary effort to reach 40 $\mu g/m^3$ in 2040 is substantial, requiring changes like those seen during the COVID-19 lockdown restrictions, in all the anthropogenic sectors. In addition to the year-round sources, a pathway is required to manage the winter heating emissions and stubble burning emissions, which are the seasonal peaks that contribute significantly to the annual average.

The cost of (technical) inaction is high. We need to focus on cutting emissions at the sources rather than thinking about managing the pollution levels after the emissions are already in the air.

The cost of (implementational) delays is also high. Every year that implementation is delayed will result in an increasing cost in terms of higher exposure rates, mortality, morbidity, and other economic metrics.
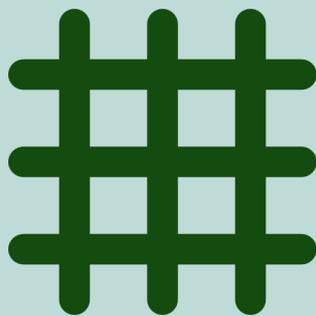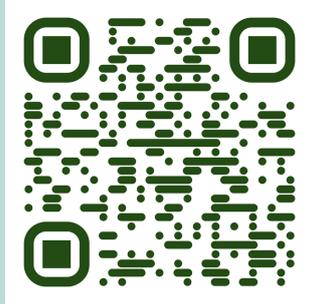
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