Air Quality Impacts of Urban Passenger Transport Reform

BRIEF FOR POLICYMAKERS

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Summary

Transport causes more than one-tenth of worldwide deaths from air pollution—a global tragedy. Fortunately, there is a clear path to dramatic reductions.

A new study from ITDP and UC-Davis is the first to quantify national primary air pollutant emissions from urban passenger transport for several future scenarios. The study finds that current trends will already produce steep declines in tailpipe emissions, such as nitrogen oxides (NO_x), fine particulate matter (PM2.5), and carbon monoxide (CO). An aggressive effort to electrify vehicles would nearly eliminate the remaining tailpipe emissions by 2050, especially in countries with heavy 2-wheeler use. However, as tailpipe emissions decline, non-tailpipe emissions from brake dust, tire wear, and road wear emerge as important sources of air pollutants, and they are not affected by stricter emissions standards and *electrification*.[1] Instead, we find that strong mode shift away from car travel can yield a dramatic reduction in PM2.5 emissions. To maximize reductions in all primary air pollutant emissions, the most effective scenario is a combination of aggressive *Electrification and Mode Shift* policies.

In the combined scenario, travel is shifted away from private vehicles via “avoid + shift” strategies. The “avoid” strategies include compact, mixed-use urban development to reduce travel distances, and the “shift” strategies include infrastructure and policy measures to make walking, cycling, and high-capacity public transport more convenient than driving. The *electrification* scenario includes EV strategies to rapidly electrify all categories of vehicles. The combination of both sets of strategies result in dramatic emissions.[2]

Table 1. AIR POLLUTANT EMISSIONS BY SCENARIO

Pollutant	**Prevention Scenario**	**Tailpipe** Engine combustion emissions	**Non-Tailpipe** Brake dust, tire wear, road wear, resuspension of road dust
PM2.5 v	EV	75% reduction relative to *BAU* (70kt -> 20kt)	20% reduction relative to *BAU* (230kt -> 190kt)
	Shift	45% reduction relative to *BAU* (70kt -> 40kt)	50% reduction relative to *BAU* (230kt -> 110kt)
	EV + Shift	90% reduction relative to *BAU* (70kt -> 10kt)	60% reduction relative to *BAU* (230kt -> 90kt)
NOx	EV	75% reduction relative to *BAU* (120kt -> 30kt)	
	Shift	10% reduction relative to *BAU* (120kt -> 100kt)	
	EV + Shift	80% reduction relative to *BAU* (120kt -> 20kt)	
CO	EV	70% reduction relative to *BAU* (3000kt -> 800kt)	
	Shift	30% reduction relative to *BAU* (3000kt -> 2000kt)	
	EV + Shift	80% reduction relative to *BAU* (3000kt -> 500kt)	

kt: kilotonnes

All numbers represent totals as of 2050, cumulative across the six studied countries (USA, Brazil, Mexico, China, India, Indonesia).

1 In the 6 countries we studied, non-tailpipe emissions jump from 64% of PM2.5 emissions in 2015 to 75% in 2050, and up to 91% in a heavily electrified scenario.

2 Our detailed analysis, available in the full report, also includes a "small vehicles" scenario. We found that intensive measures to promote smaller vehicles would only reduce greenhouse gas emissions by 5% to10%, compared to much larger impacts from *Electrification* and *Mode Shift*. Because of this, and the relative lack of research on the PM2.5 emissions benefits of smaller vehicles, we focus only on “shift” and “EV” in this brief.

Full findings, and a complete methodology, will be available in the full report. This will include a more detailed discussion of the scenarios for urban passenger transport, additional data visualizations, and discussions of other categories of impact, including greenhouse gas emissions, battery consumption, direct costs, road safety, and physical activity. In addition to maximizing air quality benefits, we find that the combined scenario brings many other benefits, including a dramatic reduction in transport costs for both individuals and governments; lower energy consumption; and reduced greenhouse gas emissions in line with the 1.5-degree scenario of the Paris Agreement on climate change. Thus, the combination of *Electrification* and compact, people-oriented cities can dramatically reduce air pollution and associated disease and death while also addressing a host of other issues.

The combination of *Electrification* and *Mode Shift* strategies will dramatically reduce tailpipe and non-tailpipe emmissions.
SOURCE: wibisono.ari via Shutterstock

BACKGROUND

Air pollution is one of the leading environmental causes of premature death worldwide, and urban passenger transport systems are a major contributor of air pollutants. This is especially true in dense urban areas, where pollutants are most likely to be inhaled. Indeed, transport causes more than one-tenth of worldwide deaths from air pollution—nearly 400,000 deaths around the world in 2015[3]—and we have every reason to believe that the number of deaths is rising. Beyond the tragic human toll, air quality–related disease and death strain health-care systems and reduce economic output. The crisis is acute, global, and multifaceted, and it is often most harmful to lower-income people and rapidly growing cities. Despite the real benefits of current emissions standards, this crisis is not sufficiently addressed by existing policy measures.

The pollution generated by urban passenger transport includes PM2.5 as well as NO_x and CO. This study considers these three pollutants from two sources (tailpipe and non-tailpipe), as shown in **Table 1** above, including a summary of how they might be addressed.

PM2.5, a particularly harmful pollutant, is responsible for cardiovascular disease, stroke, lung cancer, asthma, and other illnesses. Primary PM2.5 in cities is especially harmful because it can be present in high concentrations in densely inhabited areas. Nitrogen oxides (NO_x) and carbon monoxide (CO) are the two other primary pollutants included in our study[4]. NO_x, like PM2.5, has substantial implications for human health as a primary pollutant, and NO_2 in particular is highly relevant in an urban context because its most harmful effects are local to the environment where it was produced. NO_x and CO also act to drive the formation of secondary pollutants, including ozone and PM2.5, although we did not consider secondary pollutants because of their complexity.

We consider two main sources of air pollutant emissions from transportation in this study: tailpipe emissions and non-tailpipe emissions. (The third major source, “well-to-tank" emissions from fuel/electricity production and transport, is outside the scope of our analysis). While per-kilometer tailpipe emissions of CO, PM2.5, and especially NO_x are declining in most countries because of increasingly strict emissions standards, they remain significant in many lower- and middle-income countries. *Electrification* promises to reduce these emissions dramatically.

3 https://theicct.org/wp-content/uploads/2021/06/Global_health_impacts_transport_emissions_2010-2015_20190226.pdf
4 Sulfur dioxide (SO2) is also an important primary pollutant and precursor of secondary PM2.5, but emission rates are diminishing even more rapidly than other pollutants as ultra-low-sulfur fuels are adopted, and we therefore did not include it in this study.

However, non-tailpipe emissions—from brake and tire wear and the resuspension of road dust—are largely unregulated. *Electrification* does provide some benefit, as regenerative braking reduces brake pad abrasion, but that benefit is partially negated as heavier vehicles cause more road and tire wear. Non-tailpipe emissions are already believed to be the dominant source of primary PM2.5 from vehicles in many contexts. With the implementation of better emission standards, non-tailpipe emissions will be the predominant source of primary PM2.5 emissions from urban passenger transport in all countries by 2050, even under a *BAU* scenario.

METHODS

To understand how this crisis might be addressed, ITDP and UC Davis worked together, with technical support from the International Council on Clean Transportation (ICCT), to model primary air pollutant emissions from urban passenger transport in six of the world's largest countries: the U.S., Brazil, Mexico, China, India, and Indonesia. To our knowledge, this is the first time a multicountry urban transportation "outlook" study has included an assessment of air pollution in different scenarios. Focusing on PM2.5, NO_x, and CO, we model the quantities of these pollutants that will be emitted by urban passenger transport through 2050.

This study considers only "primary" emissions — pollutants released directly from vehicle use — and does not model chemical transformations in the atmosphere that generate so-called "secondary" pollutants, which are also highly impactful for human health. Although the exclusion of secondary pollutants is a conservative choice, it allows for a clearer understanding of the immediate contributions of different transport modes and technologies.

Because emissions factors were not available for minibuses and 2- and 3-wheelers for NO_x and CO, these have been omitted. This is likely most important in Indonesia and India, where 2- and 3-wheelers produce the majority of emissions, likely resulting in a significant underestimation of NO_x and CO emissions there. The four scenarios we examine are

- *Business as Usual (BAU)*: Current trends; increased car travel.
- *Mode Shift (Only)*: Increased walking, cycling, and public transport.
- *High EV (Only)*: Rapid vehicle *electrification*.
- *Shift+EV*: Combined *Mode Shift and Electrification*.

Our *Business as Usual* scenario follows industry-standard projections by the International Energy Agency describing the size, composition, and activity of each country's urban vehicle fleet. Across the board, these projections indicate an increase in car travel; this increase is most dramatic in countries like India that are rapidly growing in both GDP-per-capita and in urban population. Rates of *electrification* in *Business as Usual* are slow, and even by 2050 only an average of 40% of new vehicles are electric (although this varies widely by country).

Current trends of increased car travel mean that by 2050 about ¾ of primary PM2.5 emissions will be from non-tailpipe sources. **Source:** Daniel Supriyono via Shutterstock

The *Mode Shift* scenarios include ambitious yet feasible projections of reduced overall urban passenger travel ("avoid") and reallocation of urban passenger travel from cars to other modes ("shift"). Most important for avoiding unnecessary travel will be the adoption of more compact and mixed-use urban forms. When people live closer to their places of work, commerce, and recreation, their daily travel will be shorter and less emissions-intensive. In our *Mode Shift* scenarios, we assume that all cities will grow through infill development to a moderate, walkable level of density before they sprawl outward. In addition to compact land use, our *Mode Shift* scenarios accommodate as much travel demand as possible by expanding infrastructure for walking, bicycling, and high-capacity public transport. In India alone, for example, we project roughly 2,000km of urban rail, 12,000km of high-capacity urban busways (BRT), and 40,000km of protected bicycle lanes by 2050, saving India the cost of building the 300,000km of roadway that would have been needed for Business as Usual. (Detailed country-level projections are available in the Compact Cities Electrified Regional Roadmaps.)

Mode Shift will have little benefit in reducing NO_x because of high emissions from diesel buses.
Source: Alf Ribeiro via Shutterstock

The *Electrification* scenarios are similarly ambitious. They reflect the "maximum feasible" rate of vehicle *electrification* for all categories of vehicles: cars, buses, minibuses, and 2- and 3-wheelers. In these scenarios, all new-to-country vehicles are electric by 2040, in line with the COP26 Glasgow Declaration. This means that by 2050, there are only a vanishingly few holdouts of internal-combustion vehicles operating in cities, and practically all mobility is either human-powered or electric.

In all scenarios, tailpipe emissions factors are derived from the ICCT Roadmap model, version 2.2.5. These emissions factors are conservative underestimates, because they do not include recent data from remote sensing, which indicates that real-world emissions performance is worse than previously thought[5]. Non-tailpipe PM2.5 emissions factors are based on two primary sources: a 2023 report by the European Environment Agency (EEA) and a 2020 study by the OECD. These sources show relatively close agreement in estimates of particulate matter emissions from tire, brake, and road dust mechanisms, but because the study of non-tailpipe emissions is an emerging field, they should be considered as uncertain estimates. No reduction over time is projected for non-tailpipe emission factors, as current policy efforts globally remain insufficient to address them.

E*lectrification* strategies to rapidly electrify all categories of vehicles will provide the greatest reduction of local air pollution and have the greatest benefit to health outcomes.
Source: Jean Luclchard via Shutterstock

5 ICCT tailpipe emissions factors are available for all modes of travel for PM2.5, but only for bus and car for CO and NOx, so we could not calculate the contribution of minibuses and 2/- and 3-wheelers to emissions of these pollutants.

The study only models urban passenger transport — not freight, intercity travel, or rural mobility — and therefore does not capture total transport emissions. Within cities, however, it captures the largest and most direct sources of pollutant exposure for the urban population.

Due to the lack of appropriate reduced-form or mechanistic exposure-response models at this scale, we do not quantify the public health impacts of these emissions in this analysis. We instead report pollutant emissions directly.

RESULTS

We found that an urban passenger transport scenario combining Avoid + Shift and *Electrification* strategies would lead to the largest reduction of primary emissions of fine particulate matter (PM2.5) by 2050 (reductions ranging from 55% to 80%), with other primary pollutants seeing even more dramatic reductions.

The analysis also shows that *Avoid + Shift* and *Electrification* strategies play complementary roles. The avoid + shift strategies provide the greatest reduction of primary PM2.5 because they reduce PM2.5 emissions not only from vehicle exhaust but also from non-tailpipe emissions, such as brake wear, tire wear, and road dust resuspension. PM2.5 is not the only important pollutant; nitrogen oxides (NO_x) and carbon monoxide (CO) are also found in vehicle exhaust and have important direct and indirect implications for human health. EV strategies dramatically reduce emissions of both NO_x and CO

In summary, our analysis shows that:

- **Current trends show steep declines in NOx and CO.** Per-kilometer tailpipe emissions of NO_x and CO are projected to decline worldwide by a factor of about 4 because of improved emissions standards, even in the *Business as Usual* scenario. *Mode Shift* will have little benefit in reducing NO_x, because of the high number of emissions from diesel buses, but *Electrification* will be highly effective in ending NO_x and CO emissions from urban passenger transport.
- ***Electrification* substantially reduces remaining tailpipe emissions of PM2.5, NO_x, and CO,** nearly eliminating them by 2050.
- **Non-tailpipe emissions become a major source of pollutants.** Due to improved vehicle emissions standards, tailpipe emissions will fall on a per-kilometer basis even in *Business as Usual*, but in some countries, the increase in total travel activity outweighs this reduction. By 2050, these improved tailpipe emissions standards mean that about three-quarters of primary PM2.5 emissions will be from non-tailpipe sources.
- ***Mode Shift* away from car travel reduces PM2.5 emissions more than *Electrification*.** In four of the six countries we analyzed, *Mode Shift* away from private motor vehicles would reduce a quantity of PM2.5 emissions that is several times larger than what would be reduced by *Electrification*. This is primarily because of reductions in non-tailpipe sources, such as tire wear, road wear, brake wear, and road dust resuspension. This impact is especially pronounced in China because of the already high rate of bus *electrification*.
- ***Electrification* is most effective for reducing emissions in countries with heavy 2-wheeler use.** In Indonesia, and to a lesser extent in Mexico, *Electrification* is more effective at reducing PM2.5 because of the greater number of motorcycles, which have very high levels of tailpipe emissions per vehicle-kilometer (projected to increase significantly in *BAU*).
- **The deepest reductions in all primary pollutant emissions can be realized by the combination of Electrification and Mode Shift.** *Electrification and Mode Shift* each target different emissions sources (tailpipe and non-tailpipe), and the combination of the two yields the greatest reduction in pollutant emissions.

Detailed charts below show the three different pollutant emissions by country and scenario.

Fig. 1: PM2.5 Emissions by Country, Scenario, and Year

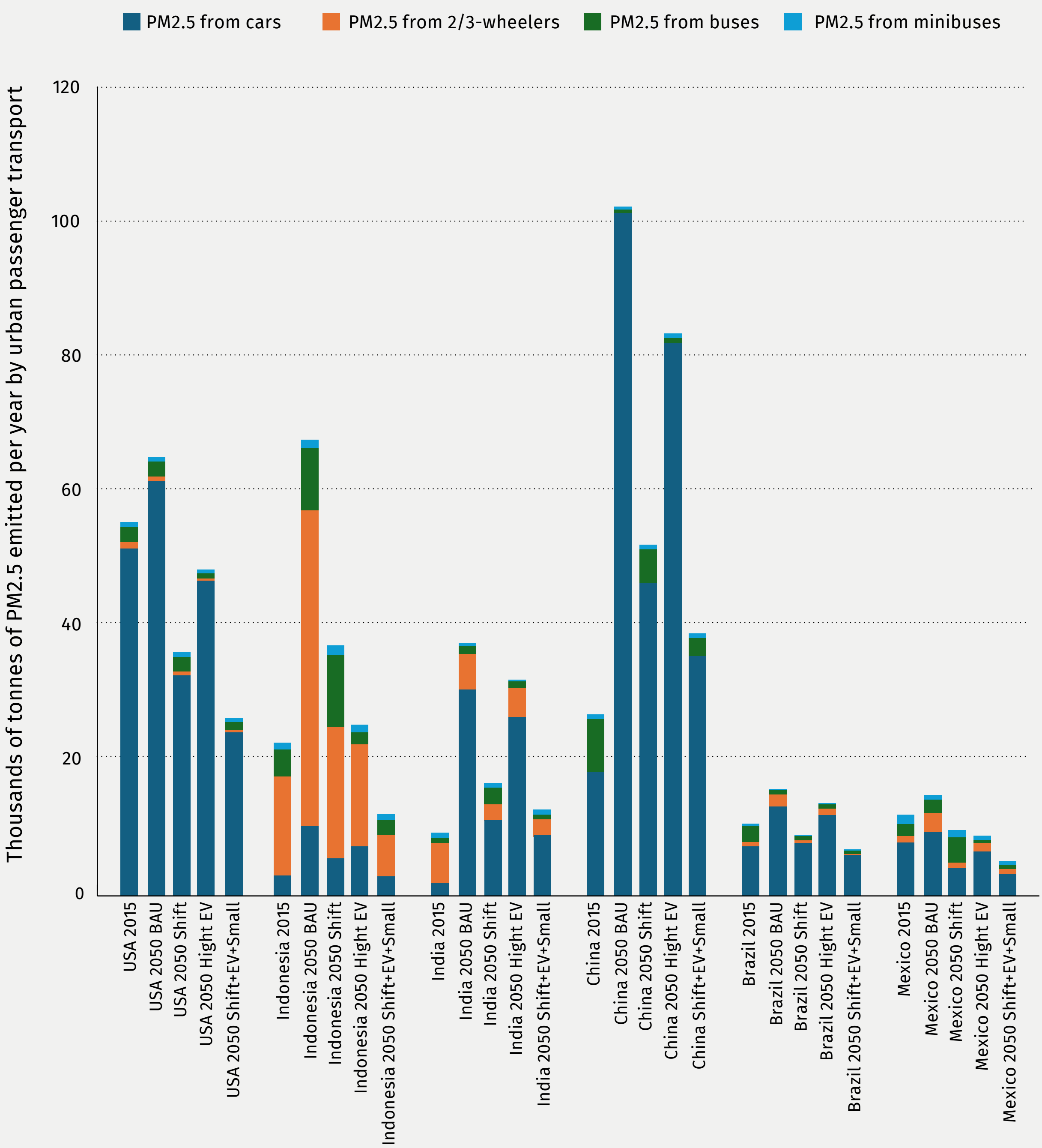


Fig. 2: CO Emissions by Country, Scenario, and Year

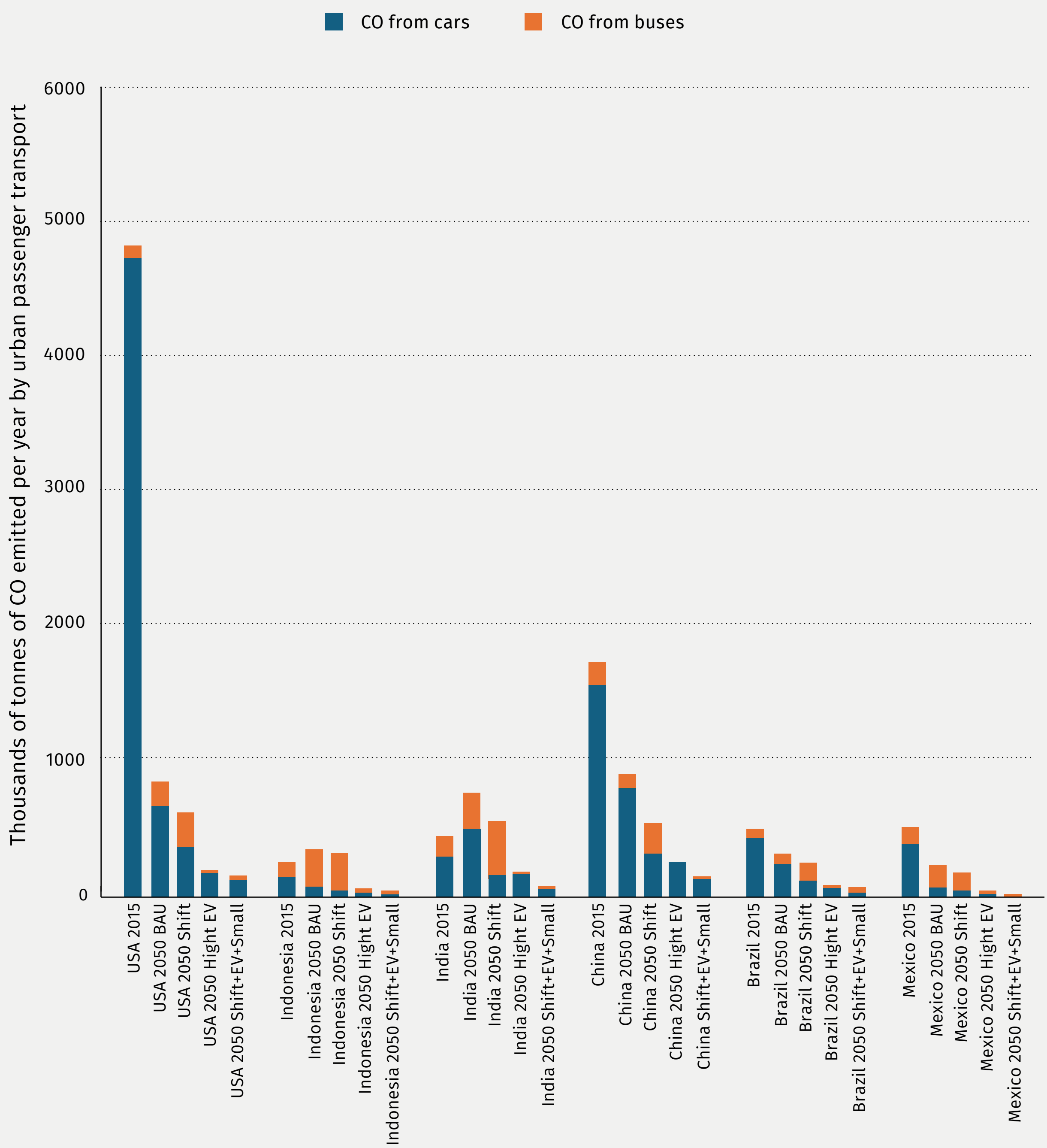
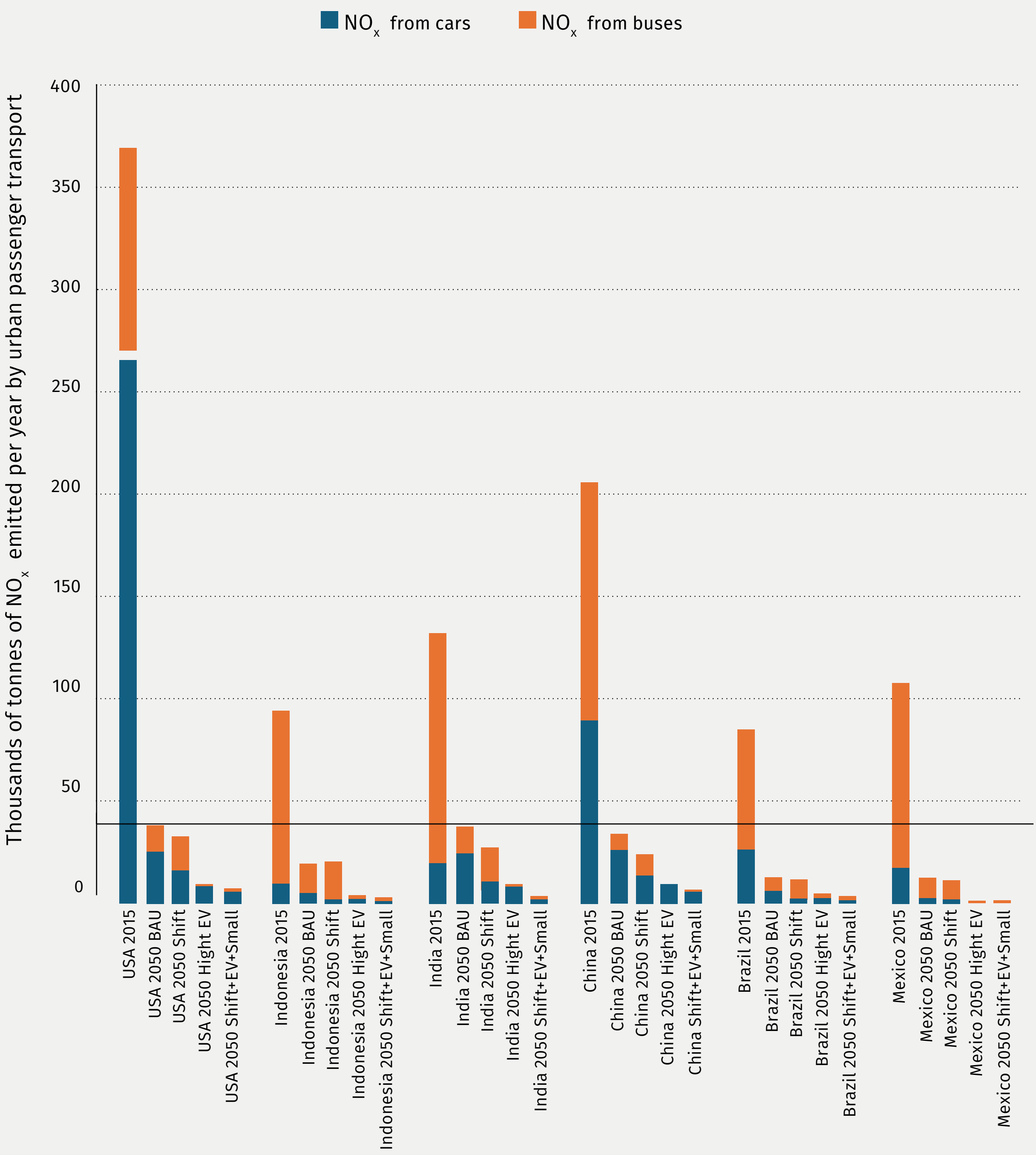


Fig. 3: NO_x Emissions by Country, Scenario, and Year



POLICY GUIDANCE

Achieving *Electrification*: Widespread *electrification* of urban passenger transport is necessary to minimize tailpipe emissions. Governments must provide a strong regulatory framework, financial incentives, and infrastructure investment to make electric vehicles viable

- Adopt vehicle *electrification* targets and commitments
- Support and facilitate large public electric fleet procurement
- Encourage fleet *electrification* in public transit, delivery, and shared mobility services as well as for government-owned fleets
- Expand charging infrastructure in both public and private spaces
- Provide financial incentives, such as subsidies and tax breaks, to lower upfront EV costs; impose counterbalancing fees on internal-combustion vehicles
- Adopt low-emission zones to further incentivize *electrification* in urban areas.

Achieving *Mode Shift*: Policies that encourage more compact cities as well as modal shift from private cars to shared, public, and active transport, are necessary to reduce non-tailpipe emissions. Effective measures often combine investment in attractive alternatives with disincentives for private car use.

- Prioritize investment in integrated networks of frequent, fast, high-quality, affordable public transport, especially electric buses
- Expand safe and accessible infrastructure for walking and cycling, with a focus on connected sidewalks and physically protected bicycle lanes
- Implement demand-management measures, such as parking reform and congestion/roadway pricing
- Integrate land-use planning to support mixed-use, compact development.

Electrification of public transport, especially buses, is a keystone of both scenarios.

CONCLUSIONS

Urban transport reform is essential for improving air quality and protecting public health. This study confirms that a combination of *Mode Shift* and *Electrification* strategies are crucial to reducing local air pollution from urban passenger transport in most countries. To effectively reduce primary PM2.5 from exhaust as well as from brake wear, road wear, tire wear, and road dust, cities and countries must reduce total vehicle-kilometers traveled by cars through compact, walkable urban design and high-quality public transport. To reduce the health burden of air pollutant emissions from urban passenger transport it is also essential to electrify transport vehicles. This would virtually eliminate tailpipe emissions, especially nitrogen oxides, which are emitted in large quantities by diesel buses and drive secondary emissions.

In the coming decades, as emissions standards reach the limits of their effectiveness, the only truly sustainable path to clean urban air lies in comprehensive transport reform: fewer, smaller, and cleaner vehicles serving cities designed for people rather than for cars.

A reform of urban transportation combining multiple strategies would lead to the greatest reduction in primary emissions.
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