COBENEFITS STUDY

October 2019

Improving health and reducing costs through renewable energy in India

Assessing the co-benefits of decarbonising the power sector

Executive report

This study has been realised in the context of the project "Mobilising the Co-Benefits of Climate Change Mitigation through Capacity Building among Public Policy Institutions" (COBENEFITS). This print version has been shortened and does not include annexes. The full version of this report is available upon request.

IASS POTSDAM

renac renewables academy

UfU Independent Institute for Environmental Issues

IET International Energy Transition

teri

This project is part of the International Climate Initiative (IKI). The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) supports this initiative on the basis of a decision adopted by the German Bundestag. The COBENEFITS project is coordinated by the Institute for Advanced Sustainability Studies (IASS, Lead) in partnership with the Renewables Academy (RENAC), Independent Institute for Environmental Issues (UfU), International Energy Transition GmbH (IET) and in India The Energy and Resources Institute (TERI).

October 2019

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Supported by:

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

based on a decision of the German Bundestag

INTERNATIONAL CLIMATE INITIATIVE (IKI)

COBENEFITS of the new energy world of renewables for the people of India

India is in the midst of an energy transition, with important social and economic implications depending on the pathways that are chosen. India's energy pathway will define the basis for its future development, including economic prosperity, business and employment opportunities as well as health impacts. At the same time, current investment decisions in India's energy sector will have a substantial impact on combatting global warming and securing the livelihoods of people in India and elsewhere.

With its bold decision to substantially ramp up renewable energy generation capacity, from 80 gigawatts as of May 2019 to 175 GW by 2022, the Government of India has sent a strong signal on both the direction and pace of India's energy transition. Political decisions on India's energy future link the missions and mandates of many government departments and agencies beyond energy and power, such as environment, industrial development and labour. Hence, the timely debate on India's energy future boils down to assessing how renewables can improve the lives of Indian people.

Employing scientifically rigorous methodologies and the most recent technical data, the study at hand contributes to estimating such co-benefits associated with the shift to renewables. It also provides guidance to government agencies on further shaping an enabling political environment to unlock the social and economic co-benefits of the new energy world of renewables for the people of India.

The Energy and Resource Institute (TERI), as the India Focal Point, together with the Institute for Advanced Sustainability Studies (IASS) invited ministries and government agencies such as the Ministry of New and Renewable Energy, Ministry of Environment, Forests and Climate Change, Ministry of Power, Ministry of Finance and NITI Aayog to join the COBENEFITS Council India, to provide their guidance to the COBENEFITS Assessment studies along with the COBENEFITS Training Programme and Enabling Policies Roundtables. Since its constitution in November 2017, the COBENEFITS Council India has guided the programme in framing its assessment topics for India and ensuring their direct connection to the current political deliberations and policy frameworks of their respective ministries.

We are also indebted to our highly valued research and knowledge partners, for their unwavering commitment and dedicated work on the technical implementation of this study. This COBENEFITS study was facilitated through financial support from the International Climate Initiative (IKI) of Germany.

India, among 185 parties to date, has ratified the Paris Agreement to combat climate change and provide current and future generations with opportunities to flourish. With this study, we seek to contribute to the success of this international endeavour by offering a scientific basis for harnessing the social and economic co-benefits of building a low-carbon, renewable energy system while facilitating a just transition, thereby **making the Paris Agreement a success for the planet and the people of India.**

We wish the reader inspiration for the important debate on a just and sustainable energy future for India!

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Executive Summary

COBENEFITS

Improving health and reducing costs through renewable energy in India

Assessing the co-benefits of decarbonising the power sector

India has experienced a remarkable transition in reducing absolute poverty, improving standards of living and creating livelihood opportunities for the impoverished, and enhancing access to cleaner and affordable energy. Through the National Action Plan on Climate Change (NAPCC), the Indian Government recognised that India needs a directional shift in its economic growth pathway in order to achieve its developmental objectives while effectively addressing the threat of climate change.

At the same time, ambient air pollution has emerged as the second leading health risk factor in India, contribute significantly to India's burden of cardiovascular diseases, chronic respiratory diseases and lower respiratory tract infections. Since electricity generation in India is still largely coal-based, the power sector is an important contributor to ambient air pollution. In view of the above, India's Nationally Determined Contribution (NDC) aims to base 40% of the total installed power generation capacity on non-fossil fuel resources by 2030 with international support on technology transfer and financing. This includes an ambitious target of achieving 175 GW of renewable energy by the year 2022 and reducing the emissions intensity of GDP by 33 to 35% from 2005 levels by 2030. In early 2019, the Ministry of New and Renewable Energy (MNRE) announced that this objective might be met earlier, by procuring 500 GW of additional RE capacity by 2028.

In this context, this study assesses the impact of ambient air pollution on human health in India. This is carried out in the context of the COBENEFITS project with the aim of assessing the range of additional benefits[1] resulting from a low-carbon energy transition in India. The report quantifies both the health and economic costs associated with $PM_{2.5}$/PM_{10} exposure. The analysis first assesses the impacts of ambient air pollution from all sectors of the Indian economy. It then quantifies the specific impact of the Indian power sector, assessing the health benefits of increased share of renewables in the Indian energy and power sector. The economic savings resulting from improvements in air quality are analysed based on three different energy scenarios for the years 2020, 2030, 2040 and 2050:

- The **Business-as-Usual scenario** (BAU), representing India's present climate policies rolled out until 2016.
- The **NDC scenario** (NDC), designed to chart out the strategies needed to achieve the targets laid out in India's NDCs.
- The **NDC PLUS scenario** (NDC PLUS), adopting strategies for deeper decarbonisation over and above the NDC scenario.

This study employs a five-step methodological approach.

- **Step 1: Energy-scenario building.**
- **Step 2: Emissions modelling.**
- **Step 3: Air-quality modelling (dispersion).**
- **Step 4: Health impact assessment.**
- **Step 5: Economic impact assessment.**

[1] The term 'co-benefits' refers to simultaneously meeting several interests or objectives resulting from a political intervention, private-sector investment or a mix thereof (Helgenberger et al., 2019). It is thus essential that the co-benefits of climate change mitigation are mobilised strategically to accelerate the low-carbon energy transition (IASS 2017).

- **Key policy message 1:** India can markedly improve the livelihoods of its citizens by reducing ambient air pollution. In the business-as-usual scenario, during 2020 almost 500,000 people will die prematurely due to exposure to particulate matter (PM_{10}); this number would rise to 600,000 premature deaths during 2030 and 830,000 during 2050. By moving to the NDC PLUS pathway, more than 200,000 premature deaths can be avoided in 2050.
- **Key policy message 2:** India can significantly cut economic losses by greening the economy and deploying renewable energy sources. Following the business-as-usual path, economic losses related to health costs could increase from INR 4.6 trillion (USD 64.6 billion[2]) in 2020 more than two-fold in 2030 and more than ten-fold to INR 47 trillion (USD 660.3 billion) in 2050. However, by following the NDC PLUS pathway, economic losses in 2050 could be reduced by as much as INR 12 trillion (USD 168.6 billion).
- **Key policy message 3:** India should consider building and following even more ambitious energy pathways. Even the most far-reaching scenario presented in this report (NDC PLUS) is insufficiently ambitious to prevent a 4.3% reduction in Indian GDP and an increase in premature deaths in 2050 compared with 2020 levels.

KEY FIGURES:

- Mean concentration of particulate matter in India is five times higher than the levels recommended by the World Health Organization.
- Air pollution accounts for 4–5% of total mortality in India.
- The power sector accounts for about 8% of premature deaths related to air pollution.
- The economic costs of ambient air pollution will reduce India's GDP by up to 5.7% in 2050 (BAU scenario).

COBENEFITS
Improving health and reducing costs through renewable energy in India. Assessing the co-benefits of decarbonising the power sector

available on www.cobenefits.info

KEY FINDINGS:

Concentration levels of pollutants

- **In the BAU scenario, the mean $PM_{2.5}$ concentration in 2020 is five times higher than that recommended by the World Health Organization (10 Qg/m³).** The $PM_{2.5}$ concentration will remain very high in the BAU scenario all the way until 2050 (60 μg/m³ in 2030, 54 μg/m³ in 2040 and 60 μg/m³ in 2050).
- Even in the NDC and NDC PLUS scenarios, $PM_{2.5}$ concentrations will remain dangerously high. In the best case, the population-weighted mean $PM_{2.5}$ concentration will decrease to 48 μg/m³ (NDC PLUS scenario in 2050). However, this is still almost five times higher than the values recommended by the WHO. This indicates that **even more ambitious scenarios will need to be modelled (and followed) in order to significantly reduce the health impacts of air pollution on the Indian population.**
- The power sector has limited contribution to overall emissions, mainly due to increasingly stringent controls; However, its contribution increases significantly in cities, and within zones of influence around power plants.

[2] 1 INR = 0,01405030 USD as of October 2019.

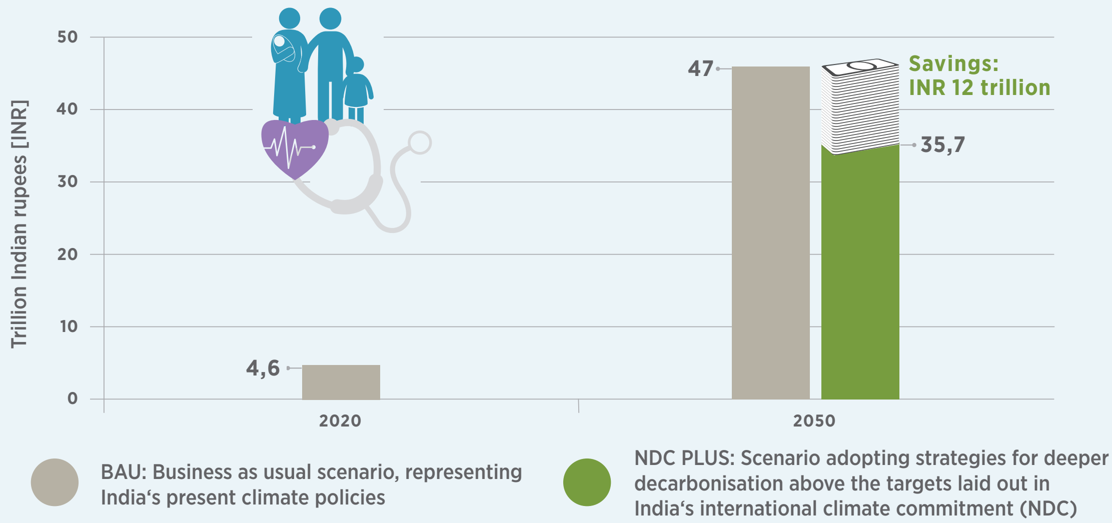
Mortality and disability-adjusted life years:

- Air pollution will account for 4–5% of total mortality in India between 2020 and 2050.
- **In the business-as-usual scenario, in 2020 almost 500,000 people will die prematurely due to exposure to airborne particulate matter (PM_{10}).** This number would rise to 830,000 premature deaths by 2050.
- By following the NDC pathway, India can reduce all-cause mortality from PM10 by about 75,000 in 2050. **By going beyond the NDC scenario (NDC Plus), all-cause mortality resulting from PM10 can be further reduced to 613,000 in 2050, which is 25% less than in the BAU scenario and around 17% less than the NDC scenario.** However, it should be noted that, compared with 2020 levels, even the NDC PLUS pathway would not prevent an increase in all-cause mortality by 2050.
- The power sector is responsible for about 8% of mortality related to air pollution (PM_{10}). **By moving from BAU to the NDC PLUS pathway, the number of premature deaths in 2050 can be reduced by 58%, from 57,000 to 24,000.**
- The five most severely affected states (Uttar Pradesh, Maharashtra, Gujarat, Bihar and West Bengal) alone constitute more than 50% of the total deaths projected in different years under all three scenarios (all-cause mortality). Focusing on the power sector, these five states account for 60% of mortality related to PM emissions.
- **Disability-adjusted life years** (DALY: a single metric to record the combined burden of mortality and morbidity) **attributable to ambient $PM_{2.5}$/PM_{10} under the BAU scenario is estimated to be 14 million in the year 2020.**
- Under the BAU scenario, DALY would increase to 24 million in 2050. However, **this value could be reduced to 21 million under the NDC scenario and 17 million under the NDC PLUS pathway in 2050.**
- Focusing on the impact of the power sector, total DALY could increase to 1.7 million in 2050 following the BAU pathway. **However, by greening the power sector the NDC PLUS scenario could reduce total DALY by 1 million, down to 0.7 million in 2050.**

Economic Impact

- Under the BAU scenario, total economic loss due to both disease-specific mortality and morbidity is estimated as INR 4.6 trillion (USD 64.7 billion) for the year 2020. **This already very high figure would increase more than ten-fold to INR 47 trillion (USD 660.3 billion) in 2050.**
- **Switching from the present energy scenario to NDC will lead to an estimated total economic benefit to the country of INR 2148 billion (USD 30.18 million) by 2050; a further economic benefit of INR 5421 billion (USD 76.16 million) can be realised if the country adopts the NDC PLUS trajectory.**
- Total economic losses due to ambient air pollution significantly reduce Indian GDP: This already cuts GDP by 2.9% in 2020 and could reach 5.7% in 2050. Even in the NDC PLUS scenario, the costs associated with air pollution will still reduce Indian GDP by 4.3% in 2050. **This indicates that India should consider even more ambitious pathways for greening the economy.**

India can significantly unburden health budgets by greening the economy and deploying renewable energy.



Health costs from the power sector

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1. The Status Quo: Air pollution and health risks in India

KEY POINTS:

- Air pollution is the second leading health risk factor in India after child and maternal malnutrition.
- In India, 111 coal-fired thermal power plants with an installed capacity of 121 GW were responsible for an estimated 580 kt of $PM_{2.5}$, 2100 kt of Sulphur Oxides (SO_X), 2000 kt of Nitrogen Oxides (NO_X), 1100 kt of carbon monoxide and 665 million tonnes of CO_2 emissions in the year 2010–11.
- Few studies have so far analysed the specific impacts of emissions from the Indian power sector. Similarly, only a couple of studies have estimated the economic losses and health costs resulting from air pollution in India.

1.1 Greening the Indian economy and mitigating climate change

The Indian Government has undertaken several policy initiatives for sustainable development, balancing the policy objectives of higher standards of living, economic development, poverty eradication and climate change mitigation. Through the National Action Plan on Climate Change (NAPCC), the Indian Government recognised that India needs a directional shift in its economic growth pathway in order to achieve its developmental objectives while effectively addressing the threats from climate change.

Electricity generation is one of India's most carbon-intensive sectors, as most of the country's power generation capacity is coal-based. At the same time, air pollution resulting from coal-fired power generation has severe negative health effects. In view of the above, India's Intended Nationally Determined Contribution (NDC) aims to base 40% of the total installed power generation capacity on non-fossil fuel resources by 2030, with international support on technology transfer and financing. This includes the ambitious target of achieving 175 GW of renewable energy by the year 2022. In early 2019, the Ministry of New and Renewable Energy (MNRE) announced that this objective might be met earlier, by procuring 500 GW of additional RE capacity by 2028.

1.2 Health risks resulting from ambient air pollution in India

Ambient air pollution is now widely known to have severe negative impacts on human health. Exposure to ambient $PM_{2.5}$ concentrations is linked with cardio-vascular and respiratory disease, and cancers (Steinle et al., 2015; WHO, 2018). As per recent estimates by the WHO, in both cities and rural areas, exposure to ambient $PM_{2.5}$ concentrations were estimated to cause 4.2 million premature deaths worldwide per year (WHO, 2018).[3] Many other studies have established a strong correlation between air pollutants and human health impacts (Kan, 2007; Pope, 2002; Schwartz, 1996; Dockery, 1993).

The Indian Council of Medical Research (ICMR) considers air pollution as the second leading health risk factor in India after child and maternal malnutrition.[4] Outdoor air pollution accounted for 6.4 percent of India's total DALYs in 2016. Air pollution was found to

[3] In 2016, around 58% of outdoor air pollution-related premature deaths were due to ischaemic heart disease and strokes, 18% were due to chronic obstructive pulmonary disease and acute lower respiratory infections respectively and 6% due to lung cancer (WHO, 2018).

[4] Child and maternal malnutrition accounted for 14.6 percent of the country's total disability-adjusted life years (DALYs).

contribute significantly to India's burden of cardiovascular and chronic respiratory diseases and lower respiratory infections.

In the past years, a number of additional studies (IIASA, 2015; TERI, 2018; Crooper et al., 2018) estimated the health effects associated with ambient air pollution in India. A study in Delhi by Guttikunda (2012) calculated the health impacts of the current PM_{10} and $PM_{2.5}$ concentrations and estimated that 7,350 to 16,200 premature deaths and around 6 million asthma attacks per annum were attributable to the effects of $PM_{2.5}$ and PM_{10}.

A study by Nagpure et al. (2014) also evaluated the human health risks associated with air pollution for all the districts of Delhi, using Risk of Mortality/Morbidity due to Air Pollution (Ri-MAP) to evaluate the direct risks arising from both mortality and morbidity. The findings showed that, during 2010, air pollution caused around 18,229 excess deaths in Delhi and 26,525 excess cases of hospitalisation. The study results also showed that both PM_{10} and $PM_{2.5}$ concentrations were the leading causes of total mortality, respiratory mortality, cardiovascular mortality and also hospitalisation due to chronic obstructive pulmonary disease (COPD) in New Delhi.

An ICMR-PHI (2018) study estimated the total number of deaths attributable to both ambient air pollution (AAP) and household air pollution (HAP). The study determined that air pollution is the second leading cause of mortality in India (following malnutrition), and that annual exposure to $PM_{2.5}$ was around 89.9 µg/m³ in 2017. The study estimated that approximately 1.24 million deaths in India during 2017 were attributable to air pollution (i.e., 12.5% of all mortality).

1.3 Health risks related to the Indian power sector

In India, 54.7% of power production is still coal-based (CEA, 2019) The production of coal fly ash and coal dust during coal combustion leads to the formation of particulate matter (PM) that penetrates the lungs, representing a health risk and leading to cardiovascular and respiratory problems (Pope et al., 2009; Chen et al., 2004). India presently has 111 coal-fired thermal power plants with a combined installed capacity of 121 GW. During the year 2010–11, it is estimated that these power plants emitted 580 kt of $PM_{2.5}$, 2100 kt of SO_X, 2000 kt of NO_X, 1100 kt of carbon monoxide and 665 million tonnes of CO_2 (Guttikunda et al., 2014).

Since coal-fired power plants and other fossil-fuel-based generation technologies are a major source of air pollution in India, it is crucial to understand their specific impacts on health and related economic costs. However, very few studies have so far quantified the contributions of the power sector in terms of deaths and DALYs attributed to ambient air pollution.[5]

The Burden of Disease study by the Health Effects Institute (HEI, 2018) studied the health effects of major sources of air pollution, including the power sector. The future scenarios examined in the study indicated that by 2050 coal combustion would become the leading cause of air pollution, causing approximately 1.3 million premature deaths annually during 2050. The study also concludes that the incorporation of appropriate pollution control devices in thermal power plants could reduce the number of premature death by 400,000 to 850,000.

Past studies from other countries, including China,[6] South Africa (IASS 2019), the EU[7] and OECD,[8] have provided more detailed estimates of the economic losses resulting from health impacts caused by air pollution (WHO, Ho and Jorgenson 2007).

[5] This study concludes that 42% of premature deaths due to ambient air pollution are due to biomass burning in residential settings, followed by anthropogenic dust (15%), coal combustion in power plants (13%) and industry (13%), burning of agricultural residues (10%) and transport and other forms of diesel distribution (7%). However, in the BAU scenario of this study, by 2050 coal combustion in power plants would become the single largest cause of premature deaths (30%) resulting from ambient air pollution.

[6] These studies employed different approaches in reaching their conclusions and quantifying the health effects. For instance, according to the World Bank (2007), the economic burden of PM pollution in China during 2003 was 157 billion Chinese Yuan when using the Amended Human Capital (AHC) approach, versus around 520 billion Chinese Yuan using the VSL approach. These economic losses represented approximately 1.2% and 3.8% respectively of total Chinese GDP (Huang, Xu and Zhang 2011).

[7] A multi-country study estimated that the net effects of ambient air pollution in Europe caused 565,271 premature deaths during 2005 and 498,538 premature deaths during 2010.

[8] The OECD (2014) report estimated that the combined total cost of the 7 million premature deaths occurring in 34 OECD countries plus India and China was USD 3.5 trillion for the year 2010.

2. Methodology: A five-step approach to assess health and economic impacts

This study assesses the impacts of ambient air pollution on human health in India. It quantifies both the health and economic costs arising from exposure to atmospheric particulate matter in the $PM_{2.5}$ and PM_{10} size ranges; and of ambient air pollution from all sectors of the Indian economy. The study quantifies the specific impacts of the Indian power sector, assessing the health benefits of increasing the share of renewable energies in the Indian energy and power sectors. The associated savings in economic losses and health costs resulting from improvements in air quality will be analysed based on three different energy scenarios for the years 2020, 2030, 2040 and 2050. This study employs a five-step methodological approach.

- **Step 1: Energy-scenario building.**
- **Step 2: Emissions modelling.**
- **Step 3: Air-quality modelling (dispersion).**
- **Step 4: Health impact assessment**
- **Step 5: Economic impact assessment.**

The overall methodology is presented in Figure 1.

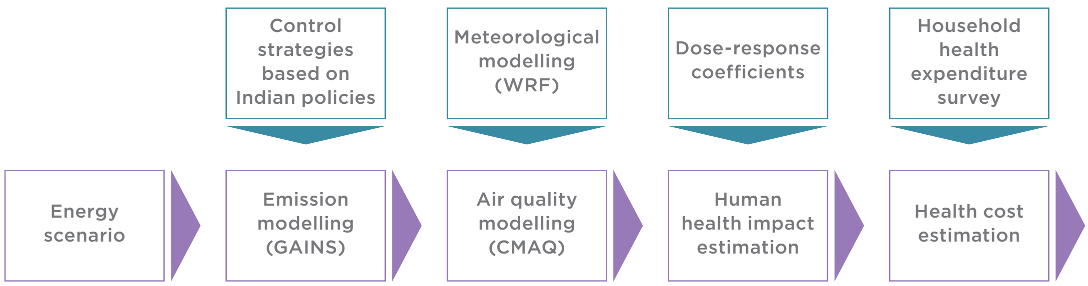

Figure 1: Overall study methodology

Source: own

2.1 Step 1: Three long-term scenarios for the Indian energy sector

The study is a forward-looking assessment of the potential health benefits resulting from a less carbon-intensive energy sector in India. Three energy scenarios were developed by The Energy and Resources Institute (TERI) corresponding to the end-use energy demand within each demand sector. These are:

1. The **Business-as-usual scenario** (BAU), representing India's climate policies rolled out until 2016, and high GDP growth.

2. The **NDC scenario** (NDC) charts the strategies needed to achieve the targets laid out in India's NDCs.

3. The **NDC PLUS scenario** (NDC PLUS) takes up strategies for deeper decarbonisation over and above the NDC scenario.

The BAU scenario assumes the uptake of more efficient technologies based on past trends, existing policies and targets rolled out by 2016. As a result, the current renewable energy targets are only partially achieved.[9] In 2050, coal remains the dominant source with an installed capacity of 888 GW; Solar and wind installations are estimated at 156 GW and 126 GW respectively; Total generation capacity reaches 1409 GW.

[9] In the BAU scenario, industrial efficiency improvement is seen mainly in PAT-designated consumers; penetration of efficient appliances is slow, as are the electrification of households and the phase-out of traditional fuels; There are few GRIHA-rated buildings in the commercial sector, and their penetration is constrained by their higher costs and lack of appropriate policies; past trends continue in the share of railways, vehicular efficiency improvements and share of electric pumps in the agriculture sector.

The NDC scenario charts the strategies needed to achieve the targets laid out in India's NDCs. The major targets accounted for in the scenario are: reducing the emissions intensity of GDP by 33–35% of 2005 levels and developing 40% non-fossil energy capacity by 2030; achieving these targets requires a multi-dimensional development action plan.[10] In this scenario, coal retains the largest installed capacity (739 GW) in 2050. The overall decline in coal is substituted with cleaner sources of generation, comprising 250 GW solar and 135 GW wind capacity. Gas-based generation capacity also increases to 134 GW in this scenario.

The NDC PLUS scenario takes up strategies for deeper decarbonisation over and above the NDC scenario. Consequently, the scenario assumes rapid uptake of efficient technologies across all sectors, accelerated efficiency improvements for both appliances and vehicles, and aggressive efforts towards improvement of specific energy consumption SEC[11] across the industrial sector. This scenario therefore assumes higher penetration of efficient and low-carbon options such as electric vehicles over petroleum-based vehicles, use of public modes of transportation over private vehicles, use of five-star-rated air conditioners, and enhanced renewable capacity. In this scenario, with deep decarbonisation priorities, installed solar capacity reaches 557 GW in 2050 followed by coal at 478 GW and wind at 222 GW.

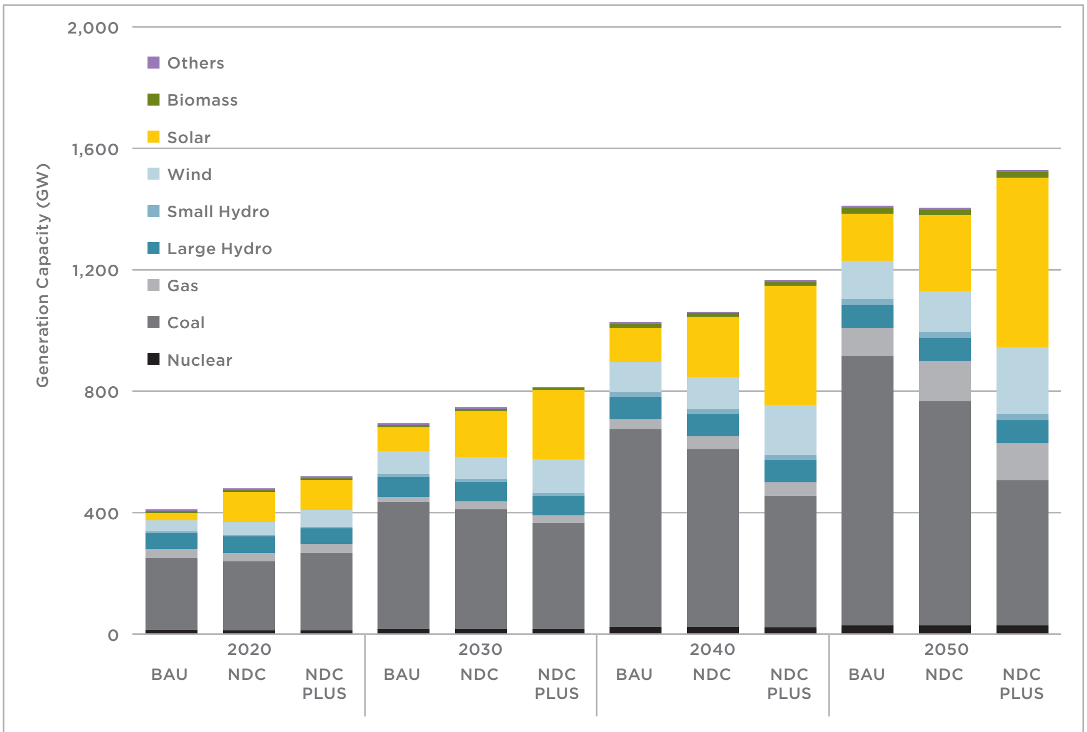

Figure 2: Power generation capacity in GW during 2020–2050 in three different scenarios

Source: own

[10] The NDC scenario considers options for enhanced technological efficiencies across all sectors; sustainable and efficient urbanisation patterns governed by smart cities; fuel substitution in transport and agriculture sectors, from petroleum-based fuels to increasing share of decarbonised electricity; increased penetration of energy-efficient buildings in the commercial sector; and a swifter phase-out of traditional fuels.

[11] SEC is defined as energy per unit of production or energy per rupee of production. Retrieved from http://wgbis.ces.iisc.ernet.in/energy/paper/part2/consumption.html

2.2 Step 2: Modelling the emissions of different sectors of the economy

The energy scenario data were fed into the GAINS-Asia online platform to estimate the annual emissions of different pollutants. Five different primary pollutant emissions were estimated through the GAINS-Asia model for the base year 2016, 2020, 2030, 2040 and 2050.

PM_{10}, SO_2, NO_x, CO and non-methane volatile organic carbon (NMVOC). The emissions estimated for different sectors are allocated to the GIS map of India divided into grids of 36×36 km.

The emission sources were broadly classified into five major sectors: i) Power, ii) Transport, iii) Domestic, iv) Industry and v) Others. The energy use in these sectors was considered in the form of: a) Coal, b) Biomass, c) Diesel, d) Gasoline, e) Kerosene, f) Heavy fuel g), Petroleum Gas (LPG) and h) Natural Gas (GAS).[12]

After estimating emissions from different sectors for 23 regions, the emissions of four pollutants were further spatially allocated at district level by using appropriate surrogate indicators. The accurate spatial allocation of emissions plays an important role in accurate estimation of pollutant concentrations through dispersion modelling and, in turn, exposure and health assessments.

To allocate the emissions from power plants, the exact locations of gas-based and thermal power plants were marked on the study domain, and power plant emissions were allocated according to fuel consumption data obtained from the Central Electricity Authority.

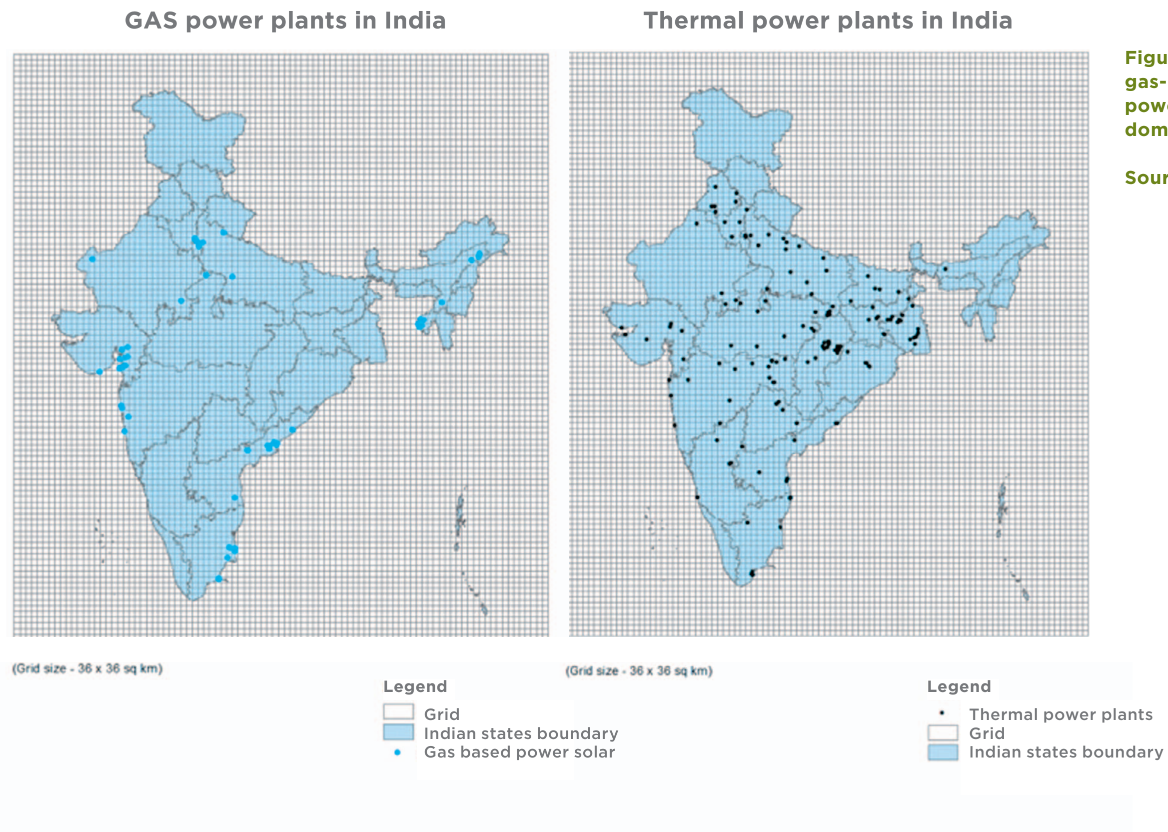

Figure 3: Locations of gas-based and thermal power plants in the study domain in 2016

Source: own

[12] Air pollution control technologies in different sectors were kept constant across different scenarios within a particular year. This is to assess the net impact of changing energy use across various sectors on air pollutant emissions in the country.

2.3 Step 3: Air quality modelling and pollutant dispersion

Air quality modelling is carried out using the Community Multi-scale Air Quality model (CMAQ). Air quality predictions for the years 2020, 2030, 2040 and 2050 were made for the whole study domain for all months of the year. Pollutant emissions (i.e., PM_{10}, NO_x, SO_2, CO and NMVOCs) were fed into the model along with the meteorological conditions generated by the Weather Research and Forecasting (WRF) model.

MOZART (Model for OZone And Related chemical Tracers) boundary conditions were used for the study domain to account for the international long-range transport of pollutants from outside the domain. The ECLIPSE database (GAINS-Asia) was used to incorporate emissions for neighbouring countries into the study domain. Biogenic emissions were accounted for using the MEGAN model. The output of the air quality modelling exercise is in the form of pollutant concentrations at each grid in the study domain.

2.4 Step 4: Assessing the impact on human health

Based on the exposure of the Indian population, health impacts are quantified in terms of all-cause mortality and disease-specific mortality. The study estimates two different types of mortality assessment. Firstly, all-cause mortality attributed to PM10 exposure, which includes all the different types of diseases; secondly, total mortality, which is the sum of the mortality occurring from the four diseases due to either PM_{10} or $PM_{2.5}$ (depending on the risk function of the disease). All-cause mortality is estimated using a separate risk–response function based on the exposure–response function of Ostro (2004) and PM10 concentrations. Concerning disease-specific mortality, the study estimates the health impacts of four diseases attributable to ambient particulate matter:

1. Cardiopulmonary diseases (COPD),
2. lung cancer (LC),
3. Ischemic heart disease (IHD) and
4. Lower respiratory tract infections (LRTI).

According to their respective risk functions, these diseases take different variants of particulate matter as an input (refer to the methodology).

The disease burden of a population, and how that burden is distributed across different subpopulations or age groups, is important information for planning mitigation measures (Ostro, 2004). For the present study, state-wise data were extracted from the ICMR website on age-specific mortality due to lower respiratory infections and lung cancer in India during the year 2016.

2.5 Step 5: Assessing health costs and economic losses

Economic losses associated with mortality can be measured through the amended human capital approach and the value of statistical life (VSL) approach (Gunatilake et al., 2014 and Lakdawalla, 2015)[13] In addition, the study proceeds with the grid-wise calculation of years lived with disability (YLDs) and years of life lost (YLLs) arising from ambient air pollution. DALY data were estimated using the WHO's approach of quantifying the burden of disease from mortality and morbidity, which defines DALY as the sum of Years of Life Lost (YLL) and Years Lost due to Disability (YLD).

[13] The VSL approach has been previously used in many Indian environmental impact assessments such as Madheswaran (2007), and also the morbidity impact captured by the cost of illness (COI) approach, which measures hospital admission cases, cost of outpatient treatment and losses resulting from illness (Haung et al., 2012). Internationally, many similar large-scale studies have been conducted, especially for developing economies which have higher air pollution incidence.

3. Reducing emissions to save lives and benefit the economy

KEY POINTS:

- The mean $PM_{2.5}$ concentration in 2020 is five times higher than that recommended by the WHO (10 µg/m³). $PM_{2.5}$ concentration will remain very high in the BAU scenario all the way until 2050 (60 µg/m³ in 2030, 54 µg/m³ in 2040 and 60 µg/m³ in 2050).
- However, even in the NDC and NDC PLUS scenarios, $PM_{2.5}$ concentrations will remain dangerously high. This indicates that more ambitious scenarios will need to be modelled (and followed) in order to significantly reduce the health impacts on the Indian population.
- Air pollution will account for 4% to 5% of total mortality in India between 2020 and 2050. In the BAU scenario, in 2020 all-cause mortality due to exposure to particulate matter (PM_{10}) will be around 500,000 people. This number would rise to 830,000 by 2050.
- In the BAU scenario, in 2020 all-cause mortality due to exposure to particulate matter (PM_{10}) will be around 500,000 people. This number would rise to 830,000 by 2050.
- The power sector is responsible for about 8% of deaths related to air pollution (PM_{10}). By moving from BAU to the NDC PLUS pathway, the number of deaths in 2050 can be reduced from 57,000 to 24,000 (a reduction of 58%).
- Switching from the present energy scenario to NDC will lead to an estimated total economic benefit to the country of INR 2148 billion by 2050, and further economic benefit of INR 5421 billion can be realised if the country moves on to the NDC PLUS trajectory.
- Total economic losses due to ambient air pollution significantly reduce Indian GDP. Already in 2020, total economic losses will reduce GDP by 2.9%. This figure could increase to 5.7% in 2050. Even in the NDC PLUS scenario, Indian GDP will be reduced by 4.3% in 2050.

3.1 Emission concentrations five times higher than WHO recommendations

Total PM_{10} emissions in India are estimated as 12,075 Kt in 2016, with major contributions from industrial (6747 Kt) and residential (3842 Kt) uses, mainly due to coal and biomass use respectively in the two sectors. The transport and power sectors make limited contributions to the emission inventory, mainly due to tighter controls; however, their contributions increase significantly in cities or at locations within their zones of influence.

In the business-as-usual scenario, population-weighted ambient $PM_{2.5}$ concentration is estimated at around 58 µg/m³ in 2020 (more than five times the limit of 10 µg/m3 recommended by the WHO). This increases slightly to 60 µg/m³ by 2030, subsequently falls to 54 µg/m³ in 2040 and settles again at 60 µg/m³ by 2050. The decline largely occurs due to more rapid shift to cleaner fuels for energy generation (particularly electricity) and their corresponding use across various sectors post-2030. The trend in $PM_{2.5}$ concentration across various scenarios is presented in Figure 4.[14]

[14] Similarly, NOx emissions increased during 2020–2050 by 84%, 73% and 51% in the BAU, NDC and NDC PLUS scenarios, respectively. In the BAU scenario, NOx emissions from power plants increase from 1373 kt in 2016 to 1720 kt in 2050; this can be reduced to 1490 kt by moving from BAU to the NDC scenario, due to greater penetration of renewable energy; and further reduced to 862 kt by following the NDC PLUS scenario.

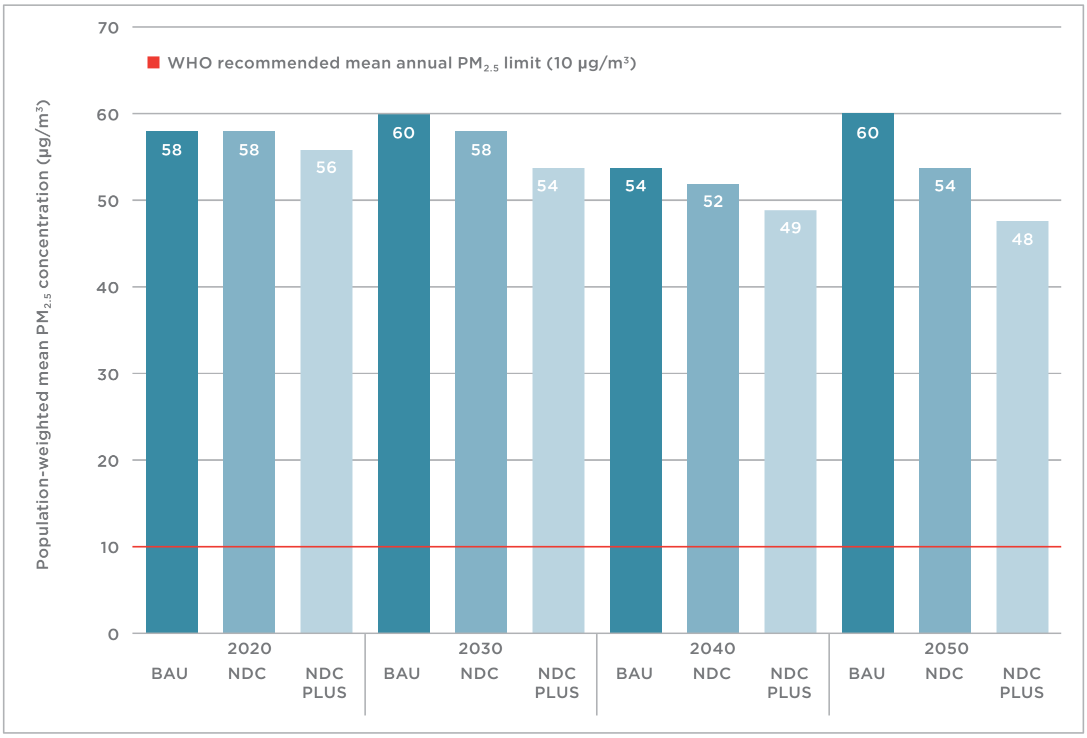

Figure 4: Projected overall (all sources) population-weighted mean $PM_{2.5}$ concentration from 2020 to 2050 under different scenarios

Source: own

By 2050, emissions are projected to be 18% and 28% lower in the NDC and NDC PLUS scenarios, respectively, compared with respect the 2050 BAU scenario. However, even in the NDC and NDC PLUS scenarios, $PM_{2.5}$ concentrations will remain dangerously high. In the best case, population-weighted mean $PM_{2.5}$ concentration will decrease to 48 µg/m³ (NDC PLUS scenario in 2050). However, this is still almost five times higher than the values recommended by the WHO. This indicates that more ambitious scenarios will need to be modelled (and followed) in order to significantly reduce the health impacts on the Indian population.

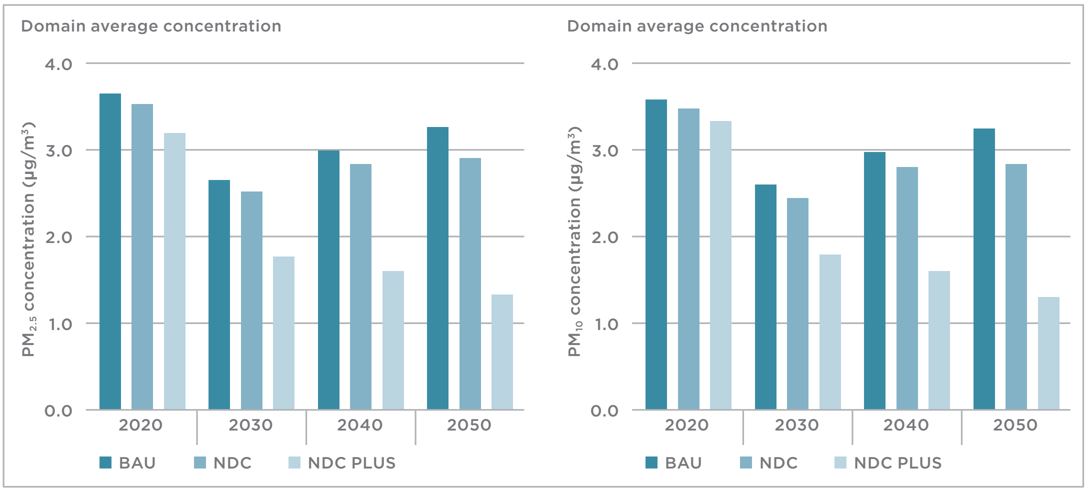

Figure 5: Domain-average concentrations of $PM_{2.5}$ and PM_{10} due to emissions from power plants in three different scenarios

Source: own

The power sector makes a limited contribution to overall emissions, mainly due to stricter controls in this sector (e.g., abatement technologies and emission standards). The domain-average particulate matter concentrations due to emissions from power plants in three different scenarios are shown in Figure 5. In 2050, $PM_{2.5}$ concentration from power plants will be reduced by 10% in the BAU scenario compared with 2020 levels. Similarly, concentrations in the NDC and NDC PLUS scenarios will be reduced by 18% and 59%, respectively, compared with 2020 levels, primarily due to greater penetration of renewables in the power sector. However, their contributions increase significantly in cities or at locations within their zones of influence.

Under the BAU scenario, PM2.5 concentrations decline from 3.6 µg/m³ in 2020 to 3.3 µg/m³ in 2050. Under the NDC scenario, the concentrations from power plants show significant decline, from 3.6 µg/m³ in 2020 to 2.9 µg/m³ in 2050. Compared with NDC, the NDC PLUS scenario shows a steeper decline, falling to 1.3 µg/m³ in 2050, largely due to the assumption of greater penetration of renewable energy technologies.

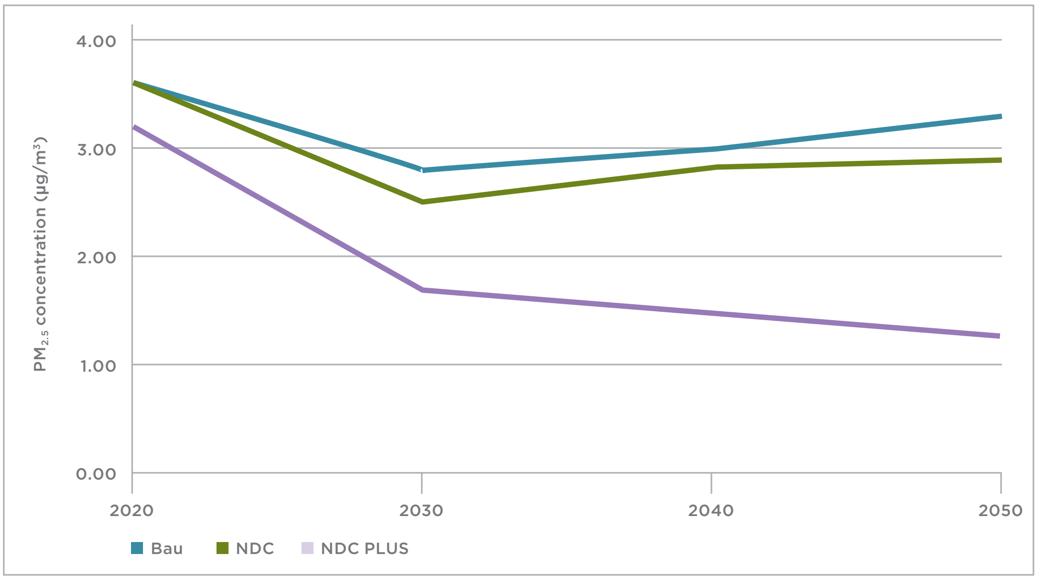

Figure 6: Population-weighted $PM_{2.5}$ concentrations (from power plants) under different scenarios

Source: own

3.2 More than 200,000 deaths can be avoided

Analysis reveals that, under the BAU scenario, PM_{10} exposure will cause nearly 500,000 deaths in India during 2020, increasing to 830,000 in 2050. By 2050, all-cause mortality due to PM_{10} will increase to 830,000, representing approximately 4.8–5.0% of total mortality in India between 2020 and 2050.[15]

By adopting the NDC scenario, India can reduce the number of deaths from PM10 exposure by 75,192 in 2050 (down from 815,886 to 740,694). This represents a decline of almost 9% by switching from BAU to the NDC scenario. Mortality can be further reduced by adopting the NDC PLUS scenario. The all-cause mortality from PM10 under the NDC PLUS scenario is estimated to be 613,050 in 2050, which is around 17% less than the NDC scenario and 25% less than under the BAU scenario. Thus, in 2050 the estimated number of deaths due to PM_{10} exposure will represent around 4.0% of all-cause mortality in the NDC PLUS scenario, compared to the 5.0% (mentioned above) estimated for the BAU scenario. In disease-specific mortality under all three scenarios, cardiopulmonary diseases are the primary cause of particulate matter exposure (around 0.34 million cases under the BAU scenario in 2020). This is followed by lower respiratory infections, lung cancer and ischemic heart disease.

All-cause mortality is predicted to increase over time in all three scenarios. However, the trends observed for the year 2020 under the NDC scenario differ from those in other years, as shown in Figure 7.[16]

[15] It is important to note that this is a conservative estimate, and that premature deaths might actually be even higher, since the exposure function might be outdated.

[16] All-cause mortality under the NDC scenario is slightly higher in 2020 compared to the results under the other two scenarios, because the benefits of adopting the pollution control strategies under the NDC will be realised after the year 2020. Hence, during 2020, the number of deaths is slightly higher in the NDC scenario.

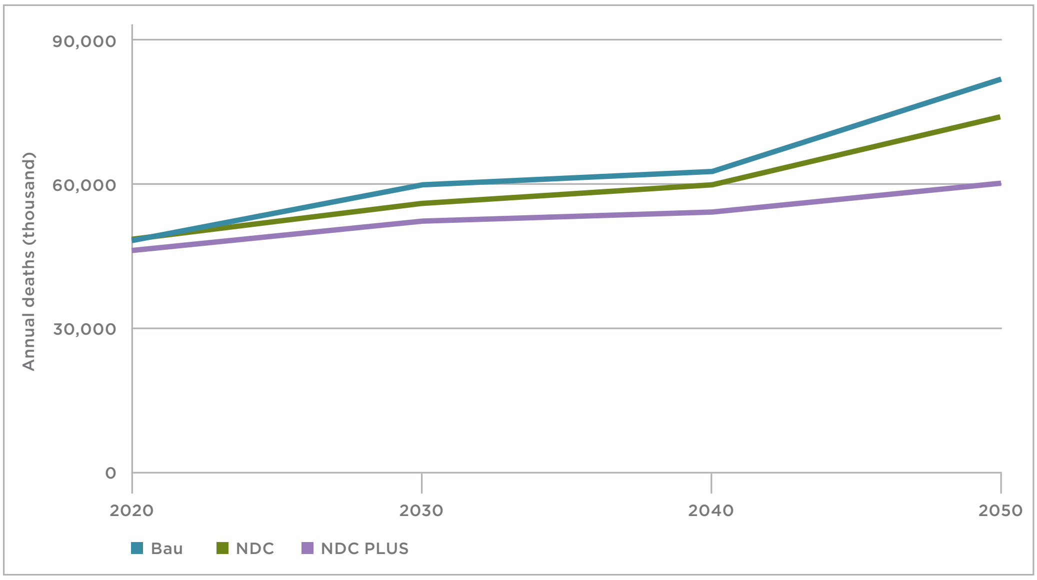

Figure 7: All-cause mortality (in thousands) due to PM_{10} exposure under different scenarios, 2020–2050

Source: own

The highest numbers of deaths is predicted in Uttar Pradesh (UP) followed by Maharashtra, Gujarat, Bihar and West Bengal over all the years and across different scenarios. Despite the changes in scenarios, estimated deaths remain highest in UP. The five most severely affected Indian states alone constitute more than 50% of the total deaths projected for India in different years under all three scenarios.

Paying particular attention to the impact of the power sector, PM_{10} attributable to thermal power plants will cause 39,748 deaths in 2020 under the BAU scenario, which is 8% of the total deaths caused due to PM_{10} from all sources. The number of such deaths declines in other scenarios (NDC and NDC PLUS) in 2020. All-cause mortality attributed to PM10 declines to 38,411 under the NDC scenario and to 38,380 under the NDC PLUS scenario.

Under both the BAU and NDC scenarios, the all-cause mortality caused by PM_{10} emissions from thermal power plants will increase by 2050. Only the NDC PLUS scenario shows declining mortality by 2050 (see Figure 8).

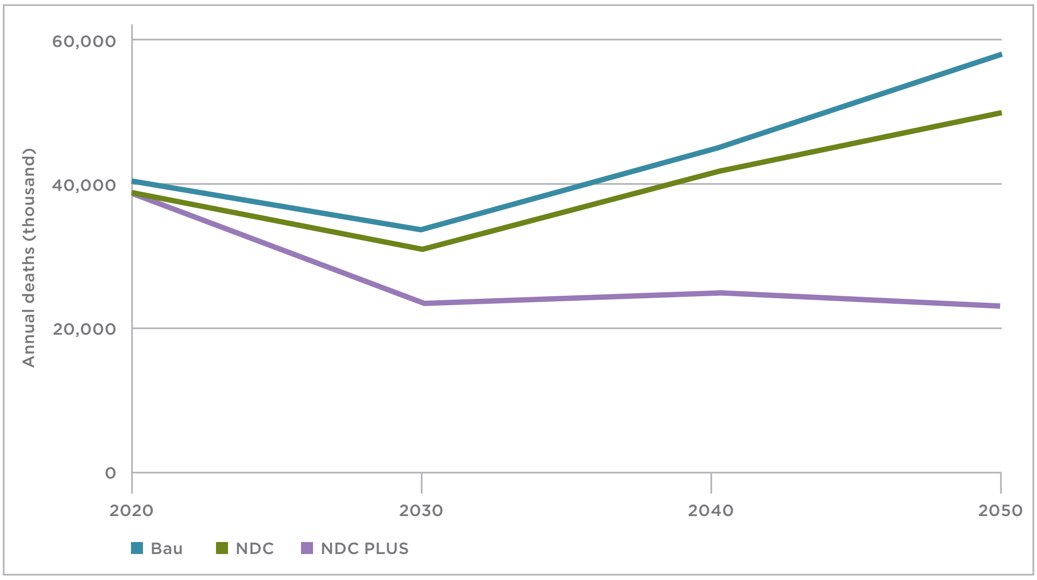

Figure 8: All-cause mortality due to $PM_{2.5}$/ PM_{10} under different scenarios caused by coal fired thermal power plants, 2020–2050

Source: own

3.3 Up to 7 million disability-adjusted life years can be avoided

Disability-adjusted life years (DALY) is often used as a single metric to record the combined burden of mortality and morbidity. DALY attributable to ambient $PM_{2.5}$/PM10 under the BAU scenario is estimated to be 14 million in the year 2020.[17] Under the BAU scenario, this would increase to 24 million in 2050.[18] However, by adopting the NDC pathway, India can reduce total DALY to 21 million in 2050, a reduction of 10%. By moving beyond the NDC pathway, the country can further reduce DALY to 17 million (NDC PLUS) (see Figure 9).

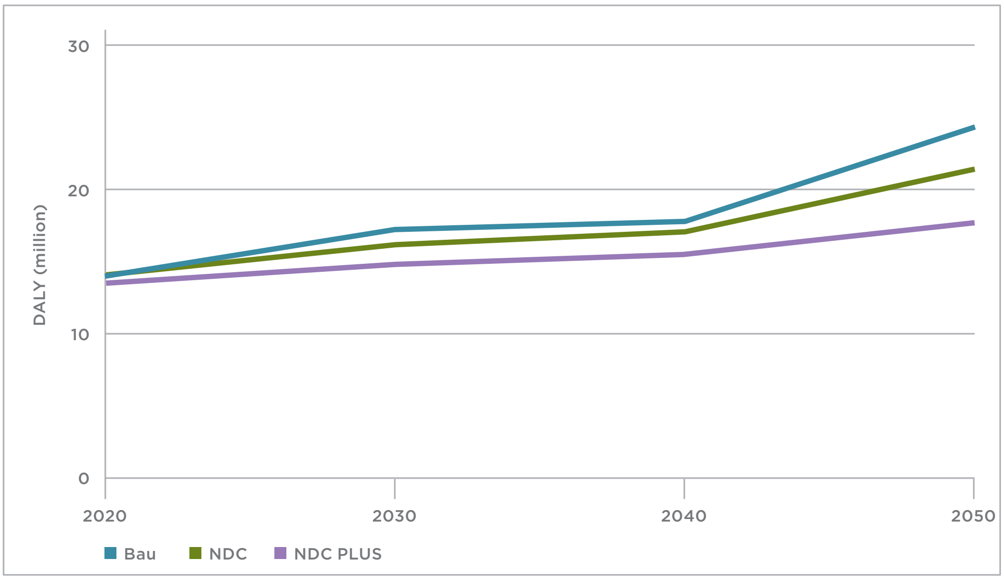

Figure 9: Total DALYs (millions) attributable to $PM_{2.5}$/PM10 (sum of four diseases: COPD, LRTI, LC and IHD), 2020–2050

Source: own

Since the risk functions vary between the four diseases, their pollutant inputs and age-specificities also vary. Uttar Pradesh has the highest number of DALY attributable to these four diseases (COPD, LRTI, LC and IHD) in the year 2020 under all scenarios. Uttar Pradesh alone accounts for around 17% of India's total DALY attributable to $PM_{2.5}$, followed by Maharashtra (10%), Bihar (10%) and Gujarat (9%). In the year 2020 under the BAU scenario, the five most severely affected states account for approximately 54% of total DALY attributable to $PM_{2.5}$. In comparison, the five least affected states together account for a very low share (approximately 0.2%) of total DALY in India.

Focusing on the power sector, disease-specific DALY predicted due to $PM_{2.5}$/PM_{10} emissions from thermal power plants is estimated to be around 1.2 million under the BAU scenario in 2020, increasing to 1.7 million in 2050. Under both the NDC and NDC PLUS scenarios, DALY is estimated as 1.1 million in 2020. Even under the NDC scenario, DALY would also increase from 1.1 million in 2020 to 1.5 million in 2050. However, under the NDC PLUS scenario, DALY would decrease from 1.1 million in 2020 to 0.7 million in 2050 (see Figure 10).

[17] This is total DALY associated with four specific diseases (cardiopulmonary diseases, lung cancer, ischemic heart disease and lower respiratory tract infection).

[18] In the BAU scenario in 2020, of the four diseases, ischemic heart disease makes the largest contribution to total years of life lost (44%), followed by lower respiratory tract infection (32%), COPD (22%) and lung cancer (2%). Similar disease contributions are observed for YLD and DALY.

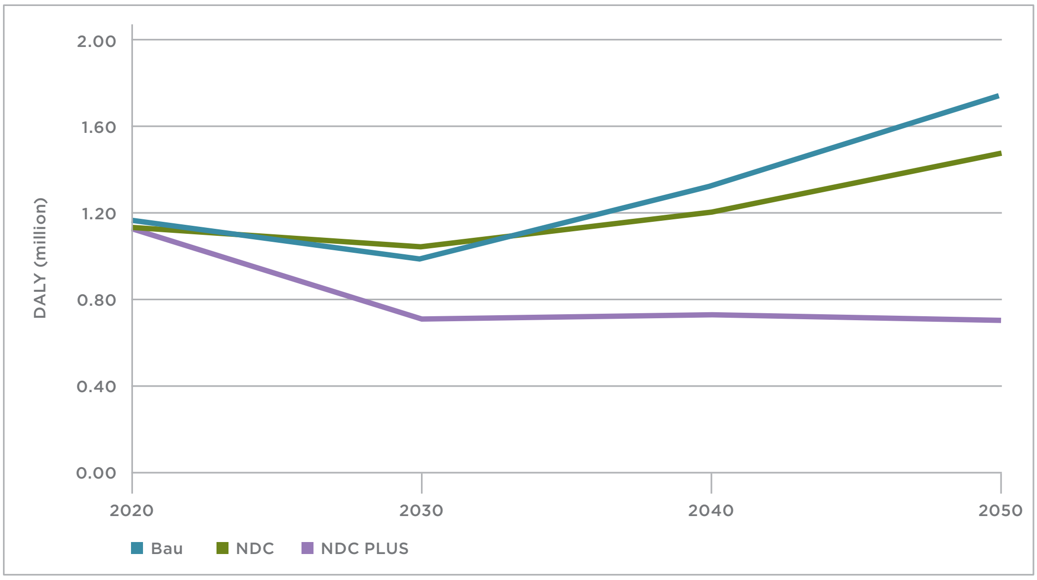

Figure 10: Total DALY (millions) attributable to $PM_{2.5}/PM_{10}$ from coal-fired thermal power plants (sum of four diseases: COPD, LRTI, LC and IHD), 2020–2050

Source: own

3.4 Rapidly increasing economic losses can be avoided

Total economic losses associated with the four example diseases resulting from ambient particulate PM2.5/PM10 are calculated via the VSL approach using predicted DALY. Under the BAU scenario: Total economic loss due to both disease-specific mortality and morbidity for the year 2020 is estimated as INR 4604 billion (i.e., 4.6 trillion). The implications of persisting with BAU include a TEN-FOLD increase in economic losses, to INR 47 trillion in 2050.

By following the NDC pathway, total economic losses in 2050 could be reduced from INR 47 trillion to INR 45 trillion in 2050. By going beyond the NDC trajectory and following the NDC PLUS pathway, total economic losses could be reduced by INR 12 trillion to INR 35.7 trillion in 2050 (see Figure 11).

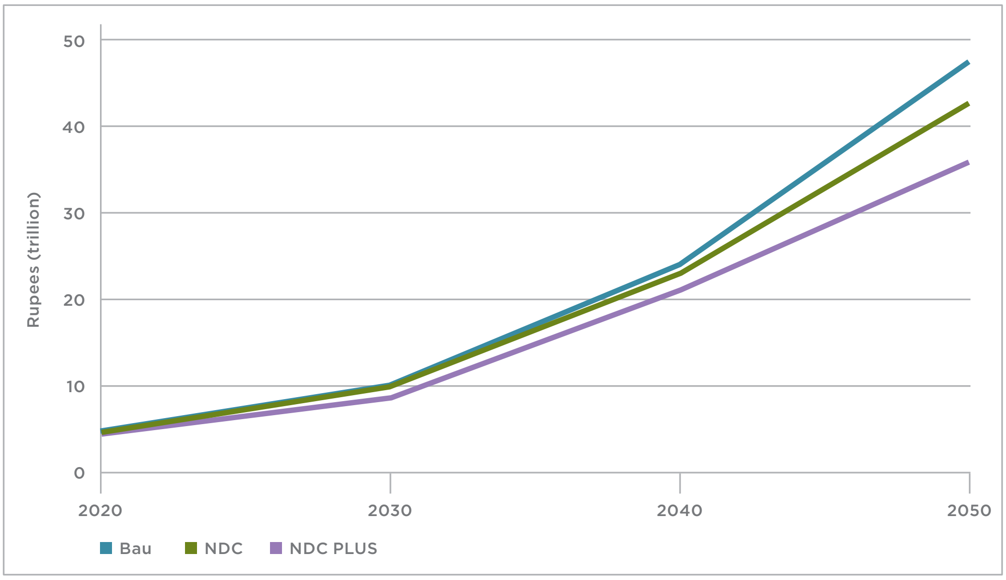

Figure 11: Total economic loss (in trillion Rupees) due to COPD, LRTI, LC and IHD, 2020–2050

Source: own

Looking at the specific impact of the power sector, total economic loss arising from COPD, LRTI, LC and IHD is estimated as INR 325 billion (i.e., INR 0.32 trillion) in 2020 under the BAU scenario. In the following decades, this total economic loss will rise at a CAGR of 7%, thus increasing to INR 2567 billion (INR 2.5 trillion) in 2050 (BAU). In the NDC and NDC Plus scenarios, total economic losses will increase more slowly. However, even under the NDC PLUS trajectory, total economic losses resulting from air pollution from the power sector will exceed INR 1 trillion in 2050 (Figure 12).

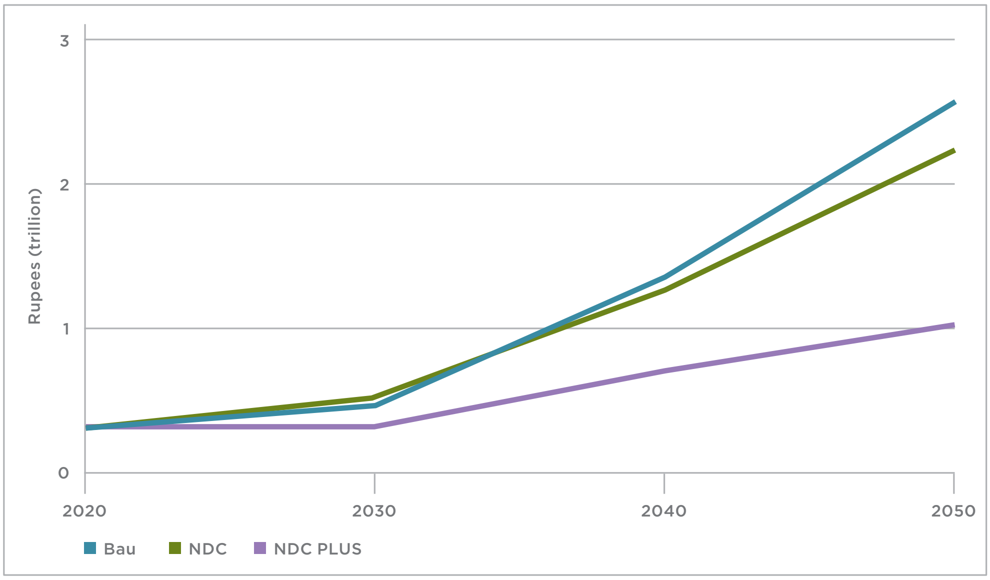

Figure 12: Total economic loss (in trillion Rupees) resulting from four diseases (COPD, LRTI, LC and IHD) caused by thermal power plants, 2020–2050

Source: own

Total economic losses due to ambient air pollution significantly reduce Indian GDP. This disease-specific economic loss estimated for the year 2020 under the BAU scenario represents around 2.9% of India's total GDP. These economic losses will increase by more than ten times under the BAU scenario between 2020 and 2050, mainly due to the multiplicative effect of various socio-economic and demographic factors in the economy. In the BAU scenario these economic losses will increase from 2.9% of GDP in 2020 to 5.7% in 2050.

Under the other two scenarios total economic losses will also increase significantly as a proportion of GDP, but at slower rates. The economic losses attributable to ambient $PM_{2.5}/PM_{10}$ show alarming increases throughout the thirty-year prediction horizon. Even in the NDC PLUS scenario, Indian GDP will be reduced by 4.3% in 2050. This again indicates that India should consider even more ambitious pathways for greening the economy.

4. Creating an enabling environment to improve health and reduce economic costs

Impulses for furthering the debate

This COBENEFITS study assesses the impact of ambient air pollution on human health in India. It quantifies both the health and economic costs arising from $PM_{2.5}/PM_{10}$ emissions. The study assesses the impacts of ambient air pollution from all sectors of the Indian economy. For the power sector specifically, the health benefits are quantified as resulting from increased share of renewable energies in the Indian energy and power sector.

The study finds that India can markedly improve the livelihoods of its citizens by reducing ambient air-pollution. In the business-as-usual scenario, in 2020 all-cause mortality will amount to 500,000 people due to exposure to particulate matter (PM_{10}), increasing to 830,000 by 2050. By moving to the NDC PLUS PATHWAY, more than 200,000 deaths can be avoided. At the same time, India can significantly cut economic losses by greening the economy and deploying renewable energy sources. Following the business-as-usual pathway, total economic costs could increase from INR 4.6 trillion in 2020 by more than ten-fold, to INR 47 trillion in 2050. However, by following the NDC PLUS pathway, economic costs in 2050 could be reduced by as much as INR 12 trillion.

What can government agencies and political decision makers do to create a suitable enabling environment to maximise health benefits for the Indian people and unburden the health system?

How can other stakeholders unlock the social and economic co-benefits of building a low-carbon, renewable energy system while facilitating a just energy transition?

Building on the study results and the surrounding discussions with political partners and knowledge partners during the COBENEFITS Round Tables, we propose to direct the debate in three areas where policy and regulations could be put in place or enforced in order to reduce air pollution within the shift to a less carbon-intensive power sector.

- Adoption of air quality as an additional criterion for power plant retirement. Improve independent emission monitoring and law enforcement through third-party assessments.
- Foster interdisciplinary exchange between researchers and ensure methodological standards and joint monitoring.

Adoption of air quality as an additional criterion for power plant retirement

India has been attempting to retire old, inefficient coal-based thermal plants for quite some time. Smaller non-reheat type units, having high specific fuel consumption, mostly fall into this category, making them economically unviable for operation. Hence, decisions related to the closure of power stations are determined by their economics. Improved efficiency will lead to increased utilisation of heat, thereby reducing the emissions per unit of electricity generated. The Government of India also introduced new emission norms for all coal-based power generation in India several years ago. Repeated non-compliance with standards will lead to issuance of notices to non-compliant power stations. Although there is a positive correlation between inefficiency and emissions, it is nevertheless the former that is prioritised. There is, however, scope to explore ways of incorporating emissions as a part of the decision-making process. Inefficiency will not only lead to increased operational costs, but frequent non-compliance also has environmental costs associated with higher CO_2 emissions. Assessing power plants based on both their efficiency and emissions might thereby lead to better decision-making processes.

One option for promoting more consistent decisions on the retirement of coal-fired power plants is to explore how these factors are included in preparing decision matrix guidelines for practical purposes. In other words, the additional cost to the environment due to inefficiency should also be factored in, to create a case for phasing out such power plants in the future.

Improve independent emission monitoring and law enforcement through third-party assessments and extended mandates for CPCB and SPCBs

Although emission standards have been introduced in India, robust monitoring of these power plant emissions remains a challenge. A shortage of staff in nearly all State Pollution Control Boards (SPCBs) results in insufficient control visits by SPCB officers to power plants. Therefore, reports from experts hired by power plant operators are used as a primary information source. The SPCBs' restricted mandate for enforcing compliance with emission regulations further hinders effective measures in this area.

Providing the Central and State Pollution Control Boards with more staff and a mandate to establish a system of progressive financial penalties for violations of emission regulations might establish financial incentives for operators to comply with emission standards or even retire power plants when they are no longer financially viable.

Monitoring of power plant emissions by a third party would further contribute to obtaining more reliable emissions data, as demonstrated by experiences gained in a flagship project in Gujarat. The Central Pollution Control Board (CPCB) might be the most appropriate organisation to establish third-party assessments of power plant emissions and to hire independent scientific institutes and resource centres to conduct field research.

Foster interdisciplinary exchange between researchers and ensure methodological standards and joint monitoring

Studies and assessments carried out in the nexus of energy planning, renewable energies, air quality and health research in India vary widely regarding the scientific methods and approaches used. While digitalisation and new technologies provide opportunities to gain new knowledge through the use of innovative research approaches, it remains a challenge to assess the scientific reliability of different methodologies. Consequently, it is often difficult for policymakers and officials to judge the validity of such assessments.

The sharing of data, existing studies and results, as well as further strengthening networks of renowned experts tasked with ensuring the quality of scientific studies through peer-review, are therefore crucial steps towards more coordinated and targeted research to identify synergies in the energy planning–air quality–health nexus.

Setting up a shared research platform – ideally supported by responsible line ministries – encourages interdisciplinary exchange among researchers from different backgrounds and fosters transparency by assembling and organising existing data and studies within the nexus. Through forums and other functions for gaining feedback from other experts on the methodologies used, such platforms also enhance transparency and contribute to ensuring robust scientific standards throughout the nexus.

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List of abbreviations

AAP	Ambient Air Pollution
AHC	Amended Human Capital
BAU	Business-As-Usual Scenario
CMAQ	Community Multiscale Air Quality Modeling System
CO_2	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Disease
CPCB	Central Pollution Control Board
DALY	Disability-Adjusted Life-Year
GAINS ASIA	Greenhouse Gas And Air Pollution Interactions And Synergies
GDP	Gross Domestic Product
GW	Gigawatt
HAP	Household Air Pollution
IASS	Institute for Advanced Sustainability Studies
ICMR	Indian Council of Medical Research
IHD	Ischemic Heart Disease
LC	Lung Cancer
LPG	Petroleum Gas
LRTI	Lower Respiratory Tract Infections
MEGAN Model	Model of Emissions of Gases and Aerosols from Nature
MG	Megawatt
MNRE	Ministry Of New And Renewable Energy
NAPCC	National Action Plan On Climate Change
NDC	Nationally Determined Contribution
NMVOC	Non-Methane Volatile Organic Carbon
NO_x	Nitrogen Oxides
OECD	Organisation for Economic Co-operation and Development
PM_{10} and $PM_{2.5}$	Particulate Matter
RE	Renewable Energy
Ri-MAP	Risk of Mortality/Morbidity due to Air Pollution
SECs	Specific Energy Consumption
SO_x	Sulphur Oxides
SO_2	Sulphur Dioxide
SPCBs	State Pollution Control Boards
TERI	The Energy and Resources Institute
VSL	Value of a Statistical Life
WHO	World Health Organization
WRF	Weather Research and Forecasting
YLD	Years Lost due to Disability
YLL	Years of Life Lost

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COBENEFITS
Connecting the social and economic opportunities of renewable energies to climate change mitigation strategies

COBENEFITS cooperates with national authorities and knowledge partners in countries across the globe such as Germany, India, South Africa, Vietnam, and Turkey to help them mobilise the co-benefits of early climate action in their countries. The project supports efforts to develop enhanced NDCs with the ambition to deliver on the Paris Agreement and the 2030 Agenda on Sustainable Development (SDGs) and to enable a just transition. COBENEFITS facilitates international mutual learning and capacity building among policymakers, knowledge partners, and multipliers through a range of connected measures: country-specific co-benefits assessments, online and face-to-face trainings, and policy dialogue sessions on enabling political environments and overcoming barriers to seize the co-benefits.

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