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AN OVERVIEW ON CARBON FOOTPRINT OF COAL-BASED POWER PLANTS AND SUSTAINABILITY

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Abstract: By the rapid expansion in the coal-based power generation in India, the sector's coal consumption increased from 300 million tonnes in 2006–2007 to 600 million tonnes in 2017–2018 which is about two-thirds of the country's total coal consumption. Carbon dioxide (CO_2) emissions from the sector have also risen, from 500 million tonnes in 2005 to 1,000 million tonnes in 2015. In 2016, India generated 3.1 giga tonnes (Gt) of CO_2 equivalent (CO_2) emissions nearly 6.5% of global GHG emissions. India's coal power generation's contribution was nearly 1.1 Gt CO_2 eq. approximately 2.4 % of global emissions and 50 % of the country's fuel-related emissions. As central Electricity Authority's (CEA) projections, coal-based power will continue to play a crucial role in India's energy security, with the capacity expected to rise from 205 GW in 2020 to 266 GW in 2030. As our reliance on coal extends into the future, we need to identify pathways to decarbonize our fleet through technological, regulatory and policy interventions and decisions.

Keywords: Coal-based power plants, Global Warming, Greenhouse gases,

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INTRODUCTION

There has been a rapid rise in CO_2 levels in the atmosphere due to anthropogenic activities in the last two centuries. Being a greenhouse gas (GHG), increasing levels of CO_2 are resulting in rise in global temperature. The global average annual concentration of CO_2 in the atmosphere averaged 407.4 ppm in 2018, a substantial increase from pre-industrial levels, when it ranged between 180 and 280 ppm (Anon, 2020a). The world has already witnessed a temperature rise of 0.8ºC, which is further set to increase up to 2ºC if stringent action to curb GHG emissions is not taken. Global CO_2 emissions stand at 46 Gt, in which the energy sector contributes 36 Gt (78 %). Coal is the single biggest contributor to anthropogenic climate change. Coal-based electricity contributes nearly 15 Gt (30 %) of global GHG emissions and contributes 41 % of GHG emissions from energy-related activities (Mengpin and Johannes, 2020). A major portion of these emissions occur in Asia, where the average plant is only 12 years old and can still look forward to many years of economic feasibility. In 2016, India generated 3.1 Gt of annual CO_2 eq. emissions, which contributed nearly 6.5 % to total global GHG emissions. India's annual fuel related CO_2 emission are 2.16 Gt. Coal, being the primary fuel of the Indian economy, contributes 70 % to the overall fuel-related CO_2 emissions. Power sector contributes nearly 50 % of the sector-wise CO_2 emissions. Coal-based power generation contributes nearly 1.1 Gt, which is about 50 % of the total fuel-related emissions.

Requisite for India's energy security More than two-thirds of India's coal consumption happens in coal-based power generation (around 600 million tonnes). Coal-based power generation sector contributes around 50 % of India's fuel-related CO_2 emissions. The sector has played a vital role in meeting India's growing energy needs. During the last two decades, India has witnessed a rapid expansion in its coal-based power generation. During the period 2010–2017, India's coal capacity almost doubled from 95 GW in 2010 to 195 GW in 2017. Electricity deficit has also gone down from 7 % to 0.8 %. Between 2012–2017, coal power's contribution in total installed capacity and total generation have been around 60 % and 73 % respectively. In 2017, it was 56 % and 74 % respectively. By 2030, even with rapid increase in renewable energy as per India's INDC under the Paris Agreement, 60 % of installed capacity will remain fossil fuel-based, 90% of which will be coal-based and the rest (10 %) oil- and gas-based. Installed capacity of coal-based power generation is expected to increase to 266 GW by 2030. It will contribute 32% to the total installed capacity and 50 % to electricity generation.

In recent decades, with the rapid expansion in coal-based power generation, coal consumption has increased from 300 million tonnes in 2006–2007 to 600 million tonnes in 2017–2018. Simultaneously, CO_2 emissions related to coal-based power have almost doubled, from 500 million tonnes in 2005 to almost 1,000 million tonnes in 2015. To keep global warming to less than 2ºC from pre-industrial levels, countries agreed to INDCs to reduce GHG emissions. India, being the world's third largest emitter of GHGs after China and the US, promised to reduce its GHG emissions intensity by 33–35 % by 2030 from 2005 levels (UNFCC, 2020).

India needs to retire around 40–50 GW of its existing capacity by 2030. These units are subcritical with a design efficiency of 35 %. When they are replaced by ultra-supercritical plants of 43 % efficiency, CO_2 footprints of the sector will be reduced by 14–21%. Renovation and modernization (R&M) and life extension of coal power plants can contribute substantially to reduction in India's overall CO_2 emissions. Under the new policy, the primary focus will be on 500 MW units that are more than 15 years old. Introduction of efficient coal technology will need larger investment and has limited CO_2 reduction scope whereas R&M is cost effective. If old power plants are shifted to biomass co-firing or waste-to-energy plants through life extension projects, significant reduction can be achieved in coal-based power's CO_2 footprints.

CURRENT CO_2 EMISSIONS

Specific CO_2 emissions from a coal power plant are a function of its size, vintage and the technology it employs. These parameters determine the efficiency of operation. Overall, India has a relatively young fleet around 64 % (132 GW) of the capacity is less than a decade old. About 73 % (150 GW) is less than 15 years old. About 16 % (33 GW) is older than 25 years. Of the 33 GW of older capacity units, a major share (~76 %) belongs to small units of up to 250 MW and less. Till 2009, all installed capacity was subcritical. In 2010, India installed its first supercritical plant, which has 3–4 % higher design efficiency than subcritical plants. In 2012, under the 12th five-year plan, it was decided that 50 % of subsequent coal capacity will be supercritical and from the 13 five-year plans onwards, 100 % capacity will be supercritical. There was no clear roadmap for ultra-supercritical plants or advanced ultra-supercritical plants. By 2019, less than one-third of India's coal capacity was supercritical, the rest was subcritical. In that year, NTPC installed the first ultra-supercritical plant in Khargone, Madhya Pradesh, with a capacity of 1,320 MW. NTPC is also planning to install ten such plants in the near future.

India's power plant fleet has remained among the least efficient in the world. In 2005, the average net efficiency of the entire fleet was merely 29 % (Chikkatur et al., 2007). Chandra et al. (2015) highlighted critical issues with India's coal-based power plants and the fleet's poor efficiency was one of the them. As per the International Energy Agency (IEA), there has been a dramatic increase in India's average fleet efficiency, which has risen to 37.2 % in 2016, from 32 % in 2014 (Qian, 2020). An Ecofys (2018) analysis yielded similar numbers.10 India is now only the third-lowest performer. This change is likely due to significant supercritical capacity being installed and inefficient older plants being retired. Due to higher GHG emissions intensity with respect to the world's best, there is significant scope of improvement in India's coal-based power sector. The country can potentially achieve a 26 % reduction in specific emissions from thermal power plants.

POTENTIAL PATHWAYS TO REDUCE CO_2 EMISSIONS

Design efficiency of a thermal power plant—its coal consumption and CO_2 emissions—is mainly determined by the technology it utilizes. The main difference between subcritical, supercritical, ultra-supercritical and advanced ultra-supercritical technologies are the temperature and pressure at which they operate, which affect the heat carrying capacity of the steam and its efficiency can be measured in terms of heat rate. Heat rate is the energy required to produce one unit of electricity and is measured in kcal/kWh. Lower the heat rate, more efficient the plant and lesser will be the coal consumption at and CO_2 emissions from the plant. Estimates of CO_2 emissions for a plant are primarily based on coal consumption. However, if we want to correlate CO_2 emissions directly with a plant's efficiency, about 1 % rise in efficiency reduces CO_2 emissions by 2–3 %. So, if a subcritical plant of 35 % efficiency is replaced by an ultra-supercritical plant of 43 % efficiency, the CO_2 footprints will be reduced in the range of 16–24 %.

India's average fleet efficiency rose to 37.2 % in 2016, from 32% in 2014. The 5 percentage points increase in efficiency means India achieved 10–15 % reduction in CO_2 emissions. Under the 12th five-year plan (2012–2017), half of the new capacity planned was supercritical and from 13th plan (2017–2022) onwards, all new capacity was to be supercritical. In 2018, supercritical technology contributed about 26 % to India's total capacity. All new planned capacity (660–800 MW) is supercritical. No official roadmap or projection for the coal-power fleet by 2030 is available.

The 2018 National Electricity Plan (NEP) included plans to build 94 GW of new coal-fired capacity (mainly supercritical) between 2017–2018 and 2026–2027. CEA has outlined a large potential investment in new coal plants up to 2030 (105 GW of pithead plants and 44 GW of load-centered plants). In its draft report Optimal Generation Capacity Mix, 2029–2030 the authority has projected that India will have 266 GW coal capacity in 2030, which roughly translates into 100 GW of capacity addition, considering NEP retirement plans. NITI Aayog, in its generation mix projection for 2030–2047, has considered significant contribution from ultra-supercritical technology or IGCC. As per NITI Aayog's clean coal technology (CCT) projections for 2032, the share of supercritical, ultra-supercritical and Integrated Gasification Combined Cycle (IGCC) plants will be 35 %, 45% and 10 % respectively in total electricity generation. All subcritical coal-based power capacity is projected to retire by 2032. These projections seem to be unreliable as they require nearly 100 GW of subcritical capacity to retire by 2032. On the other hand, as coal capacity has been continuously missing installation targets since 2017, it is extremely difficult to predict future installations of coal power in India.

In 2018, the NEP included a new target for the closure of 48.3 GW of end of-life coal plants. Coal-based capacity of 22,716 MW is under consideration for retirement during 2017–2022. This is based upon an assessment made by CEA and consists of 5,927 MW of capacity assuming that the normal trend of past retirement process would continue along with a coal-based capacity of 16,789 MW which doesn't have space for installation of flue gas desulphurization (FGD) systems to curb SO_2 emissions. Additionally, a coal-based capacity of 25,572 MW has been considered for retirement during 2022–2027, which will be completing 25 years of operation by March 2022.

India is missing out on the benefits it could obtain by timely retirement of old capacity. Only 4.67 GW capacity has been retired between 2018–20 (March 2020). This is a far cry from the 22.72 GW retirement plan under the NEP. Along with this capacity, an additional 20 GW capacity will be ready for retirement during 2022–2027 and can be retired by 2030. Overall, this capacity, when replaced by supercritical capacity, can reduce coal consumption by 30 million tonnes and CO_2 emissions by 55–60 million tonnes. The retirement of old and inefficient units of thermal generating stations and their replacement with new and more efficient units is one of the major initiatives required to improve average efficiency of the fleet and reduce its CO_2 emissions footprints.

The rationale for renovation and modernization (R&M) has been:

- New installation is capital-intensive; it is considered prudent to maximize generation from existing power stations to ensure optimal utilization.
- Thermal power stations were designed for a given quality of coal which has deteriorated over a period of time. These power plants need to augment systems such as coal feeding and ash handling systems to burn coal of worse quality while maintaining the rated capacity.
- To bring down the cost of energy to consumers, Merit Order Dispatch is being adopted at the plant level, which may require renovation and modernization for improving operating performance.

Renovation and modernization have played a limited role in improving efficiency as the larger focus has remained on maximizing generation with improved availability, especially in smaller units. No estimates have been compiled by the government on how much renovation and modernization projects have helped in reducing CO_2 emissions and pollution in general from coal power plants. As per the new 2019 draft policy for renovation and modernization, there is significant scope of improvement if renovation and modernization projects are utilized efficiently to move the sector towards use of biomass. Biomass co-firing consists of combusting biomass and fossil fuels together at thermal power plants. In most cases, biomass co-firing in coal power plants takes place by mixing biomass with coal before burning, but biomass can also be gasified and burned in separate burners, after which the gaseous fuel or steam is mixed with the boiler streams of the coal-fired power plant. It has been generally accepted that co-firing biomass with coal can offer a quick, cost-effective way to partially decarbonize power generation in the short-to medium term. Biomass co-firing has an enormous potential to reduce CO_2 emissions with minuscule investment. The substitution of only 10 % of coal in the current globally installed coal-fired electrical capacity would result in installation of about 160–180 GW biomass power capacity, which is 2.5 times more than the current globally installed biomass power capacity.

Co-firing is the process of utilization of a certain portion of biomass with the existing base fuel. Currently, three co-firing technologies are widely used in coal plants: direct, indirect and parallel. The purpose of co-firing is to maximize the use of biomass within the existing system without impacting efficiency. Net electric efficiency of dedicated state-of-the-art biomass power plants is 25–36 %, whereas conventional subcritical coal-fired power plants in Organization for Economic Cooperation and Development (OECD) countries operate at efficiencies of around 36 % and modern ultra-supercritical units can exceed 45 % lower heating value. Thus, co-firing enables power generation from biomass with the high efficiency achieved in modern large-sized coal-fired power plants, which is much higher than the efficiency of dedicated 100 % biomass power plants. At present, co-firing projects in coal-fired power plants exceed the biomass capacity of dedicated biomass plants. The total energy efficiency can be increased even further if biomass co-firing takes place in combined heat and power plants. The other advantage of biomass co-firing is that the incremental investment required for burning biomass in coal-fired plants is significantly lower than the cost of dedicated biomass power. Co-firing also helps to extend the life of the plant. Co-firing has played an important transitional role in the decarbonization of the coal fleet and has extended the lives of power plants in Europe (Anon, 2013).

Co-firing offers an advantage to developing countries since the use of agricultural residue will increase the economic value of this sector. Instead of being burned on the fields, as is commonly done, agricultural waste could be used profitably in co-firing power plants. International cooperation is needed to ensure the environmental and social sustainability of biomass exploitation, especially in the case of wood or forestry-based biomass usage. As per Ministry of Power's (MoP) policy on biomass utilization, for every 1 GW capacity at 7% co-firing, nearly 0.25–0.3 million tonnes of biomass pellets are required (Anon, 2017). Thus, for 100 GW capacity, nearly 25–30 million tonnes of biomass pellets will be required. The problem of climate change cannot be dealt with through a single strategy. Thus, along with increasing overall efficiency of the coal power fleet, adoption of carbon capture and storage (CCS) will play a crucial role in combating global warming. CCS technology is designed to capture CO_2 emissions from fossil fuel combustion. It has the capacity of absorbing 85–95 % of CO_2 emissions. The process starts with the capture of generated CO_2, which then undergoes a compression process to form a dense fluid. This eases the transport and storage of the captured CO_2. The dense fluid is transported via pipelines and then injected into an underground storage facility (Tabbi et al., 2019). Captured CO_2 can also be used as a raw material in other industrial processes such as urea making or methanol production. NTPC has signed a memorandum of understanding with Larson and Turbo Hydrocarbon Engineering (L&THE) to build a CO_2-to-methanol demonstration plant at an NTPC power station. Under this agreement, L&THE and NTPC will also collaborate on accelerated development and commercialization of CO_2 to methanol plants Anon, 2020b). Since CO_2 storage is a major bottleneck, the success of the project will be a positive sign for adoption of CCS technology.

PAT SCHEME

Perform Achieve and Trade (PAT) scheme of Bureau of Energy Efficiency (BEE) is a market-based mechanism announced under the National Mission on Enhanced Energy Efficiency (NMEEE), designed to accelerate energy savings in energy-intensive sectors by incentivizing them. Under PAT cycle I, the scheme identified nine energy-intensive sectors and set targets for reduction in energy intensity for each of them. One of nine sectors was thermal power. Of the 144 thermal power plants covered under the PAT cycle I, 97 were coal or lignite-fired plants. In spite of immense potential of efficiency improvements in the thermal power sector, BEE PAT cycle I was criticized for setting easily achievable targets, particularly in the thermal power sector, the stakeholders felt that the targets for heat rate reduction are quite low which are possible merely through process optimization and improved operation and maintenance (Nihar et al., 2020).

In PAT cycle I, the thermal power sector alone contributed about 50 % of CO_2 emissions reduction (3.1 million metric tonnes of oil equivalent of the reduction which is equivalent to around 7 million tonnes of coal and 12 million tonnes of CO_2). The results of PAT cycle II were scheduled to be declared in December 2019 but have been delayed. The average heat rate reduction target given to the plants was 2 %. Thus, efficiency improvements will be similar to those under the PAT I cycle, i.e. 0.6 percentage points. Hence, CO_2 emissions reduction of around 1–2 % (10–15 million tonnes of CO_2) can be expected. Similar CO_2 emissions reduction can be assumed for the upcoming PAT cycles in 2020–2030.

But the sector needs more:

- Stringent target setting for aligning PAT cycles with CERCs norms on heat rate. PAT targets should either be at par with or more stringent than CERC norms.
- Deeper analysis of the sector for a better rationale for target setting under PAT.
- Clarity on enforcement or timelines for defaulters on energy targets.
- Transparency and clarity in the trading mechanism and regulations that will build confidence among industries and control liquidity interactions and balance in the system.

EMISSION TRADING SYSTEMS

Carbon pricing and trading systems play an important role in limiting the consumption of fossil fuels and generating funds for cleaner energy. There are two types of initiatives that put explicit monetary cost on greenhouse gases:

Emission Trading System (ETS) and carbon taxes. An Emission Trading System (ETS) sometimes referred to as a cap-and trade system, caps the total level of GHG emissions, allowing industries with lower emissions to sell their extra allowances to larger emitters. By creating supply and demand for emissions allowances, an ETS establishes a market price for GHG emissions. The cap ensures that required emissions reductions takes place to keep emitters within their pre-allocated carbon budget (Anon 2020c). A carbon tax sets a price on carbon by defining a tax rate on greenhouse gas emissions or the carbon content of fossil fuels. It is different from an ETS in that the emissions reduction outcome of a carbon tax is not pre-defined but the carbon price is. The choice of the two most important carbon pricing mechanisms (carbon emission trading and carbon tax) should be based on the specific environment and should be consistent with the national economic focus. In fact, carbon emissions trading and carbon tax can play a complementary role in different areas of emissions reduction.

Carbon pricing is much easier and there are more indirect ways of pricing carbon, such as through fuel taxes, the removal of fossil fuel subsidies and regulations that may incorporate a ‘social cost of carbon. Of the 185 countries that have submitted their INDCs to the UN, 96 have stated that they are planning or considering to use a carbon pricing mechanism as a tool to achieve their INDC commitments. The total carbon emissions of these countries account for 55 % of global emissions. As of 1 April 2020, there were 58 different carbon pricing mechanisms worldwide, of which 28 were carbon emissions trading markets and 30 were carbon tax mechanisms. These carbon pricing mechanisms cover nearly 9 Gt of CO_2 eq. in 46 countries and 28 regions around the world, accounting for about 16 % of the world’s GHG emissions. Three more carbon trading systems are scheduled to operate in China, Germany and the US covering 4 Gt of CO_2 eq. representing 7.2 % of global GHG emissions.

There has been a rapid increase in carbon pricing regimes; still, most of them are in the developed countries. A unified international emissions trading market is yet to be formed. A nationwide Clean Energy Tax on coal (or coal cess) was adopted in 2010. It was levied on coal production and imports. The tax was initially set at Rs 50 (US $0.72) per tonne of domestic and imported coal, but was quadrupled to Rs 200 (US $2.88) per tonne of coal in 2015 and doubled again to Rs 400 (US $5.75) per tonne in 2016. The revenue was initially allocated to the National Clean Energy and Environment Fund (NCEEF) to invest in clean energy projects and technologies. A total of US $4.2 billion accrued to the NCEEF until it was subsumed under the Goods and Services Tax (GST) reform in 2017. Earlier known as the Clean Energy Cess, it was renamed GST Compensation Cess in 2017, changing the ambit of the tax towards compensating states for losses incurred due to the GST rather than allocating it for clean energy. However, the Ministry of Finance expressed confidence that financing of clean energy and environment projects should not suffer due to the GST reforms (Anon 2020d).

In late 2019, the Central government proposed to cancel the coal cess altogether. The savings from removing the carbon tax would improve the financial health of utilities and distribution companies, besides helping power producers install ‘pollution-curbing equipment’, the government reasoned (Anon, 2020e).

CONCLUSION

India’s reliance on coal will continue for its energy security. Coal capacity is scheduled to increase to 266 GW by 2030 from 205 GW in 2020 and will contribute 50 % to the generation mix by 2030. Global pressure is already building up to phase out coal. Many developed countries have vowed to phase out coal plants and have already set deadlines in this regard. Nineteen countries have planned to stop coal power use by 2030 and some by 2040. Under such circumstances, even for developing countries, a BAU approach will not work. Thus, if developing countries want to continue to use coal for their energy security, the onus is on them to ensure it is burnt in a highly efficient and clean manner. India has the opportunity to eliminate more than

250 million tonnes of CO_2 emissions annually by 2030 in comparison with a BAU approach. To achieve this, the country will require a robust, concrete and comprehensive plan. Some of the major initiatives may work for sustainability *viz*. Clear roadmap for new technology; Renovating old plants; Renovation and modernization and life extension; Biomass co-firing; Carbon capture and Storage; Carbon tax and emissions trading mechanisms; Coal washing; Merit Order; PAT scheme etc.

REFERENCES

Anon, (2013). Technology: Policy Brief E21, IEA-ETSAP and IRENA 2013

Anon, (2017). Biomass Utilization for Power Generation through Co-Firing in Pulverized Coal Fired Boiler, Ministry of Power

Anon, (2020a). Emissions–Global Energy & CO2 Status Report 2019– Analysis, International Energy Agency. Available at https://www.iea.org/reports/global-energy-CO_2-status-report-2019/emissions, as accessed on 2 June 2020

Anon, (2020b). LET Hydrocarbon Engineering Signs Pact with NTPC for CO2-to-Methanol Plants- ET Energy World. ETEnergyworld.com, 20 August 2020. Available at https://energy.economictimes.indiatimes.com/news/power/let-hydrocarbon-engineering-signs-pact-with-ntpc-forco2-to-methanol-plants/77649687, as accessed on 20 August 2020

Anon, (2020c). What Does It Mean to Put a Price on Carbon? World Bank. Available at https://www.worldbank.org/en/news/feature/2014/06/11/what-does-it-mean-to-put-a-price-on-carbon, as accessed on 14 July 2020

Anon, (2020d). India 2020, Energy Policy Review, International Energy Agency

Anon, (2020e). Government Proposes Waiving Carbon Tax on Coal, Business Today, 31 December 2019. Available at https://www.businesstoday.in/current/economy-politics/big-win-coal-industry-pmoproposes-waiving-carbon-tax/story/392877.html., as accessed on 5 May 2020

Chandra Bhushan, Priyavrat Bhati, Sanjeev Kumar Kanchan, Angeline Sangeetha, Sai Siddhartha, Soundaram Ramanathan and Abhishek Rudra (2015). Heat on Power: Green Rating of Coal-based Power Plants, Centre for Science and Environment, New Delhi

Chikkatur, Ananth P., Ambuj D. Sagar, Nikit Abhyankar and N. Sreekumar (2007). Tariff-based incentives for improving coal-powerplant efficiencies in India, Energy Policy 35, no. 3,744 :7–3,758

Mengpin Ge and Johannes Friedrich (2020). 4 Charts Explain Greenhouse Gas Emissions by Countries and Sectors, World Resources Institute. Available at https://www.wri.org/blog/2020/02/greenhousegas-emissions-by-country-sector, as accessed on 5 May 2020

Nihar R. Sahoo, Pratap K.J. Mohapatra, Biresh K. Sahoo and Biswajit Mahanty (2017). Rationality of Energy Efficiency Improvement Targets under the PAT Scheme in India—A Case of Thermal Power Plants, Energy Economics. Available at doi:10.1016/j.eneco.2017.06.004, as accessed on 5 May 2020

Qian Zhu (2020). Historic Efficiency Improvement of the Coal Power Fleet, International Energy Agency CCC/300 978–92–9029–623-2

Tabbi Wilberforce, Ahmad Baroutaji, Bassel Soudan, Abdul Hai Al-Alami and Abdul Ghani Olabi (2019). Outlook of carbon capture technology and challenges, Science of the Total Environment 657: 56–72

UNFCC, (2020). India's Intended Nationally Determined Contribution to UNFCC. Available at https://www4.unfccc.int/sites/ndcstaging/Published Documents/India%20First/INDIA%20INDC%20TO%20 UNFCCC.pdf, as accessed on 5 May 2020

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