Managing Delhi's Air Quality: Exploring Economic Implications of Airshed Management Approach

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9.1 INTRODUCTION

In the last decade, major Indian cities—especially, those located in northern India including the national capital territory of Delhi (referred to as NCT in the rest of this chapter)—have achieved the dubious distinction of being the most polluted in the world (IQAir, 2020). NCT and surrounding National Capital Region (Image 9.1) are one of the most

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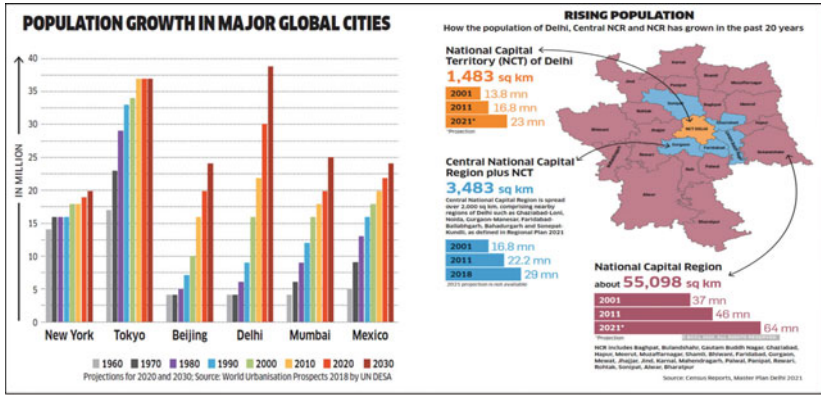Regulatory Assistant Project, Montpelier, VT, USA

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Image 9.1 Population growth in and around National Capital Territory (*Source* Sharma, S. N. [2019])

rapidly growing urban sprawls in India (Koppikar, 2016), heading toward becoming world's most populous city agglomerate by 2028 (UN, 2018).

According to a Lancet study published in 2018, the annual population weighted mean exposure to $PM_{2.5}$ in India was 89.9 $\mu g/m^3$ in 2017— greater than 40 $\mu g/m^3$, which is the limit recommended by the National Ambient Air Quality Standards in India (Dandona, 2019). In year 2019, Delhi recorded the highest average annual $PM_{2.5}$ levels of 98.9 $\mu g/m^3$ among world regional capitals (IQ Air, 2020). The World Health Organization estimates that 4.2 million premature deaths globally are linked to ambient air pollution, mainly from heart disease, stroke, chronic obstructive pulmonary disease, lung cancer, and acute respiratory infections in children (WHO, 2020). The State of Global Air 2020 report indicates that India had the highest burden of infant deaths due to air pollution; over 116,000 infants in India died within a month after their birth due to exposure to severe air pollution in 2019 (HEI, 2020).

According to the World Bank, at a global level the cost associated with health damage from ambient air pollution is estimated to be $5.7 trillion, equivalent to 4.8% of global GDP (World Bank, 2020). Unplanned urban growth along with mounting population pressures makes NCT a hotspot of deteriorating air quality and concomitant morbidity. Yet, there is limited—if any—effort to address this issue from policymakers.

Faster deterioration of air quality in the NCR makes it highly suscep-tible to pandemics and alleviated ozone levels (Sati & Mohan, 2017). Latest study by Indian Medical Association attributes 13% of new COVID pandemic cases in the region to ongoing severe deterioration in air quality post opening of the nationwide lockdown (The Wire, 2020).

The year 2020, although, did make us witness a rare binary where in the third week (April 2020) of the pandemic-induced national lock-down, citizens of Jalandhar in Punjab woke up to the wonderful sight of the Himalayas that are located ~ 100 miles away (Picheta, 2020). Such a sighting had been unheard of for more than three decades. Reports from all over India described the marvelously clean air that most citizens were experiencing for the first time in their lives. Figure 9.1 details air quality conditions pre- and post-lockdown in Delhi.

This feat was achieved by the total nationwide shut down of most human activities for more than a month. Most major polluting sources such as transportation, construction, and others were either partially or completely shut down (Guttikunda, 2020). With the pandemic still continuing at the time of writing, the economic impact of this total nationwide shut down is still being assessed. Instead of experiencing another year of economic growth, various agencies are estimating that the Indian economy will contract by 9–12% (Mishra, 2020).

This real-world and ongoing experiment suggests that improved air quality and the commensurate health benefits (and associated economic
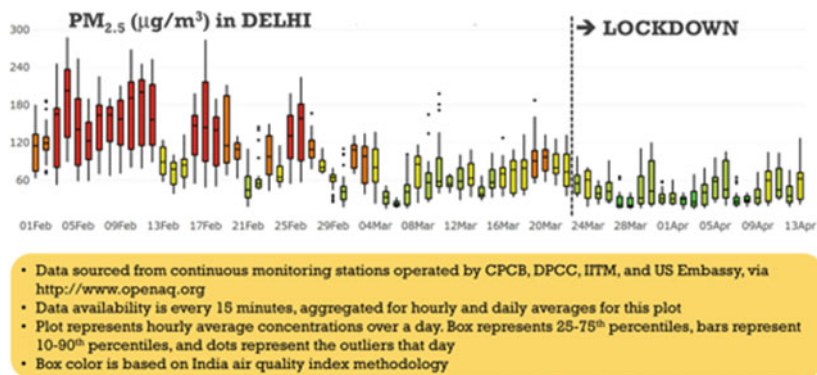

Fig. 9.1 Air quality monitoring in Delhi pre and post-lockdown (in µg/m^3) (*Source* Urban Emissions [2020])

benefits) may force India to confront the trade-off of high economic costs incurred through lower economic growth, rising unemployment, and falling incomes. In this chapter, we attempt to assess these trade-offs systematically in a disaggregated (e.g., state, sector, income category, etc.) manner.

An understanding of existing interlinkages between drivers of economic growth, sources of air pollution and existing interventions for improving air quality in the national capital region will be critical for designing any effective air quality management program. The sources of air pollution in India are myriad, ranging from coal-based thermal power plants (referred to as TPPs) to individuals burning small amounts of garbage in residential neighborhoods. Further, they vary by region. At a qualitative level, there is a robust understanding of the key sources of pollution even though there is a very high degree of uncertainty regarding the exact contribution of each source of pollution and more importantly, the impact of the pollution on health.

Ever changing meteorological conditions—e.g., prevailing wind patterns, precipitation, ambient temperature, etc.—has major implications for both the transport and transformation of emissions from various sources into specific health impacts. Sophisticated numerical models that, typically, require an extremely high level of computational power—e.g., super-computers—are necessary for establishing the connection between the emission source and the health impact (Guttikunda et. al., 2019).

A key component of air pollution impact analysis is how it is transformed subject to meteorological and geographical aspects of the region. The technical term that combines both the meteorological and geographical aspects—is "airshed" (Khanna & Sharma, 2020). The Delhi Capital region has a unique distinction of not only being an air quality hotspot that emanated out of increased urbanization and rapid migration of population to urban agglomerate, but also as a meteorological zone with limited capacity to process air pollution specifically during winters. The Delhi airshed is known to have distinctly different meteorological conditions during summers and winters. October marks withdrawal of monsoon in North western India and direction of wind changes from Easterly to Westerly carrying dust and long-range transport of particulate matter from Rajasthan and even as far as Pakistan and Afghanistan. According to a study by National Physical Laboratory, 72% of Delhi's wind in winters come from northwest while remaining 28% from Indo Gangetic plains (Joshi, 2020). Coincidently the phenomenon is also

coupled with higher agrarian activity in the North Western states with harvest season coupled with intensive stubble burning which adversely impacts the air quality of landlocked regions in the airshed. Studies show that long-range dispersion of pollutants from the west leads to 9–57% contribution of the total $PM_{10-2.5}$ mass during different seasons (Pawar et al., 2015). Recent emission source apportions studies point at 4 major source of air pollution in Delhi, industry, transportation, biomass/waste burning, and dust—see Fig. 9.2 and Table 9.1.

Within each category we focus on major sources as follows:

1. *Dust—construction activity*. Dust primarily from construction activities contributed over 16% of $PM_{2.5}$ loading in winters for NCR primarily attributed to extensive construction activity within the region. Pre-COVID projections attribute NCR with highest real estate growth in India specifically in residential, commercial, and hospitality space (IBEF, 2019). The policy considered here is reducing construction activity during bad air quality episodes (e.g., as NCT has already attempted in 2019). We also consider an augmentative policy of increasing green cover as an alternative to simply banning construction activity.

2. *Transportation—vehicles*. Vehicles contribute over 30% of $PM_{2.5}$ loading in winters for Delhi. The number of registered vehicles
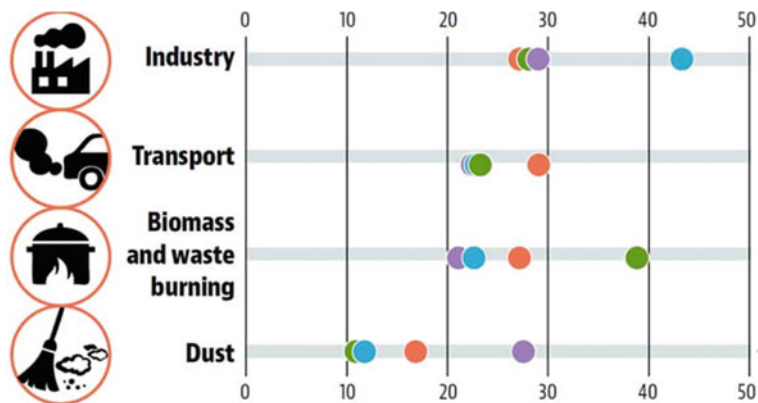

Fig. 9.2 Major sources of pollution in Delhi (in percentage) (*Source* Dubash and Guttikunda [2018])

Table 9.1 Literature review on emission sources in NCR and Delhi

Sr. no	Location	Method	Source apportionment studies	Studies on emission sources
1 ● IIT Kanpur (2016)	Delhi	Top-down	Based on Urban Emissions' re-interpretation of Sharma and Mukesh (2016), which redistributes secondary particles	**Industry**—It is a fuel-based study. The coal estimate is used for industry; hence diesel generator sets are not included but are reported under transport for this study **Transport**—Diesel and Petrol categories are used, which may overestimate transport since it included diesel generator sets **Biomass and waste burning**—Includes municipal waste burning only
2 ● CPCB (2011)	Delhi	Top-down	Based on Urban Emissions' re-interpretation of CPCB (2011), which converts PM_{10} and $PM_{2.5}$ data	**Biomass and Waste Burning**—Include municipal and commercial waste
3 ● TERI and ARAI (2018)	NCR	Bottom-up	Based on averages of summer and winter seasons (not 12 months)	**Biomass and Waste Burning**—Include municipal and commercial waste **Dust**—The study says dust is a higher share of emissions in summer (38%)
4 ● Urban Emissions (2018)	NCR	Bottom-up	–	–

Note SAFAR (2018) not included because it is an emissions inventory rather than a source apportionment study
Source Dubash and Guttikunda (2018)

in NCR is growing at 7–9% per annum. Further, there is heavy incoming traffic of vehicles from neighboring states of Punjab, Haryana, and Uttar Pradesh for trade and other reasons on daily basis, contributing significantly to vehicular emissions in the region. We consider a policy of substituting vehicles that use petrol and diesel with electric vehicles for all the four states. Policy that reduces the use of vehicles and the number of vehicles is not considered even though tire degradation and dust from roads are also considered major sources of air pollution.

3. *Biomass and waste burning—paddy farms*. Biomass and waste burning on an average contributes over 23% of $PM_{2.5}$ loading in winters for NCR. However, the winter peak loading $PM_{2.5}$ due to stubble burning in Punjab, Haryana, Uttar Pradesh, and Uttarakhand was estimated to be 42% on Nov 5, 2020 (*The Economic Times*, 2020). Therefore, the only policy considered here is reduction in burning of rice stubble in paddy farms post-harvest by implementing strategies such as Happy Seeders and using rice stubble for productive uses such as biomass-based electricity generation and manufacturing cardboard. Policies that target other waste and biomass burning are not considered in this analysis due to lack of sufficient underlying data.

4. *Industry—power sector*. NCT has 13 thermal power plants with a capacity of over 11,000 MW within a 300-km radius and coal, fly ash, and secondary particles from thermal power plants often blown into the NCR by the northwesterly winds contributing significantly to $PM_{2.5}$ levels in winter (CPR, 2018). We considered two policy options of installing air pollution control equipment on sources such as coal power plants and substituting coal power plants with renewable energy plants (e.g., solar and wind). Other industries are not included in this analysis as there are no techno-economically proven ways to reduce air pollution from many of them.

Some of these emission sources can simply be replaced by clean technologies—e.g., solar/wind for electricity generation instead of coal, and electric motors running on batteries instead of internal combustion engines for transportation. However, there also exist technologies that can reduce the emissions without such replacement. For example, emissions from fossil-fired power plants can be controlled through the use of mature and easily available technologies such as electrostatic precipitators

(for particulate matter), flue gas desulfurizers (for SO_2), selective catalytic reduction (for NO_X), and washing coal (for ash) while catalytic converters are available for eliminating tailpipe emissions from internal combustion engines.

Emissions from sources such as biomass/waste burning cannot be controlled as there is no single point source (e.g., smokestack in case of power plants or tailpipe in case of internal combustion engine). The need for combustion can be minimized through strategies such as use of Happy Seeders for addressing rice stubble waste. Experts have also suggested that paddy farming can itself be reduced thereby reducing the problem of rice stubble. Increasing green cover—i.e., afforestation activities—can significantly reduce dust. Construction activities can also deploy strategies such as using water to settle dust down and installing covers over the construction activity to contain the dust.

Some of these approaches to reducing emissions have incremental costs that the entities that are responsible for those emission sources have to incur. These incremental costs could lead to lower profits if not outright losses for these entities as a result of policies that seek to reduce emissions. While the cost–benefit analysis—at a societal level—for the use of these emission reduction approaches is overwhelmingly beneficial as established by numerous studies conducted in many parts of the world, the stakeholder-level cost–benefit analysis is likely to create winners and losers.

As Dubash and Guttikunda (2018) assert that a majority (as high as 70 percent) of the air pollution observed in NCT is generated beyond the borders of NCT, we adopt an Airshed Management approach—i.e., applying policies to not just the NCT but also its neighboring states such as Punjab, Haryana, and Uttar Pradesh.

Taking cognizance of deteriorating air quality in Delhi NCR, the supreme court of India in 2019 took governments of the states Punjab, Haryana, Delhi, and Uttar Pradesh to the task for not being able to control the life-threatening pollution in the combined region. Usually, a successful airshed management will entail multilevel air quality governance and effective enforcement regimes. State of Delhi came up with a comprehensive Graded Response Action Plan (GRAP) notified in 2017. GRAP requires implementation of actions by respective state authorities and coordination among 13 agencies of Delhi, UP, Haryana, and Rajasthan. Table 9.2 provides the details of GRAP implemented by NCT starting October 15, 2020.

Table 9.2 Graded Response Action Plan implemented in National Capital Territory—2020

Air Quality Category	Actions
Severe + or Emergency Category Air Quality (When PM 2.5 over 300 cubic metre or PM10 over 500 cu.m. for more than 48 h is recorded)	No entry for trucks into Delhi; only trucks carrying essential commodities allowed Stop Construction work Introduction of odd/even scheme for vehicles Task Force decides additional steps such as closing of schools
Severe Category Air Quality (PM 2.5 over 250 cu.m. or PM10 over 430 cu.m. is observed)	Closing of brick kilns, stone crushers and hot mix plants Maximisation of power generation only from natural gas to minimise generation from coal Encourage public transport Frequent sprinkling of water on roads
Very Poor Category Air Quality (PM2.5 of 121–250 cu.m. or PM10 of around 351–430 cu.m. is recorded)	Ban on use of diesel generator sets Increase parking fee by 3–4 times Increase bus & metro services Discourage burning fires in winters in apartments Movement of people outside to be restricted for people with respiratory or cardiac conditions
Moderate to Poor Category Air Quality (PM2.5 of 61–120 cu.m. or PM10 of 101–350 cu.m.)	Fine on garbage burning Enforce pollution control regulations in brick kilns & industries Mechanised sweeping & sprinkling of water on roads Ban on firecrackers

Source Pruthi (2020)

Most actions for emissions controlled under GRAP try to reduce the activities in key economic sectors, i.e., transportation, construction, combustion of fossil fuels—e.g., fossil-fired power plants (coal, natural gas, oil), internal combustion engines (diesel, petrol, and natural gas), diesel genset, biomass and waste burning, industrial processes, etc. create pollution. Additional sources of pollution include fugitive emissions (e.g., dust) from activities such as construction. We focus on the quantification of the economic impacts of controlling emissions from various sources.

The dynamics between the winners and losers influences the relevant policymakers when it comes to designing, implementing, and enforcing policies. For example, in 2015, Indian policymakers announced specific policies to reduce emissions from coal-fired power plants. A compliance period of two years was provided. At the end of the compliance period, it was clear that limited progress toward compliance had been made that resulted into litigation. In 2018, the Indian Supreme Court extended the compliance period to 2022 including specific milestones. As of November 2020, none of the relevant milestones have been achieved while the likelihood of compliance by 2022 is extremely low. Further, some of the stakeholders have started making a case for further extension (Dahiya, 2020).

The primary reason for non-compliance stated by the affected parties— i.e., owners of coal power plants—is that the incremental cost that they have to incur for installation of the pollution control equipment may not get reimbursed by the buyers of the electricity they produce (i.e., chronically loss-making distribution companies referred to as Discoms). In fact, Discoms have not been making full and on-time payments to electricity generators for a long time and hence, no bank is willing to even provide loans to the coal power plants for undertaking this new investment. The steadily deteriorating economics of coal power relative to new sources such as wind/solar and the diminished use of electricity because of the overall economic slowdown that pre-dates the pandemic has even raised the question whether it is better to simply retire coal plants immediately instead of spending more money on them (Fernandes, 2020).

In this chapter, our goal is to illustrate the application of the economic impact analysis methodology to a specific airshed—the National Capital Territory of Delhi (NCT). E3-India model is used to quantify potential economic benefits of integrated management and commensurate reductions in emissions from fossil fuel-based combustion. In recent years, increasing resources are being allocated for comprehensive data collection and development of sophisticated models for robust quantitative understanding of the sources of pollution and their health impacts. This chapter assesses how emerging options of trading clean electricity, coordinated regional policies for integrated management of power generation, vehicular emissions, construction, afforestation, and agriculture sector can help improve both air quality while also reducing the greenhouse gas emissions at regional level.

Each of these sources of pollution is complex and deserves a comprehensive treatment individually as presented in the discussion about coal power plants earlier in this section. For example, to reduce air pollution from TPPs one can consider policies that consist of consumer-focused energy efficiency. Similarly, for transportation, policies that focus on shifting passenger transport from individual vehicles (e.g., cars and motorcycles) to mass transit should be considered. The agricultural economy—especially, pertaining to a major crop such as paddy—is incredibly complex where policy levers such as international trade, water management, minimum support prices, market structures, and others can all contribute to a reduction in paddy cultivation. The construction sector can also be targeted with custom policies that go beyond—e.g., construction practices and materials—the blunt instrument of banning it for defined periods of time.

What is unequivocal is that all four sources of pollution also happen to be the building blocks of any economy. We don't want to leave the reader with the wrong impression that in this chapter we have been able to comprehensively represent the full range of policy levers that can be deployed to reduce air pollution from these four major sectors of the Indian economy. Our objective is to illustrate how E3-India can serve as an important tool in developing a deeper and more nuanced understanding of the linkages of these sectors with the broader economy and the distribution of the economic impacts across politically defined geographical units (i.e., states) and economic sector.

We also recognize that the timing of this research is such that underlying conditions are changing quite rapidly—e.g., India recently created a new policy framework for the agricultural sector that is being contested by key agricultural states such as Punjab. Harish et al. (2019) continue to advocate for a nationwide comprehensive multi-year approach for improving air quality (Harish et al., 2019). We encourage researchers to build on the analysis presented in this chapter in terms of both extending and updating it regularly as the overall global economic situation evolves during the ongoing pandemic.

This tussle among various key stakeholders—i.e., public health experts, environmental advocates, electricity consumers, Discoms, coal power plants, banks, electricity regulators, environmental policymakers, and courts spread out across multiple states—continues in the absence of robust quantitative analysis of the aggregate economic impacts and their distribution across various stakeholders. With such analysis, stakeholders

will have a clear understanding of not just the winners/losers but also the size of the impact on each one of them. Stakeholders could then—potentially—explore strategies in which the winners could compensate losers in way that everyone is better off. The analysis presented in this chapter aims to fill in this analytical gap.

One can imagine a process in which development of stakeholder consensus is achieved through an iterative use of the E3-India model in a transparent and participatory manner over a period of time. For example, the newly announced Commission for Air Quality Management in National Capital Region and Adjoining Areas (CAQM) could establish a committee consisting of all relevant stakeholders and experts (Dubash et al., 2020). This committee could formally collaborate with a dedicated E3-India modeling team in order to develop a wide range of policy scenarios that would serve as a key input to the broader policymaking process.

Section 9.2 details the key inputs for scenario creation, analytical approach, and insights on key interlinkages modeled in the analysis. This is followed by delineation of key results and discussion for the eight distinct scenarios studied in the chapter in Sect. 9.3. The last Sect. 9.4 concludes and lists some of the limitations of the study.

9.2   Analytical Approach

The E3-India model is introduced in Chapter 2 of this book. The scenarios in this chapter use both the economic and energy modules within the model. Due to data limitations, E3-India does not provide estimates of air quality at state level, so we cannot assess the positive economic impacts of reducing pollution. Instead, we focus the analysis on the effects of the policies to reduce air pollution on economic activity. We modeled the following scenarios that reflect specific policy proposals that are currently under discussion in India. The detailed description of the model baseline is presented in Chapter 2.

We compare the baseline and scenarios with additional policies in an *ex-ante* analysis. In order to facilitate greater synergies and easy comparison with already existing research we calibrate the default model baseline such that the generation mix and electricity consumption at national level closely meet baseline estimates of a recently released energy transition commission report. The key reason for this calibration was to ensure that power sector scenarios are also aligned with the existing grid capacity

projections till 2030. The details of baseline calibration are presented in Table 9.8 in the Appendix.

9.2.1   *Dust Control Through Reduced Construction Activity*

Construction is one of the key economic sectors in India and, especially, in the NCT. Under the Graded Response Action Plan (GRAP), construction activity is banned only under severe or emergency conditions when PM 2.5 concentrations are over 300 $\mu g/m^3$ or PM10 is over 500 $\mu g/m^3$ for more than 48 h. Until 10 February 2020, the Supreme Court had banned construction activity in NCT (Bhowmick, 2020). However, closure of other construction supply chain elements like brick kilns, hot mix plants, and stone crushers are mandated under even severe air quality deterioration conditions (PM 2.5 over 250 $\mu g/m^3$ and PM10 over 430 $\mu g/m^3$) (CPCB, 2020).

During the initial months of the COVID-19 pandemic, there was a complete standstill of construction activity during the formal lockdown periods. The ongoing pandemic has constrained the revival of the sector due to limited availability of labor as a vast majority of labor migrated back to their villages during the lockdown and have continued to stay there. We expect that the pandemic—hopefully—ends in the near future and the construction sector, over time, regains its pre-pandemic level of activity.

In order to model the scenario of improving air quality by banning construction during bad air weeks, we reduce construction output by 20% until 2030 for all four states in the airshed. In other words, we assume that construction is banned for ~ 2.4 months every year during the winter season. For this scenario, we expect that the impact would be severely negative across most economic indicators as this is a major economic sector. Further, as air quality is a pertinent problem in the NCT, the probability of construction and allied activity to be banned annually during winters is very high. The objective—for this scenario—is to assess the magnitude of the economic impact in absolute terms while also serving as a benchmark for comparison with the other scenarios, along with exploring intersectoral linkages.

9.2.2   *Urban Afforestation for Dust Reduction*

Plants are known to scavenge significant amounts of dust from urban environment (Weyens et al., 2015). In Beijing (China) trees in the city center removed 772 tons of PM10 on a yearly basis and in Chicago, USA, trees occupy 11% of the city area and eliminate approximately 234 tons of PM10 per year (Yang et. al., 2005; McPherson et al., 1994). We model a generic scenario of increasing green cover—i.e., afforestation—which will create opportunities for new employment when construction activity is stopped and help in reducing the movement of dust through the region.

National forest policy of India since 1988 iterates the goal of bringing 33% of land area under forest and tree cover. Further, in year 2015, India has pledged to create 2.5–3 Billion tons of carbon sinks by 2030. The carbon sinks are to be created through programs such as National Afforestation Program, National Green India Mission, Green Highway Mission, National Agroforestry Policy, and others. As detailed in Table 9.3, the total land area under tree cover stands at 24.56% for India but only 2.89% of it can be attributed to rural and urban tree cover. We find that the NCT maintains comparatively much higher (approx. 3 times) tree cover when compared to states of Haryana, Uttar Pradesh, and Punjab. The states do have the bandwidth to create necessary incentives to enhance tree cover through various ongoing initiatives, specifically, in the urban pockets thereby improving carrying capacity in the Delhi airshed along with contributing to respective state climate actions plans.

Table 9.3   Tree cover across the Delhi airshed

	Area under forest cover (Sq Km)	% Geographic area	Area under tree cover (Sq Km)	% Geographic area	Total area under forest & tree cover (%)
Delhi	195.4	13.18	129	8.73	21.91
Haryana	1602	3.62	1563	3.54	7.16
Punjab	1849	3.67	1592	3.16	6.83
Uttar Pradesh	14,806	6.15	7342	3.05	9.2
Total India	712,249	21.67	95,027	2.89	24.56

Source FSI (2019)

A national-level scenario is modeled to estimate the total investment requirement for creating a carbon sink of 2.5 Billion tons. The total carbon stock per hectare is estimated at ~ 100 tonnes and hence, total land required for afforestation for 2.5 billion tons of carbon sink is ~ 25.5 million hectares (FSI, 2017). The investment required is ~ $600 per hectare National Mission for a Green India (2011). The total investment is allocated to forestry and agriculture sector at national level.

9.2.3   Emission Reduction from Transport by Substituting Petrol/Diesel Vehicles with Electric Vehicles

India imports the majority of the oil that is used, primarily, as fuel in the transportation sector and hence, there are major economic implications of any reduction in oil consumption due to switching away from internal combustion engines (ICE) to electric vehicles (EVs). Under the Graded Response Action Plan, if $PM_{2.5}$ concentrations are over 300 $\mu g/m^3$ or PM_{10} is over 500 $\mu g/m^3$ for more than 48 h, then diesel trucks carrying freight (except essential commodities) are banned from entering the NCT, and an odd–even scheme for private vehicle use is implemented.

As transportation is a year-round activity, band-aid measures such as odd–even schemes will need to be implemented and enforced numerous times throughout the year causing widespread disruption in daily life. Consequently, it is crucial for policymakers to focus on policies that lead to structural shifts. For example, a sustained shift to non-motorized transportation (e.g., walking and cycling) and mass transit (e.g., buses and trains) have been shown to significantly reduce the use of ICEs. The construction and operation of the infrastructure to support these policies—e.g., pedestrian plazas, dedicated bicycle paths, bus rapid transit, metros, etc.—will also result in new employment opportunities while the manufacturing of equipment such as bicycles, buses, and trains can offset the reduction in jobs in the car manufacturing sector. Good quality data is not available for modeling these policies in the NCT yet although a few researchers have initiated efforts. Consequently, in this chapter, we focus on one structural policy—i.e., substituting ICEs with EVs—that can be relatively easily analyzed.

Several states—including the four states in the NCT airshed—have formulated state-level EV policies (Government of Punjab, 2019; Government of Uttar Pradesh, 2018; Government of NCT of Delhi, 2020; and Tornekar, 2020). In addition, the Indian government has launched

its Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles schemes that encourages, and in some segments mandates, the adoption of electric vehicles (EV), with a goal of reaching 30% EV penetration by 2030 (Sahay, 2019). Further, NITI Aayog has proposed setting up electric battery manufacturing factories for a targeted capacity of 50 GWh per year over the next ten years at projected cost of USD 5 billion (Pimpalkare, 2020).

In this scenario, we model a conservative switch of 10% from oil to electricity in the land transportation sector by 2030 in all four NCR states. The energy switch is calibrated to account for added energy efficiency offered by efficient electric vehicles (half the energy consumption). The increase in demand of electricity from the land transport sector will lead to greater investment in the power sector which is endogenously captured through the model. This switch is also augmented by modeling an estimated investment of $5 Billion in battery manufacturing (through the electrical equipment sector) by 2030 at the national level. We do not model additional automobile manufacturing as we assume that existing manufacturing facilities for oil-based vehicles will be re-configured to manufacture EVs.

For this scenario, we expect the impact to be modestly positive across most economic indicators due to the decrease in oil imports, combined with increases in domestic investments (e.g., battery manufacturing) and the subsequent new economic activity.

9.2.4   Reducing Biomass Burning by Crop Residue Utilization

Agriculture is one of the key economic sectors in India and especially important one for three of the states in the NCT airshed—Punjab, Haryana, and UP. It is also one of the most politically sensitive topics in India. In September 2020, the Indian government passed new legislation that reforms major elements of the sector which has led to substantial protests by farmers in many places but especially, in Punjab. In fact, for the last 50 days the farmer protests in Punjab have prevented movement of railways (both freight and passenger) because of which the negative economic impact on Punjab is estimated to be as high as USD 4.28 billion (Rs. 30,000 crores) (Sharma, 2020).

Within agriculture, paddy is considered one of the most important crops. Not only is rice consumed domestically as it is part of the staple

diet, India is the largest exporter of rice in the world bringing in valuable foreign exchange (Chandresekhar & Ghosh, 2019). A large share of domestic purchase of rice is by the Indian government at a regulated price while the price achieved in international markets is dependent on the global supply–demand balance. Unsurprisingly, paddy farmers are extremely concerned with any policy that could raise their costs as they may not be able to pass on this incremental cost on to consumers through higher prices.

Paddy is usually harvested in October and within a short period of time—as short as a week—the field has to be prepared for planting the next crop. This short period of time is a consequence of a law that seeks to conserve groundwater and instead maximize use of rainwater because Punjab, as well as most of the Indian sub-continent, has seen rapid depletion of groundwater (Rodell et al., 2009). Overuse of groundwater that has to be pumped out has negative implications for the power sector as most of the electricity sold to the agriculture sector is significantly below the cost to serve it. A recent study reveals that though flat tariffs have low administrative costs and more equitable distributional outcomes, they do not provide incentives to farmers for water conservation (Sidhu et al., 2020). Further, the subsidy is offset by seeking direct financial support from state budgets and over-charging commercial/industrial consumers of electricity leading to adverse impacts in those sectors.

Today, the easiest and cheapest (practically, free!) way to prepare the field—i.e., getting rid of the rice stubble remaining in the ground post-harvest—is to burn it. Burning crop residue is a crime under Section 188 of the IPC and under the Air and Pollution Control Act of 1981. Yet the stubble burning has not stopped. The resultant smoke from these fields spreads across most of northern India during this period. Burning fields also degrades the fertility of soil by loss of nutrients and microbial cover and increases dependence on chemical fertilizers by farmers (Agricoop, 2014). It is crucial to note that there is minimal agricultural activity in the NCT due to urbanization and it is therefore no surprise that the Graded Response Action Plan does not include measures to reduce the burning of rice stubble, though Delhi's government has recently started pilots for facilitating use of organic decomposers in the NCT (*India Today*, 2020). While the focus of this chapter is on improving the air quality in the NCT, the adverse impacts of smoke from rice stubble burning and reduction in soil fertility adversely affect the rural population (including the paddy farmers) in Punjab, Haryana, and UP the same as the NCT population, if

Table 9.4 Total investment per year for happy seeder in Haryana, Punjab and Uttar Pradesh

State	Total area under paddy cultivation (thousand Hectares)	Total area for Happy Seeders (thousand Hectares)	Total No of Happy Seeders	2011 USD million per year till 2030
Haryana	1354	451	836	1.2 (84)
Punjab	2975	992	1836	2.6 (184)
Uttar Pradesh	5867	1956	3622	5.17 (362)

Note The values were provided in Rs. Million which was converted into USD million using th exchange rate 1 USD = 70 INR
Source MOSPI (2018), Author's estimate

not worse. In other words, these states have the same incentives to reduce rice stubble burning as does the NCT.

We model a scenario where instead of burning the rice stubble, one-third is removed using Happy Seeder technology, one-third is used as fuel for electricity generation, and one-third is used as input to cardboard manufacturing by 2030.[1] It is important to note that this is one policy scenario among many that could be modeled.

The Happy Seeder machine cuts and extracts rice stubble, plants wheat (i.e., the next crop), and spreads the extracted rice stubble over the newly sown area as mulch. The benefits of the machine continue to be debated as the use of these machines by farmers is not yet widespread. While some claim that the productivity increase is substantial, others have not been able to see any change because of the machine (Goyal, 2019).

We estimate total investment—equally divided over the next 10 years—on Happy seeders that will be sufficient for avoiding the burning of one-third of the rice crop residue generated annually in Punjab, Haryana, and Uttar Pradesh by 2030. The total area under paddy cultivation is presented in Table 9.4. The number of total happy seeders was estimated on the basis of 54 hectares per season (15–20 days use) and the prevailing

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[1] Using rice stubble as fuel for electricity generation—if uncontrolled—will have emissions. We assume that these biomass-based electricity generation facilities are regulated and hence have installed the necessary air pollution control systems.

seeder cost of INR 1.5 lakh was used to do the estimation (Singh et al., 2017).

The use of happy seeders also leads to increases in productivity by reducing the need for irrigation as the wheat seeds are sown deeper in the soil. Studies reveal that in a no drought normal crop season, total consumption of energy for wheat cultivation can reduce from 5770 MJ/hectare to 1000 MJ/hectare. This energy saving is converted into GWh of power saved per year toward irrigation gradually phasing in over 10 years in the scenario (Table 9.5).

Several successful models where biomass-based generators have taken the entire responsibility of collecting the crop residue from the farm to the power plant and provide cash to the farmers per ton of residue collected have been implemented in India (Sood, 2015). As described earlier, one-third of the crop residue is utilized for electricity generation where the farmer receives cash compensation of Rs. 800/ton (Singh et al., 2020). The total power generation potential is estimated on the basis of average use of 325 ton per day for a 12 MW plant with generation of 288 MWh per day (Rao, et al., 2013). The remaining one-third is sold as input to cardboard manufacturing, yielding a cash compensation of Rs. 1500/ton to the farmer. The cash transfers are modeled as an increase in income for rural households commensurate to the landholding patterns in each state. Increased incomes will lead to a relative increase in consumption expenditure and demand across economic sectors (Table 9.6).

The objective of this exercise is to demonstrate the value of the E3-India model in accurately assessing the comprehensive implications of

Table 9.5 Total energy saving for wheat crop due to happy seeder in Haryana, Punjab and Uttar Pradesh

State	Total area under wheat cultivation (thousand Hectares)	Total MJ of Energy saved/year	KWh	GWh/year till 2030
Haryana	2,576	3,597,813,333	971,409,600	97.1
Punjab	3,499	4,886,936,667	1,319,472,900	131.9
Uttar Pradesh	9,645	13,470,850,000	3,637,129,500	363.7

Source MOSPI (2018), Author's Estimates

Table 9.6 Estimations for total biomass based generation potential in Haryana, Punjab and Uttar Pradesh

State	*Total Crop Residue estimated (M Ton) through IPCCC default coefficients	Total Generation Potential Per year (GW)	Total Cash transfer for biomass @ INR 800/ton (Million USD)	Total cash transfer for cardboard making @ INR 1500/ton (Million USD)
Punjab	2.28	0.29	1217.8	2283
Haryana	4.43	0.57	2364.4	4433
Uttar Pradesh	7.46	0.95	3978.7	7460

Source Singh, R. et. al. (2020) and Authors' estimates

policies targeted to individual sectors such as agriculture that are extensively linked in myriad ways with the broader economy. For example, experts suggest that excessive paddy farming can be discouraged through changes to minimum support prices set by the Indian government and also through capping procurement by the government. Instead, the government could incentivize farmers to grow less water-intensive crops that would address multiple issues such as less water use (and hence, electricity use for water pumping), lower pollution (i.e., no need for stubble burning), and better public health (through lower consumption of carbohydrates). The complexity of these comprehensive policies is beyond the scope of the analysis in this chapter.

9.2.5 Power Sector Interventions for Reducing Industrial Emissions

Electricity is one of the key inputs to most economic activities as well as directly improving the quality of life. It is important to note that propagation of changes through the economy that result from power sector-specific policies such as those modeled here in the Indian context is likely to be far more complex in the real world due to inherent distortions such as low prices charged to poor consumers that are offset by subventions from state government budgets (which impact other state government expenditures) and cross-subsidies from wealthy consumers who are charged high electricity prices. The prices paid by electricity consumers do not reflect the marginal cost of electricity but are set administratively by state electricity regulators. The existence of long-term

power procurement arrangements between each electricity generator and distribution company further distorts the use of the cheapest marginal cost generation (i.e., out of merit-order dispatch). These two distortions together contribute to major financial losses faced by distribution companies that in turn get transmitted to electricity generators.

As both distribution companies and generators borrow from the banks (most of them owned by the central government), the losses on the banks' balance sheets eventually get addressed by central government's re-capitalization initiatives which would impact overall central government expenditures. For the analysis presented here, we do not incorporate these financial distortions but focus on two key air pollution control alternatives for the power sector.

Today, one of the major sources of electricity in India is thermal power plants (TPPs) that burn coal as fuel. The four states in the airshed account for about 19% (~ 43.8 GW) of total installed thermal capacity in India (CEA, 2020). Consequently, TPPs are a major source of air pollution. We model two scenarios through which air pollution from TPPs can be reduced within the NCT.

9.2.5.1 Installation of Air Pollution Control Equipment

Since 2015, TPPs have been subject to policies that limit their emissions, which increase the cost of the electricity they generate. However, despite ongoing efforts, very few TPPs have installed air pollution control equipment and recent reports suggest that it is unlikely that they will install them in the near term (Vishnoi, 2020).

Bharat Heavy Electricals Limited was contracted for the installation of a Flue Gas Desulfurization system at NTPC's 2×490 MW Dadri plant for removing sulfur dioxide at a cost of Rs 5,600 million, indicating that the capital cost is USD 81,728/MW (Rs 5.7 million/MW) (PowerLine, 2018). The impact of this additional expenditure by TPPs on the average generation cost is approximately, USD 0.002/kWh (INR 0.19/kWh). We assume these two representative values as inputs for our analysis. The scenario is modeled as increased investment by the power sector in electrical equipment, along with a tax on thermal power generation to pay for the equipment. The cost of this tax is passed on to consumers across India.

As mentioned in earlier scenarios, the objective of this exercise is to demonstrate the use of E3-India in providing insights about the impacts of sector-specific policies. Consequently, we use point estimates for the

control of a single pollutant—i.e., SO_2—in this analysis. Additional analysis is necessary for assessing scenarios where alternative SO_2 reduction strategies are deployed (e.g., switching from high-sulfur coal to low-sulfur coal). Similarly, analysis can be done to assess the implications of controlling other major pollutants such as NO_X, PM (1.0, 2.5, and 10.0), mercury, ash, and others. Analysis is also possible for reducing the use of water in Indian TPPs through the deployment of water recirculation systems.

There are two ways in which this investment is propagated through the model—a investment in air pollution control equipment leads to additional economic activity and by an increase in the cost of electricity leads to both lower economic activity and reduction in coal generation and capacity for the airshed. Generation levels are estimated by E3-India's Future Technology Transition (FTT) module (Mercure, 2012; Mercure et al., 2014). The net effect of these impacts on each state varies because of the TPP capacity located in each state and their consumption of TPP-sourced electricity.

9.2.5.2   *Greater Use of Renewable Energy in the NCT Airshed*

New renewable energy (RE) generation technologies such as solar and wind are now cheaper than TPPs (Bharvirkar et al., 2019). Consequently, it is expected that far fewer—if any—new TPPs are likely to be built in the future than what was expected a few years ago. More use of RE instead of TPPs reduces air pollution from electricity generation, while also reducing the overall cost of electricity. Further, the advent of a wholesale power market also creates opportunities for managing air quality through cost-effective planning to reduce coal-based generation during poor air quality seasons (Athawale & Bharvirkar, 2019).

In order to model this scenario, the outputs from TERI-ETC's recently published "Renewable power pathways: Modeling the integration of wind and solar in India by 2030" were taken as inputs to E3-India (Spencer et al., 2020). The ETC's Baseline Capacities Scenario (BCS) reflects the assumptions of the 2018 National Electricity Plan, developed by the Central Electricity Authority (CEA, 2018). The High Renewable Energy Scenario (HRES) has a higher level of renewable energy production capacity, reflecting the assumptions of the CEA's Optimal Mix study (CEA, 2019). The details of scenario inputs are detailed in the Appendix (Sect. 9.5). As the electricity demand is expected to grow and, consequently, new electricity generation capacity is required—whether TPP or

RE—the overall economic impact is expected to be positive due to new economic activity.

Assessing the impact of policies individually provides insights on their relative strengths and weaknesses. In reality, all the policies modeled in this chapter are at least at an advanced stage of discussion if not being partially implemented. Consequently, there is the potential for interactions among these policies. These interactions will need to be assessed to ensure that they are reinforcing each other—i.e., in terms of reducing emissions and improving various other metrics such as GDP, employment, and others—instead of offsetting the gains from each other. We present two integrated scenarios in addition to the individual policy scenarios described earlier: 1. high share of RE combined with the EVs and 2. all policies implemented.

A potential downside of growth of EVs is that incremental electricity demand is met by the dominant source of electricity—i.e., coal generation. In other words, tailpipe emissions are substituted by smokestack emissions (Knobloch et al., 2020). Considering that substantial thermal capacity is homed in the airshed, it is crucial to ensure that TPP emissions are reduced simultaneously with the increase in use of EVs. The "All Policies" scenario is self-explanatory and will allow us to evaluate the simultaneous impacts of all the interventions together, along with probable interactions as we expect in a real-life scenario.

9.3   Results and Discussion

All the scenarios described in Sect. 9.4 are summarized in Table 9.7. In order to simplify the figures, the nomenclature shown in Table 9.7 is used.

The analysis presented in this chapter is focused on reducing air pollution from four sectors of the Indian economy. The ideal metric for measuring the efficacy of the various policies that are used to reduce air pollution would require accurate estimates of the amount of pollution from each source. Unfortunately, three sectors—agriculture, transportation, and construction—are diffused in nature and no accurate estimates exist for the amount of pollution they cause. The power sector—specifically, TPPs—is relatively easier to monitor from an emissions perspective.

The policies analyzed in this chapter will reduce pollution from all four sectors—i.e., rice stubble burning is eliminated, electric vehicles substitute petrol/diesel vehicles, construction activity is banned, green cover is increased, and TPPs are either replaced by RE or install air pollution

Table 9.7   Summary of source-wise assessment scenarios

Name	Short description
Construction	Ban on construction for 2.4 months each year in NCT
Afforestation	Increased investment in expanding green cover nationwide
Transportation	Substitution of ICEs with EVs in the NCT
Agriculture	No more burning of rice stubble; Instead, use of Happy Seeder, biomass-based electricity generation, and cardboard manufacturing from rice stubble
High RE	Increase in renewables nationwide
Emission Control	Equipment added to coal power plants to reduce emissions nationwide
High RE and Transportation	A combination of more renewables and a shift to EVs
All	A combination of all the different policies

control equipment. The primary focus of the analysis is to understand the impacts of airshed management on underlying economic linkages in each state. Gaps in the available data mean that it is not possible to assess impacts on the level of pollution.

The metrics presented in this section include Gross Domestic Product (GDP), Consumption, Employment, Lowest Rural Income Quintile, Coal Generation, and CO_2 emissions. GDP measures the final value of the goods and services produced in one year in the specific state and/or country. Consumption refers to consumer spending and employment refers to the number of jobs created. Population is categorized in 24 income classification, 12 each for rural and urban citizens. The results presented in this section refer to the lowest rural income category as a way of assessing the equity impacts of policies. Coal generation refers to the amount of electricity generated by TPPs in one year while CO_2 emissions refer to economy-wide annual emissions. Several other outputs—e.g., sectoral employment—are also available in E3-India that can, potentially, provide more nuanced insights. In the interest of brevity, we present results across only these six metrics.

For the High RE, Transportation, integrated High RE and Transportation, and afforestation scenarios, we observe an increase in GDP in all four states in the NCT airshed, as well as at national level. However, in the case of the Emission Control, Agriculture, and Construction scenarios

we see a significant contraction of GDP across all four states and at the national level. Not surprisingly, in the All scenario—where, all policies are modeled simultaneously—the distribution of GDP growth and contraction is uneven across the four states because of the interactions. This is precisely why a modeling platform such as E3-India is invaluable for understanding both aggregate (e.g., national/regional) and disaggregated (i.e., state-level) implications of policies (Fig. 9.3).

For the High RE scenario, the drivers for GDP expansion are primarily two-fold: 1. new economic activity resulting from new investments (i.e., new RE power plants) and 2. expansion of existing economic activity resulting from a lower cost of electricity (because RE-sourced electricity is less expensive than TPP-sourced electricity). Similarly, for the Transportation scenario, new investments in battery manufacturing and allied sectors such as automobile manufacturing result in new economic activity while the overall increase in energy efficiency because of the switch from internal combustion engine to electric motors yields higher economic productivity and, hence, growth. The High RE and Transportation scenario unsurprisingly reinforces these growth trends resulting in an even larger expansion of the GDP. The afforestation scenario is modeled as increase in investment in forestry and agriculture sectors leading to concomitant increase in GDP.

For the Emissions Control and Agriculture scenarios, while there is new investment (i.e., installation of FGDs, purchase of Happy Seeders,
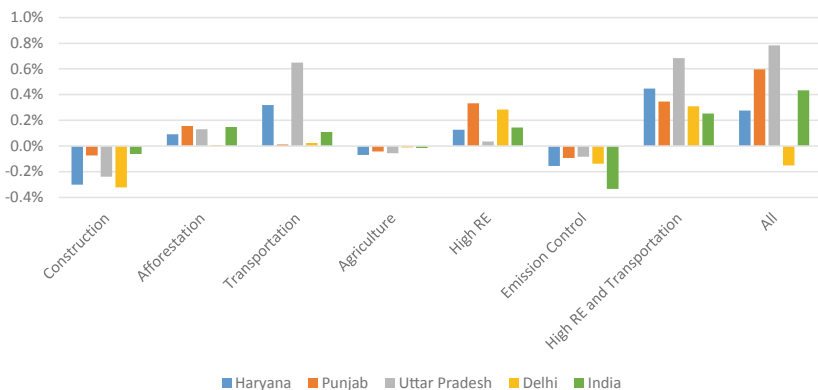

Fig. 9.3 Percentage change in GDP in 2030 (*Source* Results from the model)

and cardboard manufacturing), the aggregate expansion of GDP induced by this is offset by the increase in the cost of electricity. Installation of emission control equipment increases the cost of electricity for consumers, leading to a reduction in output and consumption for the economy, causing a reduction in GDP. In the case of the agriculture sector, the combined economic impacts of increased biomass-based generation (which is inflationary in the state power mix) and a reduction in power consumption due to lower need for irrigation (from happy seeder use) offsets the impacts associated with cash transfers to farmers. Electricity is a crucial input to most economic activity while paddy is a major component of food consumed by most citizens. Individual analysis of any sector (e.g., power, agriculture, etc.) would not be able to assess such offsetting impacts and hence, the overall implications for the economy. The construction sector output contributes only 2–6% of total output of individual states by value but engages close to 8–11% of labor in the NCT airshed region. E3-India captures this as a contraction in GDP across the states.

From the perspective of employment, a politically sensitive issue, the negative impact observed under the Construction scenario is of the highest concern—see Fig. 9.4. Construction is one of the major employers in the Indian economy and especially, in an overwhelmingly urban state such as Delhi. A blunt policy approach such as an outright
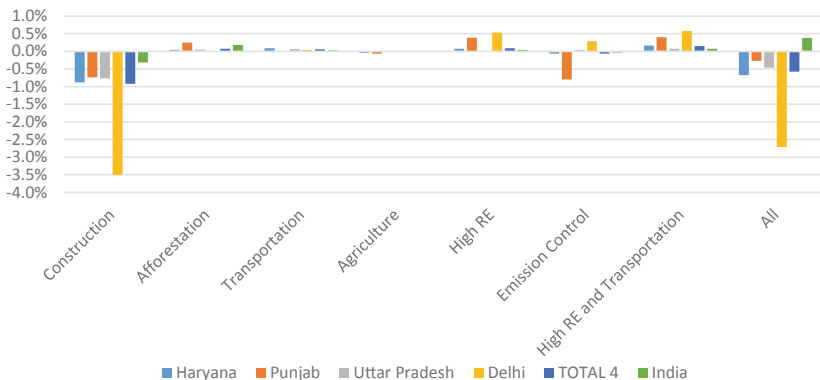

Fig. 9.4 Percentage change in employment in 2030 (*Source* Results from the model)

ban on it, even for a short period of time, leads to a substantial increase in unemployment, especially, in urban states such as Delhi. The striking aspect of these results is the relative size of the change. Unlike the changes seen in GDP and investment, the impact on employment is far larger (in percentage terms) and reiterates the labor-intensive nature of the Indian economy in general and specifically, a sector such as Construction. We also find that only 15–20% of the jobs lost from the construction sector get reallocated to other labor-intensive sectors like food and beverages, textiles and leather, and motor vehicles. Instead of simply shutting down construction activity, alternative measures for reducing dust pollution from this activity must be explored. Further, a larger diversification of the labor force in other activities like afforestation during the sensitive period could lead to better economic outcomes even under the COVID constraints (Pollitt, 2020). If bans on construction are designed to be episodic in nature lasting a few days when the air quality is especially bad then income support schemes for the labor employed in this sector could be considered.

Under the High RE and Transportation scenarios, there is a modest increase in employment resulting from new investments and lower-cost electricity. The largest increases in employment in the High RE scenario are found in electric supply, electronics and electrical equipment sectors, followed by a large positive indirect impact on construction activity and other business services. The Transportation scenario reveals an increase in employment in other vehicle manufacturing, along with electronics and electrical manufacturing. The scenario also sees a large positive impact on employment in the construction sector. The impact on employment is somewhat mixed under the Emissions Control scenario because of the offsetting policies—i.e., new investment but higher-cost electricity—and varies substantially across the four states. Punjab sees a major decrease in employment, driven largely by the construction, agriculture, and hotels and catering sectors, while Delhi sees a large increase in jobs in both sectors like construction, textiles, and food and beverages along with high-tech sectors like electrical equipment and electronics. The Agriculture scenario suggests minimal negative impact on employment, primarily due to constrained economic activity in the power sector.

Combined together—the negative impact of the Construction scenario overwhelms the positive impacts of other policies. Consequently, from a political economy perspective, it is crucial to develop alternative strategies to limit pollution from the construction sector, even if it results in

a somewhat higher cost of construction activity. Further, as a long-term policy, strategic diversification of the labor force to other environmentally benign but skill-intensive sectors for seasonal employment creation will be vital to manage the adverse impacts of seasonal reduction in construction activity. A ban on construction activity under GRAP is more of a kneejerk reaction to environmental consequences and does not provide a permanent solution to the problem. The development of intrinsic flexibility to switch economic activities proactively for better management of the NCT airshed is critical.

Changes in employment also have an impact on consumer spending. The trends in consumer spending—see Fig. 9.6—confirm the discussion presented in the context of the impacts on economic growth and employment. High unemployment in the Construction scenario—especially, among the workers who are already in the lower income strata—results in a relatively high decrease in consumer spending. It is important to note that most of the consumption spending of poor citizens is not on discretionary items but on items necessary for survival (e.g., food, medicines, etc.). Consequently, the reduced spending is likely to have further adverse impacts on their health and overall quality of life.

The Emission Control scenario also shows a negative impact on consumer spending similar in size as under the Construction scenario even though there is no major impact on employment. The primary driver for this is the increase in electricity price which reduces consumer spending on other things as electricity is one of the relatively inelastic commodities that consumers purchase. It is no surprise that Discoms and electricity regulators in addition to state governments absolutely abhor raising electricity prices. Historically, instead of raising electricity prices, Discoms have accrued financial losses that periodically have to be addressed through schemes such as UDAY. In contrast to the Emissions Control scenario, consumer spending increases under the High RE and Transportation scenarios because of increase in employment. Under the High RE scenario, the reduction in electricity costs also creates more opportunity for increased consumer spending. Under the Agriculture scenario, there is modest reduction in consumer spending driven by reduced employment, increase in input costs (investment in Happy Seeders), and increase in electricity costs (biomass-based generation) that is not offset by the income growth. In aggregate, the negative impact seen under the Construction, Emission Control, and Agriculture scenarios

easily overwhelms the relatively small positive impacts under the High RE and Transportation scenarios (Fig. 9.5).

Implications for the poorest citizens of India—i.e., living in rural areas with incomes in the lowest quintile (0–5 percentile)—are crucial for understanding the overall equity implications of policies. Income impacts can be disproportionate across various income quintiles because of both consumption patterns and also the ability to survive a potentially negative impact. Both the Emissions Control and Construction scenarios result in the biggest reduction in rural incomes in the lowest quintile, across all four states and at the national level. The increase in the cost of electricity disproportionately impacts poorer households due to prevalent energy poverty conditions (Khandker et al., 2010). Poorer households suffer along with everyone else when there are reductions in GDP and employment across the economy. In contrast, the High RE and Transportation scenarios yield a relatively small increase in the income of the poorest citizens because they either reduce the cost of electricity to low-income households or provide a general boost to the wider economy that raises incomes in all household groups.

The large positive impact on the income of the poorest citizens of UP under the Agricultural scenario is a result of the way this scenario
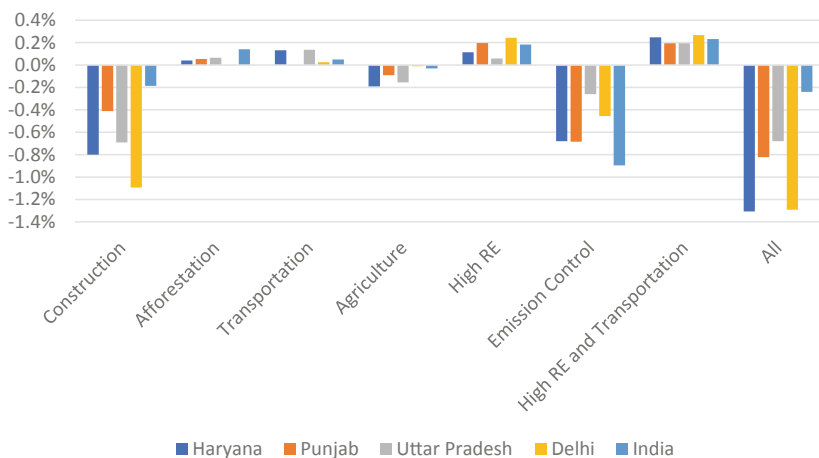

Fig. 9.5 Percentage change in consumer spending in 2030 (*Source* Results from the model)

was modeled in the form of cash transfer to farmers toward crop residue collection on the basis of land ownership patterns. In the case of UP, more than 62% of landholding is by small farmers. Therefore, a relatively (as compared with farmers in Punjab and Haryana) greater share of cash benefits was received by small (i.e., low income) farmers. The results suggest that distributive impacts of cash transfers for crop residue utilization can result in larger income benefits to small (and poor) farmers who are most likely to resort to burning rice stubble (Fig. 9.6).

One of the direct impacts of the policies analyzed in this chapter is likely to manifest itself in the power sector—due to a change in cost of electricity and/or demand—and especially, in the major source of electricity, i.e., TPPs. In the following figure, coal generation decreases substantially in all the scenarios except Emission Control and Transportation. The increase observed for the Transportation scenario is simply due to the increase in demand for electricity to charge electric vehicles (direct impact) and new battery manufacturing (direct and indirect). In the case of the Emission Control scenario, the increase in coal generation is because of the increase in electricity demand to meet the large increase in investments in new equipment (i.e., installation of emission control systems on TPPs) that result in new economic activity. Some of this increase in electricity demand is dampened by the higher cost of electricity. However, the net impact is on increased TPP generation.
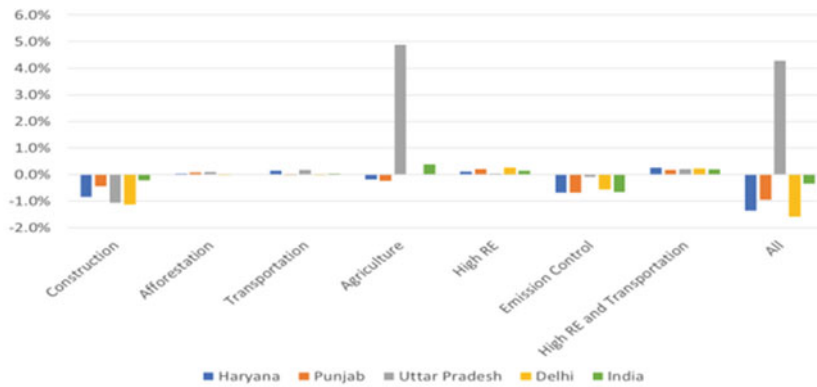

Fig. 9.6 Percentage change in rural income (lowest percentile) in 2030 (*Source* Results from the model)

Both the High RE and Agriculture scenarios yield a significant reduction in coal generation. The High RE scenario has a straightforward explanation—i.e., the objective of the policy is to substitute TPP-sourced electricity by RE. In case of the Agriculture scenario, some of the coal generation is replaced by biomass generation and also results in a higher cost of electricity that further depresses electricity demand. The contraction in GDP suggests lower demand for electricity with no major new investments that can offset this reduction through increased activity in the rest of the economy. The cumulative impact of these drivers results in a significant reduction in coal generation under the Agriculture scenario. Taken together, under the All scenario, a substantial reduction in coal generation is observed across all four states with Haryana and UP leading the way followed closely by Punjab and a relatively small decrease in Delhi. The major decrease results from the High RE and Agriculture policies and a minor decrease because of the periodic ban on construction activity (Fig. 9.7).

Lastly, we present the overall impacts of policies on CO_2 emission across the economy. Except for the Transportation scenario, in case of all other scenarios we find that CO_2 emissions decrease. The largest decrease is observed under the Agriculture and High RE scenarios followed by modest decreases under the Construction and Emission Control
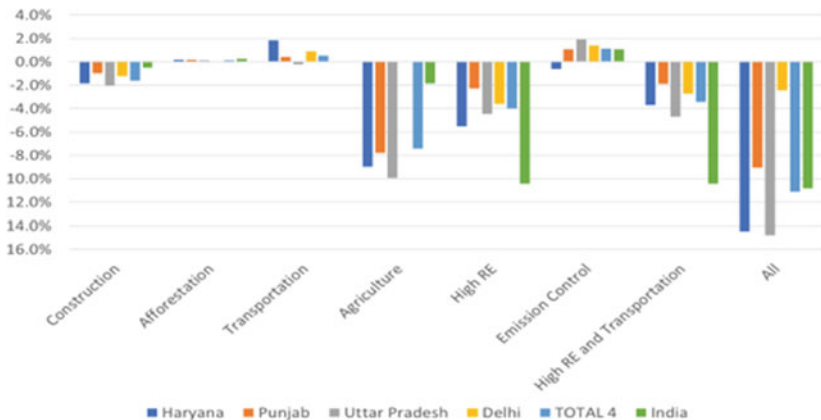

Fig. 9.7 Percentage change in coal generation in 2030 (*Source* Results from the model)

scenarios. The increase under the Transportation scenario is driven by the increase in coal generation even though some of it is offset by fewer ICEs. A combination of High RE and Transportation policies ensures that even there is no increase in CO_2 emissions across the economy (Fig. 9.8).

Poor air quality—especially in the NCT—has been a chronic and vexing problem. While various policies continue to get discussed and sometimes implemented in a stop-gap manner, sustained progress in improving air quality has been elusive. Even in 2020, a year in which the Indian economy was practically brought to a standstill for six weeks because of the raging global pandemic, the air quality in the NCT was in the Severe category during the entire first week of November.

The sources of air pollution have been identified, even though high-quality data and analysis is not yet available for accurate apportionment. The strategies for reducing air pollution from these well-known sources are technologically viable and institutionally feasible while being cost-effective when assessed in the context of the overall health benefits from improved air quality. Yet, there is resistance to implement these strategies immediately and at the scale needed.

Economic impacts—both direct and indirect—underpin the overall political economy that makes decisions not only about the design of policy but also its implementation and enforcement. Direct financial impacts of policies to individual stakeholders are relatively well understood. However, broader economic impacts are not yet part of the policy discourse.
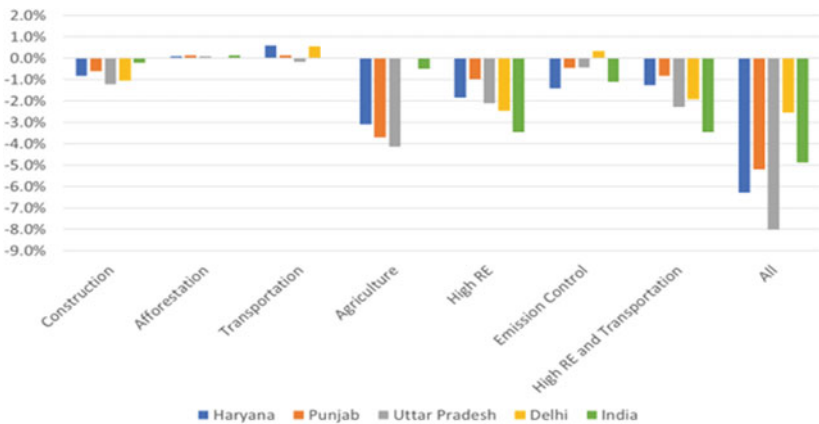

Fig. 9.8 Percentage change in CO_2 emissions in 2030 (*Source* Results from the model)

9.4   Conclusion

The key takeaways from the analysis are presented in this section. In this chapter, through stylized policy scenarios, we have attempted to estimate the broader impacts for the four major states relevant in the NCT airshed. We present results for both individual policies and integrated policies where more than one policy are simultaneously implemented. The objective of this analysis is not precision in terms of the policy design but a demonstration of the E3-India platform to illuminate how the policy propagates through the state and national-level economies.

A periodic ban on construction activity in the four states results in a massive negative economic shock to their economies resulting in GDP contraction, reduced investment, decrease in employment, and a substantial loss in income for the poorest citizens. Consequently, this blunt policy instrument should be considered as a last resort and substantial efforts toward developing alternative strategies to reduce pollution from this sector should be undertaken immediately.

A nationwide shift toward a High RE future for the Indian power sector results in the expansion of GDP, increased investments, higher employment, increased consumer spending, and a larger income for the poorest 70% of the rural citizens of India. These results—at varying levels—are observed in all four states in the NCT airshed. From an air pollution perspective, this scenario also yields the highest reduction in coal generation (and hence, emissions from it) as compared with other policies. The additional benefit of this policy is the decrease in CO_2 emissions which is a major global concern from a climate change perspective.

Installing emission control equipment on TPPs results in significant new investments in the four states which are politically attractive. However, the net impact of this policy is negative with an overall contraction in GDP, decrease in employment, significant drop in consumer spending, and reduction in income of the poorest citizens. Both the generation and capacity of TPPs increase under this scenario. Yet, there is an overall decrease in CO_2 emissions that are the primary driver for global climate change. As there are no easy and cheap ways to reducing CO_2 emissions from TPPs yet, the only remaining approach is to minimize the use of TPPs. In many parts of the world TPPs are—in fact—being phased out in favor of less carbon-intensive technologies (e.g., gas) and carbon-free technologies (e.g., RE, batteries, etc.).

Substituting internal combustion engines to electric motors yields a significant expansion in GDP for UP and Haryana driven mostly by the new investments in battery manufacturing. However, impacts measured in

terms of employment, income, consumer spending, and coal generation are minimal at best.

Instead of simply burning rice stubble, using a portfolio of strategies consisting in equal parts of Happy Seeders (to mechanically remove stubble and plant wheat), utilizing stubble for electricity generation, and cardboard manufacturing from stubble result in a significant reduction in coal generation. The impact on GDP, investment, employment, and rural incomes are minimal relative to other policies.

Assuming that all these policies are implemented simultaneously results in a wide range of impacts distributed among the four states. Delhi sees the largest GDP contraction followed by Haryana, while UP sees the largest GDP expansion followed by Punjab. All four states see a significant increase in investments with Haryana and Punjab benefiting by more than double that of UP and Delhi. A reduction in employment is observed for all four states but the primary driver for this result is the policy banning construction activity periodically. There is a dramatic reduction in coal generation in all four states with the smallest amount observed for Delhi. Incomes—especially, for the poorest rural citizens—drop for all states except UP where it increases by almost 4%.

Various permutations and combinations of policies can be easily modeled using the methodology presented in this chapter which can provide additional insights. One such variation that we modeled included the combination of the High RE and Transportation scenarios. Across all four states, GDP expands, investment increases, employment grows, coal generation reduces, and income of poorest rural citizens rises. In other words, these two policies are mutually reinforcing.

As with all modeling exercises, it is important to be aware of the limitations of the analysis. The main limitation here relates to the data issues noted above and the difficulties in linking air pollution to different sources. This means that the benefits to health of reducing air pollution are not assessed in our analysis. There are also places in the scenarios where the use of more detailed input assumptions (e.g., on the costs of measures in the Agriculture scenario) could improve the accuracy of results. Readers are urged to view this analysis as a starting point in the process of evidence-based policymaking pertaining to air quality.

Appendix

See Table 9.8.

Table 9.8 Capacity addition under baseline and High renewable energy scenario (in GW)

Capacity Installed Year	National			Haryana			Punjab			Uttar Pradesh			Delhi		
	Base year 2019	Baseline 2030	HRES 2030	Base year 2019	Baseline 2030	HRES 2030	Base year 2019	Baseline 2030	HRES 2030	Base Year 2019	Baseline 2030	HRES 2030	Base Year 2019	Baseline 2030	HRES 2030
Coal	185.08	248.84	262.98	8.64	12.35	13.77	8.56	15.09	17.35	14.99	23.20	26.16	5.57	11.19	12.73
Onshore	37.94	126.82	164.98	0.89	0.57	1.13	0.79	0.57	1.13	0.00	0.00	0.00	0.00	0.57	1.13
Solar PV	27.44	175.47	224.10	0.53	2.48	4.70	1.93	2.08	3.19	0.99	10.02	14.52	0.20	0.83	2.40

Source Authors' Calculation

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