January–March 2021

ENERGY FUTURE

The Complete Energy Magazine

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FEATURE

EMISSIONS CONTROL IN THERMAL POWER STATIONS

VIEWPOINT

UNDERSTANDING AIR POLLUTION AND WASTE MANAGEMENT

COVER STORY

AIR POLLUTION IN INDIA: MAJOR ISSUES AND CHALLENGES

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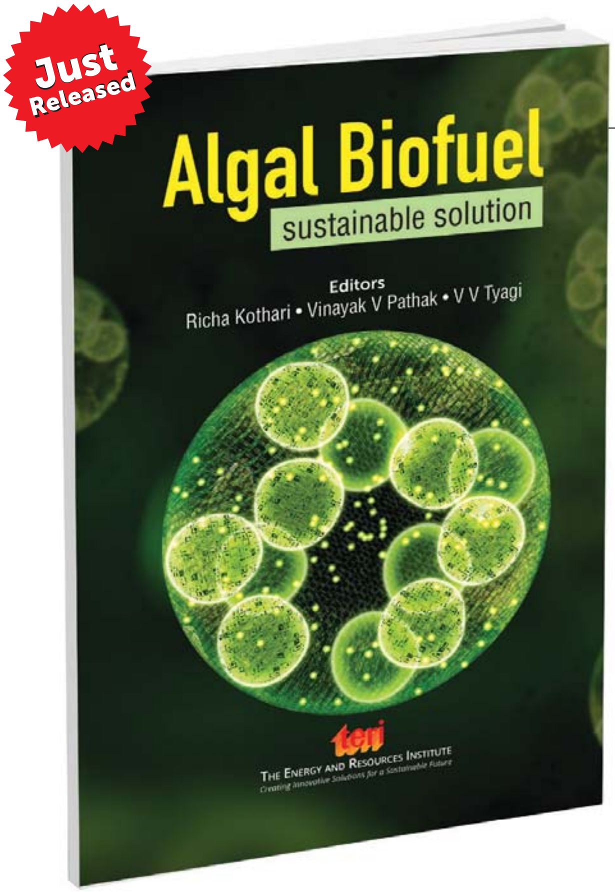
SUSTAINABLE ENERGY SOLUTIONS FROM BIO SOURCES



Major topics covered

- Algal biomass harvesting for biofuel production
- Biogas as bioenergy option
- Application of algal biomass as a feedstock
- Bioethanol production from lignocellulosic/ algal biomass
- Crop residues as a potential substrate for bioenergy production
- Biodiesel production from non-edible oilseeds

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Algal Biofuel: sustainable solution explores a wide spectrum of bioenergy sources, including their applications. It provides latest information in the field of bioenergy technologies and their future prospect including lipid content. It discusses governance of biofuel at global and national levels and the potential of biofuel to meet the rising energy demand. The book focuses towards the strategies to ensure the availability of algal biomass, effective cultivation and harvesting techniques. The strategies to enhance the algal lipid synthesis and its conversion for biodiesel production have been also elaborated.

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From the editor's desk...

While ritually focus on air pollution seems to get traction only during the peaks occurring in winters (particularly in Delhi NCR), the fact that even during rest of the year we are not breathing healthy air is conveniently forgotten. Various studies have established that in the Indo-Gangetic plains the annual concentrations of PM_{10} and $PM_{2.5}$ in ambient air remain way above National Ambient Air Quality Standards (NAAQS). And contrary to a rosy image, there is no difference in levels of air pollution between urban and rural areas across the country, as brought out by a study carried out by Colorado State University, USA and Indian Institute of Technology Bombay. Industries, power generation, vehicles, biomass burning, and dust can be ascribed as major sources of air pollution in India.

As far as industries are concerned, it is imperative that they switch to clean fuels. Diesel generators in industries and commercial places could be easily done away with immediately only if our distribution utilities were able to guarantee 24x7 reliable electricity supply. For other requirements, natural gas or biomass pellets made out of agriculture residues (like paddy stubble) could be made mandatory. Initially, industries may have to be incentivized to shift to clean fuels.

The share of biomass-related emissions is not only because of stubble burning in fields but also because of biomass being used in households for cooking as well as garbage burning in open. While programme like `Ujjwala' is meant to move households to LPG, sustained campaign coupled with appropriate fiscal incentives for economically weaker section could be necessary to wean them away from biomass cookstoves for good.

The current status of implementation of emissions control norms in Indian coal power plants, particularly norms pertaining to limiting SO_2 emissions, tells of the seriousness with which it is being taken up by all concerned. Original deadline of December 2017 had already been pushed back to December 2022. While arguing about better utilization of resources and indigenous capabilities, etc. conveniently ignored are the costs that a common citizen has to bear on account of air pollution. And health impacts apart, there are environmental implications of emissions applicable even to remote and relatively inhabited places, namely the acid rain formed when SO_2 combines with water and forms sulfuric acid (the main component of acid rain). Adverse effects of acid rain on aquatic ecosystems in rivers and lakes and damage to forests, crops, and other vegetation are well documented. In addition, SO_2 is a precursor of fine particle or $PM_{2.5}$ pollution.

It is evident that in order to provide permanent succour, the mitigation measures must be designed to address the root-causes of emissions and not the superficial ones treating the symptoms. Let us change our attitude towards the environment where we forego preventive measures to let the situation reach critical proportions, and then rush to make stop gap arrangements. Given the complexity of the problem, the Centre and States must work closely with local governments and other stakeholders in a concerted fashion. Ultimately the future hinges on our present action!

Amit Kumar

Amit Kumar
Senior Director, Social Transformation, TERI

Editor: Amit Kumar Radheyshayam Nigam
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New Message

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Letter to the Editor

I loved reading the feature article on flood early warning system for Guwahati published in the October-December 2020 issue of *Energy Future*. The authors have enlightened the readers that flood early warning systems that can predict the flood hotspots of the city based on information regarding the rainfall intensity and duration can be a major boost towards enhancing the resilience of flood-prone cities such as Guwahati. Early warning systems for disasters can go a long way in helping build the resilience of disaster-prone cities. However, it must be reiterated that early warning systems are just one aspect of disaster preparedness.

K P Singh
New Delhi

"The Cover Story published in the latest issue of your magazine summarizes the existing data sources and research to illustrate the vulnerability of power systems to natural shocks. An analysis of outages shows that natural shocks account for 55 per cent of all power outages, thus making natural shocks the leading cause of power outages in the USA. The authors have very succinctly explained that estimates from various countries demonstrate that the vulnerability of electricity networks to natural shocks is not simply explained by the income status of a country, as lower income countries are not necessarily more or less vulnerable to natural shocks. Instead, electricity network vulnerability depends on a variety of factors, including network density, vegetation, and maintenance practices."

Prakash Jain
Indore, Madhya Pradesh

"I liked the Viewpoint section published in the October–December 2020 issue of *Energy Future*. Mr Narasimhan's views are quite noteworthy that there are various technologies and innovations which are already helping with disaster management and post-disaster recovery. The innovations in satellite-based assessments are enhancing the early preparedness about upcoming disaster events in power system. The periodically updated information by the Indian Meteorological Department has continuously helped in keeping a track on the path of various cyclones hitting Indian coastlines. The time-stamped trajectory with wind speed is helpful in identifying possible impact areas."

Hema Ramachandran
Chennai, Tamil Nadu

"The article published in the Solar Quarterly section of the October–December 2020 issue of *Energy Future* is quite apposite. Buildings and construction sector is one of the largest sources of carbon emissions, and residential buildings alone account for 22 per cent of global energy use and 17 per cent of energy-related carbon-dioxide emissions. The combination of energy efficiency measures and onsite or offsite renewable energy is a powerful tool for tackling building-related emissions. Therefore, utilizing rooftop solar potential in the residential sector is very important."

Anand Shankar
Kolkata, West Bengal

Thank you very much for your encouragement. The editorial team of Energy Future will ensure that the magazine caters to your information and knowledge needs. We welcome your suggestions and comments to further improve our content and presentation.

Email: teripress@teri.res.in
Editor
Energy Future

CONTENTS

INDIA TO WITNESS FASTEST RISE IN ENERGY DEMAND BY 2040: IEA

In a report titled, '*The India Energy Outlook 2021*', the International Energy Agency (IEA) said, the rapid expansion of solar power combined with favourable policies is transforming India's electricity sector, allowing the country to offer clean, affordable and reliable power to a growing number of households and businesses.

The International Energy Agency (IEA) has forecast India's energy demand to grow at the fastest pace globally over the next two decades in line with the country's economic expansion.

'India's energy future depends on buildings and factories that are yet to be built. Based on India's current policy settings, 60% of its CO_2 emissions in late 2030s will be coming from infrastructure that does not exist today. This represents a huge opening for policies to steer India onto a more secure and sustainable course,' the report noted.

Additional funding of $1.4 trillion, or 70% more than the current estimates, will be needed in clean-energy technologies to place India on a sustainable path over the next two decades, the IEA said, adding that the country's combined import bill for fossil fuels is projected to triple during the period with crude oil as the largest component. Domestic production of oil and gas continues to fall behind consumption trends and net dependence on imported oil may rise above 90% by 2040, up from 75% at present, the report noted. EF

Source: https://www.hindustantimes.com/business/india-to-witness-fastest-rise-in-energy-demand-by-2040-iea-101612916139283.html

GUJARAT CANCELS RESULTS OF SOLAR AUCTIONS, FEELS TARIFFS ARE HIGH

Gujarat's main power distribution company, Gujarat Urja Vikas Nigam, has now obtained permission from the state power regulator to hold the auctions again for the 700 MW Dholera Solar Park and the 100 MW Raghanesda Solar Park. The record low tariff of ₹1.99 per unit reached at a solar auction in Gujarat in December has had immediate fallout, with the state cancelling the results of two previous auctions where the discovered tariffs were much higher. EF

Source: https://economictimes.indiatimes.com/industry/energy/power/gujarat-cancels-results-of-solar-auctions-feels-tariffs-are-high/articleshow/80764943.cmsjanuary-september-period/articleshow/78891954.cms

A ROAD MAP FOR A CLEANER, GREENER INDIA

India is the world's sixth-largest economy and is expected to become the third largest by 2030. In terms of consumption, India currently is the third-largest energy consumer in the world. As per *BP Energy Outlook 2020*, India's share of global energy consumption is expected to rise from 6% to 8% by 2030.

The need of the hour is to opt for a fuel that is not only efficient but also environment-friendly. Decarbonization — a reduction of CO_2 emissions per unit of energy — can be achieved in two ways. The first is to use less polluting fossil fuel-based energy sources and the second is to adopt technologies that permit the use of fossil fuels while preventing the build-up of CO_2 in the atmosphere.

Natural gas is an abundant energy resource found in many regions of the world. The worldwide recoverable resource of natural gas is estimated at 199 TCM, which is sufficient to meet the energy demands for several decades.

Natural gas is also the least carbon intensive fossil fuel and has a high hydrogen/carbon ratio. Due to this, natural gas on combustion releases up to 50% less CO_2 than coal and 20–30% less than oil. Globally, the share of natural gas in the energy mix is around 24%, while in India, it's only 6%.

India needs to make further efforts to make its primary energy mix cleaner and more sustainable. The government has a vision of increasing the share of natural gas in the energy mix from 6% to 15% by 2030. EF

Source: https://www.thehindubusinessline.com/opinion/a-roadmap-for-a-cleaner-greener-india/article33794886.ece

POWER DEMAND REMAINS HIGHER IN 1ST WEEK, CROSSES RECORD PEAK OF FEB '20

India's peak power demand met or the highest supply in a day has remained higher in the first week of February till Friday and surpassed the record high supply of 176.38 GW for February last year.

According to the Power Ministry data, the peak power demand met was recorded at 187.71 GW on February 1; 188.15 GW on February 2; 188.11 GW on February 3; 183.81GW on February 4; and 184.34 GW on February 5.

The peak power demand met in this month so far is higher than the monthly record power demand met of 176.38 GW for February 2020.

Experts opined that the data clearly indicates all likelihood of high electricity consumption growth in the month of February this year. They are of the view that if power supply is higher in the first five days of February than the monthly record peak a year ago, then electricity consumption would not only register high growth but would remain at much higher level than that in 2020. Peak power demand had touched an all-time high of 189.64 GW on January 30, 2021, breaching the previous record high of 188.45 GW recorded on 28 January. EF

Source: https://www.business-standard.com/article/economy-policy/power-demand-remains-higher-in-1st-week-crosses-record-peak-of-feb-20-121020700192_1.html

CAPACITY ADDITION IN RENEWABLE SECTOR SLUGGISH

Capacity addition in the renewable energy sector fell by 42% in the third quarter of the current fiscal. For the first nine months, the decline was 46%, according to MNRE data.

For the December 2020 quarter, the renewable sector added just 1924 MW new capacity when compared with 3319 MW in the year-ago quarter. For the nine-month period of this fiscal, the total new capacity added to the grid was 4076 MW (7592 MW) representing 28% of the target set for the renewable sector in this fiscal.

The solar segment continues to drive new capacity addition at 2837 MW (includes 1846.5 MW of ground-mounted and 990.3 MW of rooftop) capacity during April–December 2020 period. The wind sector added 880 MW of new capacity to the grid, according to the data of the Union Ministry of New and Renewable Energy.

As of December 2020, the total grid-connected renewable power capacity in India stood at 91,154 MW, of which wind power was 38,624 MW. The solar segment had a cumulative installed capacity of 37,465 MW (includes both ground-mounted 33,959 MW and 3,506 MW of rooftop capacity).

'While solar module prices fell due to stoppage of construction work on account of COVID-19, the prices shot up in the second half of 2020 due to supply chain disruptions and spurt in international demand,' according to renewable energy consulting firm Bridge to India.

After a muted scenario in October and November, tender issuance shot up in December and January. Supported by Andhra Pradesh tender, close to 8000 MW of utility scale and 85 MW of rooftop tenders were issued in December. In January 2021, about 6963 MW of renewable tenders were issued.

Meanwhile, the Union Budget 2020–2021 has announced some measures to revive the momentum in the renewable sector. EF

Source: https://www.thehindubusinessline.com/news/capacity-addition-in-renewable-sector-sluggish/article33741661.ece

ALL-WOMAN CREW IN LADAKH RUNS LPG PLANT THAT ARMY DEPENDS ON

Every morning, Tsering Angmo leaves her two-year-old son with neighbours and commutes 20 km through a frozen landscape from her home in Choglamsar, a settlement near Leh, to work at Ladakh's only LPG bottling plant near Leh.

Angmo is part of a 12-member all-women crew making sure that the 50,000 Indian soldiers eyeballing the People's Liberation Army in Arctic temperatures do not have to march on empty stomachs.

The plant, built by state-run IndianOil, is Ladakh's only source of cooking gas and a lifeline once snow snaps road connectivity with the rest of the country. About 40% of the refills produced at the plant go to the defence establishment. It is also the country's only LPG unit to be operated by women.

The women work the production line, check quality of seals, etc., and manage security. All the crew members, except security officer Tsetan Angmo, are contract workers. Only loading, involving heavy lifting, is handled by five men. EF

Source: https://economictimes.indiatimes.com/industry/energy/oil-gas/all-woman-crew-in-ladakh-runs-lpg-plant-that-army-depends-on/articleshow/80609865.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst

GOVERNMENT EXTENDS TENURE OF CENTRAL ELECTRICITY REGULATORY COMMISSION CHIEF, MEMBERS TILL NEXT YEAR

The government has issued order for extension of the tenure of former Gujarat cadre bureaucrat Pradeep Kumar Pujari as chairperson of the Central Electricity Regulatory Commission (CERC) till mid-next year.

The tenure extension order is also likely to apply to the other two members – I S Jha, former Power Grid Corp chairman, and Arun Goyal, ex-bureaucrat – of the regulatory commission, giving them five years of service or till they attain 65 years, sources said. The tenure of the commission's recently appointed member law Pravas Kumar Singh is already fixed as five years.

Pujari is the first chairman of the power regulator to get tenure extension even as the Electricity Act, 2003 forbids it.

As per the modified approval received from DOPT, 'the Appointments Committee of the Cabinet has approved the proposal for appointment of P K Pujari as Chairperson, Central Electricity Regulatory Commission (CERC) for a term of 5 years w.e.f. the date of assumption of charge of the post, or until he attains the age of 65 years, or until further orders, whichever is the earliest, in terms of Section 89(1) of the Electricity Act, 2003,' an order issued by the Power Ministry said. EF

Source: https://economictimes.indiatimes.com/industry/energy/power/government-extends-tenure-of-central-electricity-regulatory-commission-chief-members-till-next-year/articleshow/80601516.cms

AP LOOKS TO BOLSTER GRID MANAGEMENT TO TAP MORE RENEWABLE ENERGY

With the state government planning to source more energy from mega solar units, which would make grid maintenance tedious because of the variable nature of power, the energy department has planned to have processes in place for a more stable grid. The plan includes implementation of the Automatic Generation Control System, Agriculture Power Supply Demand Disconnection scheme, forecasting and scheduling tools, and pumped storage hydroelectricity plants.

The state has 8424.018 MW of renewable power commissioned as of January 18 this year, out of which wind generation capacity accounts for 4079.37 MW and solar generation for 3752.24 MW.

Since renewable energy is variable in nature, the grid management is one of the critical aspects for the power utilities to take care of. As the state has initiated steps for the installation of another 6400 MW of mega solar units, as a part of the 10,000 MW solar power plants to meet the free agriculture power demand, the variation, which is cited by the power distribution companies (DISCOMs) as the reason for short-term purchases, is further expected to increase.

For 2022–2023, DISCOMs project the agriculture demand to be approximately in the range of 2861 MW to 4813 MW with maximum solar dispatch being around 70% of the installed capacity. In this context, it is learnt that the department is in the process of implementing four initiatives. The officials said that an automatic generation control system to control renewable energy generation as per the grid requirement duly taking into considering the commercial aspects would be implemented. EF

Source: https://www.newindianexpress.com/states/andhra-pradesh/2021/jan/31/ap-looks-to-bolster-grid-management-to-tap-more-renewable-energy-2257449.html

GLOBAL ACTIONS DELIVERING ELECTRICITY FOR RURAL HOUSEHOLDS THROUGH OFF-GRID RENEWABLE ENERGY

The Sustainable Development Goal set forth in SDG 7.1 calls for universal access to affordable, reliable, and modern energy services by 2030. It is estimated that currently, 789 million people do not have access to electricity in their homes or communities. Rural inhabitants encompass 80% of the total number of people lacking household electricity access. On a global scale, rural inhabitants have been gaining access to electricity at a rapid rate over the past couple of decades. However, certain regions have seen little improvement in this area. The Sub-Saharan Africa (SSA) is the starkest example.

The International Energy Agency (IEA) estimates that 548 million people in SSA currently have no access to electricity in their homes. Over the last two decades, the rate of rural electrification has been rapid due to grid extension programmes in Asia, Latin America, and parts of Africa. Yet in many regions, geographic variables and low rural population density make grid extension too costly a method to provide electricity access for every household. In order to fill the gaps, governments and development organizations have used off-grid solutions to provide rural households and villages with access to electricity. EF

Source: https://www.pv-magazine.com/2021/01/28/global-actions-delivering-electricity-for-rural-households-through-off-grid-renewable-energy/

TWO-THIRDS OF THE WORLD'S POPULATION THINK CLIMATE CHANGE IS AN EMERGENCY

The UN conducted the survey through ads in popular games like Angry Birds and Words With Friends.

More than two-thirds of the world's population believe climate change is an emergency and think four key policy areas can fix it: conservation, renewable power, climate-safe farming, and investing in green businesses and jobs.

That's according to the results of the Peoples' Climate Vote, a UN survey of 1.2 million people in 50 countries and 17 languages — a sample representing 56% of the world's population over the age of 14.

The most significant proportion of people who felt climate change is an emergency (74%) came from Belize, Fiji, and Trinidad and Tobago — countries the report identifies as 'Small Island Developing Nations,' or SIDS, that are particularly vulnerable to climate-change impacts like sea-level rise and drought.

People in high-income countries were close behind, with 72% saying climate change is an emergency. The percentages were smaller in middle-income countries (62%) and less-developed countries (58%).

Of the participants who said climate change was an emergency, 59% thought that everything possible should be done to solve the problem, while 20% approved a slower, more incremental response. Only one in ten thought the world is currently doing enough.

All participants were given 18 policy choices from six different areas — energy, economy, transportation, farms and food, protecting people, and nature — and were asked to choose which they'd like to see become law. EF

Source: https://www.worldoil.com/news/2021/1/28/biden-s-oil-and-gas-drilling-ban-may-end-offshore-gulf-of-mexico-work

BIDEN'S OIL AND GAS DRILLING BAN MAY END OFFSHORE GULF OF MEXICO WORK

President Joe Biden's temporary halt to drilling on federal lands leaves the vast majority of US crude production untouched, though it may be the death knell for the Gulf of Mexico's already dwindling output.

Should the halt become permanent, the US would stand to lose as much as 200,000 barrels a day of output by the end of this decade, according to Artem Abramov, Head of Shale Research for Rystad Energy. It's a small fraction of America's roughly 11 million barrels a day of production.

"The regions that would bear the brunt of this ban are the deep waters of the Gulf of Mexico since it's entirely owned by the government," said Elisabeth Murphy, ESAI Energy LLC upstream analyst for North America. It would mean a 40% output drop for the Gulf by 2030, she added. It's a corner of the US oil industry that has already seen investments shrink in recent years, with drillers focusing mostly on shale.

For the oil market, Biden's restrictions on the energy industry, a focus on fiscal spending and a probable lack of urgency in lifting sanctions on Iran may actually help support crude prices this year and the next, Goldman Sachs Group Inc. said.

Abramov doesn't see a short-term price impact from a drilling ban. The total spending in the Gulf of Mexico dropped by half in the four years through 2019, to less than $14 billion, Abramov said. Exploration spending went down by nearly 70% over the same period. EF

Source: https://www.worldoil.com/news/2021/1/28/biden-s-oil-and-gas-drilling-ban-may-end-offshore-gulf-of-mexico-work

CHINA SET TO ADD 140 GW RENEWABLE ENERGY CAPACITY IN 2021

China is expected to add 140 GW of renewable energy power generation this year as its electricity consumption continues to grow, according to forecasts from the China Electricity Council (CEC).

The total new capacity additions are expected at 180 GW, the CEC said in its forecasts.

Last year, China added 190.87 GW of new power generation capacity, of which 133 GW was renewable electricity in the form of hydropower, wind power, and solar power, the CEC said. New hydropower capacity additions totalled at 13.23 GW, wind power additions soared to 71.67 GW, and newly-installed solar capacity reached 48.2 GW in 2020, the data from the CEC showed.

China's renewable capacity additions in 2020 hit a record high, thanks to a surprising surge in wind capacity additions, data compiled by Bloomberg showed. The previous record for new capacity additions was set in 2017, with 83 GW installed that year.

The reported new wind and solar installations were so high that analysts said that China might have changed the way it calculates installed capacity by counting the entire capacity of partially installed projects at the end of last year.

This year, electricity demand in China is set to rise by 6–7% compared to last year, when the 7.51 trillion kWh of electricity used was up by 3.1% compared to 2019. EF

Source: https://oilprice.com/Latest-Energy-News/World-News/China-Set-To-Add-140-GW-Renewable-Energy-Capacity-In-2021.html

GLOBAL OIL DEMAND TO RISE, BOOSTED BY VACCINE DISTRIBUTION AND ECONOMY

The global oil demand is expected to rise by nearly 7% this year, boosted by quicker vaccine distribution and a better economic outlook, consultancy Wood Mackenzie said.

The total liquids demand is expected to average 96.7 million barrels per day (bpd) in 2021, 6.3 million bpd higher than last year when the COVID-19 pandemic caused an unprecedented oil demand shock.

'Our short-term forecast assumes vaccine distribution accelerating through 2021 and is underpinned by 5% expected growth in global GDP, according to our macroeconomic outlook, following the global economy's 5.4% contraction last year. The pace and strength of the global liquids demand recovery will depend on the pace of COVID-19 vaccine distribution and global economic recovery,' said the consultancy's vice president Ann-Louise Kittle.

In terms of supply, WoodMac expects oil output from the US Lower 48 states to reduce by about 500,000 bpd this year, moderating from last year's decline. EF

Source: https://energy.economictimes.indiatimes.com/news/oil-and-gas/global-oil-demand-to-rise-boosted-by-vaccine-distribution-and-economy/80491439

JAPAN ENERGY FIRM INPEX SETS 2050 NET-ZERO EMISSION GOAL

Inpex Corp, Japan's biggest oil and gas producer, said it is targeting net-zero carbon emissions by 2050 through the expansion of renewable and hydrogen energy as well as the use of carbon capture technology.

The move comes after Japanese Prime Minister Yoshihide Suga pledged to make Japan carbon-neutral by 2050 and with global oil and gas companies shifting away from fossil fuel to green energy.

Inpex plans to fully offset carbon emissions from its own oil and gas production and the energy it uses by 2050. It also aims to reduce its net carbon intensity by 30% by 2030 compared to the level in 2019.

Mitigation would rely on offsetting emissions, such as tree planting or carbon capture technology, which has not yet reached commercial scale.

At the same time, Inpex will expand its green energy assets, such as renewable energy and hydrogen.

It will spend 20–30 billion yen ($193–$289 million) a year on decarbonization, out of planned annual spending of 250–300 billion yen for the next five years. 'We want to become an innovator for energy transition,' Inpex President Takayuki Ueda told at a news conference. EF

Source: https://energy.economictimes.indiatimes.com/news/renewable/japan-energy-firm-inpex-sets-2050-net-zero-emission-goal/80497827

SOUTH AFRICA PLANS THREE RENEWABLE ENERGY ROUNDS OVER COMING YEAR

South Africa plans to launch three procurement rounds for 6800 MW of renewable energy over the next year, as well as a combined 5000 MW of new coal, gas and storage, a presentation by the governing African National Congress (ANC) showed.

Africa's most industrialized nation is heavily dependent on coal-fired power but plans to move towards a more diversified mix of generation sources.

It regularly suffers outages because of faults at ailing state-owned utility Eskom that have deterred investment in the country and hobbled economic growth.

President Cyril Ramaphosa has pledged to fix Eskom and add generation capacity, but progress has been slow.

The presentation, made at a three-day meeting of party officials and allies, showed the ANC planned to launch the first renewables round in January or February for 2600 MW of wind and solar, with another 2600 MW round in August and a third for 1600 MW in January or February 2022.

A procurement round for roughly 500 MW of energy storage would start around September, followed by rounds for 1500 MW of coal and 3000 MW of gas around December.

The coal is contentious as the country is a major polluter, and banks are increasingly reluctant to lend to coal projects because of environmental concerns. EF

Source: https://energy.economictimes.indiatimes.com/news/renewable/south-africa-plans-three-renewable-energy-rounds-over-coming-year/80460509

INVESTORS SEE GREEN RETURNS AS RENEWABLE ENERGY RISES

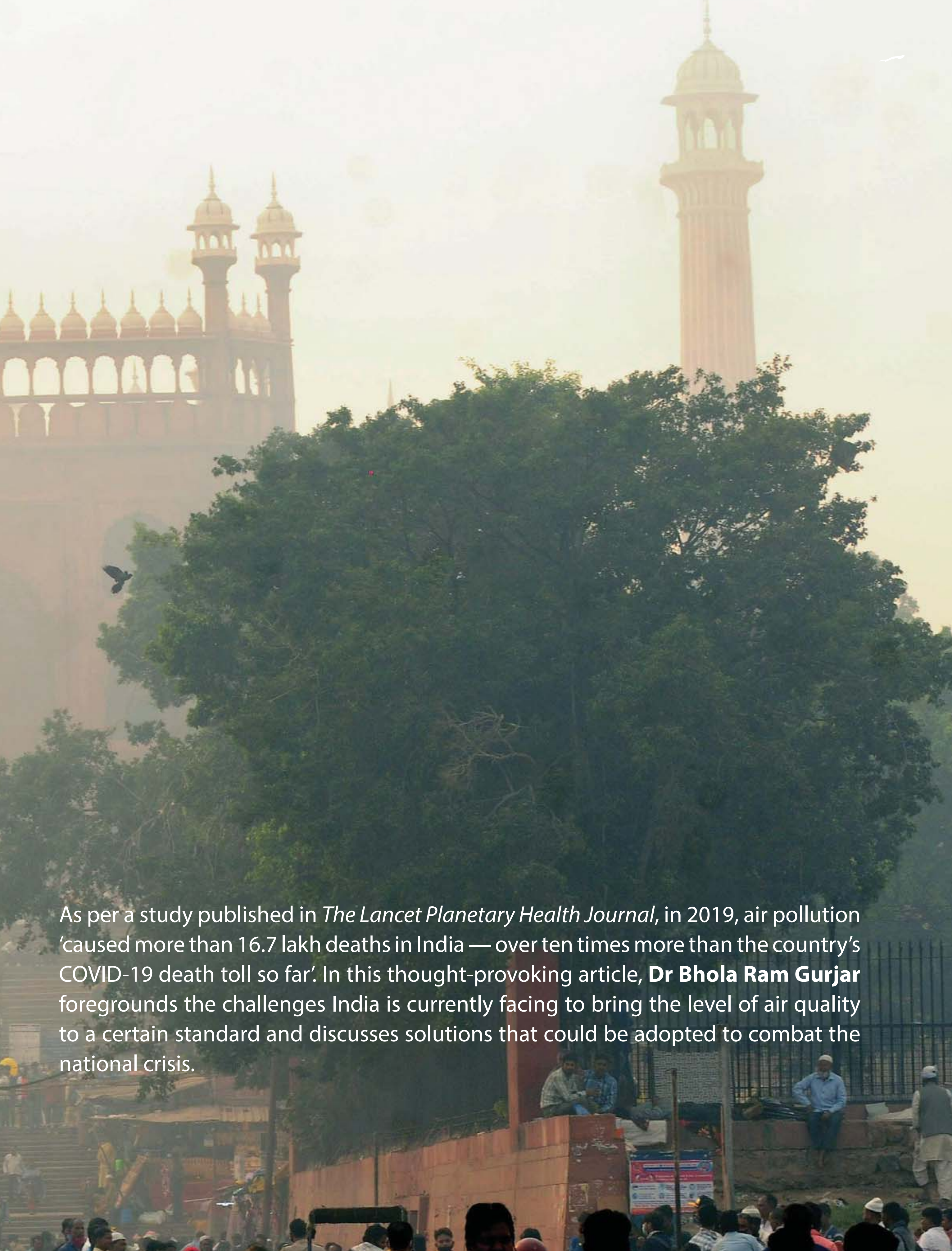
The future looks bright for solar and other renewable energy technology. FirstSolar, Enphase and SunPower are among the renewable energy stocks that are benefiting from a much friendlier administration in the White House, whose agenda includes tackling climate change and bolstering green energy. Their stocks soared last year, far outpacing the wider market's gains. On his first day in office, President Joe Biden rejoined the 2015 Paris Climate Agreement, revoked a permit for the Keystone XL oil pipeline, and halted oil and gas leasing in Alaska's Arctic National Wildlife Refuge.

'Part of what drove that move last year was the idea there would be a bit more policy support for these initiatives going forward,' said David Lebovitz, global market strategist at J P Morgan Asset Management. Renewable power sources, such as wind and solar now make up 12% of all energy generation, up from 4% in 2011. During the same period, energy generated from hydroelectric sources remained at 8%, while coal fell to 24% from 44%. EF

Source: https://energy.economictimes.indiatimes.com/news/renewable/investors-see-green-returns-as-renewable-energy-rises/80550698

AIR POLLUTION IN INDIA

MAJOR ISSUES AND CHALLENGES



As per a study published in *The Lancet Planetary Health Journal*, in 2019, air pollution 'caused more than 16.7 lakh deaths in India — over ten times more than the country's COVID-19 death toll so far'. In this thought-provoking article, **Dr Bhola Ram Gurjar** foregrounds the challenges India is currently facing to bring the level of air quality to a certain standard and discusses solutions that could be adopted to combat the national crisis.

Introduction

Rising urbanization, booming industrialization, and associated anthropogenic activities are the prime reasons that lead to air pollutant emissions and poor air quality. It is expected that by 2030, around 50% of the global population will be residing in urban areas (Gurjar, Butler, Lawrence, *et al*. 2008). More than 80% of population in urban areas is exposed to emissions that exceed the standards set by World Health Organization (WHO 2016). Air pollution is one of the key global health and environmental concerns (Nagpure, Gurjar, Kumar, *et al*. 2016) and has been ranked among the top five global risk factors of mortality by the Health Effects Institute (HEI 2019). According to HEI's report, particulate matter (PM) pollution was considered the third important cause of death in 2017 and this rate was found to be highest in India. Air pollution was considered to cause over 1.1 million premature deaths in 2017 in India (HEI 2019), of which 56% was due to exposure to outdoor $PM_{2.5}$ concentration and 44% was attributed to household air pollution. As per WHO (2016), one death out of nine in 2012 was attributed to air pollution, of which around three million deaths were solely due to outdoor air pollution.

The rising trends in population growth and the consequent effects on air quality are evident in the Indian scenario. For example, the megacities of Delhi, Mumbai, and Kolkata combined holds a population exceeding 46 million (Gurjar, Ravindra, and Nagpure 2016). Over the years, there has been a massive-scale expansion in industries, population density, anthropogenic activities, and the increased use of automobiles has degraded the air quality in India (Gurjar and Lelieveld 2005). In the last few decades, the greenhouse gas (GHG) emissions and other emissions resulting from anthropogenic activities have increased drastically (Gurjar and Nagpure 2016). As per WHO (2016) estimates, 10 out of the 20 most populated cities in the world are in India. Based on the concentrations of $PM_{2.5}$ emissions, India was ranked the fifth most polluted country by WHO (2019), in which 21 among the top 30 polluted cities were in India. The Indian cities, on average, exceeded the WHO threshold by an alarming 500%.

The consistent population growth has led to an excessive strain on the energy consumption, thereby affecting the environment and the air quality of the megacities (Gurjar and Nagpure 2016). Kumar, Khare, Harrison, *et al*. (2015) calculated the increase in the total energy demand for both mobile and point sources and inferred that in Delhi, the energy demand had grown by 57.16% from 2001 to 230,222 TJ in 2011. A subsequent rise in energy

consumption can be expected in the coming years, with no reliable sources available for monitoring the rate of energy consumption.

The continuous degradation of ambient air quality in the urban centres of India demands effective measures to curb air pollution. Though various policy measures are being introduced by the Government of India (GoI) to reduce the vehicular and industrial emissions, the extent to which these measures are implemented is questionable. The lack of infrastructural facilities, inadequacy of financial resources to implement advanced infrastructural innovations, difficulty in relocation of the industries from the urban centres even after mandatory court decisions, and above all, the behavioural patterns among people in accepting the green solutions are some of the crucial impediments on the road to environmental protection that our country seems to be struggling to overcome today.

Background information

There have been various efforts to study the air quality in Indian cities. The potential of the atmospheric carcinogenic emissions to put human health at risk has been studied by Gurjar, Mohan, and Sidhu (1996). Gurjar, Aardenne, Lelieveld, *et al*. (2004) framed a comprehensive emission inventory model to understand the emission trends in Delhi, India's capital, for a period from 1990 to 2000. A multi-pollutant index (MPI) rating scale was used by Gurjar, Butler, Lawrence, *et al.* (2008) to rank the megacities with respect to their ambient air quality. According to this study, out of 18 megacities considered worldwide, the Indian cities, namely, Delhi, Kolkata, and Mumbai were ranked 7, 9, and 11, respectively. Gurjar, Nagpure, Kumar, *et al*. (2010) evaluated the vehicular emissions in Kolkata between 2000 and 2010 and inferred that the older vehicles in the city contributed more to the pollution load and should be phased out. A Vehicular Air Pollution Inventory (VAPI) model was developed by Nagpure and Gurjar (2012) that could estimate the vehicular emissions from road traffic in Indian cities. Later, Gurjar, Nagpure, and Kumar (2015) evaluated the potential gaseous emissions from the agricultural wetlands of Delhi and inferred that man-made wetlands were responsible for 48–49% of the total GHG emissions in the capital city. The study intended to develop an emission inventory for agricultural activities to evaluate their contribution to pollution in Delhi.

Several policy measures have been taken by the Ministry of Environment, Forest and Climate Change (MoEFCC), GoI to tackle the adverse effects of air emissions in short and long terms. The government's decision to adopt compressed natural gas (CNG) as an alternative fuel to petrol and diesel, the odd-even measures introduced in Delhi, and the improvements in fuel and vehicle quality to lower emissions are some of the recent commendable steps towards curtailment of air pollution. Moreover, the increasing number of studies related to this field shows the importance of research on this subject. Several studies have assessed the trends of air pollutant emissions from different sources across several cities in India. However, there is an urgent need for a comprehensive review of the existing issues in the Indian scenario. More focus is needed on studying the impacts of these pollutant emissions on various forms, such as the ecosystem, biodiversity, buildings and materials, and primarily the health risks that people are vulnerable to due to breathing foul air.

A comprehensive review is done to understand the current scenario in the Indian context. The following section comprises a detailed review focusing on air pollution studies in India, the various sources, and the effects of the pollutants on the ecosystem, biodiversity, materials and buildings, and on human health, which are discussed in the later sections of this article. The various air quality standards followed by countries worldwide are included as well. The Discussion section of the article consists of the mitigation strategies adopted for emission control in India, the challenges posed by various sectors in the Indian scenario, and the research gaps that have been identified from the available literature. The key conclusions and a few recommendations form part of the last section.

Reviewing Literature

The present review is divided into three sub-sections: The first sub-section discusses the literature that focuses on air pollution in India on a national scale; the next segment highlights the various sources of air pollution and the effects of the pollutants. The major sources are categorized into seven sectors. Thereafter, the various effects of pollutant emissions are pointed out. The air quality standards adopted by various countries for controlling air pollution have been discussed in the later sections of this article.

Studies on air pollution in India

Though various studies have addressed the issue of air pollution and its impacts on urban Indian cities, most of these studies are limited to specific cities and do not necessarily give a complete picture of the situation. Some of the highlights of these studies are discussed in the following paragraphs.

Pandey and Venkataraman (2014) evaluated the effects of emissions from various modes of transport in India. Their study inferred that on-road transportation contributed over 97% of the estimated emissions in India, when compared to other modes of transport, such as railways, waterways, and airways.

Gurjar, Ravindra, and Nagpure (2016) did a comprehensive study on various anthropogenic emission sources in Indian megacities, such as Delhi, Mumbai, and Kolkata. The global impact of urban pollution is also discussed in their study. Upadhyay, Dey, Chowdhury, *et al*. (2018) evaluated the major anthropogenic sources of $PM_{2.5}$ and the potential benefits to human health, if sufficient control measures are applied to curb emissions. A recent study by Jat, Gurjar, and Lowe (2021) examined the extent of pollution during the winter months in India. The study used a WRF-Chem model, that is, Weather Research and Forecasting (WRF) coupled with chemistry, to evaluate the concentrations of pollutants, such as $PM_{2.5}$, oxides of sulphur (SO_X), oxides of nitrogen (NO_X), black and organic carbons, and non-methane volatile organic carbons (NMVOCs) that were identified for the winter months. The various sources of air pollution can be classified into seven major sources and the consequent effects are discussed in this article.

Sources of air pollution

The various sources of air pollution are classified into seven major sectors, which include transportation, industries, agriculture, power, waste treatment, biomass burning, residential, construction, and demolition waste.

Vehicular/Transport Emissions

The transportation sector is the main contributor of air pollutants in almost every city, but this phenomenon is worse in urban cities (Gurjar, Aardenne, Lelieveld, *et al*. 2004). This could be due to the increased number of vehicles when compared to the existing infrastructural facilities, e.g., roads, fuel stations, and the number of passenger terminals provided for public transport. In India, the amount of motorized transport increased from 0.3 million in 1951 to 159.5 million in 2012 (Gurjar, Ravindra, and Nagpure 2016). A significant share of vehicular emissions comes from urban cities, such as Delhi, Mumbai, Bengaluru, and Kolkata. Carbon monoxide (CO), NO_X, and NMVOCs are the major pollutants (>80%) from vehicular emissions (Gurjar, Aardenne, Lelieveld, *et al*. 2004). Other trace emissions include methane (CH_4), carbon dioxide (CO_2), oxides of sulphur (SO_x), and total suspended particles (TSPs).

In an urban environment, road traffic emissions are one of the prime contributors of air pollution. Road dust is a major contributor to PM emissions in Delhi (37%), Mumbai (30%), and Kolkata (61%). Road transport is the largest source of $PM_{2.5}$ in Bengaluru (41%), Chennai (34%), Surat (42%), and Indore (47%) (Nagpure, Gurjar, Kumar, *et al*. 2016). In the Indian context, some of the essential factors of high traffic emissions include extreme lack of exhaust measures, the highly heterogeneous nature of vehicles, and poor quality of fuel.

Industrial Processes

Over the last few decades, India has witnessed large-scale industrialization. This has degraded the air quality in most urban cities. The Central Pollution

Control Board (CPCB) has categorized the polluting industries into 17 types, which fall under the small and medium scale (Gurjar, Ravindra, and Nagpure 2016). Out of these categories, seven have been marked as 'critical' industries that include iron and steel, sugar, paper, cement, fertilizer, copper, and aluminium. The major pollutants comprise SPM, SO_x, NO_x, and CO_2 emissions.

The small-scale industries, which are not regulated like the major industries, use several energy sources apart from the primary source of state-provided electricity. Some of these fuels include the use of biomass, plastic, and crude oil. These energy sources are neglected in the current emission inventory studies. In Delhi, after the intervention of the judiciary in 2000, many industries were relocated from urban areas to adjacent rural areas (Nagpure, Gurjar, Kumar, *et al*. 2016). In Delhi, a major fraction of the pollution load comes from the brick manufacturing industries, which are situated at the outskirts of the city. Rajkot (42%) and Pune (30%) are the two cities where industries play a prominent role in contributing to the highest amount of $PM_{2.5}$ (Nagpure, Gurjar, Kumar, *et al*. 2016).

Agriculture

Agricultural activities produce emissions, which have the potential to pollute the environment. Ammonia (NH_3) and nitrous oxide (N_2O) are the key pollutants released from agricultural activities. The other agricultural emissions include methane emissions from enteric fermentation processes, nitrogen excretions from animal manure, such as CH_4, N_2O, and NH_3, methane emissions from wetlands, and nitrogen emissions from agricultural soils (N_2O, NO_x, and NH_3) due to the addition of fertilizers and other residues to the soil (Gurjar, Aardenne, Lelieveld, *et al*. 2004). Agricultural processes, such as 'slash and burn' are prime reasons for photochemical smog resulting from the smoke generated during the process. Crop residue burning is another process that results in toxic pollutant emissions. This is how neighbouring cities of Delhi contribute to the agricultural pollution load. This is an example of how external sources contribute to the menace of air pollution in the city (Nagpure, Gurjar, Kumar, *et al*. 2016).

Power Plants

The contribution of power plants to air emissions in India is both immense and worrisome. The thermal power plants manufacture around 74% of the total power generated in India (Gurjar, Ravindra, and Nagpure 2016). According to The Energy and Resources Institute (TERI), the emissions of SO_2, NO_x, and PM increased over 50 times from 1947 to 1997. Thermal power plants are the main sources of SO_2 and TSP emissions (Gurjar, Aardenne, Lelieveld, *et al*. 2004), thereby contributing significantly to the emission inventories. In Delhi, power plants contributed 68% of SO_2 emissions

and 80% of PM_{10} concentrations over a period from 1990 to 2000 (Gurjar, Aardenne, Lelieveld, *et al*. 2004). Thus, there is an urgent need to adopt alternative power sources including green and renewable resources for meeting the energy requirements.

Waste Treatment and Biomass Burning

In India, about 80% of municipal solid waste (MSW) is still discarded into open dumping yards and landfills, which leads to various GHG emissions apart from the issues of foul odour and poor water quality at nearby localities. The lack of proper treatment of MSW and biomass burning has been responsible in causing air pollution in urban cities. In Delhi alone, around 5300 tonne of PM_{10} and 7550 tonne of $PM_{2.5}$ are generated every year from the burning of garbage and other MSW (Nagpure, Gurjar, Kumar, *et al*. 2016).

Methane (CH_4) is the major pollutant released from landfills and wastewater treatment plants. Ammonia (NH_3) is another by-product, which is released from the composting process. The open burning of wastes, including plastic, produces toxic and carcinogenic emissions, which are a grave concern (Gurjar, Aardenne, Lelieveld, *et al*. 2004).

Domestic Sector

Households are identified as a major contributor of air pollution in India. The emissions from fossil fuel burning, stoves or generators come under this sector, thereby affecting the overall air quality. Domestic energy is powered by fuels, such as cooking gas, kerosene, wood, crop wastes or cow dung cakes (Gurjar, Aardenne, Lelieveld, *et al*. 2004).

Though liquefied petroleum gas (LPG) is used as an alternative source of cooking fuel in most urban cities, the major share of India's rural population continues to rely on cow dung cakes, biomass, charcoal or wood as the primary fuel for cooking and other energy purposes and demands. These lead to severe implications on air quality, especially the indoor air quality, which could directly affect human health. According to HEI (2019), about 60% of India's population was exposed to household pollution in 2017.

Construction and Demolition Waste

Another major source of air pollution in India is waste, which is an outcome of construction and demolition activities. Guttikunda and Goel (2013) inferred from their study that around 10,750 tonne of construction waste is generated in Delhi every year. Even after the construction phase, these buildings have the potential to be the major contributors of GHG emissions. Nowadays, the increasing interest in green building technologies and the application of green infrastructure and materials during construction could tackle this issue to a large extent, thereby preserving our biodiversity and maintaining cleaner air quality.

Impacts

On the Ecosystem

The terrestrial ecosystem is widely affected by ground air pollution. The ill-effects include respiratory and pulmonary disorders in animals and humans (Stevens, Bell, Brimblecombe, *et al*. 2020). The effects on the marine ecosystem include acidification of lakes, eutrophication, and mercury accumulation in aquatic food (Lovett, Tear, Evers, *et al*. 2009). These processes may indirectly affect the health of the living beings. Similarly, soil acidification is another phenomenon that is common in forest ecosystems as a result of long-term pollutant accumulation. The deposition of sulphate, nitrate, and ammonium is the main reason for soil acidification. Bignal, Ashmore, Headley, *et al*. (2007) inferred that traces of heavy metals were found in soil samples in areas adjacent to roadways due to cumulative deposition of pollutants. Soil pollution indirectly affects the ecosystems of plants and animals that are reliant on soil for nutritional intake. Nitrogen deposition in wet and dry forms on vegetation and soil surfaces can occur from vehicular and agricultural activities (Driscoll, Whital, Aber, *et al*. 2003). The results of these activities on the ecosystem have long-term environmental implications, such as global warming and climate change (Lovett, Tear, Evers, *et al*. 2009). A recent study by Stevens, Bell, Brimblecombe, *et al*. (2020) discussed four threats to the global ecosystem from pollution, namely, the effects of primary pollutants, such as SO_2 and NO_2 in a gaseous state, the consequences of wet and dry depositions from SO_x and NO_x emissions, effects of eutrophication by nitrogen deposition, and the impact of ground-level ozone concentrations.

On Biodiversity

The ill-effects of air pollutant emissions could impact the biological diversity. Though it is evident that air pollution contributes to ground-level emissions, limited studies have been conducted to address the effects on our biodiversity. Acid rain, which is a result of air pollution, is caused by the oxidation and wet deposition of SO_2 and NO_x emissions in the atmosphere (Rao, Rajasekhar, and Rao 2016). Therefore, acid rain can have harmful effects on our biodiversity.

Nitrogen deposition on plants is a serious outcome of air pollution (Lovett, Tear, Evers, *et al*. 2009). Bignal, Ashmore, Headley, *et al*. (2007) investigated three sites adjacent to roadways in the UK to study the impact of pollution on the health of oak and beech trees. Several damages, such as increased defoliation, discolouration, poorer crown condition, and increased pest attacks were observed during the study. It was inferred that significant effects on plants could be found within 100 m from the roadways due to NO_2 emissions.

Ozone is another pollutant which is toxic to both plants and animals. Ozone results in reduced photosynthesis and slower growth in plants. In animals and humans, ozone can affect the lung tissues causing respiratory conditions, such as asthma (Stevens, Bell, Brimblecombe, *et al*. 2020). The effect of ground-level ozone on the crop yield was studied by Sharma, Ojha, Pozzer, *et al*. (2019), where the researchers evaluated the pan India losses in crop

yield and financial problems incurred during 2014–15 due to the ozone. Poor air quality and exposure to anthropogenic pollution had a negative effect on the health of animals as well (Isaksson 2010).

Moreover, the reproductive performance of animals also gets affected due to increased oxidative stress (Isaksson 2010), thereby impacting the population of any species. This may not prove healthy especially for the endangered species. Considering the rapid urbanization, more focus should be given to this study area in the future.

On Materials and Buildings

SO_X and NO_X emissions can harm the flora, fauna, material surfaces, and even damage buildings and structures. The negative effects may be in the form of discolouration, loss of material, structural failing, and soiling. This can reduce the service life of buildings and can severely damage historical monuments and structures. One such example is India's white-marble Taj Mahal, which is turning yellow as a result of being exposed to SO_X emissions from industries and acid rain. Another historical monument in India is Hyderabad's Charminar, which is turning black due to it being situated in a highly polluted area (Rao, Rajasekhar, and Rao 2016). The erosion of such heritage zones poses a grave concern.

On Human Health

People residing in areas exposed to poor air quality and high pollution levels are prone to hazardous health risks. Such deleterious implications can lead to both minor respiratory disorders and fatal diseases (Gurjar, Jain, Sharma, *et al.* 2010). Molina, Molina, Slott, *et al*. (2004) inferred that the studies conducted worldwide had similar conclusions regarding the impact of pollutants on humans. Emissions such as PM, O_3, SO_X, and NO_X have the potential to damage the cardiovascular and respiratory systems of humans. In recent years, the study of human health risks as an outcome of poor air quality has been of prime focus. Gurjar, Jain, Sharma, *et al*. (2010) evaluated the health risks people in urban areas were prone to due to air pollution in terms of mortality and morbidity. However, there are several limitations associated with the application of this health risk assessment methodology, which must be addressed in the future studies. The HEI (2019) assessed the impact of $PM_{2.5}$ concentrations in India and concluded that around 1.1 million deaths in 2015 were a result of being exposed to air pollution. Upadhyay, Dey, Chowdhury, *et al*. (2018) inferred that a total of 92,380 lives would have been saved if control measures were applied in the transport, residential, industries, and energy sectors, which are some of the prominent contributors of air pollution.

Gurjar, Ravindra, and Nagpure (2016) concluded in their study that around 30% of Delhi's population complained of respiratory issues due to air pollution in the selected year. Another study by Nagpure, Gurjar, and Martel (2014) evaluated that the mortality rate due to air pollution had doubled between 1990 and 2010 in the capital city. According to Gurjar, Mohan, and Sidhu (1996), the number of premature deaths in Mumbai due to air pollution was recorded at 2800 in 1995, which later increased exponentially to 10,800 in 2010 (Gurjar, Ravindra, and Nagpure 2016). In Kolkata, the premature deaths were estimated to be around 13,500 in 2010. Similarly, Delhi reported about 18,600 premature deaths per year (Lelieveld, Evans, Fnais, *et al*. 2015).

Air quality standards

The acceptable threshold level of air pollution in terms of its potential impacts on health and environment is defined as the ambient air quality standards. These standards are adopted and enforced by a regulatory body or authority. Every standard should have a standalone definition and its threshold values should be justified appropriately (Molina, Molina, Slott, *et al*. 2004). The air quality standards may vary for different countries due to various factors, such as economic conditions, technological know-how, and indigenous air pollution-related epidemiological studies. These are known as the National Ambient Air Quality Standards (NAAQS) in countries, such as India, China, and the US. However, in Canada and the European countries, the limit values are predefined (WHO 2005). Table 1 gives a representation of the different standards adopted by different countries (WHO 2005).

For India, the NAAQS developed by the Central Pollution Control Board (CPCB 2009) are given in Table 2.

Discussion

Mitigation strategies for emission control in India

In India, the central and state governments have taken several steps to control air pollution and improve the ambient air quality. Various initiatives, such as the use of compressed natural gas (CNG) as an alternative fuel, the odd-even measures implemented in Delhi, the introduction of Bharat Stage VI vehicle and fuel standards, the Pradhan Mantri Ujjwala Yojana (PMUY), and the National Clean Air Programme (NCAP) are some examples in this endeavour. The CPCB ensures the monitoring and regulation of the NAAQS in the cities, towns, and industrial areas with the cooperation of the respective state pollution control boards (SPCBs). Under these plans, various sector-wise measures have been implemented in the urban cities of India. For the transport sector, for instance, some of these measures include the use of electric vehicles (EVs) as a mode of public transportation, development of cycling infrastructure, use of bioethanol as fuel, and the construction of multi-level car parking facilities and peripherals to tackle congestion. Within the industrial sector, some of the measures undertaken comprise the implementation of zig-zag technology for the stack emissions from brick kilns, online monitoring of discharges through the Online Continuous Emission Monitoring Systems (OCEMS), and the installation of web cameras in highly polluting industries. To tackle the problem of open burning of garbage and household wastes, door-to-door collection of segregated wastes has been introduced and several compost pits have been established in urban cities. In the residential sector, the government has set a target of achieving 100% usage of LPG for cooking purposes. Further, to control the concentrations of particulate matter (PM) and dust particles, various steps, such as the green buffer around cities, maintenance of 33% green cover around urban areas, installation of water fountains across the cities have been taken over the years (Ganguly, Kurinji,

Table 1: Air quality standards of various countries worldwide (WHO 2005)

Pollutant	Time	WHO	European Union	United States	California	Japan	Brazil	Mexico	South Africa	India (i1/ i2/i3)[d]	China (I/II/ III)[d]
Sulphur dioxide (μg/m^3)	1 year			78			80	78	50	15/60/80	20/60/100
	24 h	20	125	366	105[c]	105	365	341	125	30/80/120	50/150/250
	1 h		350		655	262					150/500/700
	10 min	500							500		
Nitrogen dioxide (μg/m^3)	1 year	40	40	100			100		94	15/60/80	40/40/80
	24 h					113			188	30/80/120	80/80/120
	1 h	200	200		470[c]		320	395	376		120/120/240
PM_{10} (μg/m^3)	1 year	20	40	50	20		50	50	60	50/60/120	40/100/150
	24 h	50[a]	50[b]	150	50	100	150	120	180		50/150/250
$PM_{2.5}$ (μg/m^3)	1 year	10		15	12			15			
	24 h	25[a]		65	65			65			
Ozone (μg/m^3)	8 h	100	120	157	137			157[c]			
	1 h				180[c]	118[c]	160	216	235		120/160/200
Carbon monoxide (μg/m^3)	1 h	30	-	40	23	11	40	-	30	4	10
	8 h	10	10	10	10	23	10	11	10	2	-

[a]: Not to exceed more than 3 days per year; [b]: Not to exceed more than 35 days per year ; [c]: Photochemical oxidants;

[d]: i_1: Sensitive population; i_2: Residential population; i_3: Industrial population.

Class I: tourist, historical, and conservation areas; Class II: residential urban and rural areas; Class III: industrial and heavy traffic areas

Table 2: CPCB standards for India (CPCB 2009)

Pollutant	Weighted average	CPCB standards	
		Concentrations in ambient air	
		Industrial, residential, rural, and other areas	Ecologically sensitive areas
Sulphur dioxide (μg/m^3)	Annual avg*	50.0	20.0
	24 hours**	80.0	80.0
Oxides of nitrogen as NO_2 (μg/m^3)	Annual avg*	40.0	30.0
	24 hours**	80.0	80.0
PM_{10} (μg/m^3)	Annual avg*	60.0	60.0
	24 hours**	100.0	100.0
$PM_{2.5}$ (μg/m^3)	Annual avg*	40.0	40.0
	24 hours**	60.0	60.0
Ozone (μg/m^3)	Annual avg*	100.0	100.0
	24 hours**	180.0	180.0
Carbon monoxide (μg/m^3)	8 hours**	2.0	2.0
	1 hour**	4.0	4.0

*Annual arithmetic mean of minimum 104 measurements in a year taken twice a week, 24 hourly at uniform interval;

**24 hourly/8 hourly or 1 hourly monitored values as applicable.

and Guttikunda 2020; Sharma, Mallik, Wilson, *et al.* 2018; Sharma, Rehman, Ramanathan, *et al*. 2016).

Other potential mitigation strategies

Air quality management in megacities is a four-stage process that involves problem identification, formulation of policies, their implementation, and control strategies (Molina, Molina, Slott, *et al*. 2004). The various management tools to ensure emission control and attainment of air quality standards include, air quality modelling, emission inventories, monitoring the concentration of pollutants, and source apportionment studies. These methodologies involve a complex analysis of extensive data sets for the effective management of air quality standards. Due to the lack of transparency and unavailability of data, uncertainties are introduced in the estimation of atmospheric concentrations. Minimizing these uncertainties with our scientific understanding is one of the major challenges towards addressing the issues related to air quality (Gurjar and Ojha 2016).

The increase in private vehicles is the prime contributor of air pollution in Indian cities (Molina, Molina, Slott, *et al*. 2004). Therefore, there should be some policy norms that would set a certain limit to private vehicle ownership. Second, the age of vehicles degrades the air quality and such ageing vehicles should be phased out over a period of 10 years or so. Threshold limits should be imposed on emissions from all sources, primarily vehicles and industries, and the violators should be penalized.

Infrastructural modifications to limit traffic in polluted areas, development of efficient public transport facilities, such as the Bus Rapid Transit (BRT) system or other public transit systems, improved facilities for walking, biking, and public transport, and relocation of point sources out of urban centres could help curb emissions significantly.

Technology modifications, such as the introduction of hybrid vehicles or fuel cell vehicles or fuel modifications, such as ultra-low sulphur fuels, or alternative fuels like CNG, methanol in Brazil or hydrogen fuel in Japan (Molina, Molina, Slott, *et al*. 2004) could reduce air pollution levels. In recent years, owing to the reduced sulphur fractions in the fuels, decreasing trends in SO_x have been observed (Gurjar, Ravindra, and Nagpure 2016) and such a development could further control air pollutant emissions.

Control points should be identified and prioritized in urban areas that would help reduce pollutant emissions significantly. The development of sustainability matrices could help monitor and regulate the emissions. Emission trading, also known as cap and trade, is another control strategy that could be applied in urban cities, a practice already prevalent in the US, where economic incentives are offered to reduce the pollutant concentrations (Molina, Molina, Slott, *et al*. 2004). Congestion pricing, as followed in London, where a driver is charged each time they enter the peak zones of a city could be another avenue to explore within the Indian context as well. However, such a strategy would require strong public awareness and support to become successful.

A combination of effective policies, technologies, and land-use planning could help develop a control strategy for emission control. Stricter emission standards, cleaner fuels, advancements in engines, manufacture of cleaner and green vehicles, and post-emission treatment technologies could curtail pollution levels in urban areas to a great extent. Concrete policy measures could be imposed that would further limit the exposure of people to pollutant emissions. Relocation of industries to the outskirts of the city is a fine example (Molina, Molina, Slott, *et al*. 2004) to consider in this regard.

Limiting the emissions from combustion sources could curb pollution. One such example was the use of CNG-fuelled vehicles in Delhi from 2001 to 2006, which had reduced the emissions of PM, CO, NO_x, and SO_2 levels considerably.

Challenges in the Indian scenario

Air pollution poses serious risks to human health, economic assets, and the overall environment (Gurjar, Butler, Lawrence, *et al*. 2008). In the current Indian scenario, urban cities are mostly polluted by vehicular emissions, industries, and thermal power plants (Gurjar, Ravindra, and Nagpure 2016). Nagpure, Gurjar, Kumar, *et al*. (2016) studied and inferred that vehicular emission is the major contributor of increasing pollution in Delhi. Gurjar, Aardenne, Lelieveld, *et al*. (2004) had earlier indicated that there is a lack of India-specific emission factors for several air pollutants, which could be a major concern towards developing realistic emission inventories for Indian cities. Further, Nagpure, Sharma, and Gurjar (2013) observed that neither ratio nor realistic numbers are available for two-stroke and four-stroke two-wheelers or for light and heavy commercial vehicles. Similarly, for evaluating the utilization factors for vehicles, which indicate how frequently a vehicle is being used in a given period of time, the escalating travel demand in the country is not considered. This results in uncertainties in the estimated emissions of air pollutants.

Over the last decades, industrialization has boomed and India ranks among the top 10 industrialized countries, globally (Gurjar, Ravindra, and Nagpure 2016). Guttikunda and Calori (2013) studied and listed the improvements that could be made in the emission estimates from Indian cities by monitoring capacity, regular documentation of pollutant sources, fuel usage patterns, and receptor modelling studies.

In India, the methodologies associated with emission estimation from biomass burning have certain limitations. For instance, Gurjar, Aardenne, Lelieveld, *et al*. (2004) exempted several sources from estimation due to non-reliable data sets pertaining to biogenic emissions. Guttikunda and Calori (2013) estimated that the burning of roadside garbage and the landfill fires have an uncertainty of ±50%. The study also estimated that the data on fuel used for cooking and heating in the domestic sector have an uncertainty of ±25%. This uncertainty of fuel usage data for the *in-situ* generators used in large institutions, hospitals, and hotels was ±30% for the year 2010.

As discussed in the previous section, the implementation of strict policy measures and the use of advanced technologies and infrastructure could tackle the problem of air pollution to a great extent. Though stringent measures and policies are being adopted to curb vehicular and stack emissions, most Indian cities lack the technological and infrastructural wherewithal. In a developing country like India, financial constraints faced during the timely planning and implementation of advanced urban infrastructural changes could pose a serious hurdle to air pollution mitigation strategies (Gurjar and Nagpure 2016).

Irresponsible human behaviour is another major issue that makes the existing challenges difficult to overcome. The lack of public interest in the emission control measures and inefficient traffic management system are major hurdles to realizing the goal of clean air. The lack of public interest in certain measures taken by the government could result in significant losses of investments in infrastructural facilities (Gurjar and Nagpure 2016).

Research Gaps

Several studies focus on air pollutant emissions in Indian urban cities and industrial clusters. However, India-specific emission factors are either unavailable or difficult to interpret for various sources in most cases (Gurjar, Aardenne, Lelieveld, *et al*. 2004). Also, there is a lack of adequate research on the extent of pollution concentrations in medium-scale cities, which are likely to expand in the near future. For a country like India, nearly 68% of population (Chandramouli 2014) resides in rural areas and is dependent on domestic cooking fuels, such as wood and cow dung cakes. Moreover, practices such as biomass and crop burning create additional point sources of air pollution. This further gives an opportunity to evaluate the strategies to reduce emissions from such sources.

A recent national-level emission inventory for India at fine resolution is not available in the public domain and research on policy measures using regional air quality modelling mostly depends on global emissions inventories, which are at coarser resolutions. For Indian cities with limited or no air quality monitoring infrastructure, researchers and authorities are dependent on the data available through secondary sources. However, these data sets are non-reliable and the accuracy of such data is also uncertain (Gurjar, Jain, Sharma, *et al*. 2010)Risk of Mortality/Morbidity due to Air Pollution (Ri-MAP.

With the increasing rate of industrialization, Gurjar, Aardenne, Lelieveld, *et al.* (2004) discussed the lack of factual data on industrial production and fuel statistics for Indian cities.

The urban population in India is anticipated to increase exponentially and the number of cities will grow as well. This suggests that the MSW generation will also increase, which must be managed efficiently. However, in India, proper MSW management and treatment techniques need to be implemented other than the current practices of landfilling and composting. Moreover, data sets on detailed MSW statistics regarding the amount of wastes collected, segregated, stored, and treated were absent (Gurjar, Aardenne, Lelieveld, *et al*. 2004).

Over the years, indoor air quality (IAP) has become an area of scientific interest and researchers worldwide are studying the threats IAP poses to human life. However, in the Indian context, there are limited studies which have stressed on the impact of indoor air pollution concentrations.

Conclusion and Recommendations

An effective and successful emission control strategy should be holistic (Molina, Molina, Slott, *et al*. 2004). It must be a combination of successfully applied scientific ideas and technological advancements; should support the economy and be supported by the public. Various steps taken by the Government of India to control air pollution in Indian cities have been highlighted in the previous sections. These measures have the potential to tackle pollution only if implemented successfully in the coming years.

India is facing serious issues of poor air quality in many urban areas. Apart from the much discussed megacities, like Delhi, various reports suggest that several medium-scale cities are equally at the brunt of filthy air. The ill-effects could impact human health in a negative way, also affecting the biodiversity, other life forms, heritage, cultural buildings and even climate in the longer term. It is about time that the government comes forward to support cities for the development of infrastructure and treatment facilities.

The control strategies adopted to tackle air pollution must be sustainable in nature. For example, the urban air pollution control strategy should depend mainly on sustainable means of public transportation modes, such as BRTs, metros, trams, cycle lanes and well-connected pedestrian facilities, which can further ensure minimum use of private vehicles, thereby reducing air pollution levels. People must be motivated to opt for an efficient public transport system instead of relying on private vehicles. Similarly, some strict laws must be enforced, such as emission trading and congestion pricing, which have the potential to reduce emissions drastically. Apart from these, the use of alternate fuels and e-cars, e-bikes and hybrid vehicle types must be promoted by the government. All these measures could reduce city emissions significantly.

The residents of rural areas are seldom aware of the harmful effects of air-borne pollutants and their consequence to human health. Public awareness programmes should be initiated by the government in every city, both rural and urban, highlighting the importance of managing air pollution at source and the various control measures that could be adopted to reduce pollutant emissions. Such initiatives could significantly reduce the activities, such as open burning of wastes, crop burning, use of biomass as a fuel for cooking and burning of plastic and rubber materials during winters. A holistic approach incorporating all of the mentioned measures could be beneficial to attain cleaner air quality in Indian cities and guarantee a healthier place to inhabit.

In this context, the NCAP launched by the Government of India appears to be a timely intervention. It is based on a long-term, time-bound, national-level strategy to tackle air pollution in a comprehensive manner with targets to achieve 20–30% reduction in particulate matter (PM) concentrations by 2024, keeping 2017 as the base year for the comparison of concentration levels. A total of 122 non-attainment cities have been identified across the country based on the 'Air Quality' data obtained for the period 2014–2018 under NCAP. The city-specific action plans are being prepared which, inter-alia, include measures for strengthening the monitoring network, developing emission inventories, carrying out source apportionment studies, reducing vehicular/industrial emissions, and generating public awareness, among others. It is expected that such initiatives by the central and state governments along with the participation of local bodies and other stakeholders comprising academia, research institutions, and public interest groups would result in ensuring better air quality in India.

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EMISSIONS CONTROL IN THERMAL POWER STATIONS

A Long Road to Cross

In this article, **Raghav Pachouri** brings out the current situation and the challenges confronting us regarding emissions control in thermal power stations (TPSs) in India. While analysing the impact of the power sector on air pollution levels, he highlights the current status of compliance in India (especially Delhi-NCR and critically polluted areas) till June 2020 after revised emission norms for TPSs came into effect on December 7, 2015. He also dwells on the major roadblocks in the timely compliance of emission norms and also offers a few solutions.

Out of the 15 most polluted cities with regard to $PM_{2.5}$ level in the world, 11 cities are in India. Some of these cities mostly along the River Ganga belt are Delhi, Kanpur, Faridabad, Varanasi, Agra, Lucknow, and Patna. Ambient air pollution is widely known to have severe negative impacts on human health. When emitted into the atmosphere, oxides of sulphur (SO_x), oxides of nitrogen (NO_x), and mercury undergo chemical reactions to form compounds that can travel long distances. These fine particle compounds contribute to death and serious respiratory illnesses (e.g., asthma, chronic bronchitis, and so on). Exposure to particulate matter (PM) leads to various diseases that have short- and long-term health effects. The Indian Council of Medical Research (ICMR) reported India's ambient air pollution-related premature mortality at 0.67 million in 2017. A recent assessment at The Energy and Resources Institute (TERI) on the health impacts of air pollution reveals that total mortality due to ambient air pollution could be 0.76 million in 2020.

> Short-term effects include severity of asthma and lower respiratory infections (LRIs) in children and adults. Long-term exposure leads to increased likelihood of suffering chronic illnesses, including chronic obstructive pulmonary disease (COPD), ischemic heart disease (IHD), lung cancer (LC), and systemic oxidative stress, among others.

Impact of Power Sector on Air Pollution

In India, of the total environmental pollution in 2016, the power sector reportedly accounted for 51% of SO_2, 43% of carbon dioxide (CO_2), 20% of NO_x, and 7% of $PM_{2.5}$ emissions.[1] The coal-fired power generation is considered one of the major sources of environmental pollution in India. Coal-based power plants have dominated the power supply mix since the 1980s. As of March 31, 2020, around 55% of India's total installed capacity, that is, 370 GW came from coal-based power stations and these accounted for 71% of the total electricity generation during the same financial year. Indian coal has a lower sulphur content (0.3–0.5%) as compared to imported coal (0.6–2%), which is why initially, not many norms were in place for SO_x curtailment from thermal power stations (TPSs).

Current Norms in Place and Deadline for Implementation

The Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India (GoI), revised the emission norms for TPSs on December 7, 2015, requiring the implementation of the emission control systems (ECSs) within two years from the date of notification.[2] The new limits for PM, SO_x, and NO_x were defined as per Figure 1. Mercury (Hg) emission from power plants was limited to 0.03 mg/Nm^3.

The deadline for ECS implementation, December 2017, had to be pushed to December 2019 for all TPSs situated in the national capital region (NCR) and December 2022 for the rest of the TPSs in the country in view of the sheer volume of work, implementation issues and challenges, new admission of

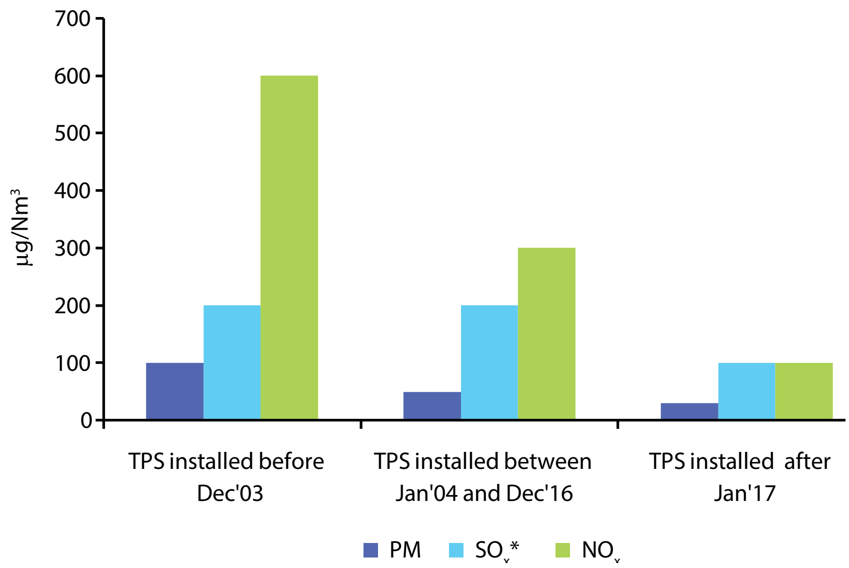

Figure 1: Emission control norms for coal-fired power plants in India

Source: MoEFCC

*Note: *for TPS more than 500 MW*

[1] Pachouri, R. and A. K. Saxena. 2020. Emissions Control in Thermal Power Stations – Issues, Challenges, and the Way Forward. New Delhi: TERI. Details available at https://www.teriin.org/sites/default/files/2020-02/emissions-control-thermal-power.pdf

[2] MoEFCC 2015. Notification for new environmental regulations – 7th December, 2015. Details available at http://www.indiaenvironmentportal.org.in/files/file/Moef%20notification%20-%20gazette.pdf

chimney height and lining guidelines, and the critical need to maintain the supply of electricity.

Current Status of Compliance in India

The Central Electricity Authority (CEA) prepared a detailed plan in consultation with the utilities that include flue gas desulphurizers (FGDs) and electrostatic precipitator (ESP) implementation in a phased manner to obey the target date. As far as the PM emission norm compliance is concerned, out of 66 GW TPS capacity identified for ESP implementation/upgradation, an implementation plan for 65 GW (99%) is already in place.[3]

Progress and plans in regard to compliance of SO_x emission norms, however, remain a matter of serious concern. As of now, only 1% of the total planned capacity, that is, 170 GW complies with the latest SO_x emission norms. Out of the planned installation of FGDs, bids have been awarded for only 57 GW (34%) thermal capacity, of which 45 GW capacity is in the central sector. While there seems to be some action on the part of central sector power plants, the ones in private and state sectors are lagging behind significantly. The situation in the state sector is alarming where FGD is to be installed in units with a total capacity of 53 GW, but only 1 GW capacity had been awarded up to June 2020. Figure 2 shows sector-wise quarterly progress of FGD bids award.

For NO_x emission control, a few pilot tests by combustion modification were carried out in NTPC units. Out of 7 monitored units, only 5 units were found in compliance with the NO_x emission standards of 300 mg/Nm^3 at full load only. So, it was agreed in-principle to seek for revision of the NO_x norms from 300 mg/Nm^3 to 450 mg/Nm^3 for thermal power plants installed between January 1, 2004 to December 31, 2016 and the same would be presented for a final decision to the Secretary, MoEFCC and Secretary, Ministry of Power (MoP), GoI. As mercury abatement from the emissions can be achieved as a co-benefit of reduction of NO_x, SO_x, and dust, as of now, a higher degree of focus is towards reduction of SO_x and NO_x emissions.

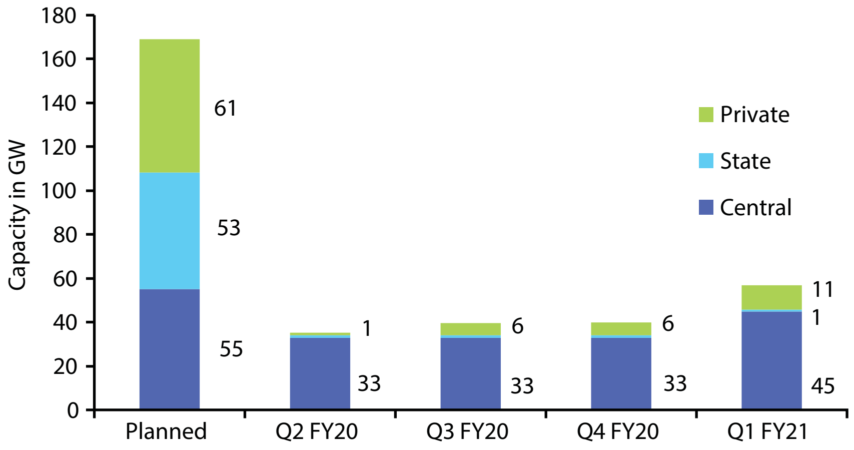

Figure 2: Sector-wise quarterly progress of FGD bids award

Source: CEA, June 2020

Current Status of Compliance in NCR and Critically Polluted Areas

The implementation of ECSs, such as ESP for PM control, FGD for SO_x control, in all except one power station located in NCR has missed the December 2019 deadline. Presently, only 15% of the planned capacity of 13 GW complies with SO_x norms and 61% FGD bids have been awarded.

More importantly, in critically polluted and high population (population density > 400/km^2) areas in the country, awards in respect of only 50% of the plants have been placed for FGD implementation till June 2020 (Figure 3).

Major Roadblocks in Timely Compliance of Emission Norms

A number of factors have impeded the implementation of pollution control measures in the TPSs; some of these major roadblocks are as follows:

» Conventional wet-type FGD has a life of 25 years (same as that of coal

[3] CEA Quarterly Review Report, Renovation & Modernisation of Thermal Power Stations. Details available at https://cea.nic.in/reports/quarterly/trm_quarterly_review/2020/trm_qrr-06.pdf

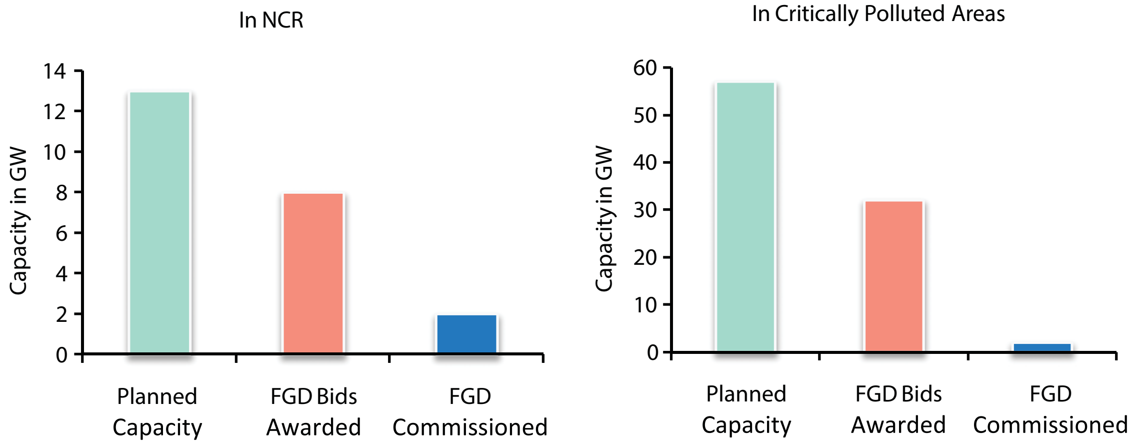

Figure 3: FGD implementation status in NCR, and critically polluted and high populated areas

Source: CEA, June 2020

power plant) and the additional capital expenditure (capex) required to install the FGD gets amortized to its life. For the new TPS, the additional capex of FGD has a tariff impact on fixed cost component, but the problem occurs for TPSs that are left with less than 10 years of their life, as these TPSs will experience a higher fixed cost tariff due to amortization of complete capex of FGD in the balance life of these TPSs. This tariff change in the fixed cost component is almost twice than new plants. One alternative to avoid this situation is using dry-type FGDs, which are used for a shorter life (7–10 years), but they cost twice as much as wet-type FGDs.

» A critical issue for power generators is a high degree of uncertainty in terms of realization of additional capex (AdCap) due to implementation of ECSs for power stations that either have part power purchase agreement (PPA) or are selling power in the power market. This uncertainty in fixed cost realization also causes trust issues for lenders/banks, which result in financial problems for these generating stations. Lenders already being conscious in funding new generation projects in view of many of the new power stations having turned into stranded assets are not keen to finance emission control systems to power stations with PPAs for partial capacity.

» While the CERC has given in-principle approval to new emission norms as Change in Law (CIL), only a few state electricity regulatory commissions (SERCs) have recognized the new emission norm as CIL. In overall terms, the progress at the state level in this regard is very slow and time-consuming.

» The orders for ECSs being one-time, the manufacturing capacity in the country is not likely to be scaled up.

Regulatory Developments

1. The MoP issued directions to address the issue of downgrading of Merit Order Despatch rating due to increase in variable cost due to implementation of ECSs that the impact of operating costs incurred in the implementation of new Environmental Norms shall not be considered for Merit Order Despatch of Coal-based TPSs till December 31, 2022.
2. The Central Electricity Regulatory Commission (CERC) has given in-principle approval to new emission norms as Change in Law (CIL).
3. CERC Tariff Regulations, 2019 specify the modalities for submission of additional capital expenditure on account of revised emission standards, factors to be considered by the Commission for approval of the same, and the admitted expenditure on this account forming the basis of tariff determination.

Due to overbooking of capacity, the lead time for supply of equipment continues to remain high. Further, the high demand-supply gap due to limited number of vendors, has led to an increase in the price of FGDs by almost 50% as compared to previously discovered price of ₹45–50 lakh/MW.[4]

» An increased restriction on imports, particularly from China, is likely to impact the pace of implementation of FGD units. About 30% of machinery in FGD was being imported, out of which imports from China hold a share of ~80%. The import of equipment from Europe and Japan entails a 15–20% increase in price. Scaling up the production of the equipment would, however, continue to be a challenge in these countries as well.

» Nationwide lockdown and slow economic activities due to the COVID-19 pandemic hampered construction activities for almost 6–8 months. Resumption of pace of construction to pre-COVID level is likely to take some time. Also, due to the same reasons, the power demand suffered a dip by about 20–30% as compared to the demand during the corresponding period of 2019. The financial health of DISCOMs, particularly their liquidity position, has been impacted significantly, thereby challenging their ability to pay for increased generation tariff on account of emission control systems.

Recent Developments

As the deadline of emission norm compliance is near or already crossed (for NCR), many actions have been recently taken or proposed. Some of these are as follows:

» CEA proposed a location-based emission norm to the MoP.[5] According to the proposal, thermal power plants located in areas where SO_2 levels are under control (>0 μg/m^3–30 μg/m^3) can defer the installation of ECSs for now. Plants that are situated at high SO_2 location (>30 μg/m^3) need to put FGDs immediately.

» The Central Pollution Control Board (CPCB) imposed a penalty of ₹18 lakh/unit/month on all the defaulting thermal units that were unable to adhere to the timelines of December 2019, located in the NCR. However, the Supreme Court has granted interim stay on the penalty imposition.

» The Supreme Court has allowed revision of NOx emission norms for coal-fired power plants set up between January 2004 and December 2016 to 300 mg/Nm^3–450 mg/Nm^3 from 300 mg/Nm^3 previously.[6]

Possible Solutions

» Adopting a different approach altogether that will take a futuristic view and identify old and inefficient generating units in regions such as the NCR, where instead of now placing orders for FGD, plants will be asked to shut down completely. Shutting down such plants located in the main city area will stimulate the requirement of new PPAs and help address the issue of stranded assets of almost 40 GW thermal capacity. The cost-benefit analysis of these units, taking the environment impact assessment into consideration, may be undertaken to take a view with regard to shutting down these units rather than putting additional capex for ECSs.

» Total capex required for ECS implementation is approximately in the range of ₹150 thousand crore. The fund available from the Clean Energy Cess (now GST compensation cess) can be used for compensating an additional impact of ECSs in the tariff determination of DISCOMs. For a generating unit, even a relaxation of ~₹200/MT in cess (estimated at unit plant load factor [PLF] of 60% annually) would be sufficient to overcome the yearly additional capex liabilities.

» To solve the issue of import of specific machinery of the FGD system, a bulk procurement strategy could be made. This will lead to significant price reduction and can also be planned in a specific way. Planned approach for bulk procurement of FGD machinery, price fixation, and apportionment against vendors will help implement the programme aggressively without seeing a rise in costs and completion time.

» SERCs, same as that of CERC may also consider exclusion of an increase in the variable cost on account of ECS installation from merit order despatch.

» Emission-based despatch of generating units should start seeking the attention of policymakers and regulators despite the fact that it may bring certain stations with a higher marginal cost into operation. EF

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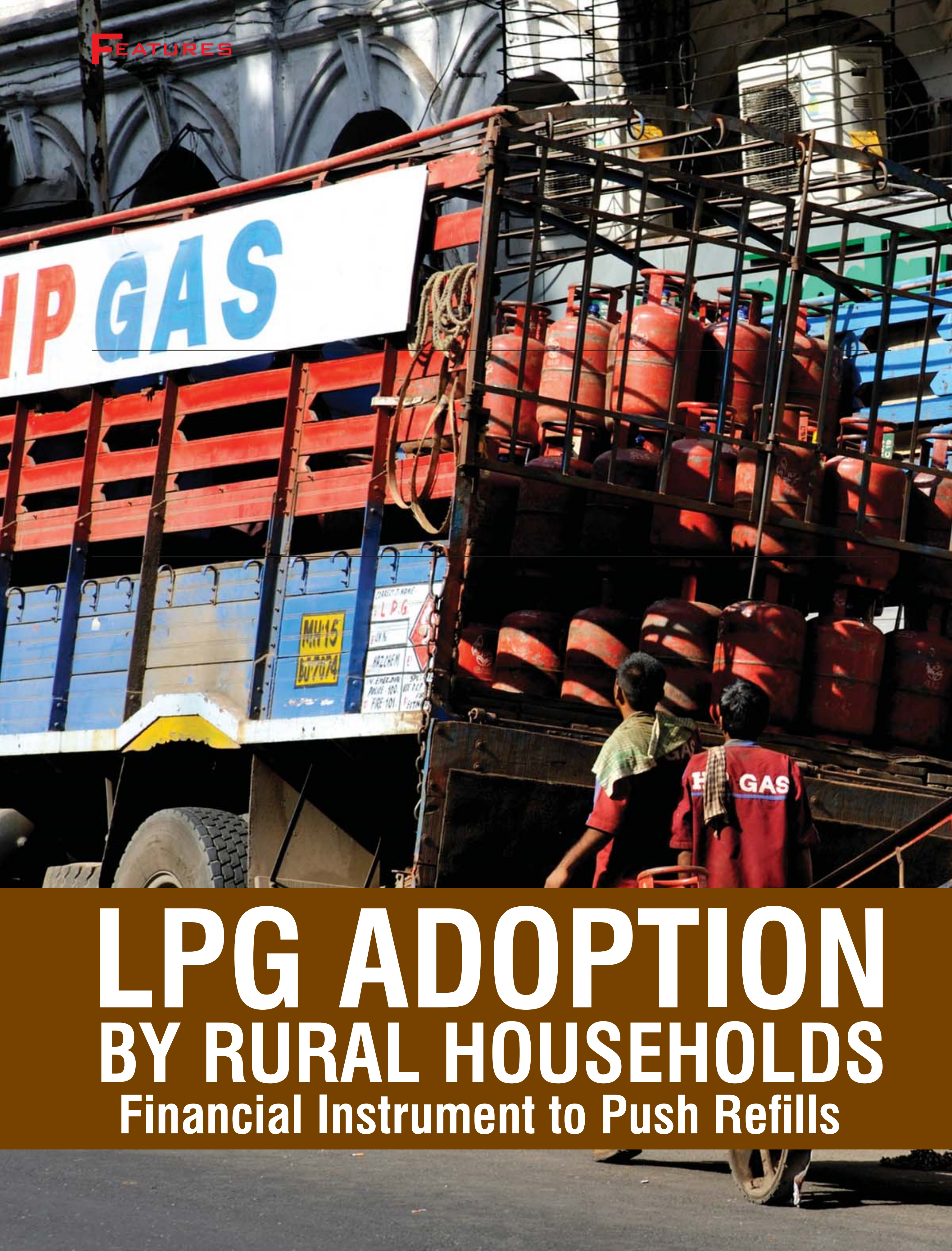
4 CEA, Norms for installation of FGD for new environmental regulations. Details available at https://www.cea.nic.in/reports/others/thermal/umpp/fgd_newnorms.pdf

5 CEA, Paper on Plant Location Specific Emission Standards. Details available at https://www.cea.nic.in/reports/others/thermal/trm/Plant_Emission_Standards.pdf

6 Supreme Court of India – Record of proceedings. Details available at https://main.sci.gov.in/supreme court/ 1985/63998/63998_1985_33_1_22733_Order_08-Jul-2020.pdf



LPG ADOPTION BY RURAL HOUSEHOLDS

Financial Instrument to Push Refills

One of the major health hazards in India stems from household air pollution. The use of the traditional cooking stove, called *chulha*, involves burning of biomass, thereby releasing smoke that is a leading cause of illness and death. In this article, **Debajit Palit, Martand Shardul**, and **Deborshi Brahmachari** discuss the advantages of replacing biomass stoves with LPG and recommend an innovative financial instrument for increasing the uptake of LPG refills by rural households

This winter, like others, the air quality range in the Delhi–NCR region has oscillated between being poor and severe. Given the criticality, this time, the Central Government formed a Commission for Air Quality Management to check the menace of air pollution (MoEFCC 2020). As in previous years, in 2020 too, one of the major causes of peak pollution during winter in the Delhi–NCR region was stubble burning in Punjab and Haryana.

Stubble burning, however, is seasonal. The other major causes, such as vehicular pollution, construction dust, and pollution from industries, contribute to poor air quality throughout the year. Another major contributor to air pollution levels across North India, which is not talked about as much, is biomass burning for cooking in rural households (Chowdhury, Chafe, Pillarisetti, *et al*. 2019). Traditional cookstoves (*chulhas*) that use solid biomass as fuels increase direct exposure to household air pollution (HAP). According to World Health Organization (WHO), roughly 30% of the ambient air pollution in India is attributable to HAP, thereby impacting both rural and urban homes (WHO 2016). A simulation-based study by IIT Kanpur observed that, on average, 17% reduction in $PM_{2.5}$ is possible across India if all biomass stoves are replaced with liquefied petroleum gas (LPG) stoves (Sharma 2020). The positive externality of LPG use in areas such as climate change mitigation, public health, and gender is also well documented. For instance, with the reduction in HAP, life expectancy in India could be increased by 0.7 years (Balakrishnan, Dey, Gupta, *et al*. 2019). Owing to the potential of Pradhan Mantri Ujjwala Yojana (PMUY) to cut toxic emissions, it can also be regarded as a pollution abatement and public health initiative and millions of premature deaths could be averted (Tripathi and Sagar 2019). A conservative estimate for health benefit stands at INR 69,000 per non-LPG household (as per WHO CHOICE method).

Pradhan Mantri Ujjwala Yojana

With a historically slow rate of LPG connections for cooking, the Government of India launched the Pradhan Mantri Ujjwala Yojana (PMUY) in May 2016 to facilitate underprivileged households' access to LPG (Cabinet Committee on Economic Affairs 2019). The scheme, aimed to empower women and safeguard their and their children's health, was launched based on a 2015 Government of India-commissioned study, which identified high upfront costs and high refill costs as the main barriers for the non-adoption of LPG over biomass in Indian households (CRISIL 2016). Under PMUY, the Central Government provided a subsidy of ₹1600 to state-owned fuel retailers for every LPG gas connection (₹1450 security towards one cylinder and ₹150 was security towards regulator). The balance amount towards stove, installation charges, and first LPG refill that each household paid was

to be adjusted against future subsidy disbursements for refills. By fully subsidizing new connections, India has successfully increased the penetration of LPG in rural areas from 56% in 2015 to over 97% now (MoPNG 2020). PMUY can be lauded for its unique approach, design, and implementation, having covered over 80 million underprivileged consumers across 715 districts in India.

While the achievement is commendable, PMUY faces several impediments that are affecting significant adoption of LPG cylinders in rural areas, despite the high rate of connections. These include, among others, affordability of refills, cultural or behavioural beliefs, and issues with supply chain and access. The public sector oil marketing companies (OMCs) are constantly striving to overcome these challenges. For example, the OMCs have provided LPG access using both 14.2-kg and 5-kg LPG cylinders for domestic use. This was done to address affordability concerns and transportation-related issues in hilly areas. While some practitioners and researchers opine that 5-kg cylinders could help in boosting both LPG consumption and refills among poor households (Harish, *et al*. 2019), this will only help in addressing affordability-related concerns of a household in a limited way (by distributing the expenditure over a period of time depending on usage pattern) rather than the annual expenditure on LPG, considering the net price per kg of LPG (with subsidy) remains the same for a 5-kg or a 14.2-kg refill. Thus, the annual expenditure on LPG by a household is less likely to vary between a 5-kg cylinder and a 14.2-kg cylinder. A 5-kg cylinder may, however, help the LPG distributors improve the ease of supply to remote areas following a hub-and-spoke model.

Affordability – A Challenge towards LPG Adoption

To understand the LPG refill rate, The Energy and Resources Institute (TERI) carried out an analysis based on publicly available data for refills availed by PMUY consumers from May 2016 to June 2019. The analysis revealed that one-fourth of these consumers never returned for a refill, roughly one-third availed only one to three refills, and the rest took four or more refills during the period. Thus, on an average, a PMUY beneficiary availed 1.5 refills per year (Figure 1). Against this, the average requirement of a typical rural household, where all major meals are cooked using LPG, is around eight refills per year. The low refill rate by PMUY and similar consumers is indicative of continued reliance on solid biomass for cooking. The Comptroller and Auditor General (CAG) of India, in its review of the PMUY, has also raised the refill issue and recommended that for the consumers in nil or low consumption category, sustained usage must be encouraged and a greater push be made to encourage these consumers to refill LPG cylinders (CAG 2019).

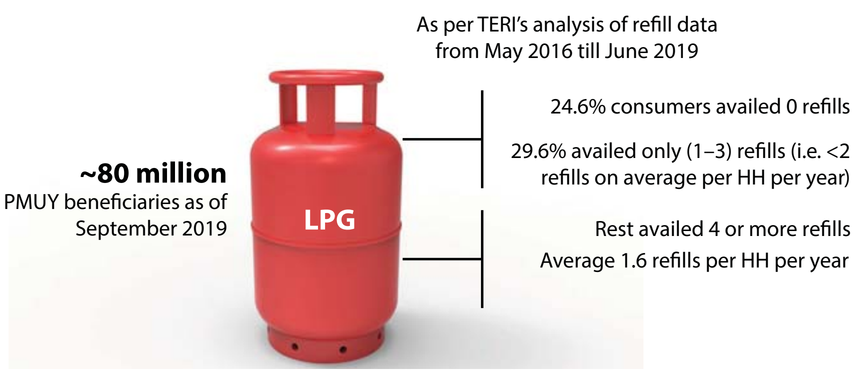


Figure 1: Refills: the core issue

Various studies indicate that the subsidized price of a 14.2-kg cylinder, which is currently around ₹600, is much higher than what poor households are willing to pay, with 'willingness to pay' being identified as being approximately ₹315 (CRISIL 2016). Addressing the issue of affordability requires deeper thought considering that according to the 2011 Socio-Economic and Caste Census, nearly three-quarters of all rural households earn ₹5000 or less per month. It thus appears that an additional support of around ₹200–₹250 over and above the existing subsidy would have to be provided to LPG users, who go for less than four refills a year. This would have to be done at least for a few years till they appreciate the benefit of using clean cooking fuel and can also afford to pay the full price for the refill.

Additional Support for LPG Refills

In January 2020, TERI worked out four different cases for providing additional support to such users. These cases are discussed in Table 1.

- **Case 1** represents the cost of providing eight 14.2-kg cylinders at a price of ₹313 (including additional support over and above the current subsidy) to all the 59.25 million PMUY beneficiaries as of 31 December 2018. The total additional support required was found to be ₹201.05 billion.
- **Case 2** shows the cost of providing eight 14.2-kg cylinders at a price of ₹313 with an additional monetary support over and above the current subsidy to only 32.14 million PMUY beneficiaries, who are reportedly in the category of 0 to 3 refills as of 31 December 2018. This amounts to ₹109.06 billion towards additional monetary support.
- **Case 3** shows the cost of providing eight 14.2-kg cylinders at a price of ₹313 with an additional monetary support over and above the current subsidy to 32.14 million PMUY beneficiaries, who are reportedly in the category of 0 to 3 refills, plus the cost of providing two 14.2-kg cylinders at a subsidized price of ₹313

Table 1: Cases to boost LPG refills through additional support

A = Case no.	B = PMUY consumers of 14.2-kg cylinder	C = No. of consumers in billion	D = Existing subsidy in INR	E= Additional support per cylinder in INR – proposed	F = No. of cylinders in a year*	G = Total cost in billion INR	H = Retail price per 14.2-kg cylinder in INR (without proposed additional support)	I = Retail price per 14.2-kg cylinder in INR (with proposed additional support #)	J= Reduction in retail price after introduction of additional support (in %)	K = Cost of economic loss per non-LPG household due to health burden arising from HAP per year (in INR)	L = Ratio of economic loss due to health burden arising from HAP to expenditure is calculated as: (C×K)/G
Case 1	All PMUY consumers as of 31 December 2018	0.059	240.13	184	8	201.05	497.37	313	37.07	69000	20.33
Case 2	All PMUY consumers as of 31 December 2018 who have reported only (0–3) refills	0.032	240.13	184	8	109.06	497.37	313	37.07		20.33
Case 3	All PMUY consumers as of 31 December 2018 who have reported (0–3) cylinder refills	0.032	240.13	184	8	132.06	497.37	313	37.07		30.95
	All PMUY consumers as of 31 December 2018 who have reported 4 or 4+ refills**	0.027	240.13	184	2		497.37	313	37.07		
Case 4	50% of the 80.34 million PMUY consumers as of 16 December 2019 with an assumption that these consumers have only availed (0–3) refills	0.040	240.13	184	8	136.3	497.37	313	37.07		20.33

* Number of cylinder refills proposed as part of the prescribed strategy
** With an assumption that this group of households has availed six cylinders of 14.2 kg each and are provided two refills, between November and February, at an additional support of ₹184 over and above existing subsidy
# Retail price of per 5-kg cylinder with proposed additional support will stand at ₹110 (on a pro rata basis)