BRIEFING

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Understanding the air quality and health impacts of large-scale vehicle electrification in India

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India's power and transportation sectors are major contributors to its poor air quality.[3] Air pollution negatively impacts human health, and the country's high concentrations of hazardous pollutants such as fine particulate matter ($PM_{2.5}$), nitrogen oxides (NO_x), and sulfur dioxide (SO_2) contribute to premature deaths and disease.[4] To reduce this air pollution and also to help mitigate climate change by reducing carbon emissions, India has adopted policies and targets for promoting the adoption of electric vehicles and the decarbonization of the power sector, the latter focused on retiring coal power plants.[5]

Building from our recent paper on the emissions impacts of an ambitious on-road vehicle electrification scenario, this study analyzes the air quality and health impacts of that analysis.[6] Our "Ambitious EV" scenario is analyzed between 2020 and 2040, with and without robust power sector emission control and decarbonization strategies. We find that large-scale vehicle electrification leads to net air quality and health benefits in India, including 13,300 and 16,700 annual avoided premature deaths in 2030 and 2040, respectively, when assuming no new policies to decarbonize the power sector or tighten power plant emission controls ("Reference" scenario). Value of statistical life (VSL) calculations show these benefits are in line with $10.3 billion

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3 Chandra Venkataraman et al., "Source Influence on Emission Pathways and Ambient $PM_{2.5}$ Pollution Over India (2015–2050)," *Atmospheric Chemistry and Physics* 18, no. 11 (2018): 8017–8039, https://doi.org/10.5194/acp-18-8017-2018

4 Kalpana Balakrishnan et al., "The Impact of Air Pollution on Deaths, Disease Burden, and Life Expectancy Across the States of India: The Global Burden of Disease Study 2017," *The Lancet Planetary Health* 3, no. 1 (2019): e26–e39, https://doi.org/10.1016/S2542-5196(18)30261-4

5 NITI Aayog & World Energy Council, "Zero Emission Vehicles (ZEVs): Towards a Policy Framework," (2018), https://smartnet.niua.org/sites/default/files/resources/ev_report.pdf; and International Energy Agency, "India 2020 Energy Policy Review," (2020), https://iea.blob.core.windows.net/assets/2571ae38-c895-430e-8b62-bc19019c6807/India_2020_Energy_Policy_Review.pdf

6 Arijit Sen et al., *Understanding the emissions impacts of large-scale vehicle electrification in India*, (ICCT: Washington, D.C., 2021), https://theicct.org/publications/EV-emissions-impacts-India-apr2021.

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(in 2020 U.S. dollars) in avoided health costs for 2030 and $19.1 billion in 2040. Importantly, we find that a greater number of premature deaths could be avoided with the adoption of stringent power sector emission control and stronger decarbonization policies, and these could result in up to 31,500 avoided premature deaths in 2030 and 70,400 avoided premature deaths in 2040 ("Combined" scenario). These larger benefits correspond to $24.4 billion in avoided health costs in 2030 and $80.7 billion in 2040, and every state in India sees improvements in air quality compared to the Baseline in 2040. These findings also underscore the benefits of accelerating efforts to decarbonize India's electricity grid and improve power plant emission controls independent of the level of vehicle electrification.

STUDY DESIGN AND METHODS

We used four different models to estimate transportation sector emissions, power sector emissions, air quality, and health impacts. First, ICCT's in-house India Emissions Model (IEM)[7] was used to calculate emissions from on-road vehicles in 2020, 2030, and 2040 for two pathways:

» A **Baseline** pathway where about 1% of the total vehicle sales in 2020 are electric vehicles (EV) and this share holds steady till 2040

and

» An **Ambitious EV** pathway where the EV share of new vehicle sales increases from 1% in 2020 to 67% in 2030 and 95% in 2040. (In our power sector analysis, we made the conservative assumption that the entirety of additional power demand from increased vehicle electrification is supplied by coal and gas power plants. This demand was estimated to be 22 TWh in 2030 and 46 TWh in 2040, and that is 0.9% and 1%, respectively, of the non-EV power demand.)

For power sector emissions, the Indian Institute of Technology (IIT) Kanpur developed four emissions control and decarbonization strategies between 2020 and 2040:

» The **Baseline** strategy assumes a gradual reduction of the share of coal power in India's generation mix from 76% in 2020 to 50% in 2030 and 15% in 2040. $PM_{2.5}$ emission controls are at 96% efficiency for all three periods. SO_2 controls at 90% efficiency are introduced in 2030 and remain at that level in 2040. And NO_x controls at 70% efficiency for older plants (operating before 2017) and at 90% efficiency for newer plants are introduced in 2030; in 2040, the efficiency of NO_x controls improves to 90% for all plants in operation.

» The **Improved Emission Control** strategy assumes that in 2030, SO_2 and NO_x controls operate at 95% and 90% efficiency, respectively, for all operating plants, and in 2040, these efficiencies are increased to 98% and 97%, respectively.

» The **Coal Phaseout** strategy assumes that the share of coal power in India's generation mix drops to 42% in 2030 and 11% in 2040.

» The **Combined** strategy combines the two strategies immediately above. Coal plants are phased out while emission controls on remaining coal power plants are improved.

The on-road transport emissions and the power sector emissions models were combined for the five air quality scenarios in this analysis, which are listed in Table 1. These represent different levels of electrification, emission control, and decarbonization.

7 Gaurav Bansal and Anup Bandivadekar, *Overview of India's vehicle emissions control program*, (ICCT: Washington, D.C., 2013), https://theicct.org/sites/default/files/publications/ICCT_IndiaRetrospective_2013.pdf

Table 1. Combined vehicle electrification and power sector scenarios

Air quality scenarios	Vehicle electrification measures	Power sector measures
Baseline	Baseline	Baseline
Reference (REF)	Ambitious EV	Baseline
Improved Emission Control (IEC)	Ambitious EV	Improved Emission Control
Coal Phaseout (CP)	Ambitious EV	Coal Phaseout
Combined (COM)	Ambitious EV	Combined Coal Phaseout and Improved Emission Control

AIR QUALITY MODELING

Emissions outputs of SO_2, NO_x, $PM_{2.5}$, and CO_2, the variables in the above two emissions models, were utilized to model air quality at a spatial resolution of 0.5° x 0.5° using the comprehensive meteorological and chemical transport modeling system Weather Research and Forecasting model with Chemistry Option (WRF- Chem).[8] For the emissions from all other sectors, default data from the Evaluating the Climate and Air Quality Impacts of Short-Lived Pollutants (ECLIPSE) V5a project's Current Legislation Scenario was utilized and remained constant for all scenarios and time periods.[9] This yielded population-weighted national and state-level air quality values, as indicated by $PM_{2.5}$ and ozone concentrations, and we compared those across the different time periods and scenarios.

Finally, the WRF-Chem air quality data was processed through ICCT's in-house Fast Assessment of Transportation Emissions (FATE)[10] model to determine health impacts associated with national-level air quality changes across different time periods and scenarios. Health impacts are calculated as the number of avoided premature deaths linked to ambient $PM_{2.5}$ and ozone exposure in India. The FATE model also calculates the avoided health cost associated with the avoided premature deaths using two VSL methodologies, and one is based on Viscusi and Masterman's methodology.[11] The other is based on the World Bank's methodology as applied in a global study on the health impacts of transportation emissions.[12]

RESULTS

In this analysis, emissions from the power and transport sectors in India in 2020 account for around 65% of anthropogenic NO_x emissions, 12% of primary $PM_{2.5}$ emissions, and 55% of SO_2 emissions. In 2040, in the REF scenario with ambitious electrification and without additional policy interventions, the emissions from these two sectors are expected to increase to 75%, 14%, and 58%, respectively, of anthropogenic emissions for the three pollutants. However, we find considerable aggregate reductions for all pollutants (Figure 1) in the more ambitious power sector emission reduction scenarios. $PM_{2.5}$ emissions from the power and transport sectors

8 Steven Elbert Peckham et al., *WRF/Chem Version 3.7 User's Guide* (Boulder, Colorado: National Center for Atmospheric Research, 2015).

9 Andreas Stohl et al., "Evaluating the Climate and Air Quality Impacts of Short-Lived Pollutants," *Atmospheric Chemistry and Physics* 15, no. 18 (2015): 10529–10566.

10 The International Council on Clean Transportation. (2021). FATE Model Documentation, https://github.com/theicct/FATE-doc

11 William Kip Viscusi and Clayton J. Masterman, "Income Elasticities and Global Values of a Statistical Life," *Journal of Benefit-Cost Analysis* 8, no. 2 (2017): 226–250, https://doi.org/10.1017/bca.2017.12

12 The World Bank study, Urvashi Narain and Chris Sall, "Methodology for Valuing the Health Impacts of Air Pollution," World Bank (2016), http://hdl.handle.net/10986/24440, as applied in Susan C. Anenberg et al., "The Global Burden of Transportation Tailpipe Emissions on Air Pollution-Related Mortality in 2010 and 2015," *Environmental Research Letters* 14, no. 9 (2019): 094012, https://doi.org/10.1088/1748-9326/ab35fc

combined are 22% less in 2040 under the COM compared to Baseline in the same year. For SO_2, NO_x, and CO_2, reductions under COM in 2040 compared to Baseline in 2040 are 85%, 29%, and 40%, respectively.

Figure 1. Aggregate emissions by sector and scenario. These are in kilotonnes for all pollutants except CO_2 emissions, which are in megatonnes.

Air quality results for the Baseline scenario show an increase in ozone and $PM_{2.5}$ concentrations of 1.96 ppb and 4.12 µg/m³, respectively, between 2020 and 2040 (Figure 2), and this indicates worsening air quality. In 2030, ozone concentrations slightly decrease by 0.019 ppb in the REF scenario compared to Baseline, but there seem to be slight increases in the other three scenarios, between 0.14 and 0.46 ppb. This trend continues in 2040, where for all scenarios there is a slight increase in ozone concentration compared to the Baseline, between 0.15 and 0.31 ppb. This likely reflects the non-linear ozone chemistry in which reductions in NO_x emissions can lead to increase in ozone production[13] (and it underscores the need for coordinated policies to reduce both volatile organic compounds and NO_x emissions to reduce ozone levels).

$PM_{2.5}$ concentration reductions are significant in 2030 and 2040. In 2030, in the REF scenario without ambitious power sector emission controls, $PM_{2.5}$ concentration decreases by 1.14 µg/m³ compared to Baseline. In both 2030 and 2040, improved power plant emission controls (IEC) play a larger role than coal phase-out (CP) in driving concentration reductions compared to the Baseline. However, the combination

13 Volker Grewe, Katrin Dahlmann, Sigrun Matthes, and Wolfgang Steinbrecht, "Attributing Ozone to NOx Emissions: Implications for Climate Mitigation Measures," *Atmospheric Environment* 59 (2012): 102–107, https://doi.org/10.1016/j.atmosenv.2012.05.002

of both strategies would result in the greatest air quality benefits. In 2030, the $PM_{2.5}$ concentration reduction from the Baseline is 1.9 µg/m³ in IEC, 1.5 µg/m³ in CP, and 2.88 µg/m³ in COM. In 2040, with higher levels of electric vehicle deployment, the air quality benefits of these scenarios compared to the Baseline that year are even larger: by 1.16 µg/m³ in REF, 2.17 µg/m³ in IEC, 1.54 µg/m³ in CP, and 4.52 µg/m³ in COM.

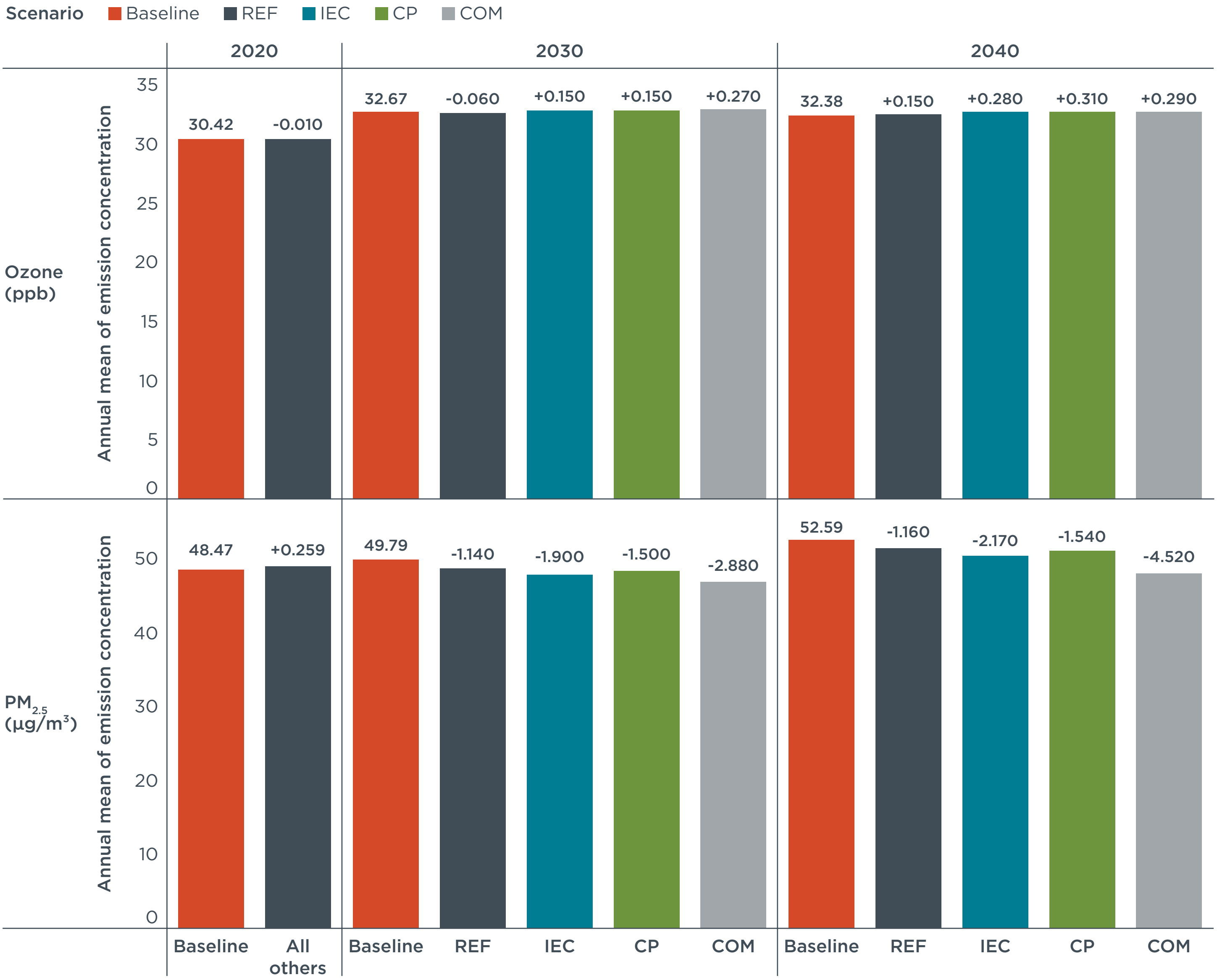

Figure 2. Annual mean of population weighted $PM_{2.5}$ (µg/m3) and ozone (ppb) concentrations by scenario.

STATE-LEVEL RESULTS

Our state level analysis of $PM_{2.5}$ concentration is shown in Figure 3. In all three time periods considered, the most polluted region in the Baseline scenario is the Indo Gangetic Plain, comprised of Haryana, Uttar Pradesh, Bihar, Jharkhand, and West Bengal. These states have concentrations generally over 60 µg/m³ largely because major industries, power plants, and highway networks are located there. Odisha, Punjab, and Rajasthan are also among the states with higher than the national average $PM_{2.5}$ concentration in the Baseline scenario.

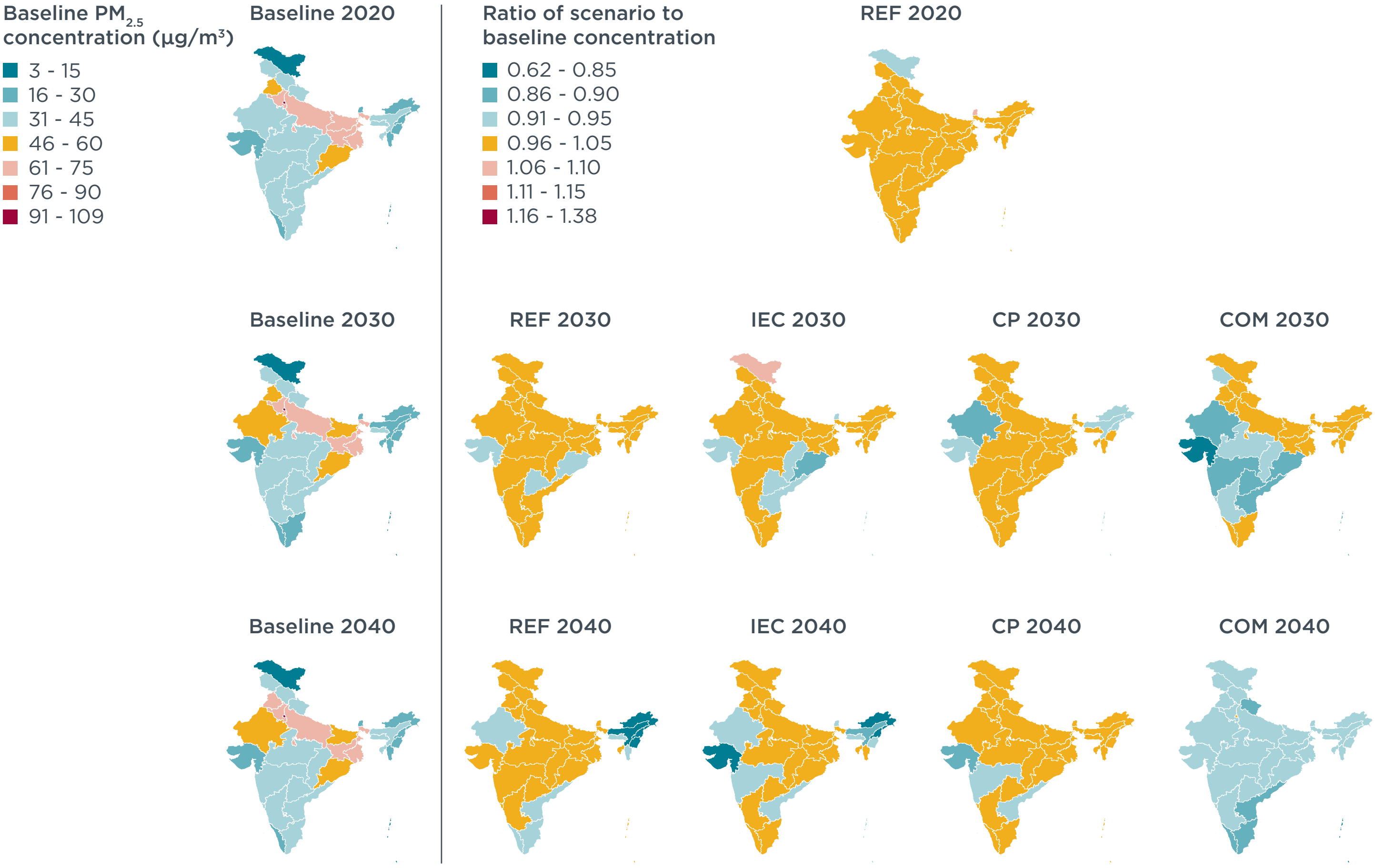

Figure 3. State-level variation in population weighted $PM_{2.5}$ concentrations (µg/m³) by scenario. Absolute values for Baseline and ratios calculate the values of other scenarios relative to Baseline in the same year.

*This map is presented without prejudice as to the status of or sovereignty over any territory, the delimitation of international frontiers and boundaries, and the name of any territory, city, or area.

Compared to the Baseline 2030, there is 20%–40% reduction in $PM_{2.5}$ concentration in Gujarat, Telangana, and Odisha in REF 2030, and additionally in Chhattisgarh and Andhra Pradesh in IEC 2030. Additional improvements are seen in Rajasthan, Arunachal Pradesh, Assam, and Nagaland in CP 2030. In COM, most states have reduced $PM_{2.5}$ concentrations compared to the Baseline in 2030. However, there are no noticeable changes in air quality in the Indo Gangetic Plain region in 2030. Further, in IEC 2030, a slight worsening of air quality is seen in Ladakh, where the $PM_{2.5}$ concentration is about 0.3 µg/m³ higher than REF 2030 and 0.7 µg/m³ higher than Baseline 2030; note that this is within error tolerance of the WRF-Chem modeling calculations after multiple simulations.

In 2040, the REF scenario brings air quality improvements in Rajasthan, Andhra Pradesh, Tamil Nadu, Kerala, and almost all the Northeastern states compared to the Baseline. In IEC, improvements are extended to Maharashtra and Gujarat. In CP, additional improvements are noticeable in Andhra Pradesh. In COM, every state in India would see noticeable improvements in air quality compared to the Baseline in 2040.

HEALTH IMPACTS

Air quality changes due to the transportation and power sector scenarios in this analysis are associated with relatively modest changes in the avoided air quality-related premature deaths in the country compared to the large total air pollution health burden in India (Figure 4). In 2030, compared to the Baseline estimate of 3.2

million premature deaths in the country attributable to air pollution, the REF scenario could avoid 13,300 premature deaths. The adoption of stringent power sector emission control and decarbonization policies would increase the health benefits compared to the Baseline. In IEC it is estimated there are 20,800 avoided premature deaths, in CP it is 16,100, and in COM, 31,500. By 2040, compared to the Baseline level of 4.9 million premature deaths in the country, an estimated 16,700, 31,500, 21,000, and 70,400 avoided premature deaths can be attributed to the REF, IEC, CP, and COM scenarios, respectively.

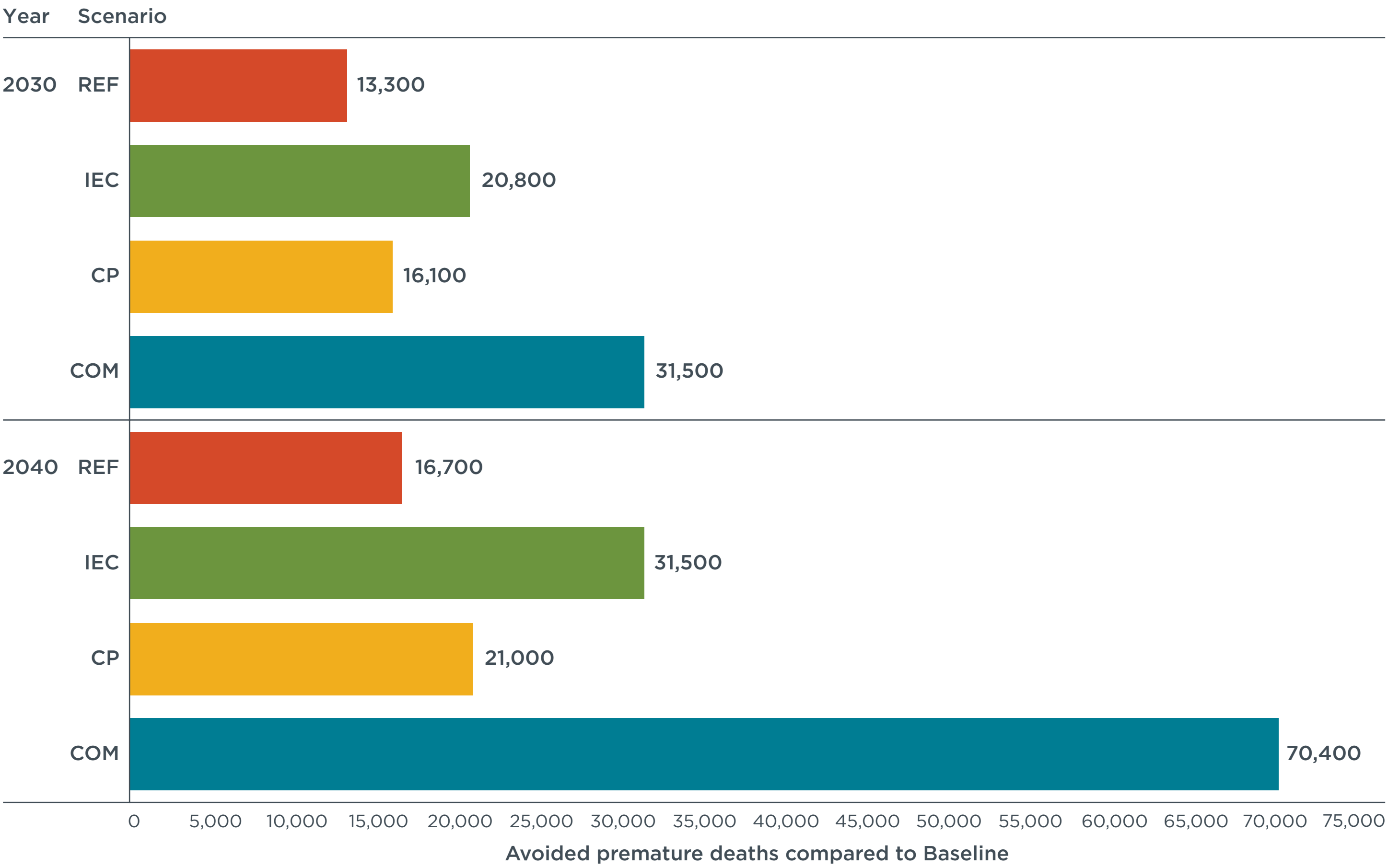

Figure 4. Avoided premature deaths due to air pollution compared to Baseline in 2030 and 2040.

In both 2030 and 2040, the pattern of avoided premature deaths compared to the Baseline suggests that stricter emission control strategies (IEC) tend to be more effective than ambitious decarbonization strategies (CP) in terms of avoiding premature deaths. The benefits are largely additive, though, and thus the combined policy of stricter emission controls and ambitious decarbonization maximizes the health benefits.

VSL ESTIMATIONS

Our VSL estimations are based on methods described by Viscusi and Masterman and by the World Bank. For each set of VSL estimates, we calculated the avoided health damages as the product of avoided premature deaths in each scenario compared to Baseline and the VSL estimate (normalized to 2020 U.S. dollars per premature death avoided). The results are in Table 2. For India, the VSL estimate based on the World Bank's methods is slightly higher than the VSL based on Viscusi and Masterman's methods. Accordingly, the avoided cost ranges from $7.9 billion to $18.8 billion in 2030 using the Viscusi and Masterman method, and from $10.3 billion to $24.4 billion in 2030 using the World Bank method. In 2040, the avoided cost ranges between $14.7 billion and $62.3 using the Viscusi and Masterman method, and between $19.1 billion and $80.7 billion using the World Bank method. In line with the avoided premature deaths, the monetized health benefits are the greatest in the COM scenario following either method, due to the additive nature of vehicle electrification, power plant emission controls, and electricity grid decarbonization policies.

Table 2. Avoided health damages compared to the Baseline for each scenario and year using the two methodologies.

Year	Scenario	Avoided health damages in 2020 U.S. dollars compared to the Baseline (Viscusi and Masterman)	Avoided health damages in 2020 U.S. dollars compared to the Baseline (World Bank)
2030	REF	7.9 billion	10.3 billion
	IEC	12.4 billion	16.0 billion
	CP	9.6 billion	12.4 billion
	COM	18.8 billion	24.4 billion
2040	REF	14.7 billion	19.1 billion
	IEC	27.9 billion	36.1 billion
	CP	18.6 billion	24.1 billion
	COM	62.3 billion	80.7 billion

DISCUSSION

Our evaluation of the effects of ambitious vehicle electrification, power plant emissions controls, and power sector decarbonization policies on emissions, air quality, premature mortality, and avoided health damages in India found that these have a significant impact on transportation and power sector emissions. There are also significant air quality improvements in all future years for each scenario compared to Baseline, with improved air quality in 2040 in every state under the most ambitious scenario compared to the Baseline. This results in as many as 70,380 avoided premature deaths, equivalent to avoided health costs of up to $80.7 billion in 2040 alone.

This study did not consider additional policies to reduce vehicle emissions such as stricter tailpipe emission control standards or improved fuel efficiency, apart from those that have already been adopted. In particular, more detailed analysis should be performed for vehicle segments such as heavy-duty trucks, which are expected to electrify more slowly and thus represent a major opportunity to accelerate vehicle tailpipe emission reductions.

Potential emission reductions in other sectors besides power and road transport were also not considered. Between 2020 and 2040, emissions from other sectors increase by 81% for NO_x, 66% for SO_2, and 31% for $PM_{2.5}$ in the Current Legislation Scenario (which was published in 2015 and thus is now a few years out of date), and this likely contributed to the worsening Baseline air quality between 2020 and 2040. This is also the reason why air quality in 2040 is not very different in the most aggressive 2040 scenario compared to the Baseline 2020 scenario. An analysis of coordinated actions across sectors to reduce ozone concentrations was also beyond the scope of this study. Thus, while the vehicle electrification and power sector emission control and decarbonization strategies discussed here have meaningful benefits that can be quantified, these would need to be part of a broader suite of policies to reduce emissions across all sectors in India if future decades are to realize an improvement in air quality compared to present day.

Our findings demonstrate that widespread vehicle electrification will yield net air quality and health benefits in India. This is under the conservative assumption that the additional power demand due to vehicle electrification is met through fossil fuel power plants. Additional policies to clean up India's electricity grid could amplify the air quality and health benefits of vehicle electrification. Although improved coal power plant emission controls are estimated to generate larger air quality benefits than progressive grid decarbonization, we find that a combined policy approach maximizes the benefits. These findings justify accelerating India's efforts to decarbonize its electricity grid and improve power plant emission controls independent of the level of vehicle electrification. They also underscore that India need not wait to pursue a pathway of ambitious vehicle electrification—rather, vehicle electrification and grid policies should proceed in parallel.