ESMAP

TECHNICAL REPORT 016/21

COAL PLANT REPURPOSING FOR AGEING COAL FLEETS IN DEVELOPING COUNTRIES

WORLD BANK GROUP

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ABBREVIATIONS

BESS	battery energy storage system
CAPEX	capital expenditure
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CIF	Climate Investment Funds
CO_2	carbon dioxide
EU	European Union
GHG	greenhouse gas
GW	gigawatt
hrs	hours
IDB	Inter-American Development Bank
INR	Indian Rupee (currency)
IRP	Integrated Resource Plan
kVArh	kilovolt amperes reactive hours
kW	kilowatt
kWh	kilowatt hour
LBL	Lawrence Berkeley National Laboratory
MOP	Ministry of Power
MU	million unit
MVArh	megavolt amperes reactive hours
MW	megawatt
MWh	megawatt hour
MRPL	Mangalore Refinery and Petrochemicals Limited
NREL	National Renewable Energy Laboratory
NTPC, Ltd.	Formerly known as National Thermal Power Corporation (India)
O&M	operation and maintenance
OPEX	operational expenditure
PLF	plant load factor
PPP	public-private partnership
PV	photovoltaic (solar)
RE	renewable energy
SynCON	synchronous condenser
¢	United States cent (currency)

All currency is in United States dollars (US$, USD), unless otherwise indicated.

ACKNOWLEDGMENTS

This report is an effort of the World Bank Group's Energy Sector Management Assistance Program (ESMAP). Its preparation was overseen by a team of World Bank staff at ESMAP, led by Debabrata Chattopadhyay (Senior Energy Specialist) and Chandrasekhar Govindrajalu (Lead Energy Specialist).

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The team is grateful for the constructive comments and contributions of the expert reviewers of the report, Jill Haizlip (Geologica) and Greg Ussher (Jacobs).

The teams extend their appreciation to Rohit Khanna (Program Manager, ESMAP) for his guidance and support throughout the development of the report, and express their gratitude to ESMAP for financial support.

The Energy Sector Management Assistance Program (ESMAP) is a partnership between the World Bank and 18 partners to help low- and middle-income countries reduce poverty and boost growth through sustainable energy solutions. ESMAP's analytical and advisory services are fully integrated within the World Bank's country financing and policy dialogue in the energy sector. Through the World Bank Group (WBG), ESMAP works to accelerate the energy transition required to achieve Sustainable Development Goal 7 (SDG7) to ensure access to affordable, reliable, sustainable, and modern energy for all. It helps to shape WBG strategies and programs to achieve the WBG Climate Change Action Plan targets.

EXECUTIVE SUMMARY

Coal plants worldwide are grappling with low-capacity utilization levels and environmental issues; and have not only become unprofitable to utilities, but also uneconomical to customers (Forbes 2018). Developed countries with significant coal capacities such as Australia, Canada, Germany, the United Kingdom (UK), and the United States (US), are taking different approaches to wean away from coal (Brown 2015). One such approach includes retiring (i.e., decommissioning) and repurposing coal plants for various productive end uses, including solar plants (e.g., Nanticoke, Canada), wind plants (e.g., Brayton Point, US), data centers (e.g., Widows Creek, US), and energy storage (e.g., Liddell, Australia).

Developing countries may gain much from the experience of their developed counterparts. Against this backdrop, we briefly examine the power situation in three developing countries, namely, South Africa, Chile, and India, based on their economic prowess within respective regions, predominance of coal in economic activities, and vulnerability to climate change, which make an interesting case for an analysis of repurposing coal plants in developing countries.

While retiring and repurposing coal plants may seem beneficial, it may encounter resistance for a few reasons, such as costs involved, identification of plants, impact on communities, and other system flexibility considerations. These retirements can be better rationalized with a clear empirical estimation of costs and benefits incurred in decommissioning plants compared with repurposing them. In view of the significant climate change benefits, there is also a case to deploy climate finance for enabling a few kickstart projects in developing countries to incentivize utilities to decommission and repurpose plants before the end of their economic lives.

Our study presents the concepts and components of a cost-benefit analysis needed for a coal plant repurposing project. We have illustrated these concepts using the example of a representative coal plant (of 1,000 megawatt [MW] capacity) in India. An existing coal plant site may have many alternative usages including continued use for energy generation. There are, in fact, several possible alternatives within energy, including alternative renewable, storage, and ancillary services technologies that can be deployed. Renewable power generation may, for instance, include solar photovoltaic (PV), solar thermal, wind, biomass, and so forth. Storage options may range from battery and thermal storage to pumped storage hydropower for pithead plants. Ancillary services may be provided by the repurposed plant through battery storage or a synchronous condenser (SynCON). Costs and benefits from repurposing would differ across technology choices.

To illustrate the basic concepts and cost-benefit components, we have examined the value proposition of repurposing over decommissioning for coal plants across three repurposing options relying on well-established technologies, namely, solar, battery energy storage system (BESS) and SynCON. Specifically, we have considered three combinations: (1) solar; (2) solar and BESS; and (3) solar, BESS, and SynCON.

Solar PV projects can be built on an existing coal plant site, part of which may have little alternative usage (e.g., ash pond) and rendering part of the land to have low opportunity cost. If the incumbent generator is in reasonable condition, it can be converted into a SynCON at a much lower cost than a new SynCON project. All three components will benefit from the existing transmission infrastructure in place, including the substation and evacuation lines.

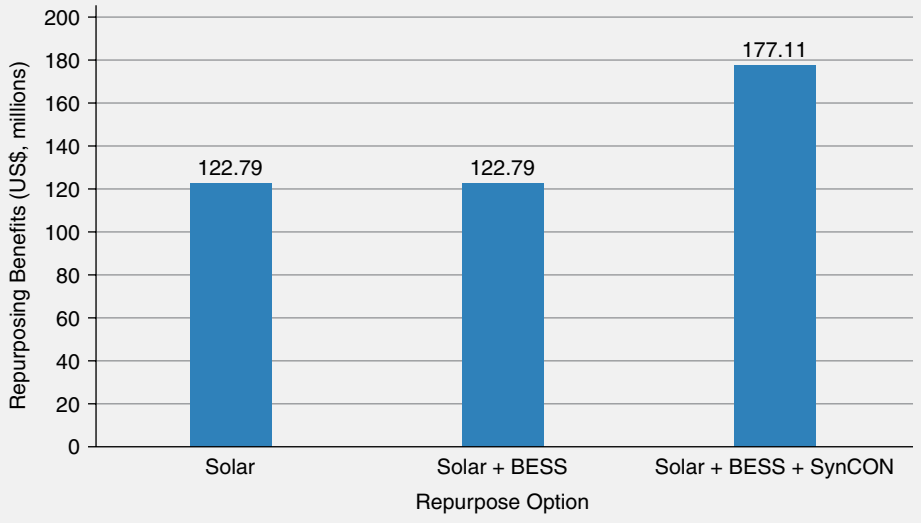
There are additional benefits that go beyond these technical components, including retention of part of the workforce and partially avoided remediation of land that would otherwise be needed for alternative usage, such as forestry/agriculture and real estate. As compared with greenfield projects, brownfield repurposing

projects address various issues including: (1) land constraints for developing new renewable energy (RE) projects; (2) managing environmental and social aspects of new development as well as social resistance to plant closures; (3) transmission constraints for new projects; and (4) addressing grid stability (as previously provided by the coal power plant). Repurposed coal projects would typically get rid of substantial operation and maintenance costs of the old plant, thereby improving the financial position of the utility. Such repurposed projects may also provide an avenue to bring in the private sector through a public-private partnership (PPP) arrangement and in turn further reduce its capital expenditure (CAPEX) requirements for repurposing, reduce overall debt, and create an additional revenue stream for the public utility. Repurposing is a good package that can address all of these in a small part, easing the path for coal plant closure.

For repurposing via solar, we assume that the entire ash pond land of a coal plant is reutilized for solar. For repurposing via solar and BESS, we assume that the storage duration for BESS is four hours. For repurposing via solar, BESS, and SynCON, we assume that the turbogenerator of the coal plant is converted into a SynCON. Broadly, various costs and benefits have been categorized as direct (one-time up-front benefits) as well as indirect (additional benefits that accrue over the lifetime of the repurposed asset). For this study, we have focused only on the direct benefits, which are incurred or accrued to the utility or the plant and can be easily monetized.

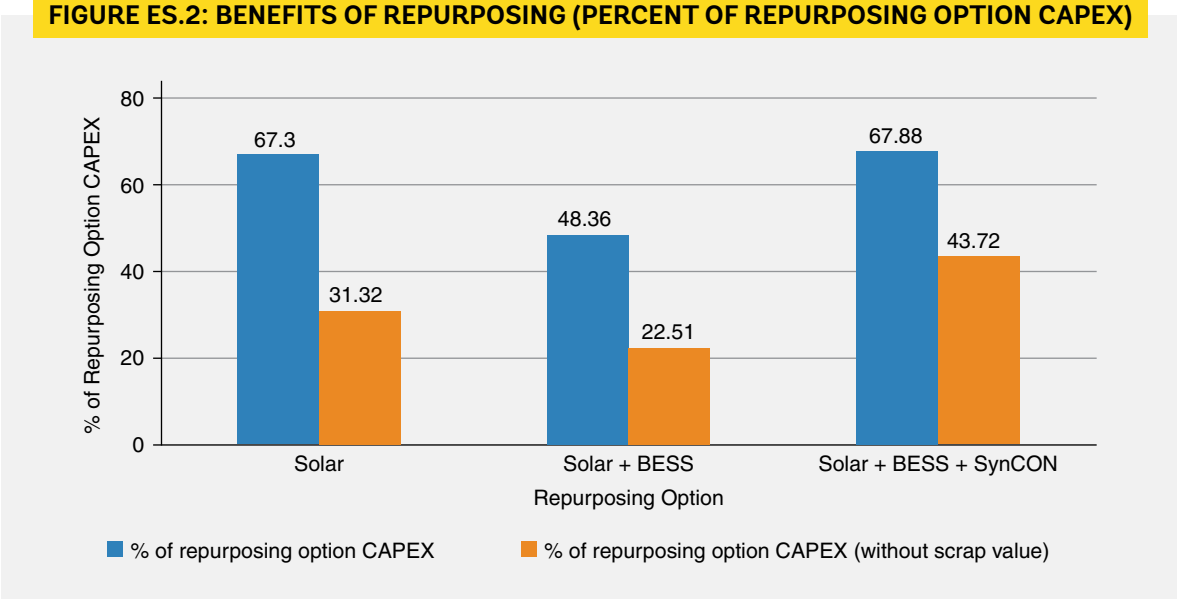
Our findings based on the illustrative case study for India reveal a strong economic rationale for repurposing existing coal plants in the country. First, the direct benefits of repurposing (i.e., at least US$122.79 million) outweigh the direct decommissioning costs (i.e., US$58.11 million). In fact, the direct costs of decommissioning are covered just by the scrap value (i.e., US$65.65 million) of the whole plant without even considering other benefits (see Figure ES.1).

FIGURE ES.1: REPURPOSING BENEFITS (US$, MILLION)



Source: Created by the authors from their analysis.

FIGURE ES.2: BENEFITS OF REPURPOSING (PERCENT OF REPURPOSING OPTION CAPEX)



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Second, the direct benefits of repurposing cover a significant fraction of the CAPEX of repurposing options. For example, even if scrap benefits are excluded, the benefits cover 31.32 percent of solar CAPEX, 22.51 percent of solar and BESS CAPEX, and 43.72 percent of solar, BESS, and SynCON CAPEX (see Figure ES.2). These numbers increase to 67.30 percent, 48.36 percent, and 67.88 percent, respectively, once the scrap value is included.

In comparison to the United States, the decommissioning cost estimates for our Indian case study are rather low. For example, while the mean decommissioning costs in the United States are US$117 kilowatt/megawatt (k/MW) (Raimi 2017), we found these to be around US$58 k/MW in the Indian context using actual decommissioning costs for a project in India.

Finally, based on various quantitative parameters (e.g., age, energy charge, etc.), we identify a prospective list of Indian coal plants that may potentially be considered for repurposing, albeit this is a complex issue that requires wider consideration of a range of economic and sociopolitical issues. We also identify various qualitative factors (e.g., RE potential, urban-rural location, policymakers interest, etc.), which may provide useful guidance to decision-makers in developing countries in selecting coal plants suitable for decommissioning and repurposing. Last but not least, coal plant/mine closure is a sensitive topic in most of the local geographies (around the thermal power plants). The scope of a repurposing project, therefore, needs to go well beyond an economic cost-benefit analysis and has to include an extensive and engaging communications plan to involve the local communities, staff, labor, and so forth. It is envisaged that the concepts and definitions of benefits and costs developed as part of this work will assist in shaping future analyses of coal repurposing projects.

Credit: © GCImages/Getty Images.

1: COAL PLANT DECOMMISSIONING AND REPURPOSING

Globally, countries are phasing out coal plants due to their ageing fleet, reduced profitability, and growing environmental concerns, and are taking different approaches to move away from coal (Energynews 2020). In Europe, Germany is one of the heaviest coal users and has been at the forefront of retiring coal plants, followed by the United Kingdom and France (Brown 2015). Outside Europe, Canada and the United States have also closed many of their coal plants and found several productive uses for them (Brown 2015).

As old and polluting coal-fired power plants become uneconomical and ready for shutdown, there are often a few opportunities to reuse the site and part of the assets. Their infrastructure and components could well be reused for other productive purposes (Energynews 2020). This strategy of conversion of shuttered coal-fired power plants, endowed with valuable assets for providing economic, energy, or grid services, is referred to as coal plant repurposing. The existing site and various components of the incumbent plant can be repurposed to produce energy, store energy, or provide ancillary services. There are in fact several possible alternatives within energy, including alternative energy, storage, and ancillary services technologies that can be deployed. Renewable power generation may for instance include solar photovoltaic (PV), solar thermal, wind, biomass, and so forth. Storage options may range from battery and thermal storage to pumped storage hydropower for pithead plants. Ancillary services may be provided by the repurposed plant itself through battery storage or a synchronous condenser (SynCON). The precise selection of the combination of technology would depend on a number of factors, including availability of land; alternative energy resource quality (e.g., wind, solar, biomass, etc.); requirement of the wider system for energy, storage, and ancillary services; relative economics of the repurposed project; and social and environmental considerations. These issues are discussed at length in the remainder of the text. It is worth mentioning up front that this is a relatively new concept and therefore how these issues are addressed for real-life repurposed projects is an area where information is scarce. Nevertheless, it is a topic that is gaining prominence rapidly in the wake of programs like Powering Past Coal and energy transition in general. In view of the significant climate change benefits, there is also a case to deploy climate finance for enabling a few kick-start projects in developing countries to demonstrate the transformation of parts of the coal supply chain by clean energy applications and to incentivize utilities to decommission plants before the end of their economic lives.

Table 1.1 provides a list of some recently repurposed coal plants and their end uses.

Decommissioning power plants entails significant costs (Raimi 2017); including dismantling, remediation, restoration, and so forth, and making it suitable for reuse for development of an industrial facility (DCES 2017). On the other hand, repurposing an old coal plant for alternative energy services allows for a coal plant to continue some of its former functions, including power generation and ancillary services. As the share of variable renewable energy increases in most power systems around the world, any opportunity to replenish ancillary services that the coal plant provides will be important, as would be the potential to use available land and transmission infrastructure to do so. For example, coal plant retirement provides an opportunity for enhancing renewable capacity addition as well as adding energy storage and repurposing

TABLE 1.1: REPURPOSED COAL PLANT SITES AND THEIR END USES

SERIAL NO.	PLANT NAME	LOCATION	COUNTRY	END USE	STATUS
1.	Nanticoke	Ontario	Canada	Solar	Completed
2.	Prosper Haniel	North Rhine-Westphalia	Germany	Pumped storage, salt thermal storage	Completed
3.	Drax	North Yorkshire	United Kingdom	Biomass	Completed
4.	Beckjord	Ohio	United States	Battery storage	Completed
5.	Eastlake	Ohio	United States	Synchronous condenser	Completed
6.	Widows Creek	Alabama	United States	Data center	Completed
7.	Mount Tom	Massachusetts	United States	Solar and battery storage	Completed
8.	Redbank	New South Wales	Australia	Solar, biomass	Proposed
9.	Liddell	New South Wales	Australia	Renewable energy, battery storage, gas, demand response	Proposed
10.	Guru Nanak Dev	Punjab	India	Solar	Proposed
11.	Brayton Point	New England	United States	Offshore wind	Proposed

Source: Created by authors from public data sources.

coal plant components for grid stability services (Chattopadhyay, Tavoulareas, and Goyal 2019). That is, coal plants can be repurposed in numerous ways, such as solar plant for energy; biomass plants for both energy and capacity; pumped hydropower or battery storage for providing frequency control ancillary services, energy storage, and capacity; and synchronous condensers for delivering reactive power and inertia. The requirements for additional renewable and ancillary services on the existing site will need to be carefully assessed through a planning study, which in turn will also determine the combination of technologies and their sizing best suited for the site.

For power utilities, repurposing offers many advantages. First, it reduces decommissioning costs because it can partially avoid some of the environmental remediation requirements and allow reuse for part of the existing assets such as generators and substations. Second, it reduces the cost of commissioning greenfield renewable energy (RE) capacity at the same site (NREL 2013). Third, for coal plants located in urban and semi-urban areas, repurposing manifests in multiple end uses (Raimi 2017), leading to economic diversification benefiting local economies (IEEFA 2019a). Fourth, it could provide a lucrative exit strategy for stranded and stressed coal plants (Chattopadhyay, Tavoulareas, and Goyal 2019).

In other words, repurposing allows for early retirement of old, polluting, and unprofitable coal plants, while capturing value by reusing part of the assets such as the substation, generator, turbine, and so forth. More importantly, repurposing can prove to be an effective strategy for developing countries such as South Africa, Chile, and India with significant RE investments in the offing. With land and reduced equipment costs, a repurposed coal plant site may potentially bring down high initial investment requirements for a greenfield RE or storage project and lower the cost of RE power generated. Repurposing may also include continued use of the generator substation obviating the need for additional transmission and interconnection costs for RE and storage projects, thus reducing the overall cost of power. Beyond direct cost benefits, coal plant decommissioning and repurposing provides environmental, social, and grid stability benefits, as discussed below.

On the grid stability front, repurposing coal plants may offer significant benefits over decommissioning (Chattopadhyay, Tavoulareas, and Goyal 2019). For instance, repurposing coal plant equipment (e.g., the turbogenerator) into a SynCON allows retaining a part of reactive power service for voltage control originally provided by the coal plant (Deecke and Kawecki 2015). Similarly, utilizing a coal plant site for installation of battery energy storage system (BESS) helps in the delivery of essential frequency control ancillary services such as faster ramping and operating reserves (NREL 2019).

There is a wide range of technology options available for repurposing, such as solar PV, concentrated solar power, biomass, BESS, offshore wind, SynCON, and so forth (Table 1.1). Among these, the choice of repurposing option(s) needs careful consideration of various factors, including resource availability, needs of the power system, and country-specific RE targets. For instance, in India, large-scale penetration of variable RE, driven by India's ambitious RE targets[1] and cheap solar PV tariffs (Mercom India 2020), would require about 27 gigawatts (GW) of BESS as well as significant ancillary services from SynCON by 2030 (CEA 2019b). Accordingly, for this analysis, we focus on these three repurposing options, namely, solar, BESS, and SynCON.

Repurposed coal projects would typically get rid of substantial operation and maintenance costs of the old plant, thereby improving the financial position of the utility. Such repurposed projects may also provide an avenue to bring in the private sector through a public-private partnership (PPP) arrangement and, in turn, further reduce its capital expenditure (CAPEX) requirements for repurposing, reduce overall debt, and create an additional revenue stream for the public utility.

On the social front, repurposing helps to mitigate the negative impact of decommissioning on employees and local communities (Raimi 2017). In case of coal plant decommissioning, the local fiscal implications are significant as power plants make up a significant portion of revenue for local governments and surrounding areas (Raimi 2017), and decommissioning can substantially reduce revenues for local governments and school districts. Repurposing allows for retaining part of the workforce for an upcoming RE or storage project at the same site (WBG 2018); this would partly ameliorate the socioeconomic impact of potential layoffs (Raimi 2017). The share of workforce that can realistically be reemployed (and retrained) in a repurposed project would depend of course on the nature of the project, but it is likely to be quite small (e.g., 10% or at best 20%). Like the original coal plant, the repurposed plant would also continue to support local economies and the surrounding communities by providing jobs and enabling economic activities and their well-being in the long run.

THE DEVELOPING COUNTRY CONTEXT

In this study, we examine three countries, namely, South Africa, Chile, and India as some of the leading economies in their respective regions—Africa, South America, and Asia. These countries are particularly vulnerable to the impacts of climate change as a significant fraction of their population is dependent on climate-sensitive economic activities such as agriculture. There are also several prominent coastal cities in these countries that are being threatened by rising sea levels due to climate change (IDB 2013).

Coal has played a major role in meeting the energy needs of these countries, and the benefits of early coal plant retirement could create a source of funds for new RE projects (WEF 2020). These countries are already witnessing falling tariffs for RE (solar), leading to accelerated penetration of RE-based generation into their grids, while the energy cost of coal-based generation has remained high, making its dispatch economically less feasible (KPMG 2017).

For these countries, a mechanism to retire coal-fired assets early toward accelerating renewable energy transition could also create potential jobs, improve public health, and transform the trajectory of carbon emissions (WEF 2020). As they look forward to altering their carbon footprints, repurposing may address the resistance to decommissioning coal plants. This is due, in part, to reemployment of a small part of the workforce and also keeping the business alive that benefits the wider community. A repurposing project also presents an opportunity to essentially share part of the net benefits of a project with those who suffer the negative impacts of decommissioning. In the following sections, we briefly discuss the contexts of these countries.

South Africa

South Africa is the largest producer of coal in Africa and is among one of the largest coal producers in the world. Its energy sector contributes about 80 percent of national greenhouse gas (GHG) emissions, of which more than 50 percent comes from fossil fuels alone (IRP 2019). Eskom, its state power utility, produces 95 percent of the nation's electricity, the bulk of this coming from coal-fired capacity, much of which has completed its economic life and finds it challenging to comply with the environmental norms (REW 2019).

The Integrated Resource Plan (IRP), instituted by the Department of Energy, provided a road map for its future energy mix, accounting for factors such as affordable electricity, reduction in emissions, energy security, and so forth (IRP 2019).[2] The IRP envisaged the addition of at least 20 GW RE out of a total 29 GW additional capacity by 2030 (IEA 2019), so that a major part of the country's electricity (i.e., 78 GW) in 2030 will come from RE (i.e., 52 GW) (REW 2019). As part of the IRP, Eskom is expected to decommission about 5 GW of its coal-fired capacity by 2022, 10 GW by 2030, and 35 GW by 2050.

Due to environmental concerns, South African coal utilities are finding it increasingly difficult to source funds, while RE projects are easily attracting funds at much cheaper rates (IEEFA 2019b). The South African power sector faces several challenges as the country looks to support and sustain its economic growth, manage energy costs, and meet increasingly ambitious environmental targets. Repurposing existing coal plants should enhance the case for decommissioning coal plants, including early retirement of the expensive and inefficient part of the fleet. In turn, this will create room for renewable energy while retaining some of the critical ancillary services that the coal plants provided. Therefore, it may be a small but important part of the solution to a greener future in South Africa.

Chile

Chile has one of the highest fossil carbon dioxide (CO_2) emissions per capita in Latin America (Statista 2020). Chile is currently formulating a new Climate Change Framework Law with an objective to achieve GHG neutrality by 2050 (CAT 2020). However, Chile also has a significant coal-based electricity supply (at 40%) and phasing out of coal capacity, along with increasing the share of RE, would play a significant role in attainment of its climate goals.[3]

By 2019, Chile had achieved a 21 percent RE share in total generation capacity, with a bulk coming from solar PV (49%) and wind (31%) (ReNow 2019). Chile has already announced plans for shutting down some of its coal plants to limit the coal-fired capacity to 20 percent by 2024 and a complete phase out by 2040, as well as increasing the share from RE generation to 59 percent by 2024 and 70 percent by 2040 (CAT 2020).

In 2018, the Chilean government signed an agreement with its four largest utilities—AES Gener, Colbun, Enel, and Engie—to close their coal-based power plants (IEEFA 2019c). Based on this agreement, the utilities embarked on an asset rotation plan for replacing coal plants with new RE plants (IEEFA 2019d) elsewhere; this is essentially a model that decommissions the coal plant at one site and the RE development happens at another better-suited site. This is not a site-specific repurposing approach but a different approach being undertaken in Chile to encourage the phasing out of coal power plants.

India

India is at a crossroads in terms of increasingly unremunerative, old, and polluting coal plants on one hand, and ambitious RE targets on the other hand with a 175 GW RE capacity addition by 2022 and 40 percent generation capacity from non-fossil fuel sources by 2030 (Shrimali 2020). There is an overwhelming dominance of fossil fuels in power generation, with 50 to 55 percent of total installed generation capacity under coal plants producing more than 65 percent of total electricity generated (MOP, 2020).

In India, old plants are not only grappling with low-capacity utilization and environmental issues but also have become uneconomical to customers and unprofitable to utilities (Forbes 2018). In line with the needs of a growing economy, India's energy demand and peak demand have grown sharply during the period 2009 to 2019; however, the average plant load factor (PLF)[4] of coal-fired plants, an indicator of capacity utilization, has seen a steady decline from 77.5 percent in 2009 to 56.1 percent in 2019 (MOP 2020). Interestingly, India's energy and peak deficits have declined. At the wholesale generation level, there is significant surplus with capacity reserve margin more than 100 percent, meaning the dependence on coal has reduced as energy needs are being increasingly met from other cheaper energy sources, such as renewable energy (PWC 2019). In addition to cheaper RE, increasing environmental concerns and the secular decline in capacity utilization of coal plants over the last decade have rendered the plants uneconomical as well as unprofitable (Shrimali 2020). Arguably, the strongest driver of decommissioning coal is that the capacity factor of coal plants that once used to be 80 percent has dropped below 60 percent and getting closer to 50 percent on average. There are several gigawatts of coal power plants that are significantly underutilized.

Therefore, a need for early retirement of coal plants is being felt, and repurposing allows such stranded assets to derive potential value and provides an exit strategy for utilities.

The policy impetus in India appears to be in favor of replacing old and inefficient units by larger efficient units at a rapid pace (CEA 2015). In 2016, the Central Electricity Authority (CEA)[5] identified approximately 9,000 megawatt (MW) coal-based thermal power plants capacity for retirement/replacement by new super-critical units on this basis of age (more than 25 years old) and uneconomic operation (CEA 2017). This not only decelerates the replacement of coal-based generation by cheaper and greener renewable energy options, but also gives rebirth to increased carbonization, albeit through new and less polluting plants.

OUR STUDY

Coal plant closures can be better rationalized with clear empirical estimation of costs and benefits incurred in decommissioning plants compared with repurposing them. This study holds special relevance for coal-based power generating nations like South Africa, Chile, and India because of three main reasons.

First, while coal has played a major role in meeting the energy needs of the developing countries, in view of growing environmental and profitability concerns, a thoughtful management of the coal fleet in these countries is a critical need. In this context, there have been examples from countries across the world to redevelop coal plants that could provide useful, particularly applicable in the context of developing countries. Countries like South Africa, Chile, and India may have much to learn from countries like the United States, Germany, and Australia, whose timely decommissioning of coal plants and their initial experiences and experiments on repurposing may be useful.

Second, while repurposing coal plants in favor of RE looks beneficial, it may encounter resistance stemming from a few factors, including the impact on communities and livelihoods, and stranded assets (Kefford et al. 2018). To create a win-win situation for all stakeholders, our study undertakes a cost-benefit analysis to establish the utility of repurposing for coal plants in favor of a combination of solar, battery, and SynCON. We assume that the owner of the incumbent coal asset continues to own the repurposed RE and flexibility center.[6] We choose these repurpose options given resource availability, system constraints, and policymakers interest for the specific case study in India we have developed, albeit there is a wider set of options that should be considered in other countries.

Third, this study focuses on coal plant decommissioning and repurposing with India as an illustrative case study, while keeping the context of other developing countries in mind. Based on data availability for coal plants, we choose the Indian context to develop a framework and illustrate the cost-benefit analysis. Our objective is to illustrate how different components of costs and benefits can be grouped to undertake a cost-benefit analysis. This is done by high level normalizing the costs and benefits to a notional single year for a “snapshot” analysis. While this is adequate for illustrating the concepts and keeping the calculations transparent, this is clearly not intended to present a full-scale economic/financial analysis needed for a real-life project.

In this context, our study addresses the following key questions:

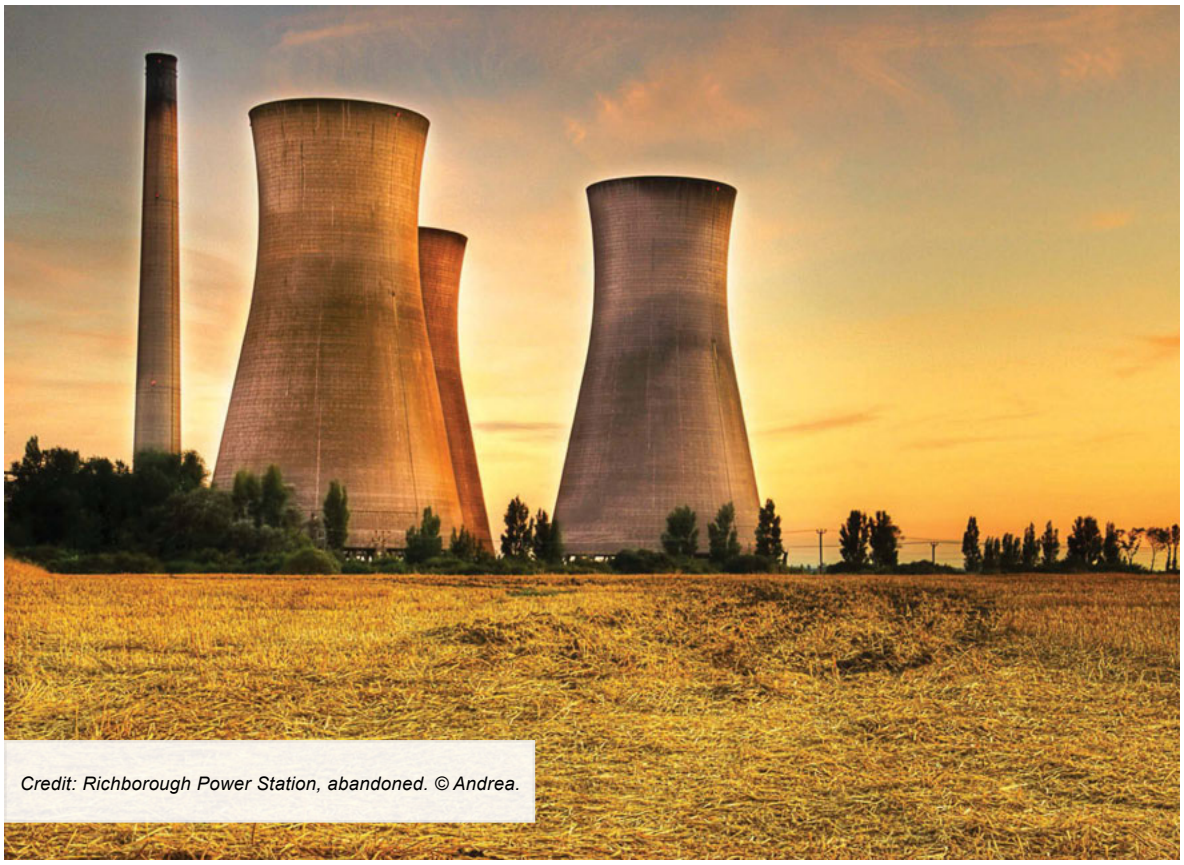
- What are the costs of decommissioning old coal plants?
- What are the benefits of repurposing decommissioned coal plants as a combination of solar, battery storage, and SynCON?
- What proportion of CAPEX of repurposing option(s) are covered by the benefits of repurposing?

We note that in addition to the direct decommissioning costs incurred by the utility or the plant, there are indirect costs which accrue to the system due to decommissioning of coal plants, as well as additional costs which are borne by the society at large. While we briefly describe all such costs, for the empirical analysis, we have considered only the direct decommissioning costs. Similarly, in addition to the direct benefits of repurposing accrued to the plant owners, there are additional system-level and society-level benefits. While we document all such benefits, for the empirical analysis, we have focused on only the direct benefits attributable to the plant. System or societal costs-benefits can be included in future studies.

In this study, we suggest appropriate sizing of RE, battery storage, and SynCON that would be installed on the existing coal plant sites. Finally, based on the available data on vintage, energy charge, and capacity, we also identify a prospective list of coal plants for repurposing.

LITERATURE REVIEW ON PLANT DECOMMISSIONING COSTS

Past literature has focused either on direct costs pertaining to the retirement of coal plants or on various (e.g., social) issues arising out of decommissioning coal plants. Studies focusing on retirement and decommissioning of coal plants include Raimi (2017), Kefford et al. (2018), and Shrimali (2020); while studies examining the impact of decommissioning on communities include Haggerty et al. (2017) and Hamilton, Valova, and Rábago (2017). Several studies have also discussed decommissioning of nuclear power plants, such as MacKerron (1989), D'Souza, Jacob, and Sanderstorm (2000), and Invernizzi, Locatelli, and Brookes et al. (2017).



Credit: Richborough Power Station, abandoned. © Andrea.

Raimi (2017) examined key issues and costs associated with decommissioning several plant types in the United States (US) and discussed how utilities focus on limiting their long-term liability while decommissioning. Kefford et al. (2018) analyzed the effect of early retirement of coal plants on asset owners and communities in four regions, namely, China, India, the European Union, and the United States; and found the challenges of early retirement most daunting in China, followed by India, in terms of the value of total stranded assets; with the European Union and the United States relatively better placed. Shrimali (2020) highlighted the need to make the Indian power system clean by retirement of expensive coal plants, and outlined the regulatory changes needed to ensure early retirement of coal plants, such as issuance of state bonds and use of clean energy funds for paying off liabilities.

Haggerty et al. (2017) studied the local impact of coal plant closures in the United States and found that there were negative consequences of an uncoordinated, contradictory policy environment at the local level and that there was a need for policy interventions to address issues of equity and efficiency. Hamilton, Valova, and Rábago (2017) examined the transition support mechanisms for communities facing coal power plant retirement in New York and recommended that policies need to be aligned for funding workforce development and training programs to ensure availability of skilled people within these communities for utilizing the opportunities created through its investments in renewable energy. In the United States, there are few reports by utilities on repurposing specific coal plants, such as Mt. Tom Power Plant Reuse (MTPPRS 2015).

From the literature review, it emerges that there is not much coverage on the various components of decommissioning of plants and the associated costs. Except for Raimi (2017), no other study, to the best of our knowledge, has examined the various components and costs of decommissioning coal plants. Even Raimi's work (2017) is limited to the power plants in the United States, whose context may be different than those in the developing countries. For this reason, in this study, in addition to Raimi (2017), we use inputs from the decommissioning experience of coal plants in India to make our work more representative of developing countries. While we describe the components and costs of decommissioning based on the NTPC, Ltd. (formerly known as the National Thermal Power Corporation of India) report[7] of decommissioning coal plants in Indian context, our analysis is largely informed by Raimi (2017).

2: METHODS AND DATA

METHODOLOGY

In this subsection, we first present the three scenarios used in our analysis, followed by detailed explanations of how the costs and benefits are calculated, and how plants are identified for repurposing.

The Scenarios

For this analysis, we develop three distinct scenarios, namely,

- **Scenario 1** (business as usual): Coal plant continues to function
- **Scenario 2** (intermediate): Coal plant is decommissioned[8] and new solar, battery energy storage system (BESS) comes up elsewhere
- **Scenario 3** (goal): Coal plant is repurposed for the appropriate option on-site (i.e., a combination of solar, BESS, and synchronous condenser (SynCON))

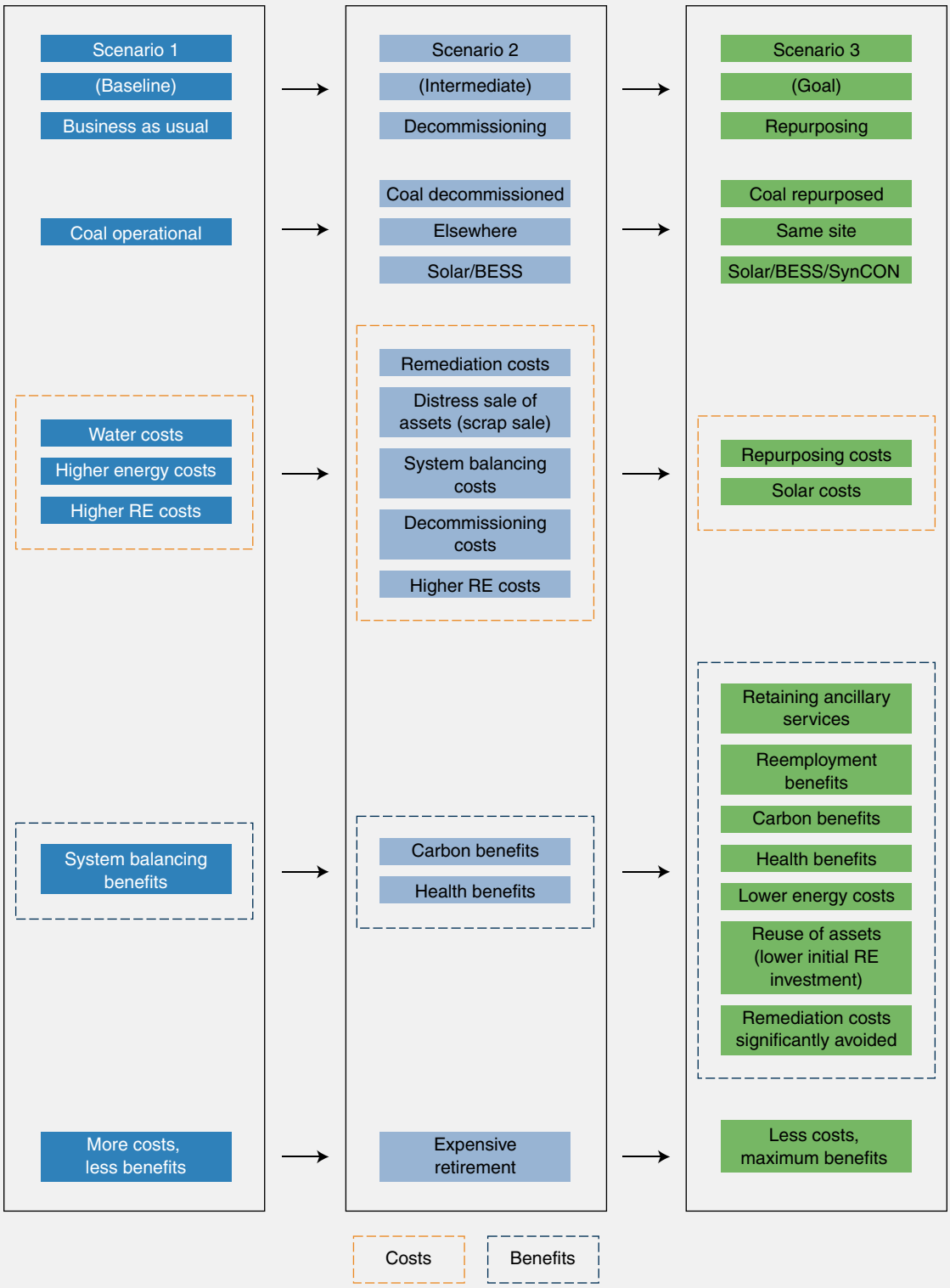
Scenario 1 is the baseline scenario, which represents the business-as-usual case and reflects the existing paradigm of the power sector in India, with coal plants staying operational. Scenario 2 considers the possibility of coal plants being decommissioned even while solar and BESS capacity addition continues in a usual manner. As we have noted before, this is like the development in Chile. Finally, Scenario 3 offers repurposing of existing coal plants into appropriate combinations of solar, BESS, and SynCON at the coal plant site. To fully demonstrate how various costs and benefits unfold, Scenario 2 is considered as an intermediate case, whereas Scenario 3 is considered the goal.

As we move across the three scenarios, we assess the costs and benefits from economic and environmental standpoints (Figure 2.1). Scenario 3 incorporates the environmental benefits offered by Scenario 2 (Benn et al. 2018), and overcomes various costs associated with moving from Scenario 1 to Scenario 2, via reusing assets as well as retaining ancillary services and employees. Scenario 3 also helps in avoiding some of the cleanup costs (e.g., ash ponds) that would otherwise be required in Scenario 2.

Various costs and benefits associated with repurposing have been categorized as direct or indirect. The direct costs are accrued to the utility/plant and are one time in nature, while indirect costs accrue to the system and would be calculated on a yearly basis. Plus, 10-year totals, assuming that the representative coal plant being repurposed would have run for another 10 years.[9] As mentioned earlier, there may be system-level costs and benefits as described in the study, but the empirical analysis primarily focuses on the direct ones which are incurred or accrued to the utility or the plant and can be easily monetized.

One of the key objectives of the paper is to identify and illustrate all related costs and benefits based on a representative coal plant actual decommissioning estimates as well as to provide engineering mathematical formulations for the computation of these, which could then act as a methodological framework for other

FIGURE 2.1: SCENARIOS FOR COAL PLANT OPERATION, DECOMMISSIONING, AND REPURPOSING



Source: Created by authors from public data sources.

Note: BESS = battery energy storage system; RE = renewable energy; SynCON = synchronous condenser.

coal plants. Our undiscounted estimates clearly establish the economic impact of largely unmonetized, yet crucial indirect costs and benefits for developing countries over a 10-year time horizon (i.e., the remaining useful economic life of the representative coal plant) thereby making a strong case of repurposing over simple decommissioning.[10]

To summarize, using a representative coal plant, we calculate costs and benefits for the following combinations of movement between scenarios: (1) simple retirement or decommissioning (i.e., from Scenario 1 to Scenario 2); (2) repurposing a decommissioned plant (i.e., from Scenario 2 to Scenario 3); and finally, (3) repurposing an operational plant (i.e., from Scenario 1 to Scenario 3).

Components of Decommissioning

Before we describe the costs and benefits, we briefly discuss various components of decommissioning to provide some context to the discussion on costs in the following section.

Decommissioning includes abatement, removal of regulated materials, structural demolition, remediation, and restoration of a site suitable for beneficial use. Typically, the entire decommissioning exercise can be divided into three major components:

1. **Pre-Demolition Stage** involves a series of events leading to the demolition of plant infrastructure, including:

   - shutdown of the power plant; modification in power supply arrangement
   - valuation of assets and transfer of materials to other coal plants; manpower planning
   - locking of various facilities and securing the plant premises safely

   The pre-demolition stage entails costs incurred toward employees, station overheads, and operation and maintenance (O&M) expenses post-retirement, as well as hazardous material remediation before commencement of the demolition activities.

2. **Demolition Stage** involves activities related to the safe demolition of chimneys, boilers, buildings, and other key structures of the plant. Supervision of demolition activity is critical for safety and security during the demolition process and entails costs incurred in actual demolition and removal of scrap from the coal plant area, which is largely a function of plant size.

3. **Post-Demolition Stage** involves environmental remediation of ash disposal and coal storage areas as well as handing over the levelled site for other purposes and entails expenditure in respect to these.

The Costs

Now, while moving from Scenario 1 to Scenario 2, we discuss applicable costs (Raimi 2017), which have been segregated into direct, indirect, and additional costs. Some of these costs are mitigated, moving from Scenario 2 to Scenario 3, and are, therefore, reconsidered as benefits in the analysis above. Direct costs are related to the decommissioning of a coal plant that has served its economic life and are one time in nature, whereas additional costs (except social costs) are related to the decommissioning of a coal plant before the end of its economic life. For the purposes of our paper, given that we mostly focus on coal

plants beyond their economic lives; we focus primarily on direct costs, which are incurred by the plant. A comprehensive list of various costs and sub-costs is below, followed by corresponding explanations.

A. Direct costs, including (as related to):

1. Employee costs, station overheads, and O&M expenses post-retirement
2. Environmental regulation, such as asbestos and hazardous material abatement
3. Demolition of the plant and scrap removal from the coal plant equipment and machinery
4. Coal combustion residuals (i.e., ash/residue ponds) cleanup
5. Coal storage areas cleanup

B. Indirect costs, including (as related to):

1. Contingency costs, such as unanticipated environmental costs

C. Additional repurposing costs, including (as related to):

1. Remaining capital expenditure (CAPEX) on the coal plant
2. Remaining operational expenditure (OPEX) margins[11] on the coal plant
3. Social costs, such as temporary income support for employee rehabilitation

Direct costs

Decommissioning a coal plant can take substantial time (1.5–2.0 years), involving employee costs, station overheads, and O&M expenses (A.1). Station overheads include expenses for security, horticulture, and water. O&M expenses include mandatory services required during decommissioning. Finally, employee costs can be calculated as:

Employee_costs = remuneration_expenses (a) + liaising_expenses (b) + relocation_expenses (c)

where,

a = expenses toward remuneration of employees during the decommissioning period (US$, million)

b = expenses toward liaising activities undertaken by employees during decommissioning period (US$, million)

c = expenses toward relocation of employees after decommissioning (US$, million)

Due to stringent environmental norms in developed countries, environmental remediation (A.2) forms a crucial part of decommissioning. It includes removal and disposal of asbestos, polychlorinated biphenyls, lead paint, hydrocarbon storage tanks, mercury, and contaminated soils (Raimi 2017). Asbestos remediation should commence prior to performing other demolition activities (Burns and McDonnel 2017).

Scrap removal costs (A.3) are incurred in identification, removal, and transportation of valuable or reused assets to a safe place before demolition begins. Demolition costs are a function of plant size as well as the safety norms followed for the safe demolition of chimneys, boilers, buildings, and other key structures. These costs are inherently dependent on the salvage value of an underlying asset and the end use of the site. For instance, in Scenario 3, since little transportation is needed due to assets being reused, these costs are expected to be relatively low. Demolition costs form a substantive component of

decommissioning costs; however, it tends to be higher for plants sited in more urban locations, due to the additional requirement of dust mitigation. For this analysis, the demolition cost includes costs incurred toward scrap removal, as well.[12]

Management of coal combustion residuals (CCR), i.e., ash disposal/pond cleanup and coal storage area cleanup (A.4 and A.5), is regarded as one of the costliest tasks associated with decommissioning. Management of coal combustion residuals for ash cleanup is critical because of the prevalence of strict environmental regulations to avoid contamination of groundwater.[13] One way to manage these ash ponds is through dewatering (Raimi 2017). These costs are significantly reduced from Scenario 2 to Scenario 3 as much of the ash pond land can be used for repurposing. Raimi (2017) clarifies that the extent of environmental remediation varies depending upon the end use of the location, and remediation costs are prohibitive for greenfield development compared with brownfield development. Repurposing via solar (photovoltaic/PV)/BESS/SynCON would significantly reduce environmental remediation costs versus other end uses such as data centers, buildings, or other urban land uses. Avoidance of these costs and time spent thereupon makes coal plant repurposing advantageous over plain decommissioning. Furthermore, going forward, environmental regulations are expected to become even stricter in developing countries, and the associated remediation costs would only move northward. The calculations for ash pond cleanup cost and coal area cleanup cost are as follows:

ash pond_cleanup_cost = ash_area (a) * earth_filling (b) * rate (c)
coal area_cleanup_cost = coal area (a) * earth_filling (b) * rate (c)

where,

a = ash disposal area/ash pond or coal bearing area to be remediated (m^2)

b = earth filling needed (in terms of thickness of soil) to be added to the remediated area (m)

c = rate (of execution of cleanup and filling) inclusive of cost of filling as well as labor ($/$m^3$)

Indirect costs

Indirect decommissioning costs are considered over the remaining plant life,[14] and include two main components. First, post-decommissioning expenditure toward monitoring and mitigation of the negative effects of a coal plant toward soil, habitat, and so forth; and meeting contingencies related to unanticipated damages in the future. Second, system balancing costs, necessitated due to the decommissioning of a coal plant in terms of reactive power, inertia, peaking requirements, and so forth. However, this study limits the analysis to the former as the latter would require a more detailed system-level investigation.

Additional costs

Scenario 3 may entail three additional costs, remaining CAPEX/OPEX and social costs. The first two arise mainly due to retirement of coal plants before the end of their economic lives and, therefore, are unlikely to exist for plants being retired after the end of their economic lives. These do not form part of our analysis, as the representative plant under consideration for repurposing has been assumed to have completed its economic life. If utilities are interested in retiring plants before their economic life, consideration of these additional costs may be useful. In this context, we also note that we have ignored some additional benefits—both CAPEX and OPEX—covered in Shrimali (2020), given that the former is unlikely to be present for plants beyond their economic life and the latter may be debatable given the assumptions on levelized costs.

Finally, social costs may include additional costs toward post-layoff (temporary income) support and rehabilitation of people dependent on coal plants for their livelihood. Continuing with our assumption that the plant may have been used for another 10 years, while decommissioning takes approximately 1.5 to 2.0 years, these costs would be calculated for the remaining 8.0 to 8.5 years. We believe that these costs are not very typical to Indian context and therefore have not been considered for our analysis.[15] However, these may form a significant part of total costs in other contexts.

The Benefits

We first need to revisit the definition of the three scenarios introduced in earlier in this chapter. A repurposing project derives its benefits by moving from Scenario 1 (business-as-usual) to Scenario 3 (repurposed site), namely, the coal plant stops working ahead of its planned retirement. Benefits may be thought of comprising two components, namely, (1) benefits that arise from shutting down the plant and RE/BESS/SynCON that may be developed elsewhere—the avoided carbon emissions benefits in most cases due to early retirement might account for the majority of the benefits; and (2) additional cost reduction and other benefits of avoided remediation cost, reemployment, and so forth that stems from locating RE/BESS/SynCON on the same site. The distinction is somewhat artificial given that the prospect of an early retirement might be reinforced by both the tangible and intangible benefits associated with repurposing the site with RE/BESS/SynCON. The direct benefits are in terms of monetary (and guaranteed) one-time benefits connected to coal plant decommissioning and repurposing, whereas the indirect benefits are associated with the period for which the coal plant decommissioning is brought forward. Indirect benefits are further divided across societal and power system benefits, as discussed in detail below. A comprehensive list is as follows.

A. Direct benefits, including (as related to):

1. Salvage value/scrap value of coal plant machinery
2. Land reutilization
3. Equipment (i.e., switchyard, substation) reutilization
4. Remediation benefits (i.e., reduced remediation costs)
5. Transmission and interconnection evacuation reutilization
6. Reactive power benefits with SynCON by retaining system balancing services

B. Indirect benefits: societal benefits, including (as related to):

1. Carbon benefits
2. Health benefits
3. Water benefits
4. Reemployment benefits

Direct benefits

The direct benefits mostly correspond to repurposing a decommissioned plant; namely from Scenario 2 to Scenario 3; except for salvage value (A.1), which applies from Scenario 1 to Scenario 2. However, it should be noted that repurposing may create significantly higher salvage value since the candidate plant may be in relatively better shape with remaining useful life and reusable assets, in contrast to a plant being decommissioned at the end of its useful life. Salvage value is calculated as follows:

salvage_value = [CAPEX_coal_plant (a)–CAPEX_repurpose_equipment (b)] * remaining _depreciation (c);

where,

a = capital cost of the coal plant (US$, million)

b = capital cost of the repurposed equipment (US$, million)

c = remaining depreciation based on the remaining life of the plant[16] *(%)*

Utilization of land for repurposing is one of the most significant economic benefits since it reduces the CAPEX for the repurpose option. Land benefits (A.2) are calculated as follows:

land_benefits = coal_land_area (a) * available_for_repurposing (b) * repurposing_land_requirement_ norm (c) * normative_land_rate (d);

where,

a = total land available with coal plant (acre)

b = fraction of total coal plant land available for repurposing (%)

c = normative land requirement for repurpose option (MW/acre)

d = normative land rate for repurpose option (US$/MW)

Similarly, the repurpose option can reuse some coal plant equipment such as switchyard, substation, turbo-generator, and so forth, further reducing its CAPEX. Reutilized equipment benefits (A.3) are calculated as follows:

equipment_benefits = equipment_CAPEX (a) * proportional_usage (b)

where,

a = cost of the repurposed equipment (US$, million)

b = proportional usage of the repurposed equipment[17]

Finally, ash impacted land, after minor remediation, can directly be used for repurposing, resulting in savings on the environmental remediation costs compared to a fully decommissioned plant. We assume that remediation benefits (A.4) are essentially ash/coal cleanup costs as calculated earlier.

Power transmission and interconnection evacuation savings accrue due to reutilization of existing system capacity for evacuation of power from the repurpose option.[18] Transmission and interconnection benefits (A.5) are computed as follows:

transmission_interconnection_benefits = solar_capacity (a) * normative_charges (b)

where,

a = capacity of new solar plant (MW)

b = normative transmission and interconnection charges allowed (US$, million/MW)

The above benefits (A.1. to A.5) accrue when repurposing is done via solar alone as well as a combination of solar and BESS. In addition to these (A.1 to A.5.), repurposing with SynCON accrues additional benefits in terms of providing system balancing services, such as reactive power for voltage control and system inertia (if flywheels are attached to the SynCON unit). In this study, we focus on providing reactive power support via repurposing a coal plant's turbogenerator into a SynCON.

The conversion to a SynCON, while incurring some additional CAPEX, eventually provides net benefits due to gross benefits exceeding costs over the lifetime. The gross reactive power benefits[19] (A.6) under this conversion are calculated as follows:

reactive_power_benefits = coal_plant_capacity (a) * synchronous_condenser_rating (b) * hrs (c) * rate (d)

where,

a = capacity of the coal plant (MW)

b = rating of the synchronous condenser (MVArh/MW)

c = operational time for synchronous condenser (i.e., 8,760 hrs)

d = compensation rate (US$/MVArh)

Indirect benefits

Societal benefits, though indirect, are realizable at the societal level in terms of their environmental value and merit inclusion. For instance, decommissioning coal plants reduces emissions (B.1; i.e., carbon benefits), improves the health of people in the vicinity of the plant (B.2; i.e., health benefits), and saves on water consumption (B.3; i.e., water benefits). Additionally, repurposing helps in retaining part of manpower employed in coal plants(B.4; i.e., reemployment benefits), thus reducing the social costs (C.3). The indirect benefits (B.1 to B.4) do not form part of our analysis, as we focus primarily on the benefits accrued to the plant via repurposing (i.e., the direct benefits). In case other studies are interested in considering these benefits, the description provided in this study shall be useful in monetizing these.

Criteria for Identifying Plants Suitable for Repurposing

Globally, old, polluting, and expensive coal plants have been considered for decommissioning. In line with the global norm, we suggest use of age and (variable) energy costs for identifying a long list of plants to be considered for repurposing. Below, we explain these further, along with our choice of thresholds.

As a coal plant ages, it undergoes a deterioration in equipment and machinery, and it becomes increasingly inefficient (Barros and Peypoch 2008; Ghosh and Kathuria 2016; Nakano and Managi 2008). In the Indian context, units aged 25 years or more are assessed for retirement or replacement of plant and machinery under renovation and modernization schemes (CEA 2019a).

Another significant criterion for retirement is energy (or variable) costs, as higher energy cost plants are not prioritized in least-cost dispatch and, therefore, operate at lower capacity utilization levels. Accordingly, coal plants with variable energy costs greater than INR 3.0/kWh (i.e., US¢4.28/kWh), a threshold established in lieu of the current tariffs for the main competition for coal plants, namely, renewable energy sources (Shrimali 2020), may form a suitable choice for repurposing.

DATA

In this section, we first describe the representative plant chosen for the analysis, followed by the data on various variables and their sources.

The Representative Plant

Ideally, given differences in vintages, sizes, and location, each coal plant under consideration should be studied individually. However, to keep the cost-benefit analysis simple, and to illustrate our methodology, we have used data from a coal plant decommissioned in India recently[20] and have scaled all data for this plant to US$/GW terms for a 1,000 MW representative coal plant. For our analysis, we had assumed that our representative coal plant had completed its economic life of 25 years. The relevant parameters for the representative coal plant and the repurpose options are listed in Table 2.1.

Credit: Walter C. Beckjord coal power plant. © Brett Ciccotelli.

TABLE 2.1: DATA FOR REPRESENTATIVE COAL PLANT AND REPURPOSE OPTIONS

VARIABLE	VALUE	SOURCE
Coal plant capacity	1,000 MW	Representative plant
Ash disposal land	895 acres	NTPC 2010
Total land available with coal plant	1,452 acres	NTPC 2010
Employee costs	US$5.01 million	NTPC Report
Station overheads costs	US$17.01 million	NTPC Report
O&M expenses	US$2.75 million	NTPC Report
Asbestos removal	US$0.09 million	MRPL 2020[a]
Demolition costs	US$4.05 million	NTPC Report
Earth filling for ash/coal area remediation	500 millimeters	DSR 2016
Rate of earth filling	INR 427.90/m^3 (i.e., US$6.11/$m^3$)	DSR 2016
Remaining depreciation	10%	CERC 2019
Scrap value/salvage value	10%[b]	CERC 2019
Normative land rate for repurpose option	INR 2.5 million/MW (i.e., US$0.036 million/MW)	CERC 2016[a]
Standard land requirement for repurpose option	5 MW/acre	Sahoo 2019
Capital cost of the repurposed equipment	$64.59 million	NLC 2019[c]
Solar capacity (repurpose)	254 MW	Estimated
Normative transmission and interconnection charges	INR 4.4 million/MW (i.e., US$0.063 million/MW)	CERC 2016[a]
CAPEX coal (capital cost of coal plant)	INR 47.1 million/MW (i.e., US$672.86 million)	CERC 2012
CAPEX solar	INR 50.3 million/MW (i.e., US$182.45 million)	CERC 2016[b]
Capacity utilization factor for solar	20%	SM 2020
CAPEX solar and BESS	INR 7 Cr/MW (i.e., US$253.90 million)	CEA 2019[a]
Storage duration (BESS)	4 hours[d]	CEA 2019[a]
Efficiency (BESS)	85%	CEA 2019[a]
Compensation rate for SynCON	INR 0.14/kVArh (i.e., US¢0.002 /kVArh)	POSOCO 2019
SynCON rating	0.350 MVArh/MW of installed capacity	Estimated

Source: Compiled by the authors from public data sources.

Note: BESS = battery energy storage system; CAPEX = capital expenditure; INR = Indian Rupee; kvArh = kilovolt amperes reactive hours; MW = megawatts; MVArh = megavolt amperes reactive hours; O&M = operation and maintenance;

a Rates based on tenders for removal of existing asbestos roof sheet at Mangalore Refinery and Petrochemicals Limited (MRPL).

b The underlying assumption associated with 10% scrap value relates with the remaining useful life of plant (i.e., candidate plants for decommissioning may be 25–30 years old). Further, the actual scrap value obtained (after auctions in the market) for plants after 25–30 years of useful life in Indian context is also close to 10% of CAPEX coal.

c Based on confidential estimates for Neyveli New Thermal Power Plant in Cuddalore, Tamil Nadu, India.

d This is largely reflecting the BESS specification in the Central Electricity Authority (CEA) study. The precise requirement for BESS would need to be determined by the system requirements for storage and ancillary services, and will be determined through a study which is outside the scope of this illustrative analysis.

3: RESULTS AND DISCUSSION

In this chapter, we first present the results for estimated costs and benefits, followed by a comparison of the two and a discussion on potential candidate plants suitable for repurposing.

COSTS

The costs are quantified in Table 3.1 using methods and data from Chapter 2. The estimated direct (total) decommissioning costs are US$58.11 million.

TABLE 3.1: COSTS OF DECOMMISSIONING A REPRESENTATIVE COAL PLANT (US$, MILLION/1,000 MW)

SL. NO.	ITEM	ONE-TIME COSTS
A.1	Employee, station overheads, and O&M expenses	35.15
(i)	Employee costs	7.11
(ii)	Station overheads	24.14
(iii)	O&M expenses	3.90
A.2	Pre-demolition costs: environmental regulation	0.09
A.3	Demolition costs	4.05
A.4	Coal combustion residuals	15.72
A.5	Coal storage area cleanup	3.10
Direct (total) decommissioning costs (A.1 to A.5)		*58.11*

Source: Compiled by the authors from public data sources.

Note: O&M = operation and maintenance.

A.1 (i.e., US$35.15 million), associated with employees (US$7.11 million), overheads (US$24.14 million), and O&M expenses (US$3.90 million) are costs incurred from pre-decommissioning to the completion of the decommissioning phase and are typical of Indian coal plants. These values were derived from the actual numbers from decommissioning of the NTPC Badarpur plant (NTPC 2020).

The employee costs (US$7.11 million) may appear low as these were estimated based on employee remuneration and expenses for the time taken for actual decommissioning (i.e., for 18 months). This is typical to the Indian context as compensating employees for the remaining life (e.g., 10 years) is not the norm in India. An underlying assumption is the public sector ownership of such plants, where employees need not be compensated after the decommissioning period, since they can be relocated to other public sector facilities without additional expenditure.

Pre-demolition environmental regulation costs for asbestos cleanup were estimated from another plant (MRPL 2020), which necessitated asbestos removal. Given asbestos removal essentially involves labor costs, which are not likely to be different across plants, these numbers were adopted for our representative coal plant.

Before actual demolition, removal, and transportation of scrap to a safe place entails further costs, which were included in demolition cost estimates. In a real-world scenario, a consolidated contract for demolition is given to an agency that first undertakes scrap disposal and then carries out a demolition exercise. Our estimates for demolition costs were US$4.05 million based on actual costs derived from the NTPC Badarpur plant (NTPC 2020).

One key element in repurposing coal plants is the cleanup of ash pond and coal-bearing areas. These have been estimated based on respective areas filled with a 500 millimeter thick earth layer at rates of earth filling work (including labor) typical to India. The costs for ash pond and coal area cleanup are US$15.72 million and US$3.10 million, respectively.

Benefits

Like costs, the benefits described Chapter 2 have been quantified in Table 3.2, using the component numbers. For this analysis, the benefits have been estimated assuming entire ash disposal land is available for repurposing.

TABLE 3.2: BENEFITS OF REPURPOSING OPTIONS (US$, MILLION/1,000 MW)

SERIAL NO.	ITEM	ONE-TIME BENEFITS	LIFETIME BENEFITS
Solar			
A.1	Scrap value	65.65	
A.2	Land utilization	9.07	
A.3	Equipment (switchyard, substation)	16.40	
A.4	Remediation benefits	15.72	
A.5	Transmission and interconnection evacuation	15.96	
Direct benefits: Solar (A.1 to A.5)		*122.79*	
Solar and BESS			
Direct benefits: Solar and BESS (A.1 to A.5)		*122.79*	
Solar, BESS, and SynCON			
A.6	System balancing (reactive power) benefits (net)		US$54.32
Direct benefits: Solar, BESS, and SynCON (A.1 to A.6)			*US$177.11*

Source: Compiled by the authors from public data sources.

First, we analyze the benefits for repurposing via solar alone, where scrap value is the most significant contributor (at US$65.65 million), and it easily covers all the decommissioning costs (at US$58.11 million). It constitutes the salvage value of coal capital expenditure (CAPEX) minus the cost of equipment repurposed. While the land reutilization benefits amount to US$9.07 million, sizeable equipment benefits (i.e., US$16.40 million) accrue due to the proportional usage of coal plant equipment, such as a switchyard, substation, and so forth. The remediation benefits are essentially the avoided cost of ash pond cleanup (i.e., US$15.72 million). Overall, the total benefits due to repurposing via solar only, amounts to US$122.79 million. The same benefits are accrued due to the second repurposing option, i.e., solar and BESS.

Examining the benefits due to the third repurposing option (i.e., solar, BESS, and SynCON), additional system balancing (i.e., reactive power) benefits of US$54.32 million are realizable with SynCON. The total realizable benefits of repurposing range from US$122.79 million to US$177.11 million, depending on the combination of repurposing options used.

We now calculate various ratios from the estimated costs and benefits for various repurposing options (i.e., solar; solar and BESS; and solar, BESS, and SynCON) to facilitate subsequent discussion and highlight key messages (see Table 3.3).

TABLE 3.3: KEY RATIOS FOR THE COST-BENEFIT ANALYSIS OF REPURPOSING

PARAMETER	COSTS	BENEFITS (SOLAR)	BENEFITS (SOLAR AND BESS)	BENEFITS (SOLAR, BESS, AND SYNCON
Direct (US$, million)	58.11	122.79	122.79	177.11**
Direct (% of CAPEX coal)	8.64	18.25	18.25	26.32
Direct (% of repurposing option CAPEX)	—	67.30	48.36	67.88
Direct excluding scrap value* (% of repurposing option CAPEX)	—	31.32	22.51	43.72
Total (% of decommissioning costs + CAPEX coal)	—	16.80	16.80	24.23
Total (% of decommissioning costs + CAPEX coal + CAPEX repurposing option)	—	13.44	12.47	17.86

Source: Compiled by the authors from public data sources.

*Scrap value (US$65.65 million) balances decommissioning costs (US$58.11 million).

**It includes net system benefits of SynCON of US$54.32 million.

TABLE 3.4: PROSPECTIVE LONG LIST OF COAL PLANTS IN INDIA FOR REPURPOSING

PLANT NAME (UNIT NUMBER)	PLANT CAPACITY (MW)	STATE
Badarpur Thermal Power Station	705	Delhi
Kothagudem Thermal Power Station (Stage II)	720	Telangana
Neyveli Thermal Power Station (Stage I)	475	Tamil Nadu
Ramagundem-B Thermal Power Station	63	Telangana
Ukai Thermal Power Station	1,350	Gujarat
Panki Thermal Power Station	189	Uttar Pradesh
Torrent Sabarmati Thermal Power Station	362	Gujarat
Bandel Thermal Power Station	455	West Bengal
Bhusawal Thermal Power Station (2 & 3)	420	Maharashtra
Bokaro B Thermal Power Station (Stages I & II)	1,000	Jharkhand
National Capital Dadri Thermal Power Station (Stage I)	840	Uttar Pradesh
Gandhinagar Thermal Power Station (3–5)	630	Gujarat
Harduaganj Thermal Power Station (Stage I)	94	Uttar Pradesh
Kolaghat Thermal Power Station	1,260	West Bengal
Nasik Thermal Power Station (3–7)	1,130	Maharashtra
Parli Thermal Power Station (6–8)	750	Maharashtra
Raichur Thermal Power Station (1–7)	2,623	Karnataka
Dr. Narla Tata Rao Thermal Power Station (1–3)	1,260	Andhra Pradesh
Wanakbori Thermal Power Station (1–7)	1,470	Gujarat

Source: Compiled by the authors from public data sources.

Prospective Long List of Plants for Repurposing

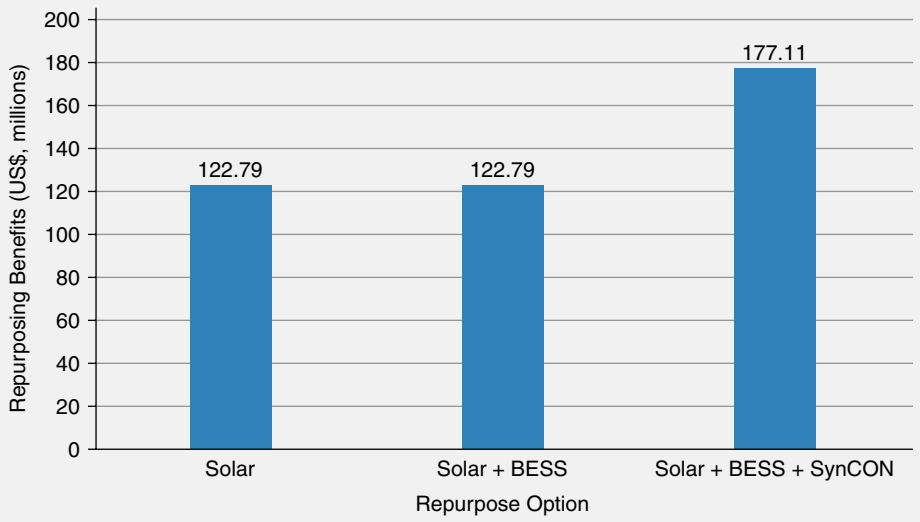
Based on the quantitative criteria mentioned in the methods section of Chapter 2, we present a prospective list of coal plants for repurposing in India[21] (Table 3.4). Under "Implementation Issues," we further discuss additional qualitative factors which also merit consideration while identifying a short list of coal plants suitable for repurposing.

KEY MESSAGES

1. Direct benefits of repurposing outweigh direct costs of decommissioning

Our analysis reveals that the direct benefits of repurposing far outweigh corresponding costs of decommissioning. For instance, while the direct decommissioning costs are US$58.11 million, the corresponding (maximum possible, for appropriate combinations of solar, BESS, and SynCON) repurposing benefits are

FIGURE 3.1: REPURPOSING BENEFITS (US$, MILLION)



Source: Compiled by the authors from public data sources.

US$122.79 million, US$122.79 million, and US$177.11 million, respectively (see Figure 3.1). Figure 3.2 illustrates the benefits under the three repurposing options both in absolute terms (US$, million) as well as a percentage of CAPEX coal.

Thus, we find that repurposing can provide much higher benefits compared to the decommissioning option only. While additional direct repurposing benefits, such as land reutilization, equipment, remediation, and transmission and interconnection benefits are clear (see A.2 to A.5, Table 3.2), a major advantage of repurposing over decommissioning are the additional net benefits due to SynCON. Here, SynCON offers net reactive power benefits amounting to US$54.32 million (see A.6, Table 3.2).

In addition to these direct benefits, there are additional societal benefits, such as avoided carbon emissions reduction, avoided SOx/NOx/fly ash emissions, and water, health, and system benefits which were considered in our empirical analysis due to the limited monetization of these in a developing country context, particularly India. However, monetizing these will add significantly to the existing repurposing benefits, and make repurposing look more lucrative. The avoided carbon reduction benefit associated with **early decommissioning of the plant** can potentially be the most significant contributor. For example, a 1,000 MW plant would typically emit somewhere between 3.9 to 6.3 metric ton (mt) of CO_2.[22] Depending on the CO_2 price and eligible years for which this benefit can apply for the remaining technical life of the plant, these costs can be high, approximately US$390 million for US$10/t CO_2 price and 10 years.

To check the sensitivity of our results, we now undertake a scenario analysis with repurposing benefits estimated in the worst and the best scenarios. The worst case represents a scenario where only half of the ash pond land is available for repurposing and the scrap value obtained is also half, or 5 percent of CAPEX (e.g., when a coal plant is retired after 35 to 40 years), whereas the best case would mean that all coal plant land is available for repurposing and the scrap value is 10 percent of CAPEX.

TABLE 3.5: SCENARIO ANALYSIS FOR REPURPOSING VIA SOLAR

		REPURPOSING BENEFITS (DIRECT)		
SCENARIO	DESCRIPTION	US$, MILLION	% OF CAPEX COAL	% OF CAPEX REPURPOSING OPTION
Scenario 1 (original case)	Entire ash pond area and 25 years economic life	122.79	18.25	67.30
Scenario 2 (worst case)	Half ash pond area and 35–40 years economic life	61.81	9.20	20.88
Scenario 3 (best case)	Entire plant land and 25 years economic life	150.65	22.39	50.89

Source: Compiled by the authors from public data sources.

Table 3.5 presents the results for direct repurposing benefits via solar options under the three scenarios. We observe that the estimated values for repurposing benefits in the original case (Case 1) lie between those for the worst case (Case 2) and the best case (Case 3). This is intuitive as the repurposing benefits increase under Case 3. Further, Case 2 yields relatively lower repurposing benefits. It is noteworthy that while the repurposing benefits increase in absolute terms from the original case (Case 1) to the best case (Case 3), these decrease as a percent of CAPEX solar, because, except for the scrap value benefits (which are the same in both cases), the increase in other benefits in the latter case is not commensurate with the increased solar capacity and the corresponding CAPEX.

Overall, this highlights the potential significance of repurposing in enabling India's energy transition from coal to renewable sources, via outlining a gainful proposition for key stakeholders, such as utilities, the power system, and society at large. Suitable monetization of these benefits, and sharing the value created by repurposing with the stakeholders equitably, would nudge these entities toward a greener future. However, additional work is needed to examine a working mechanism for the same.

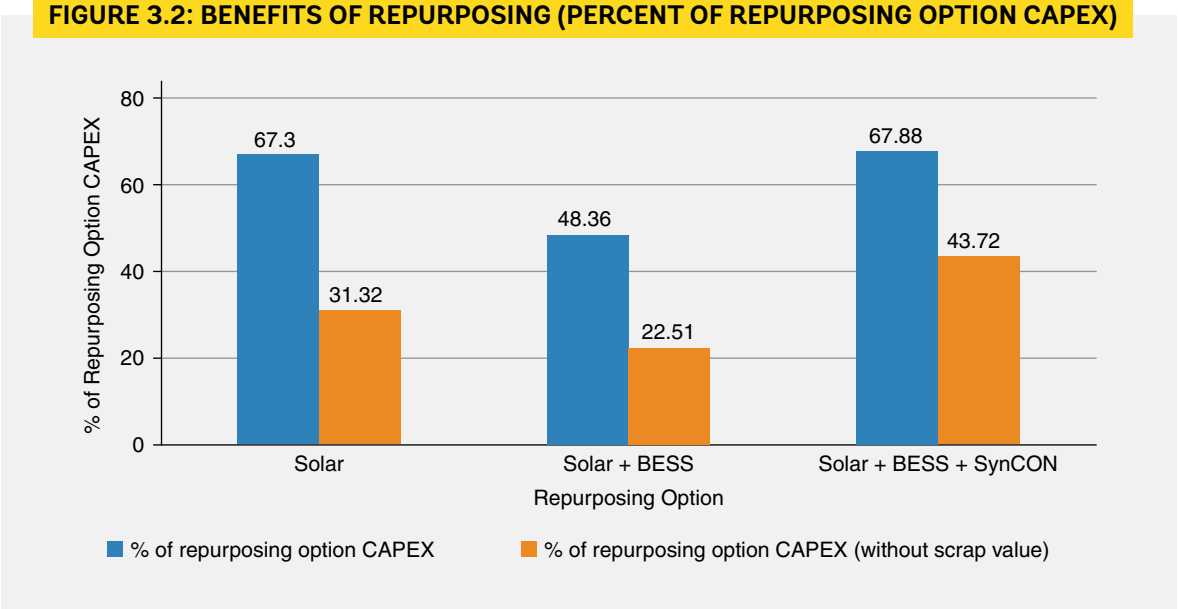
2. Direct benefits of decommissioning outweigh direct costs of decommissioning

As seen in the preceding paragraphs, the direct benefits of repurposing outweigh the costs of decommissioning. Even the direct benefits of just decommissioning outweigh the corresponding costs. Our analysis reveals that, while there are substantial costs associated with decommissioning (i.e., US$58.11 million), these get easily covered by the scrap value of the plant (i.e., US$65.65 million). In terms of percentage of coal CAPEX, the direct decommissioning costs amount to 8.64 percent, whereas the scrap value amounts to 9.75 percent.[23] Given the capital-intensive nature of a coal plant, intuitively, our estimated values for decommissioning costs and scrap value seem rather plausible, as it is expected that decommissioning costs may typically get covered by the scrap value (Watt Committee 1984). This result may provide some comfort to the utility owners of old, unprofitable, and stranded coal assets in considering decommissioning.

3. Direct benefits of repurposing are a significant fraction of the repurpose CAPEX

We observe that the direct benefits of repurposing (see A.1 to A.6, Table 3.2) cover a significant fraction of the CAPEX of corresponding repurposing options. For instance, even after excluding the scrap benefits which balance the decommissioning costs, the direct benefits cover 31.32 percent of solar CAPEX, 22.51

FIGURE 3.2: BENEFITS OF REPURPOSING (PERCENT OF REPURPOSING OPTION CAPEX)



Source: Compiled by the authors from public data sources.

percent of solar and BESS CAPEX, and 43.72 percent of solar, BESS, and SynCON CAPEX (see Figure 3.2). These numbers increase to 67.30 percent, 48.36 percent, and 67.88 percent, respectively, once the scrap value is included (see Figure 3.2). These benefits are expected to increase further, with further lowering of solar (and BESS) CAPEX in the future, if not in absolute terms but as a percentage of CAPEX for the repurposing options. We discuss this issue separately in detail in the next subsection.

It may be pertinent to mention that land reutilization forms an important component of these direct benefits, which were calculated using only the ash disposal land for the repurposing option(s). However, in many cases, besides the ash disposal land, additional land such as coal storage area land or the entire coal plant land (if available), could also be utilized for repurposing. This would not only increase the land reutilization benefits, but also allow greater repurposing for the same coal capacity. In such cases, in addition to land reutilization benefits, other components of direct benefits shall also increase in absolute terms. We find that, if the entire coal plant land could be utilized for repurposing, the direct benefits could increase from US$122.79 million to US$150.65 million.

4. In the future, repurposing would offer higher benefits as a percentage of repurposing CAPEX

As regulators worldwide revise environmental standards, the increased remediation and compliance costs would increase the decommissioning costs. However, even with more stringent decommissioning norms over the horizon, the benefits of repurposing via solar and BESS, and solar, BESS, and SynCON would make a compelling case for plants to retire cost effectively. Repurposing to solar and BESS provides a total benefit of US$122.79 million and covers 48.36 percent of solar and BESS CAPEX. This benefit (as a percentage of combined CAPEX) is expected to increase significantly in the future due to the fall in battery storage prices.

Together, solar and BESS can potentially form the bulk of the energy system in countries like India, China, and the United States, where the share of generation from solar PV is high (Ram et al. 2017). For India to meet 40 percent of its installed capacity from non-fossil fuel sources by 2030, Central Electricity Authority (CEA) has projected a battery storage capacity of 34,000 MW or 136,000 MWh (CEA 2019b). Therefore, the significance of battery storage as a source of flexibility to store energy and provide ancillary services is set to increase. In the Indian context, the cost trajectory for BESS (per MW with 4-hour storage) is expected to reduce uniformly from ₹ 7 Cr.[24] (US$1 million) in 2021–22 to ₹ 4.3 Cr. (US$0.61 million) in 2029–30 for a 4-hour battery system (CEA 2019b; LBL 2020). We, therefore, expect the benefits in case of solar and BESS to increase further considering falling battery prices globally. Using the expected CAPEX for solar and BESS in the future (i.e., 2029–30), the repurposing benefits are expected to increase from 48.36 percent (present) to 78.73 percent (2029–30) of the combined CAPEX. Given the growing utility of energy storage in view of its peaking power benefits and the expected fall in their prices, our result makes a compelling case for wide-scale repurposing of coal plants for solar and BESS in India and other developing countries with sizeable coal capacity awaiting retirement.[25]

5. As ancillary services markets develop, repurposing via SynCON would present a major revenue stream

As discussed earlier, coal plant repurposing provides significant benefits in the cases of solar as well as solar and BESS. In addition to these, repurposing via SynCON provides substantial voltage control services critical for the power system. The net additional benefits (US$54.32 million) of repurposing via SynCON are expected to increase further mainly due to two reasons. First, the ancillary services market is developing around the world, particularly in developing countries, leading to increased demand and higher compensation for these services; and, second, accelerated penetration of variable renewable energy (RE) into the grid requires greater reactive power balancing which can be provided by SynCON, thereby ensuring a major revenue stream for the repurposed plant. With solar, BESS, and SynCON combined, the repurposed site can therefore continue to provide part of the energy needs and a significant part of the frequency control and voltage support services that the original coal plant provided.

6. The decommissioning costs in India are low compared to international benchmarks

Based on the available estimates for the United States, the total decommissioning costs are found to be in the range of US$21 to $466 k/MW,[26] with a mean of US$117 k/MW (Raimi 2017). However, in our analysis, the decommissioning costs turn out to US$58 k/MW. Even though the coal capacity under decommissioning in the United States is of much larger size than that for India, the decommissioning costs estimates for Indian plants are rather low. This may be due to the following reasons:

1. While the estimates for the former (i.e., Raimi 2017) were worked out on an ex-post basis, the latter (i.e., our analysis) is an ex-ante estimation of costs, which may vary with actual market considerations of scrap value, labor costs, and so forth.

2. The low decommissioning costs for Indian plants may also be due to consideration of only a subset of costs (e.g., climate finance contingency costs for unanticipated environmental remediation and no social costs) and much lower cost components in India (e.g., reduced employee costs) compared to the United States.

3. Decommissioning costs in the United States also account for higher remediation costs due to stringent environmental regulations, social expenses as severance pay to employees laid off, and expenses toward obliging previous contracts.

IMPLEMENTATION ISSUES

While our analysis recommends repurposing existing coal plants, doing so brings up two key issues:

- Which additional factors need consideration while identifying plants for repurposing?
- What would happen to the employees and communities dependent on coal plants?

Which Additional Factors Need Consideration While Identifying Plants for Repurposing?

Under "Criteria for identifying plants suitable for repurposing" (Chapter 2), we outlined the quantitative factors (e.g., age, energy charge, etc.) which resulted in a prospective list of plants for repurposing in the Indian context (see Table 3.4). However, in addition to these quantitative factors, in the context of developing countries, state-level qualitative factors also merit consideration. These include willingness of stakeholders (i.e., state governments favorable disposition toward RE), locational attributes of the coal plant site in terms of its RE potential, and availability of cheap land. The last criteria suggest targeting coal plants located in rural locations, where land is relatively cheaper. However, even rural coal sites, where a power plant forms the only revenue source for local communities, may find it difficult to consider decommissioning/repurposing, and the policy response needs to address the economic and fiscal impacts of decommissioning such plants in rural areas (Raimi 2017).

Credit: © PeopleImages/Getty Images.

What Would Happen to the Employees and Communities Dependent on Coal Plants?

The substantial economic shift accompanying coal plant retirement affects not only the utility owners, but also the employees associated with the entire power sector value chain (Waller 2018). Shrimali (2020) points out that the impact of coal plant retirement goes beyond power plants and impacts various other sectors like coal mining, railways, and so forth. Further, as many of the state-owned plants get a generation schedule from distribution companies (DISCOMs), it can even cause potential disruptions to the power distribution sector. Therefore, the issue of employees working in coal plants poses a formidable challenge to the repurposing story and needs special attention, particularly in the case of private plants.[27] Although repurposing partially addresses this by reemploying some personnel, that may not be adequate. Private plants may explore other policy measures such as post-layoff temporary income support through sharing of gains accrued from repurposing, which may offer a viable solution.

On deeper investigation, we observe that in India, many coal plants under consideration for repurposing are either under the ownership of center or the states. Such employees (under the public sector) can suitably be relocated at other projects or plants with minimum expenses, which could prove beneficial for both the utilities and the employees.

Finally, a continuous dialogue and consultation regarding the scope, scale, and timing of closure along with adequate planning from the beginning for their rehabilitation would prove useful in mitigating the impact of coal plant closure on the employees (WBG 2018).

4: CONCLUSIONS

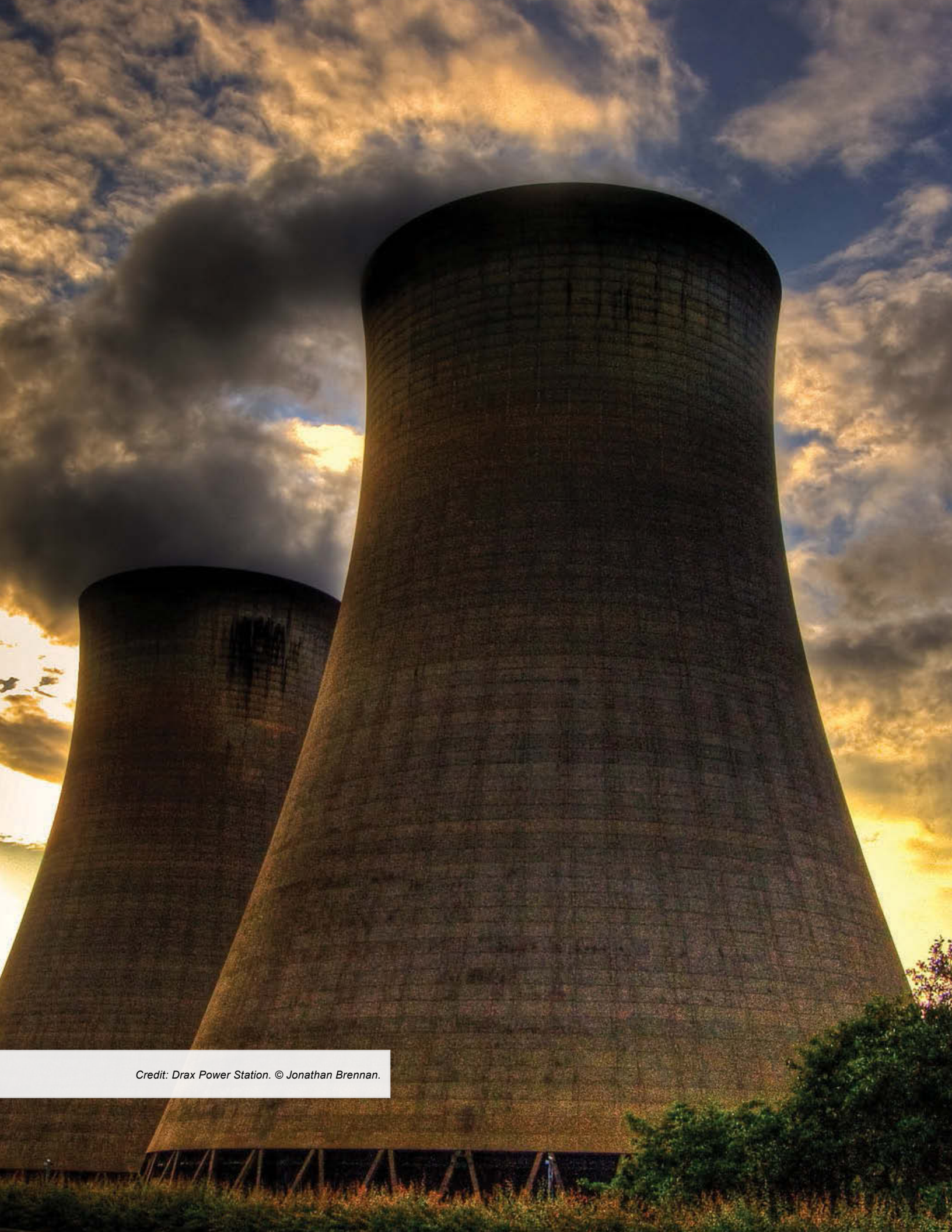
POLICY IMPLICATIONS

Through this analysis, we have provided the cost-benefit economics of repurposing as an alternate mechanism for retiring coal plants cost effectively, along with meeting renewable energy (RE) capacity addition targets. We have identified several quantitative and qualitative factors in the Indian context, which would be useful for decision-makers in selecting coal plants suitable for repurposing. Therefore, we envisage that this will be a useful guide to decision-makers in governments to develop an acceptable proposition for utilities with unprofitable stranded coal assets. As we demonstrate, there may be cases where the monetary benefits of repurposing a coal plant site for energy services far outweigh the cost of it, and this is also a solution which policymakers would find attractive given the significant environmental and social benefits these projects entail.

Further, we find that the direct repurposing benefits not only cover the decommissioning costs but also a significant fraction of the capital expenditure (CAPEX) of corresponding repurposing options. For instance, the direct repurposing benefits cover 67.30 percent of solar CAPEX, 48.36 percent of solar and battery energy storage systems (BESS) CAPEX, and 67.88 percent of solar, BESS, and SynCON CAPEX, respectively, which are expected to increase further with the lowering of solar (and BESS) CAPEX in the future. This would give the necessary fillip toward renewable energy transition in developing countries. There are several avenues for a remaining source of funds, but given the climate change impacts, climate finance sources, such as the Climate Investment Funds (CIF), could play a key role in advancing this market segment. The Inter-American Development Bank (IDB) has blended its own resources with concessional CIF resources to fund a project in Chile. The IDB is also providing technical assistance on the scale-up of low-carbon, clean technologies in these countries (IDB 2013).

FUTURE WORK

Future work may be developed along the following directions. Although our analysis has been carried out for a representative coal plant (with 1,000 MW plant capacity), the results may vary considerably for individual plants under consideration. We will need a reasonable number of case studies like the incumbent one developed for a range of plants of different size, vintage, location, etc. across several countries. Further work may investigate the optimal coal plant capacity for obtaining maximum benefits under repurposing. Other repurposing options, such as waste to energy and wind may be analyzed. Finally, coal plant/mine closure is a sensitive topic in most of the local geographies (around the thermal power plants). Therefore, the scope of a repurposing project needs to go well beyond an economic cost-benefit analysis and should include an extensive and engaging communications plan to involve the local communities, staff, labor, and so forth. The issue of employee compensation or rehabilitation may be further examined, including the impact of power plant closure on labor and local economies.



Credit: Drax Power Station. © Jonathan Brennan.

NOTES

[1] India's renewable energy targets are 175 GW RE capacity by 2022 and 40 percent generation capacity from non-fossil fuel sources by 2030 (Shrimali 2020).

[2] The Integrated Resource Plan (IRP) is regularly updated, and IRP 2019 is the latest version.

[3] Chile's overarching climate goal is a net-zero carbon target by 2050.

[4] Plant load factor (PLF) is an indicator of capacity utilization for coal-fired power plants in India.

[5] The Central Electricity Authority (CEA) of India is a statutory organization constituted under section 3(1) of Electricity Supply Act 1948, which has been superseded by section 70(1) of the Electricity Act 2003. The CEA advises the government on policy matters and formulates plans for the development of electricity systems.

[6] There are other models possible—for instance, there may be an energy service company (ESCO) model in which the RE+FLEX (flexibility) center is managed by a third party, or there is a new owner of it. There will be additional transaction costs involved in these cases, including negotiations over the salvage value of the plant, compensation, reemployment of workers, and so forth.

[7] Based on an internal report on the decommissioning of NTPC Badarapur.

[8] While we use retirement and decommissioning interchangeably, these have different meanings. When a coal plant is retired, although it stops producing electricity, its assets and equipment such as buildings, turbines, and boilers remain in place. In contrast, decommissioning, which follows the retirement of plants, entails a series of processes relating to environmental remediation, dismantlement, and restoration of the site (Raimi 2017).

[9] While this assumption may appear arbitrary, this provides a way to compare the one-time costs with lifetime costs. Of course, this calculation of lifetime costs (and benefits) would vary from plant to plant, and the 10-year assumption suffices to demonstrate our methods.

[10] In the instant case, a standard discounting approach (using arbitrary chosen discounting rates in the absence of robust data availability) could potentially deemphasize (and devalue) the economic impact of various environmental benefits (indirect), such as carbon and water benefits.

[11] OPEX margin here refers to the potential loss in notional efficiency gains when a profitable operating coal plant is repurposed. As per extant regulations, in the event of profitable operation of a coal plant, additional efficiency gains are provided by regulators due to three controllable operational parameters: heat rate, specific oil consumption, and auxiliary power consumption.

[12] In the Indian context, a contract for demolition of the plant also includes removal of scrap in its scope of work as the latter necessarily precedes the former. So, the contract value for demolition of a plant has inbuilt scrap removal costs.

[13] Ash pond is a structure constructed to dispose of coal combustion residuals, namely ash, in the case of coal plants.

[14] Remaining life here implies 10 years based on the assumption that the decommissioned coal plant would have been operational for up to 10 additional years.

[15] In the Indian context, coal plants can be divided into three categories based on ownership: state, center, and private plants (CEA 2020). Most of the coal plants beyond their economic life are either state or center. The employees at these plants can be relocated to other plants, which could prove useful for both the plants and the employees, thus avoiding significant social costs.

[16] This corresponds to 10 percent for plants which have completed their economic life (CERC, 2019).

[17] For example, in case the repurpose option is solar, this would be the ratio of solar capacity to coal capacity. For instance, for a 1,000 MW coal plant repurposed as a 254 MW solar plant, this ratio would be 0.254.

[18] It should be noted that the connection assets and transmission lines will eventually need to be replaced—no allowance for this has been made in the present analysis. This implies the transmission interconnection benefits are overstated in this case to the extent these assets will need to be replaced during the life of the repurposed plant.

[19] Net benefits have been computed after subtracting the capital cost (of repurposing a turbogenerator to a SynCON), which depends on the rating of the SynCON, system constraints, and power factor.

[20] The coal plant under reference is NTPC Badarpur, which has a total plant capacity of 705 MW, with 3 units of 95 MW each and 2 units of 110 MW each. NTPC Badarpur is chosen since it is more than 45 years old, has energy costs more than INR 4.5/kWh (i.e., US$0.06/kWh), and is regarded as one of the most polluting plants in the country (ET 2015). NTPC had declared its intention to decommission the Badarpur plant in 2018 (CEA 2018).

[21] This list is only suggestive in nature and not exhaustive. We are aware of the fact that there are some candidates on this list that are already being considered for renovation and modernization, rather than decommissioning and repurposing.

[22] Assuming an emission factor of 0.9 tons (t)/megawatt hours (MWh) and 50 to 80% capacity factor.

[23] In general, the scrap value is 10% of the initial coal CAPEX (CERC 2019).

[24] ₹ = Indian rupee. Cr. = 1 crore = 10 million.

[25] This analysis does not consider the additional benefits of plummeting tariffs of renewable energy sources which would add further to the acceptability of repurposing.

[26] US$ k/MW implies US$1,000 per megawatt.

[27] In the Indian context, the power plants can be divided into three categories based on ownership, state, center, and private plants, wherein the state and center plants are collectively referred to as public plants.

[28] The Integrated Resource Plan (IRP) is regularly updated, and IRP 2019 is the latest version.

[29] Chile's overarching climate goal is a net-zero carbon target by 2050.

[30] Plant load factor (PLF) is an indicator of capacity utilization for coal-fired power plants in India.

[31] The CEA is a statutory organization constituted under section 3(1) of the India Electricity Supply Act 1948, which has been superseded by section 70(1) of the Electricity Act 2003. The CEA advises the government on policy matters and formulates plans for the development of electricity systems.

APPENDIX A: BRIEF OVERVIEW OF THE POWER SUPPLY POSITION IN SOUTH AFRICA

South Africa is the largest producer of coal in Africa and among one of the largest coal producers in the world; its energy sector contributes about 80 percent of national greenhouse gas (GHG) emissions, of which more than 50 percent comes from fossil fuels alone (IRP 2019). *Eskom*, its state power utility, produces 95 percent of the nation's electricity, the bulk of this coming from coal-fired capacity, much of which has completed its economic life and does not comply with the environmental norms (REW 2019). The Integrated Resource Plan (IRP), instituted by the Department of Energy, Republic of South Africa in 2011, provided a road map for its future energy mix considering key factors like affordable electricity, reduction in emissions, energy security, and so forth (IRP 2019). The IRP 2019[28] envisages, addition of at least 20 gigawatt (GW) renewable energy (RE) out of a total 29 GW additional capacity by 2030 (IEA 2019), so that a major part of the country's electricity (78 GW) in 2030 came from renewable energy (52 GW) (REW 2019). As part of the IRP 2019, *Eskom* is expected to decommission about 5 GW of its coal-fired capacity by 2022, 10 GW by 2030, and 35 GW by 2050.

Due to environmental concerns, South African coal utilities are finding it increasing difficult to source funds, while RE projects are easily drawing funds at much cheaper rates (IEEFA 2019b). The South African power sector faces several challenges as the country looks to support and sustain its economic growth, manage energy costs, and meet increasingly ambitious environmental targets. These challenges can be successfully addressed if it turns to repurpose its coal plants toward renewable energy–based options. The generation capacity of South Africa from different sources is shown in Table A.1.

TABLE A.1: GENERATION CAPACITY AND SOURCES: SOUTH AFRICA

SOURCE	GENERATION CAPACITY (MW)
Thermal (including coal)	46,776
Hydroelectric	661
Renewables	3,872
Total	51,309

Source: USAID 2020.

APPENDIX B: BRIEF OVERVIEW OF THE POWER SUPPLY POSITION IN CHILE

Chile is one of the highest fossil carbon dioxide (CO_2) emissions per capita in Latin America (Statista 2020), ranking higher than several European countries. Like South Africa, Chile is currently formulating a new Climate Change Framework Law with an objective to, among other things, achieve Chile's greenhouse gases (GHG) neutrality in 2050 (CAT 2020). However, like many other developing countries, Chile also has a significant coal-based electricity supply (40%) and phasing out of coal capacity along with increasing the share of renewable energy (RE) would play a significant role in attainment of its climate goals.[29] By 2019, Chile had achieved a 21 percent RE share in total generation capacity of the country, with a bulk of it coming from solar photovoltaic (PV) (49%) and wind (31%) (ReNow 2019). Chile has already announced plans for shutting down some of its coal plants to limit the coal-fired capacity to 20 percent by 2024 and complete phaseout by 2040; as well as increasing the share from RE generation to 59 percent by 2024 and 70 percent by 2040 (CAT 2020). In 2018, the Chilean government signed an agreement with its four largest utilities, AES Gener, Colbun, Enel, and Engie, to close their coal-based power plants voluntarily and gradually without carbon capture and storage technology (IEEFA 2019c), resulting in the utilities embarking on an asset rotation plan for replacing coal plants with new RE plants (IEEFA 2019d).

APPENDIX C: BRIEF OVERVIEW OF THE POWER SUPPLY POSITION IN INDIA

Today, India is at a crossroads in terms of increasingly unremunerative, old, and polluting coal plants on one hand and ambitious renewable energy (RE) targets on the other, specifically, 175 gigawatt (GW) renewable energy (RE) capacity by 2022 and 40 percent generation capacity from non-fossil fuel sources by 2030 (Shrimal, 2020). There is an overwhelming dominance of fossil fuels in power generation, with as much as 50 to 55 percent of total installed generation capacity under coal plants producing more than 65 percent of total electricity generated (MOP 2020). Table C.1 presents mode wise installed capacity in India as of March 6, 2020.

TABLE C.1: MODE WISE INSTALLED CAPACITY: INDIA

MODE	MEGAWATTS (MW)	PERCENTAGE OF TOTAL (%)
Total Thermal	230,906	62.2
Coal	198,525	53.6
Lignite	6,610	1.8
Gas	24,992	6.7
Oil	510	0.1
Hydropower (renewable)	45,699	12.3
Nuclear	6,780	1.8
Renewable Energy Sources	87,669	23.6
Total	**371,054**	**100.0**

Source: Ministry of Power 2020.

In line with the needs of a growing economy, India's energy demand and peak demand have grown sharply during the period 2009–2019 (Table C.2). Despite this, the average plant load factor (PLF)[30] of coal-fired plants, an indicator of capacity utilization, has seen a steady decline from 77.5 percent in 2009 to 56.1 percent in 2019–2020. Interestingly, India's energy and peak deficits have declined, which means that the dependence on coal has reduced as energy needs are being increasingly met from other cheaper energy sources including renewable energy (PWC 2019). In addition to cheaper RE, increasing environmental concerns and the secular decline in capacity utilization of coal plants over the last decade have rendered the plants uneconomical as well as unprofitable (Shrimali 2020). Therefore, a need for early retirement of coal plants is being felt, and repurposing allows such stranded assets to derive potential value and provides an exit strategy to utilities.

TABLE C.2: OVERVIEW OF THE POWER SUPPLY POSITION IN INDIA

YEAR	PLANT LOAD FACTOR–COAL PLANTS (%)	ENERGY DEMAND (MU)*	PEAK DEMAND (MW)	ALL INDIA ENERGY DEFICIT (%)	ALL INDIA PEAK DEFICIT (%)
2009–10	77.5	830,594	119,166	10.1	12.7
2010–11	75.1	861,591	122,287	8.5	9.8
2011–12	73.3	937,199	130,006	8.5	10.6
2012–13	69.9	995,557	135,453	8.7	9.0
2013–14	65.6	1,002,257	135,918	4.2	4.5
2014–15	64.5	1,068,923	148,166	3.6	4.7
2015–16	62.3	1,114,408	153,366	2.1	3.2
2016–17	59.9	1,142,929	159,542	0.7	1.6
2017–18	60.7	1,213,326	164,066	0.7	2.0
2018–19	61.1	1,274,595	177,022	0.6	0.8
2019–20	56.1	1,290,247	183,804	0.5	0.7

Source: Ministry of Power 2020.

Note: *MU = million unit (1 MU = 1,000 megawatt hours [MWh] = 1 gigawatt hour [GWh]).

The policy impetus in India appears to be in favor of replacing old and inefficient units by larger efficient units at a rapid pace (CEA 2015). In 2016, the Central Electricity Authority (CEA)[31] identified approximately 9,000 MW coal-based thermal power plants capacity for retirement/replacement by new super-critical units on this basis of age (more than 25 years old) and uneconomic operation (CEA 2017). This not only decelerates the replacement of coal-based generation by cheaper and greener renewable energy options, but also gives rebirth to increased carbonization, albeit through new and less polluting plants.

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