Platform India, n.d.). Another significant imperative that involves coal burning is its impact on the optimum ambient air quality, as envisioned under the *National Clean Air Programme*. Combustion of coal in power plants contributes to 13 per cent of the ambient particulate matter (PM2.5) at a national level and accounts for a much higher share of PM2.5 in peninsular India and other pockets (Cropper et al. 2021). It is estimated that 112,000 deaths annually are attributable to air-borne pollution from existing and planned coal power plants in India (Cropper et al. 2021). In order to curb the emissions from coal power plants, the Ministry of Environment, Forest, and Climate Change (MoEFCC) notified stringent emission norms in December 2015 for various pollutants and set a deadline of December 2017 for adherence to these norms. The deadline was first extended to 2022 and, in the most recent notification in March 2021, the deadline for installing retrofits to control for SO_x and NO_x emissions have been pushed to 2025. It would have taken a full decade for plants to comply, if at all the power generators do (MoEFCC, 2015; CPCB, 2017; MoEFCC, 2021). In addition, more than a billion tons of pond ash has built up over decades and millions of tons of ash generated each year polluted the soil and water in the vicinity of these plants (CEA, 2020b). Seventeen major incidents of pollution resulting from improper ash handling and breaching of storage structures occurred in FY21 and adds to the burden of local communities (Kumar et al. 2021).

13% of the ambient PM2.5 pollution in India is attributable to power plant emissions

The issue of retrofitting of plants gave rise to the important debate of retirement of thermal assets. Many of the 166 GW of plants identified for pollution control retrofits were also indicated to be retired within this decade (by 2027), under the *National Electricity Plan* (NEP) (CEA, 2018) as it was deemed that it would not make commercial sense to retrofit them. In a study published in 2019 (Garg et al. 2019), we found that nearly 39 GW of capacity, which was indicated for retirement by 2027, would cost the system INR 14,300 crore in retrofits. At the fleet level, the health benefits of retrofitting and continuing the plant operations far outweigh the cost of retrofitting the plants in the longer run (Srinivasan, et al., 2018). But from a financial perspective, plant owners and regulators may show an unwillingness to resort to retrofitting. The latest notification, delaying the retrofit timelines to 2025, also allow plants that submit an affidavit that they would be retiring to continue operating with relatively small penalties, which would go up should they continue to operate beyond the timeline specified in the affidavit (MoEFCC, 2021).

Under the NEP, the CEA has proposed a phase-out plan with timelines for coal power plants in two tranches—22,715.5 MW by 2022 based on age and emission norms compliance and 25,572 MW by 2027 based on age as a criterion (CEA, 2018)—without really specifying if these plants can continue to operate beyond the specified timelines.[1] We establish in this study that many plants continue to operate well beyond the age limits specified in the NEP for plants to be retired. Many question age as a criterion, as older plants are still technically able to generate and provide competitive generation. However, there is dissonance in arguments made over the financial viability of pollution control retrofits that express doubt over continuing 'older' plants. It is then necessary to arrive at an objective and meaningful criteria through which the decommissioning plan should be pursued. This must take into account medium-term and long-term needs of the system and public health, and must necessarily result in cost savings and efficiency improvements for the power system.

The environmental fall outs of fly-ash generated in power plants has been overlooked

The Indian power system is still in its growth phase and our dependence on coal-based generation is likely to rise over the course of this decade. However, even in such a system, it is important to assess opportunities to reduce dependence on coal. We have laid out the imperatives for such an effort, but the evidence that efficiency improvements in the system are indeed possible is what needs to be presented. We set out to find such opportunities to reduce the carbon intensity of India's coal-based generation and the additional benefits, if any, that emerge from such an exercise.

1 Nearly 4.4 GW of capacity out of this 48 GW has already been decommissioned as of 2018.

Objective

Given this background to the thermal generation fleet in India, in this study, we set out to assess the following:

1. How are thermal power plants utilised and what are the different ways of characterising their utilisation?
2. How efficient is the generation fleet and what are the drivers of efficiency and of variable costs of generation?
3. What opportunities exist for improving the efficiency of the thermal fleet?
4. Is an efficient fleet cost-effective and what implications does it have for phase-out (mothballing or decommissioning) of thermal assets?

2. Methodology and data

Image: iStock

The methodology we use to assess plant performance begins with a descriptive assessment of plant capacities, generation, and variable costs of generation segmented by age and ownership of plants. We then attempt a regression-based parametric representation of plant efficiency, proxied by the station heat rate (SHR), as a function of average unit size in the plant, plant load factor (PLF), vintage (proxied by age), and the share of imported coal. In a second parametric representation, we attempt is to capture variable costs of generation as a function of delivered coal price, vintage, average unit size, auxiliary consumption and SHR (Equations 1 and 2).

SHR = Constant +B1*Age+ B2*Average_Unit size + B3*PLF+ B4*Import share …… (1)

Variable cost = Constant + B1*SHR+ B2*Delivered coal price+ B3*Age + B4*Average_Unit size + B5* Auxiliary consumption …… (2)

It is important to explain the choice of independent variables in this assessment. Some researchers contend that PLF is an outcome metric and in some sense may have a two-way causal relationship with SHR and variable cost. However, in theory, SHR is not considered in the way plants are dispatched today and plant loading is independent of any efficiency considerations. Equally in the case of variable cost, we see that mechanisms such as ancillary services compensate plants for flexible operation, which inherently suggests that PLF (a more aggregated metric) has an impact on the plant's variable costs. We also would like to reiterate that we pursue a regression analysis not for establishing causal relations but also for establishing a predictive expression with which we can predict the dependent variables under different counterfactual scenarios.

Further, and as the most important step, we propose a reallocation of thermal (coal) generation across stations. The reallocation assumes that the share of generation coming from other sources such as lignite, renewable energy (RE), hydro, gas, and nuclear remain untouched, that is, geographically and temporally they continue to deliver as much as they did in our study period. The reallocation of coal generation presents a counterfactual where power is dispatched from stations by using efficiency of generation to accord priority in a 'new merit-order'. Efficiency is represented by the estimated SHRs for stations. With the

We propose a counterfactual where plants are dispatched based on efficiency and not variable cost established parametric representation of SHR, we now determine SHR for the efficiency-based reallocation scenario.

SHR is estimated based on (exogenous) differential plant load factors that inherently give a leg-up to newer vintage plants. This was a logical step (and also corroborated in the parametric estimation) that newer plants far outperform older plants on efficiency (ceteris paribus). Also, this is an inherent and a necessary bias (towards newer plants) to ensure financially remunerative operations for newer plants that are yet to pay off much of their costs. This would go a long way in addressing the financial stress in the banking system by preventing newer plants from becoming non-performing assets (NPAs). Assigning higher operational hours (implicitly reducing the start–stop operations of plants) to newer plants further improves the overall system efficiency. The reassignment process is iterative and maximises utilisation based on a stack of plants ordered by efficiency, so as to fulfil the average generation requirement from coal-fired power plants over the analysis period.

Predictor equations for SHR and VC are used to assess the cost of generation in the reassigned scenario

The analysis considers plant operations over a 30-month period, starting from September 2017 to February 2020. Overall, as part of the assessment, ***we investigated 194 GW[2] of plant capacity that was operational and generating between September 2017 and February 2020***. The highest resolution data available on generation was at the daily level but given that coal consumption could only be assessed at a monthly level (CEA, n.d.), we resorted to assessing all metrics at a monthly level. The highest resolution available in generation was at the plant unit level, but again coal consumption was more consistently available at the plant level (in some cases, stages of power plants) and hence we have considered this aggregated level as appropriate (typically through capacity weighting to arrive at plant-level metrics). ***Coal consumption was then converted into energy consumption, based on the delivered grade of coal to each power plant in each of these months*** (SEVA, n.d.). The conversion to energy units is critical, as physical units of specific coal consumption can be misleading in describing the plant efficiency. The variation in delivered calorific values across plants is presented in the Annexure (Figure A2). The first parametric estimation of SHR effectively uses 30 months of data across 129 thermal power plants, which amounts to 170 GW in generation capacity.

For the parametrisation of variable cost, the delivered coal price was estimated for all the plants using the supplied coal grades, mode, and distance of coal transportation data sets obtained from Coal India Limited Koyla Grahak Seva (SEVA) (SEVA, n.d.) and CEA daily coal supply reports (CEA, n.d.) respectively. We assumed rail tariffs for all transportation to non-pithead plants, given that a large share of coal transport is carried over rail for large segments and the costs of merry-go-round were used for pithead plants. The variable generation costs of plants, while available at a high daily resolution (MERIT, n.d.), were averaged to represent variable costs at a monthly resolution over the entire period in order to create a panel dataset across the 30 months.

Using this parametrised expression for variable costs, we evaluate the cumulative variable cost of generation in the original generation mix and the reassigned generation mix, to determine overall savings in variable costs associated with the generation. We attribute the total variable costs saving to the various components that we assess as being significant determinants of variable costs.

Finally, given that the allocation process does not factor in operational constraints that requires a more detailed assessment (higher time resolution and network constraints), we provide a high-level view of the changes to regional and state generation mix. In addition, we also assess the sufficiency of the generation capacity that is 'retained' in the model in catering to the needs of the system over the course of this decade.

2 We do not consider the lignite-based generation capacity of 6 GW and a further 6 GW of coal-based capacity that was in early stages of commissioning and 4 GW capacity that was not generating at all in this period.

Methodology flowchart

1

- Segmentation of units by age and ownership
- Assessment of plant capacities, generation and variable costs in each segment. Data from CEA, MERIT and Tariff orders

2

- Estimation of SHR using monthly coal consumption, generation and coal grades (from SEVA portal) - 30 month panel data set
- Parametric representation of SHR using the panel
- Calculation of SHR for all the units using the function derived from the parametric representation SHR = f{Age, unit size, PLF, import share}

3

- Estimation of delivered coal cost using coal grades data from SEVA and notified prices (CIL)
- Transportation charges were estimated using notified freight rates (IR). Plant-mine distances were calculated using location co-ordinates, and along rail network

4

- Variable costs aggregated to plant level (from MERIT)
- Parametric representation of variable cost for all the plants as VC = f {SHR, age, average unit size of plant, delivered coal price and auxiliary consumption}

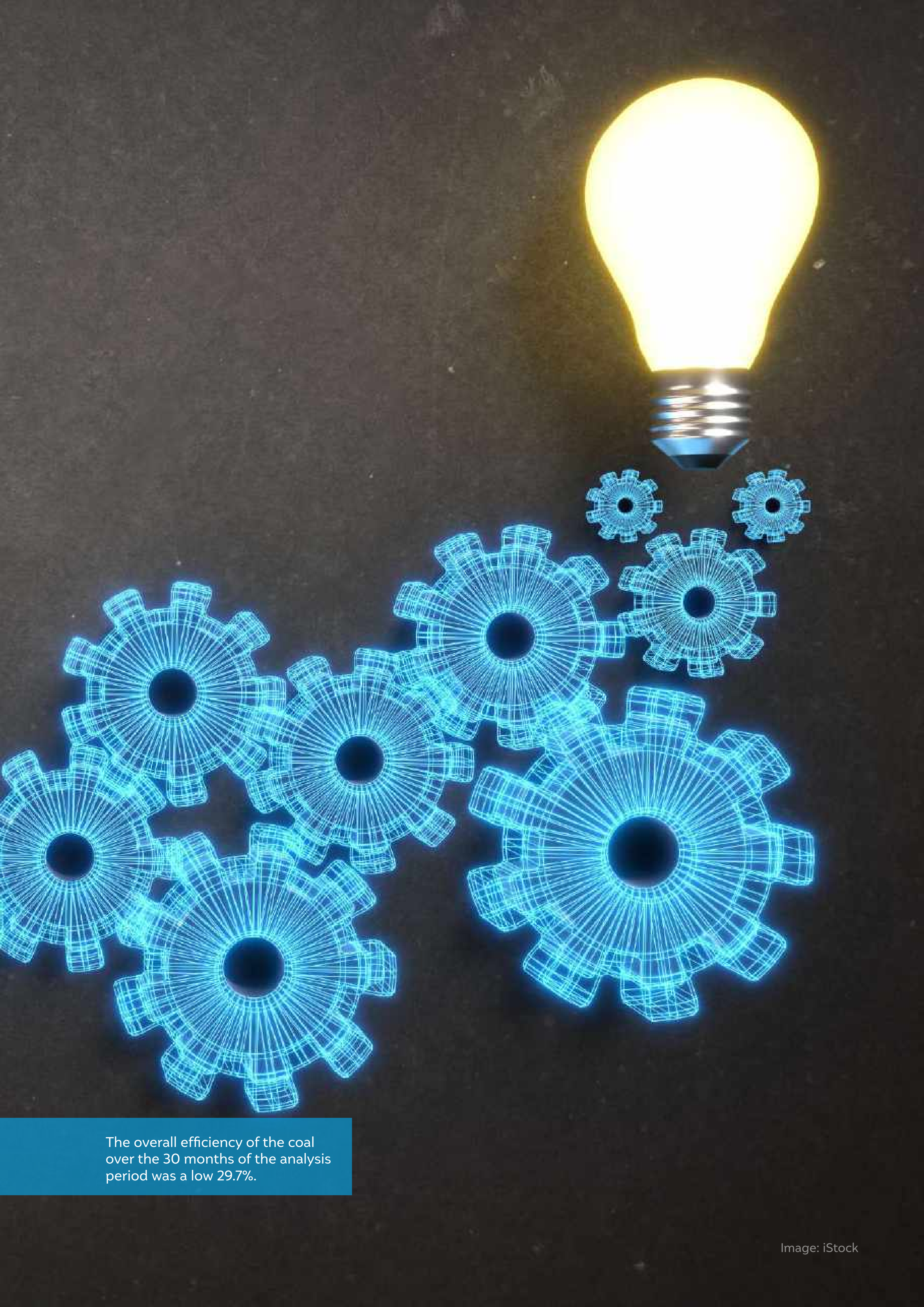
5

- Generation reassignment based on an 'efficiency' merit order, with an implicit allocation of higher operational hours for efficient plants
- The reassignment process assumes other sources of generation contribute as much as they did in the actual scenario and that temporal variations are also managed with this reassigned fleet.

6

- SHR and variable cost is calculated in the reassigned scenario for each unit based on their respective parametric representations
- Cumulative variable costs, including auxilllary consumption, is calculated for the original and reassigned generation mix to determine total cost savings as a result of the reassignment

Source: Authors' compilation



The overall efficiency of the coal over the 30 months of the analysis period was a low 29.7%.

Image: iStock