REPORT

Financial benefits of repurposing Tamil Nadu's old coal plants

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01 List of abbreviations

BESS	Battery Energy Storage System
CAPEX	Capital Expenditure
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CO_2	Carbon Dioxide
SOx, NOx	Oxides of Sulphur and Nitrogen, respectively
GW	Gigawatt
HRS	Hours
INR	Indian Rupee (currency)
kWh	Kilowatt Hour
MoP	Ministry of Power
MW	Megawatt
MRPL	Mangalore Refinery and Petrochemicals Limited
NREL	National Renewable Energy Laboratory
O&M	Operation and Maintenance
PLF	Plant Load Factor
PV	Photovoltaic (solar)
RE	Renewable Energy
SynCON	Synchronous Condenser
TANGEDCO	Tamil Nadu Generation & Distribution Corporation

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In Tamil Nadu, coal plants totaling 3,990 MW in capacity are operating beyond their economic lives. The central government has advocated that such power plants be shut down in the interests of improving air quality.[1] Based on a notification from Ministry of Environment Forest and Climate Change, by 2024, these plants either need to be retrofitted with pollution control equipment or be shut down.[2] The former is going to be costly: based on CEA estimates, pollution control retrofits for these plants would cost around ₹2,000 CR.

On the other hand, Tamil Nadu's finances are in the red, with fiscal deficit and public sector debt growing to 3.26% and 36%, respectively, of GDP. The electricity sector is the prime contributor to this crisis: In FY 2021, 90% of outstanding government guarantees were due to the power sector. TANGEDCO and TANTRANSCO are significant contributors to the state's debt burden, with TANGEDCO's total debt at ₹1,34,119.94 CR on March 31, 2021,[3] and a net loss of ₹32,553 CR in FY 2021. Interest cost is now TANGEDCO's biggest cost item, totaling over ₹11,000 CR in FY 2021. Given this background, incurring significant new capex on old units would not be financially wise.

Furthermore, given variable costs ranging from ₹3.3 to ₹4.4 per unit, these coal plants are no longer cost-competitive compared to new renewable energy. So, rather than incurring significant capital expenditure on retrofitting old, inefficient and polluting coal plants, Climate Risk Horizons (CRH) had calculated that retiring TN's old coal plants and replacing their planned generation with renewable energy would save TANGEDCO ₹9,000 CR over 5 years in terms of reduced power purchase costs.[4]

This analysis suggests that the financial benefits could be even larger if these old coal plants are not only decommissioned but also repurposed by using the coal plant lands and facilities for solar PV, battery storage and grid stabilization services.

This analysis of four coal plants—Tuticorin, Mettur, North Chennai, and Neyveli—is the first attempt to enumerate the financial benefits that such coal plant repurposing would bring. It finds that the financial benefits of repurposing would far outweigh the costs of decommissioning the plants. Further, the benefits alone could cover a significant portion of CAPEX for repurposing options.

Three options for repurposing were assessed in this analysis: 1) solar PV, 2) solar PV with battery storage (for providing flexibility), and 3) solar PV with battery storage and a synchronous condenser (to provide reactive power). The synchronous condenser would essentially repurpose the turbogenerator from the old coal plant.

While the table below provides costs and benefits from individual plants, the key findings from this analysis are as follows:

1. The financial benefits of repurposing these coal plants would be 2–3 times the costs of decommissioning.

2. Total decommissioning costs for the 4 plants assessed was approximately ₹1,300 CR, while the benefits from repurposing for solar PV with battery storage would be ₹2400 CR.

3. While repurposing coal plant for solar PV and battery storage, if the old power plant turbogenerator is also repurposed to serve as a synchronous condenser (SynCon), the benefits are even more significant at nearly ₹4,000 CR.

4. In contrast, the estimated capex for solar+battery+SynCon needed to deliver this benefit is about ₹2,500 CR. in total across all 4 plants.

5. The financial benefits will cover between 60% to over 300% of new CAPEX required, depending on which repurposing option is chosen. That is, in the worst case, a significant percentage of the cost of repurposing can be covered by the benefits provided by repurposing. In the best case, the benefits far exceed the CAPEX required.

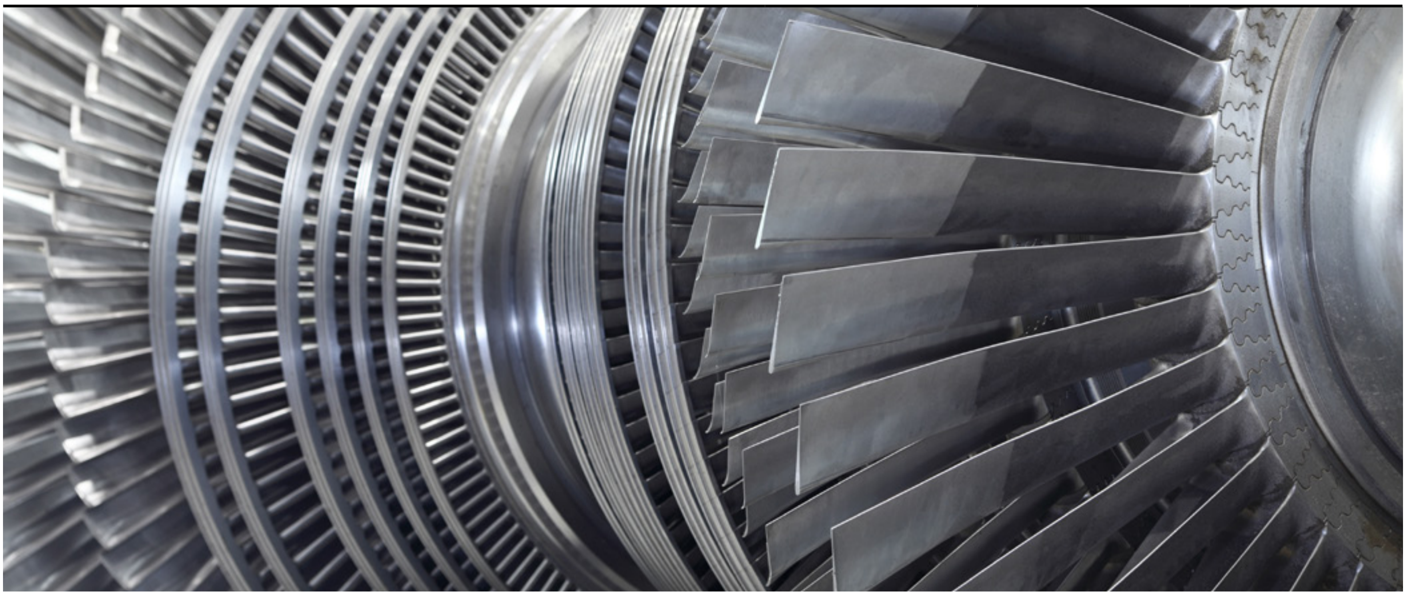
6. Utilizing the pre-existing land and grid connection facilities would result in a significantly reduced cost for the power generated—a 48% and 40% reduction, respectively, for standalone solar and solar with battery storage respectively. This would bring the Levelised Cost of Energy down to ₹1.42 and ₹2.33 per unit respectively, providing TANGEDCO with a cheap source of flexible power.

7. Repurposing the plants and their associated ash ponds for solar and battery storage would yield capacities of 348 MW of solar and 36 MW of 4-hour battery storage.

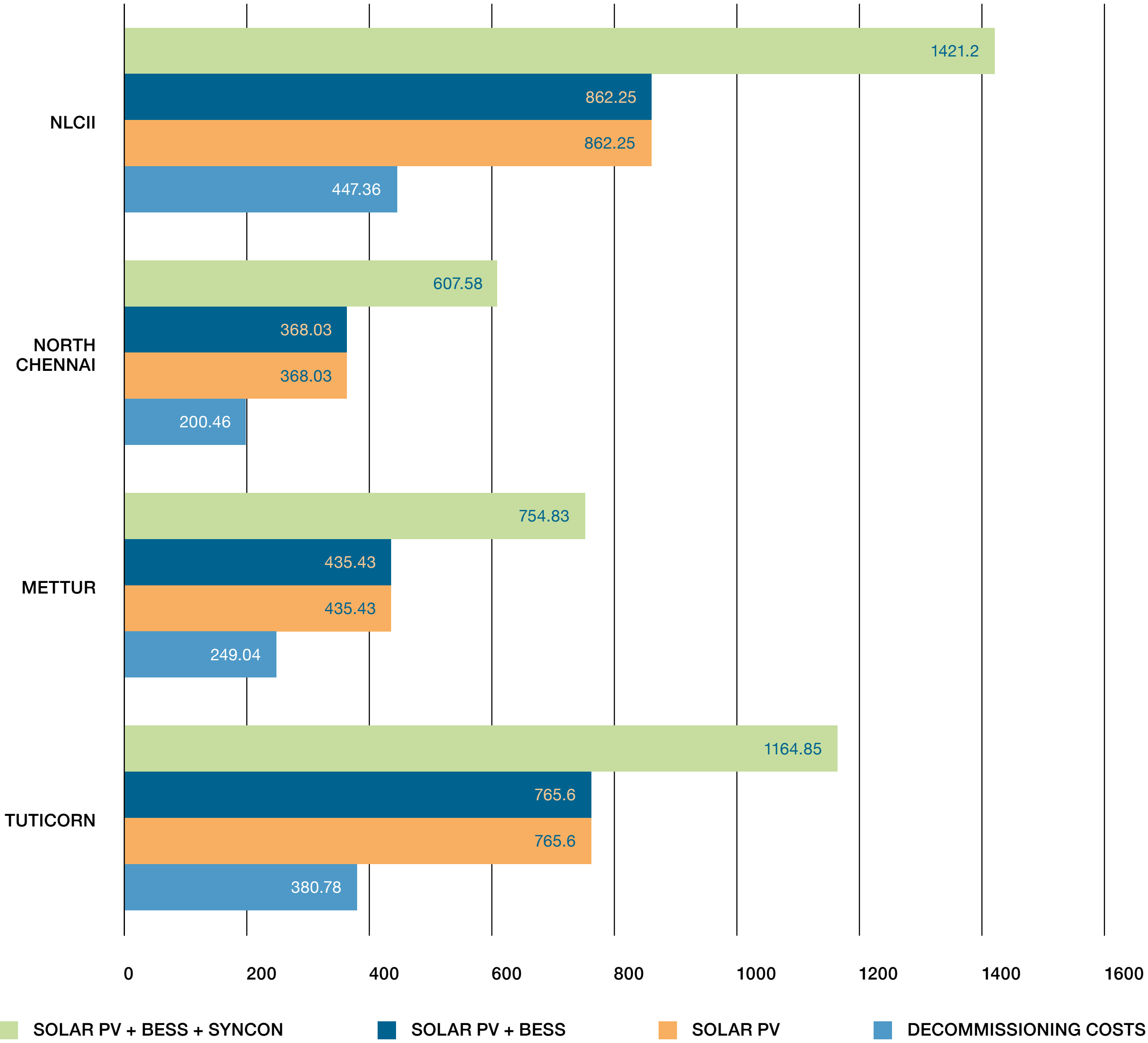
PLANT SPECIFIC SUMMARY TABLES (COSTS & BENEFITS) (INR CR)

		Benefits (INR CR)			
Plant	**Decommissioning Costs**	**SPV + BESS (Ash Pond only)**	**SPV + BESS + SynCon (Ash Pond only)**	**Entire Plant Area**	**As % of Capex (SPV + BESS + SynCon)***
Tuticorin Stage I, II & III (1050 MW)	380	765	1164	1266	92%
Mettur I & II (840 MW)	249	435	754	815	372%
North Chennai Stage I (630 MW)	200	368	607	657	168%
Neyveli II Stage I & II (1470 MW)	447	862	1421	1563	210%

**Including scrap value from decommissioned plant*



REPURPOSING BENEFITS FOR FOUR TN COAL PLANTS (ASH POND AREA ONLY)



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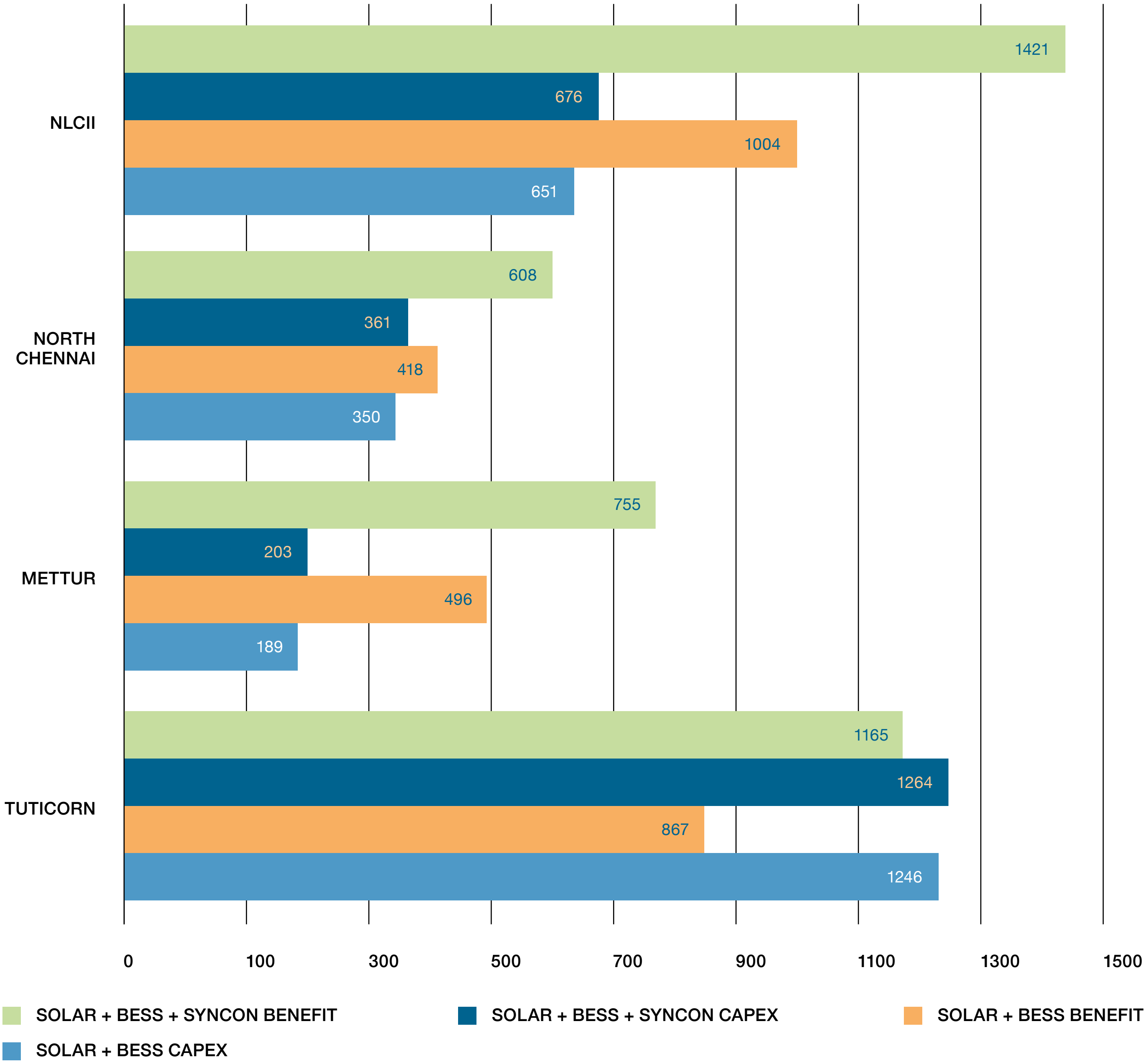
Clearly, there are significant financial benefits for the state of Tamil Nadu that would accrue from shutting down and repurposing its old coal plants. As the state grapples with the problems facing its electricity sector, shutting down and repurposing its old coal plants must be a key part of the discussion.

REPURPOSING: CAPEX NEEDED VS. BENEFITS DELIVERED (ASH POND AREA ONLY)



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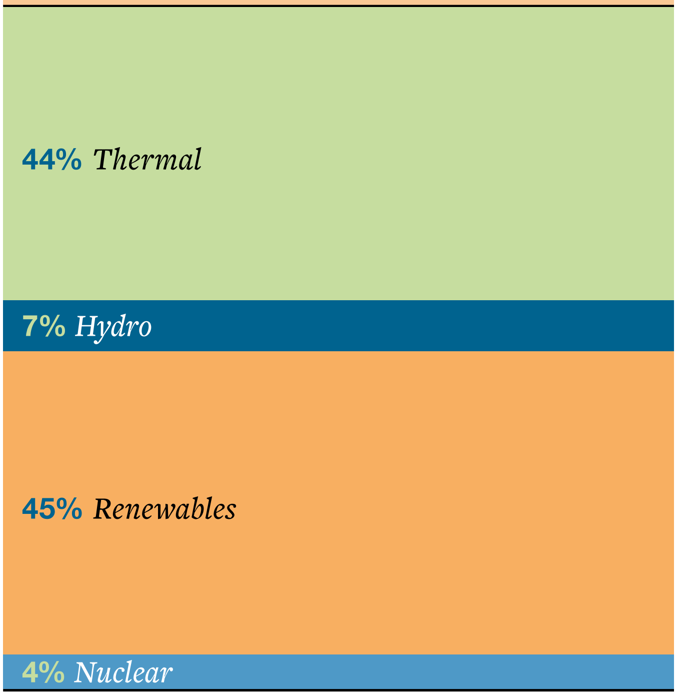
05 Overview of the power scenario in Tamil Nadu

Tamil Nadu has played a central and visionary role in the transformation of the power system and in the deployment of renewable energy (RE) resources. The state has been an early adopter in installing wind farms (as early as 1990s) and currently accounts for a quarter of India's installed capacity. The state also has an ambitious solar energy (PV) target of 9 GW by 2023. As of May 2021, TN's installed capacity for renewable energy stands at 15,250 MW, i.e., at 44% of the total installed capacity of the state.

By 2021, Tamil Nadu had surplus generation capacity, with the thermal fleet operating at PLFs of 55% to 65%

FIGURE 1: TAMIL NADU (INSTALLED CAPACITIES IN GW AS ON 31.05.2021)



Source: Created by the authors from public data sources

An acute power crisis in 2009 led the state to issue Letter of Facilitation to private parties to setup total 18,140 MW of coal power plants (Narayanan, 2019). Around the same time, necessitated by the Electricity Act of 2003, the Tamil Nadu Electricity Board (TNEB) was unbundled into TANGEDCO (for generation and distribution) and TANTRANSCO (for transmission). Also, in 2011, electricity was major poll issue in the assembly elections. By 2016, Tamil Nadu had been declared a power surplus state and by 2021, Tamil Nadu had doubled its installed capacity even as several of proposed projects had been cancelled.

By 2021, there was surplus generation capacity available in Tamil Nadu. The thermal fleet largely suffers from low plant load factors (PLFs) hovering around 55% to 65% combined across the public and private sector. Even during peak load months, there has been significant unused thermal generation capacity with PLFs of private generators ranging from 41.4% to 53.5%, while that of central and state thermal plants has been between 73% and 81% (Fernandes and Sharma, 2020). During 2020, the average PLF of coal plants in Tamil Nadu was barely 56.05% precariously close to the 55% technical minimum levels for coal plant operation, down from 60% in 2019.

In such a scenario of underutilized thermal generation, coal plant repurposing can yield substantial financial and social benefits. The report 'TANGEDCO's Recipe for Recovery' by Fernandes and Sharma (2020) illustrates that an accelerated shut down of plants 20 years and older in Tamil Nadu can yield savings of approximately Rs. 9000 Crores over a period of five years. These savings accrue in terms of avoided retrofit costs for Flue Gas Desulphurisers, Low Nox Burners and replacement of expensive scheduled dispatch of older plants with new renewable energy or from the power exchange.

For Tamil Nadu, a state with significant coal capacity struggling due to age, low capacity utilization levels, reduced profitability and growing environmental concerns, it would be advisable to explore means to wean away from coal. One such approach includes repurposing coal plants for various productive end uses ranging from solar and wind plants to datacenters and ecological parks. Retirement of such coal plants can be better rationalized with clear empirical estimation of costs and benefits incurred in a simple decommissioning of plants vis-à-vis repurposing them, which we attempt in this report.

In this study, we propose an additional component to the shutdown of Tamil Nadu's old coal plants, i.e. repurposing the existing coal assets to a combination of (i) solar PV, (ii) battery storage energy systems (BESS), and (iii) synchronous condenser (SynCON). A plant level analysis is provided illustrating the costs of decommissioning and the benefits of repurposing each plant for these repurposing options. We then try to establish the utility of repurposing over plain decommissioning for these coal plants in favor of a combination of repurposing options. In line with Fernandes and Sharma (2020), the following four plants have been analyzed for repurposing:

- Tuticorin Thermal Power Station Stages I, II & III (1050 MW)
- Mettur Thermal Power Station Stages I & II (840 MW)
- North Chennai Thermal Power Station Stage I (630 MW)
- Neyveli Thermal Power Station II, Stages I & II (1470 MW)

Tuticorin Thermal Power Station (TTPS) Stages I, II & III (1050 MW)

Tuticorin Thermal Power Station, situated in Thoothukudi, Tamil Nadu, on the sea shore of Bay of Bengal has 5 units each of 210 MW, totaling an installed capacity of 1050 MW. It is owned by Tamil Nadu Generation and Distribution Corporation Limited (TANGEDCO), a state-owned utility. The coal required is transported from coal fields of Orissa, Bengal and Bihar. Coal is transported through rail from these coal fields to the Ports of Haldia, Paradip and Vizag and from these Ports, coal is transported to TTPS through ships and unloaded at Tuticorin Port (TANGEDCO, 2021).

Water is sourced from Thamiraparani river. The plant is operated as three stages—Stage I (consisting of 2 units of 210 MW), Stage II (consisting of 1 unit of 210 MW) and Stage III (consisting of 2 units of 210 MW). All these units are vintage with an average age of about 36 years and Unit 1 being as old as 42 years old. Table 1 provides a brief overview of key characteristics of the plant:

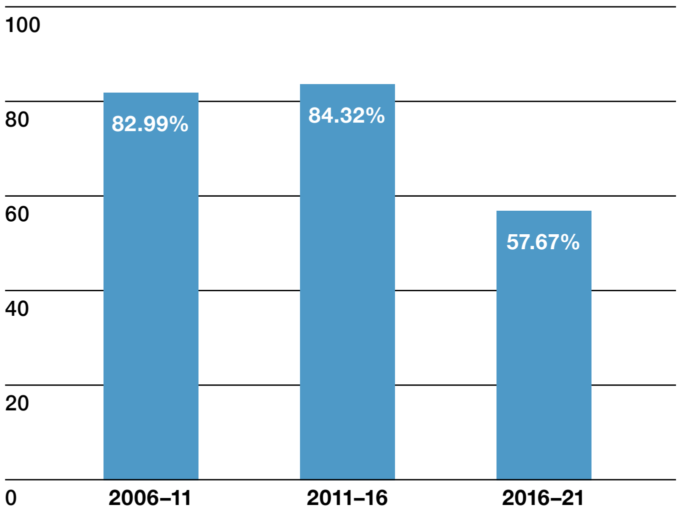
TABLE 1: PLANT CHARACTERISTICS OF TUTICORIN TPS STAGES I, II & III

Stage	Capacity	Units	Age* (in years)	Project cost** (INR CR)	PLF (%)†	ECR (INR/Kwh)
Stage I	2 X 210 MW	I, II	42, 40	1164	44.9%	4.44
Stage II	1 X 210 MW	III	39	754	44.9%	4.44
Stage III	2 X 210 MW	IV, V	29, 30	1421	44.9%	4.44

** As on 01.07.2021.*
*** The project cost estimates are dated as per the date of commissioning (commercial operation declaration COD) of the respective unit.*
† For FY 20–21.

The average plant load factor is shown in the chart below (see Figure 2). As evident from the chart the average PLF of TTPS has seen a continuous sharp decline from 83% in 2006–11 to 57.67% in 2016–21. At present, the PLFs of these units are hovering perilously close to the technical minimum levels (MTL) prescribed by Central Electricity Authority (CEA),[5] Government of India.

FIGURE 2: AVERAGE PLANT LOAD FACTOR (PLF), TUTICORIN TPS



Source: Created by authors from public data sources

Mettur Thermal Power Station Stages I & II (840 MW)

Mettur Thermal Power Station (MTPS) is located in Salem District of Tamil Nadu and is the first inland thermal Power Station of TANGEDCO established in the year 1987. Overall the station is operated under 3 stages. Stage I and II each have 2 units of 210 MW capacity each, totalling 840 MW. Stage III has 1 unit of 600MW, bringing the total installed capacity of the plant to 1440 MW. Coal for the station is sourced from Mahanadi Coal fields Ltd. (Talchar & IB Valley), Orissa, Eastern coal fields Limited, Ranikanj, West Bengal.

Stage I and II units are vintage with an average age of about 33 years and Unit 1 being as old as 34 years old. Table 2 provides a brief overview of key characteristics of the plant:

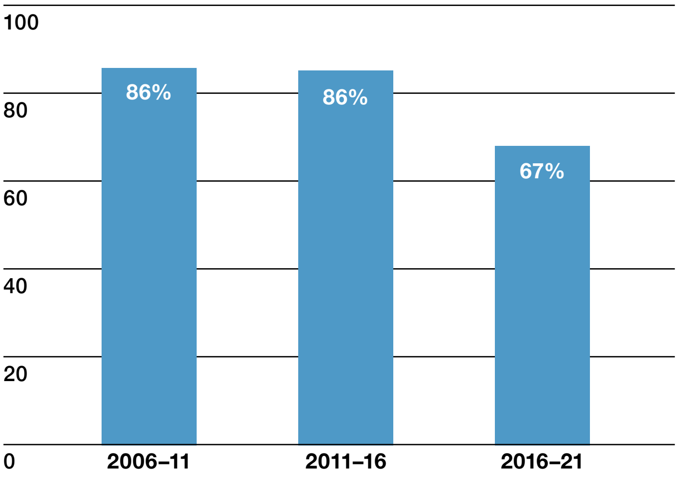
TABLE 2: PLANT CHARACTERISTICS OF METTUR TPS STAGE I & II

Stage	Capacity	Units	Age* (in years)	Project cost** (INR CR)	PLF (%)†	ECR (INR/Kwh)
Stage I	2 X 210 MW	I, II	34 (Unit I) 34 (Unit II)	384.30	48.16%	4.07
Stage II	2 X 210 MW	III, IV	32 (Unit III) 31 (Unit IV)	351.76		

** As on 01.07.2021.*
*** The project cost estimates are dated as per the date of commissioning (commercial operation declaration COD) of the respective unit.*
† For FY 20–21.

The average plant load factor is shown in the chart below (see Figure 3). As evident from the chart the average PLF of Mettur TPS has seen a continuous rapid decline from 86% in 2006–11 to 67% in 2016–21.

FIGURE 3: AVERAGE PLANT LOAD FACTOR (PLF) METTUR TPS STAGE I & II



Source: Created by authors from public data sources

North Chennai Thermal Power Station Stage I (630 MW)

North Chennai Thermal Power Station (North Chennai TPS) is located in Thiruvallur district of Tamil Nadu about 25 kilometer from Chennai city and is among the major power houses of Tamil Nadu-owned and operated by TANGEDCO. Overall the plant is operated under 2 stages wherein 3 units of 210 MW capacity each under Stage I were commissioned between 1994–1996 and 2 units of 600 MW each under Stage II were commissioned in 2013. The total installed capacity of the station is 1830 MW. One unit of 800 MW capacity under Stage III is under construction. Coal for the station is sourced from Mahanadi Coalfields Limited (through Talcher and IB Valley coal mines in Odisha), and Eastern coal fields Limited (through Ranikanj in West Bengal). As with other Tamil Nadu plants discussed above, these units are also vintage with an average age of about 26 years. Table 3 provides a brief overview of key characteristics of the plant:

TABLE 3: PLANT CHARACTERISTICS OF NORTH CHENNAI TPS STAGE I

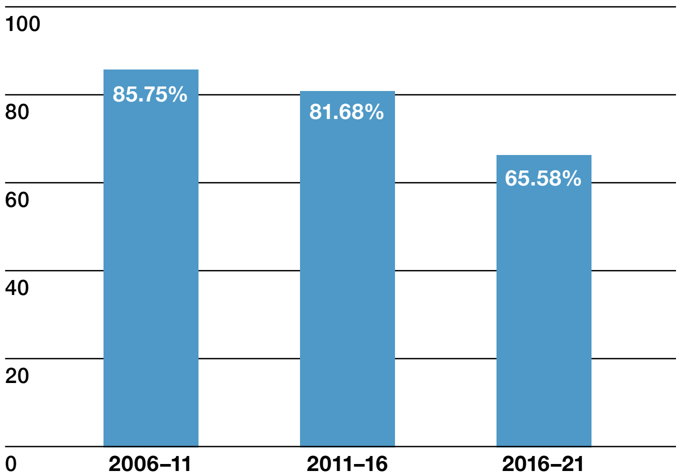
Stage	Capacity	Units	Age* (in years)	Project cost** (INR CR)	PLF (%)†	ECR (INR/Kwh)
Stage I	3 X 210 MW	I, II, III	27 (Unit I) 26 (Unit II) 25 (Unit III)	1568	40.29%	3.33

** As on 01.07.2021.*
*** The project cost estimates are dated as per the date of commissioning (commercial operation declaration COD) of the respective unit.*
† For FY 20–21.

The average PLF of North Chennai TPS Stage U has declined from 85% in 2006–11 to 65% in 2016-21

The average PLF is shown in the chart below (see Figure 4). As evident from the chart the average PLF of North Chennai TPS Stage I has seen a continuous decline from 85.75% in 2006–11 to 65.58% in 2016–21. Recent PLFs for 2020–21 are unsustainable as they are way below the MTL limits.

FIGURE 4: AVERAGE PLANT LOAD FACTOR (PLF): NORTH CHENNAI TPS STAGE I



Source: Created by authors from public data sources

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Neyveli Thermal Power Station II, Stage I & II (1470 MW)

Owned and operated by Neyveli Corporation Limited (NCL), Neyveli Thermal Power Station II (NLC TPS II) is a pithead station located at Neyveli village in Cuddalore district of Tamil Nadu. The plant is operated under 2 stages with 3 units of 210 MW capacity each under Stage I commissioned between 1986–1988 and 4 units with same capacity each under Stage II commissioned between 1991 to 1993. The total installated capacity of the plant is 1470 MW. After capacity expansion of TPS II, two units of 250 MW capacity each were added to the fleet commissioned during 2015.

As with other Tamil Nadu plants discussed above, these units are also vintage with an average age of about 31 years. Table 4 provides a brief overview of key characteristics of the plant:

TABLE 4: PLANT CHARACTERISTICS OF NLC TPS II STAGE I & II

Stage	Capacity	Units	Age* (in years)	Project cost** (INR CR)	PLF (%)†	ECR (INR/Kwh)
Stage I	3 X 210 MW	I, II, III	35 (Unit I) 34 (Unit II) 33 (Unit III)	556.75	54.01	3.36
Stage II	4 X 210 MW	IV, V, VI, VII	30 (Unit IV) 29 (Unit V) 28 (Unit VI) 28 (Unit VII)	1445.52		

** As on 01.07.2021.*
*** The project cost estimates are dated as per the date of commissioning (commercial operation declaration COD) of the respective unit.*
† For FY 20–21.

06 Results and discussion: plant-wise

In this section, we first present the results for estimated costs associated with decommissioning of older units of four Tamil Nadu Thermal Power Plants (TPPs). Next, we present the benefits arising out of repurposing these coal plants options under two scenarios (first considering ash pond land only and second considering entire coal plant area which includes ash pond). For this analysis, the repurposing options considered are a combination of 1) solar PV, 2) battery energy storage systems (BESS), 3) Synchronous condenser (SynCON). The repurposing benefits under scrap value, land and equipment reutilization including remediation benefits shall be realized as one-time benefits while addition of system balancing through SynCON shall be realized as lifetime (10 years) benefits.

Note that both the estimated costs of decommissioning and benefits of repurposing are in present value terms and could be compared with the Capital expenditure (CAPEX) of new coal plant or RE-solar, BESS, SynCON.

Tuticorin Thermal Power Station Stage I, II & III (1050 MW)

Table 5 shows the estimated cost of decommissioning of all 5 units (1050 MW) of Tuticorin TPS which have already completed their useful economic life (29–42 years). Taking into the consideration of different types of decommissioning costs discussed in methodology section, the total cost implication of decommissioning Tuticorin TPS Stage I, II and III (1050 MW) is estimated at ₹380.78 CR.

Note these are direct costs and incurred over the time period of decommissioning (usually 12–18 months). As it can be seen from the table below, the major chunk of decommissioning cost of ₹177.43 CR is incurred under station overheads followed by ₹77.02 CR under coal combustion residuals cleanup. The former is incurred from shut down till the units are fully decommissioned and the latter is part of environmental remediation needed for coal bearing areas within the plant.

TABLE 5: COSTS OF DECOMMISSIONING TUTICORIN TPS STAGE I, II & III

Sl. No.	Item		Tuticorin TPS (Stage I, II & III): 1050 MW	
			Million $	INR CR
1	**Decommissioning costs (i + ii + iii)**		36.91	258.35
	i	Employee costs	7.47	52.26
	ii	Station overheads	25.35	177.43
	iii	O&M expenses	4.10	28.67
2	**Pre-demolition costs: environmental remediation (asbestos cleanup)**		0.09	0.66
3	**Demolition costs (including scrap removal)**		4.25	29.77
4	**Coal combustion residuals**		11.00	77.02
5	**Coal storage area cleanup**		2.14	14.98
	Direct (total) decommissioning costs		**54.40**	**380.78**

Source: Compiled by the authors
Note: O&M = operation and maintenance

Analyzing the benefits of repurposing, the corresponding indented benefit in monetary terms arising out from leveraging ash pond land area (889 acres) only of TPP for repurposing option with solar PV, as well as solar PV in combination with BESS comes out to ₹765.60 CR. With additional system balancing with SynCON (which delivers reactive power) in combination with solar and BESS, the estimated net benefit (after deducting the cost of conversion of a turbogenerator to a SynCON) accrues to ₹1164.85 CR (refer Table 6). Note that for the first two repurposing options i.e., (i) Solar PV and (ii) Solar PV plus BESS, all benefits accrued are direct and one-time whereas for the last repurposing option i.e., (iii) Solar PV plus BESS plus SynCON, the SynCON benefits are indirect and for the lifetime (i.e., 10 years)[6].

TABLE 6: BENEFITS OF REPURPOSING (ASH POND LAND ONLY) FOR TUTICORIN TPS (STAGE I, II & III)

SL. No.	Item	Tuticorin TPS (Stage I, II & III): 1050 MW			
		Million $		INR CR	
		One time	Lifetime	One time	Lifetime
1	**Scrap value**	69.35		485.46	
2	**Land utilization**	6.35		44.46	
3	**Equipment (switchyard, substation)**	11.49		80.41	
4	**Remediation benefits**	11.00		77.02	
5	**Transmission and interconnection evacuation**	11.18		78.25	
Direct (plant-specific) benefits: solar PV		**109.37**		**765.60**	
Direct (plant-specific) benefits: solar PV + BESS		**109.37**		**765.60**	
6	**System balancing (reactive power) benefits (net)**		57.04		399.25
Direct (plant-specific) benefits: Solar PV + BESS + SynCON			**166.41**		**1164.85**

Source: Compiled by the authors

Examining the repurposing option on the entire plant land area, the net benefit with solar PV alone as well as solar PV in combination with BESS would increase from ₹765.60 CR to ₹867.27 CR whereas with additional system balancing (i.e., solar PV, BESS and SynCON) the net benefit accrues to ₹1266.53 CR, a jump of approx. ₹100 CR over and above that from utilizing ash pond land only (refer Table 7). Clearly, there are diminishing returns for each of the repurposing options in case the entire coal plant land is considered for repurposing.

TABLE 7: BENEFITS OF REPURPOSING (ENTIRE COAL PLANT LAND) FOR TUTICORIN TPS (STAGE I, II & III)

SL. No.	Item	Tuticorin TPS (Stage I, II & III): 1050 MW			
		Million $		INR CR	
		One time	Lifetime	One time	Lifetime
1	**Scrap value**	68.84		481.89	
2	**Land utilization**	9.17		64.22	
3	**Equipment (switchyard, substation)**	16.59		116.14	
4	**Remediation benefits**	13.14		92.00	
5	**Transmission and interconnection evacuation**	16.15		113.03	
Direct (plant-specific) benefits: solar PV		**123.90**		**867.27**	
Direct (plant-specific) benefits: solar PV + BESS		**123.90**		**867.27**	
6	**System balancing (reactive power) benefits (net)**		57.04		399.25
Direct (plant-specific) benefits: Solar PV + BESS + SynCON			**180.93**		**1266.53**

Source: Compiled by the authors

Mettur Thermal Power Station Stage I & II (840 MW)

Table 8 shows the estimated cost of decommissioning of all four units (840 MW) of Mettur Thermal Power Station Stage I & II which have already completed their useful economic life (31–34 years). The analysis reveals that the total direct cost implication of decommissioning all old units of the station would be around ₹249.04 CR with station overheads taking up the major chunk of ₹141.94 CR followed by employee costs, demolition costs and O&M expenses in that order.

We observe that, all the decommissioning cost components have reduced for Mettur Plant vis-à-vis Tuticorin Plant. The same is largely attributed to reduced plant capacity for Mettur TPS (840 MW) in comparison to Tuticorin (1050 MW) TPS. However, the reduction in station overheads is less remarkable due to the fixed nature of expenses incurred regardless of unit size (capacity).

TABLE 8: COSTS OF DECOMMISSIONING METTUR TPS STAGE I & II

Sl. No.	Item		Mettur TPS (Stage I & II): 840 MW	
			Million $	INR CR
1	**Decommissioning costs (i + ii + iii)**		29.53	206.68
	i	Employee costs	5.97	41.81
	ii	Station overheads	20.28	141.94
	iii	O&M expenses	3.28	22.93
2	**Pre-demolition costs: environmental remediation (asbestos cleanup)**		0.08	0.53
3	**Demolition costs (including scrap removal)**		3.40	23.81
4	**Coal combustion residuals**		1.64	11.50
5	**Coal storage area cleanup**		0.93	6.51
	Direct (total) decommissioning costs		**35.58**	**249.04**

Source: Compiled by the authors

Note: O&M = operation and maintenance

When Mettur plant is considered for repurposing on ash pond land only, the indented benefit comes out to be ₹435.43 CR with solar PV alone as well as for a combination of solar PV with BESS with scrap value making up for the bulk of benefits i.e., ₹393.6 CR of benefit realization. With the combination of SynCON with solar PV and BESS, an additional benefit of ₹319.40 CR can be realized taking the net benefit to ₹754.83 CR (refer Table 9). Note that the SynCON benefits estimated here are over a lifetime (i.e., for 10 years) whereas all other benefits are direct and one-time in nature.

TABLE 9: BENEFITS OF REPURPOSING OPTIONS (ASH POND LAND ONLY) FOR METTUR TPS STAGE I & II

Sl. No.	Item	Mettur TPS (Stage I & II): 840 MW			
		Million $		INR CR	
		One time	Lifetime	One time	Lifetime
1	**Scrap value**	56.23		393.60	
2	**Land utilization**	0.95		6.64	
3	**Equipment (switchyard, substation)**	1.72		12.01	
4	**Remediation benefits**	1.64		11.50	
5	**Transmission and interconnection evacuation**	1.67		11.69	
Direct (plant-specific) benefits: solar PV		**62.20**		**435.43**	
Direct (plant-specific) benefits: solar PV + BESS		**62.20**		**435.43**	
6	**System balancing (reactive power) benefits (net)**		45.63		319.40
Direct (plant-specific) benefits: Solar PV + BESS + SynCON			**107.83**		**754.83**

Source: Compiled by the authors

With entire plant of Mettur TPS land area is considered for repurposing, the net benefit with solar PV alone as well as solar PV in combination with BESS is pegged at ₹496.57 CR. When these are combined with SynCON, the net benefits accrued increase to ₹815.97 CR (refer Table 10).

TABLE 10: BENEFITS OF REPURPOSING OPTIONS (ENTIRE COAL PLANT LAND) FOR METTUR TPS STAGE I & II

Sl. No.	Item	Mettur TPS (Stage I & II): 840 MW			
		Million $		INR CR	
		One time	Lifetime	One time	Lifetime
1	**Scrap value**	55.91		391.35	
2	**Land utilization**	2.73		19.09	
3	**Equipment (switchyard, substation)**	4.93		34.52	
4	**Remediation benefits**	2.57		18.01	
5	**Transmission and interconnection evacuation**	4.80		33.60	
Direct (plant-specific) benefits: solar PV		**70.94**		**496.57**	
Direct (plant-specific) benefits: solar PV + BESS		**70.94**		**496.57**	
6	**System balancing (reactive power) benefits (net)**		45.63		319.40
Direct (plant-specific) benefits: Solar PV + BESS + SynCON			**116.57**		**815.97**

Source: Compiled by the authors

Among the plants analysed, decommissioning cost estimates are lowest for North Chennai TPS Stage I

North Chennai Thermal Power Station Stage I (630 MW)

Table 11 shows the estimated cost of decommissioning of all 3 units (610 MW) of North Chennai TPP which have already completed their useful economic life (25–27 years). The total direct cost implication of decommissioning the North Chennai power station is estimated at ₹200.46 CR with station overheads contributing to ₹106.46 CR out of the total. Among the four plants analyzed, the decommissioning cost estimates are lowest for North Chennai TPS Stage I partly due to lower installed capacity (size) of the station in comparison to the other plants.

Credits: Wikimedia

TABLE 11: COSTS OF DECOMMISSIONING NORTH CHENNAI TPS STAGE I

Sl. No.	Item		North Chennai TPS (Stage I): 630 MW	
			Million $	INR CR
1	**Decommissioning costs (i + ii + iii)**		22.14	155.01
	i	Employee costs	4.48	31.36
	ii	Station overheads	15.21	106.46
	iii	O&M expenses	2.46	17.20
2	**Pre-demolition costs: environmental remediation (asbestos cleanup)**		0.06	0.40
3	**Demolition costs (including scrap removal)**		2.55	17.86
4	**Coal combustion residuals**		3.12	21.81
5	**Coal storage area cleanup**		0.77	5.38
	Direct (total) decommissioning costs		**28.64**	**200.46**

Source: Compiled by the authors
Note: O&M = operation and maintenance

When considered for repurposing option utilizing only ash pond land of the TPS, the indented benefit (one time) is estimated to be ₹368.03 CR for solar PV alone as well as for a combination of solar PV with BESS. With the combination of SynCON with solar PV and BESS, the estimated net benefit (lifetime) accrues to ₹607.58 CR (refer Table 12) due to additional benefits (lifetime) of ₹239.55 CR derived as reactive power benefits with the use of SynCON.

TABLE 12: BENEFITS OF REPURPOSING OPTIONS (ASH POND LAND ONLY) FOR NORTH CHENNAI TPS STAGE I

Sl. No.	Item	North Chennai TPS (Stage I): 630 MW			
		Million $		INR CR	
		One time	Lifetime	One time	Lifetime
1	**Scrap value**	42.06		294.39	
2	**Land utilization**	1.80		12.59	
3	**Equipment (switchyard, substation)**	2.44		17.08	
4	**Remediation benefits**	3.12		21.81	
5	**Transmission and interconnection evacuation**	3.17		22.16	
Direct (plant-specific) benefits: solar PV		**52.58**		**368.03**	
Direct (plant-specific) benefits: solar PV + BESS		**52.58**		**368.03**	
6	**System balancing (reactive power) benefits (net)**		34.22		239.55
Direct (plant-specific) benefits: Solar PV + BESS + SynCON			**86.80**		**607.58**

Source: Compiled by the authors

When the entire plant of North Chennai TPS Stage I land area is considered for repurposing, the net benefit with both solar PV as well as solar PV plus BESS are pegged at ₹418.24 CR; whereas alongwith SynCON the total net benefit surges to ₹657.79 CR (refer Table 13) due to additional reactive power benefits of ₹239.55 CR over a lifetime of 10 years.

TABLE 13: BENEFITS OF REPURPOSING OPTIONS (ENTIRE COAL PLANT LAND) FOR NORTH CHENNAI TPS STAGE I

Sl. No.	Item	Mettur TPS (Stage I & II): 840 MW			
		Million $		INR CR	
		One time	Lifetime	One time	Lifetime
1	**Scrap value**	41.84		292.86	
2	**Land utilization**	3.41		23.85	
3	**Equipment (switchyard, substation)**	4.62		32.35	
4	**Remediation benefits**	3.89		27.20	
5	**Transmission and interconnection evacuation**	6.00		41.98	
Direct (plant-specific) benefits: solar PV		**59.75**		**418.24**	
Direct (plant-specific) benefits: solar PV + BESS		**59.75**		**418.24**	
6	**System balancing (reactive power) benefits (net)**		34.22		239.55
Direct (plant-specific) benefits: Solar PV + BESS + SynCON			**93.97**		**657.79**

Source: Compiled by the authors

Neyveli Thermal Power Station II, Stage I & II (1470 MW)

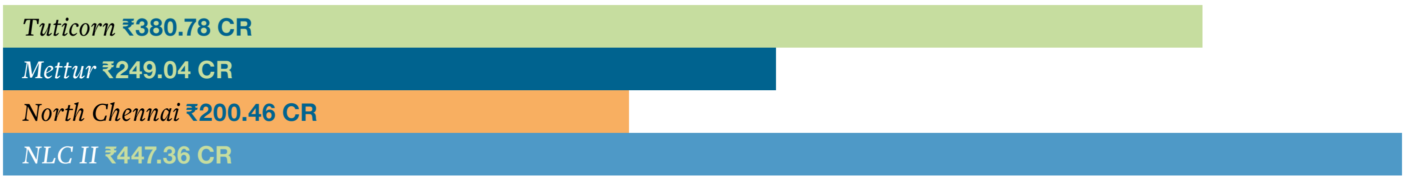
Table 14 shows the estimated cost of decommissioning of all 3 units (840 MW) of NLC TPS II Stage I & II (33–34 years) which have already completed their useful economic life. The total direct cost implication of decommissioning all units of TPP comes to ₹447.36 CR with station overheads taking up more than half of the total decommissioning cost. Among the four plants analyzed, the decommissioning cost estimates are highest for NLC TPS II partly due to higher installed capacity (size) of the station in comparison to the other plants (see Figure 5).

TABLE 14: COSTS OF DECOMMISSIONING FOR NLC TPS II, STAGE I & II

Sl. No.	Item		NLC TPS II (Stage I & II): 1470 MW	
			Million $	INR CR
1	**Decommissioning costs (i + ii + iii)**		51.67	361.69
	i	Employee costs	10.45	73.16
	ii	Station overheads	35.49	248.40
	iii	O&M expenses	5.73	40.13
2	**Pre-demolition costs: environmental remediation (asbestos cleanup)**		0.13	0.93
3	**Demolition costs (including scrap removal)**		5.95	41.67
4	**Coal combustion residuals**		5.78	40.44
5	**Coal storage area cleanup**		0.38	2.63
	Direct (total) decommissioning costs		**63.91**	**447.36**

Source: Compiled by the authors *Note: O&M = operation and maintenance*

FIGURE 5: DECOMMISSIONING COSTS (INR CR.) FOR FOUR TN COAL PLANTS



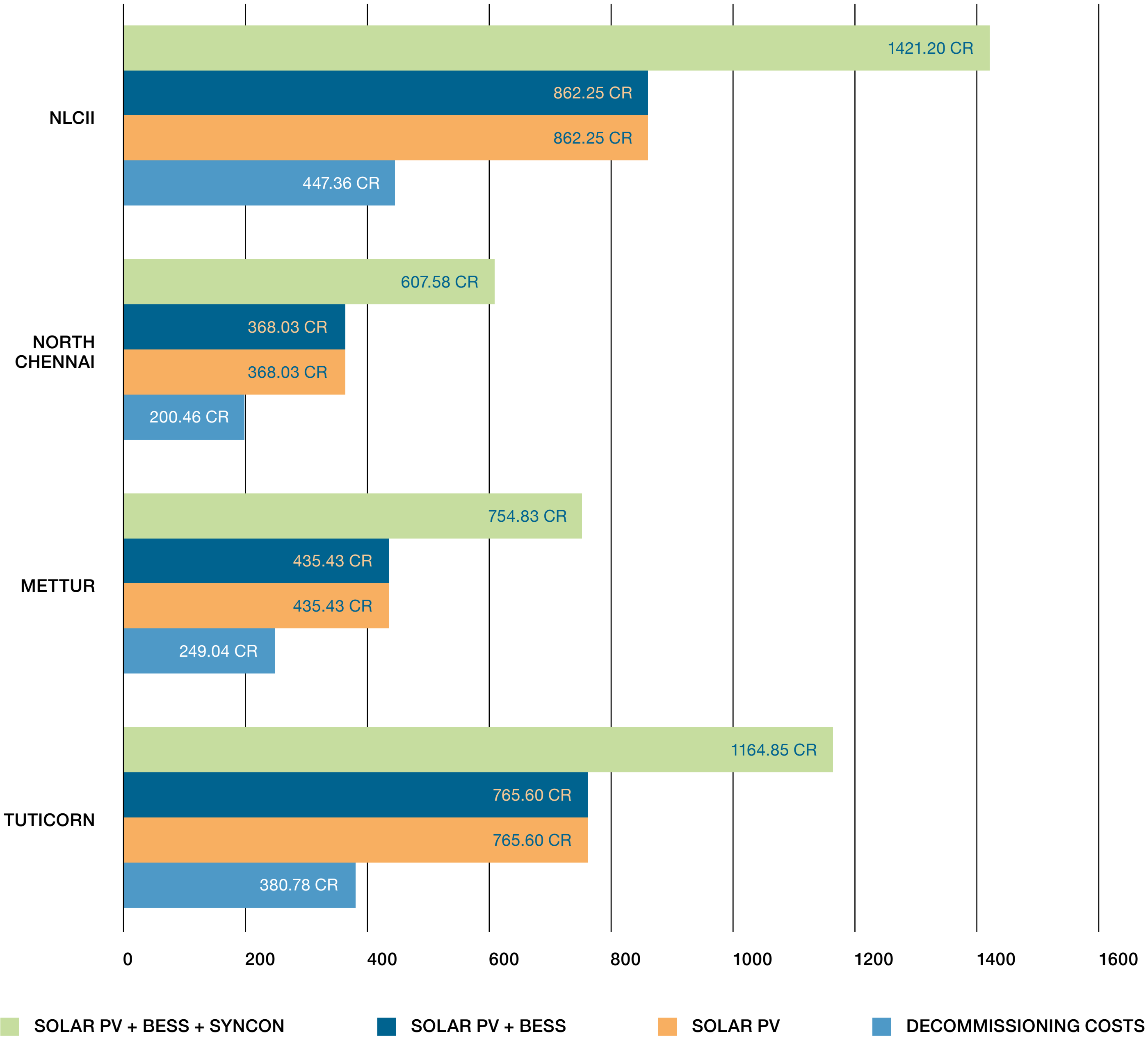
Source: Created by authors

When considered for repurposing option on ash pond land of the TPP only, the indented benefit is estimated to be ₹862.25 CR with solar PV alone as well as a combination of solar PV with BESS with major chunk of benefits coming from scrap sale. With the combination of SynCON with solar PV and BESS, additional benefits equivalent to ₹558.95 CR can be realized taking the overall estimated benefit to ₹1421.20 CR (refer Table 15). We observe that among the four plants considered for repurposing, NLC TPS II offers highest repurposing benefits for each of the three repurposing options (i.e., solar PV, solar PV plus BESS and solar PV plus BESS plus SynCON). Figure 6 shows a comparison of decommissioning costs and repurposing benefits for the four plants for the repurposing options with ash pond land.

TABLE 15: BENEFITS OF REPURPOSING OPTIONS (ASH POND LAND ONLY) FOR NLC TPS II, STAGE I & II					
Sl. No.	Item	NLC TPS II (Stage I & II): 1470 MW			
		Million $		INR CR	
		One time	Lifetime	One time	Lifetime
1	**Scrap value**	97.64		683.51	
2	**Land utilization**	3.33		23.34	
3	**Equipment (switchyard, substation)**	10.55		73.87	
4	**Remediation benefits**	5.78		40.44	
5	**Transmission and interconnection evacuation**	5.87		41.08	
Direct (plant-specific) benefits: solar PV		**123.18**		**862.25**	
Direct (plant-specific) benefits: solar PV + BESS		**123.18**		**862.25**	
6	**System balancing (reactive power) benefits (net)**		79.85		558.95
Direct (plant-specific) benefits: Solar PV + BESS + SynCON			**203.03**		**1421.20**

Source: Compiled by the authors

FIGURE 6: COMPARISON OF DECOMMISSIONING COSTS AND REPURPOSING BENEFITS (ASH POND LAND ONLY)



Source: Created by authors

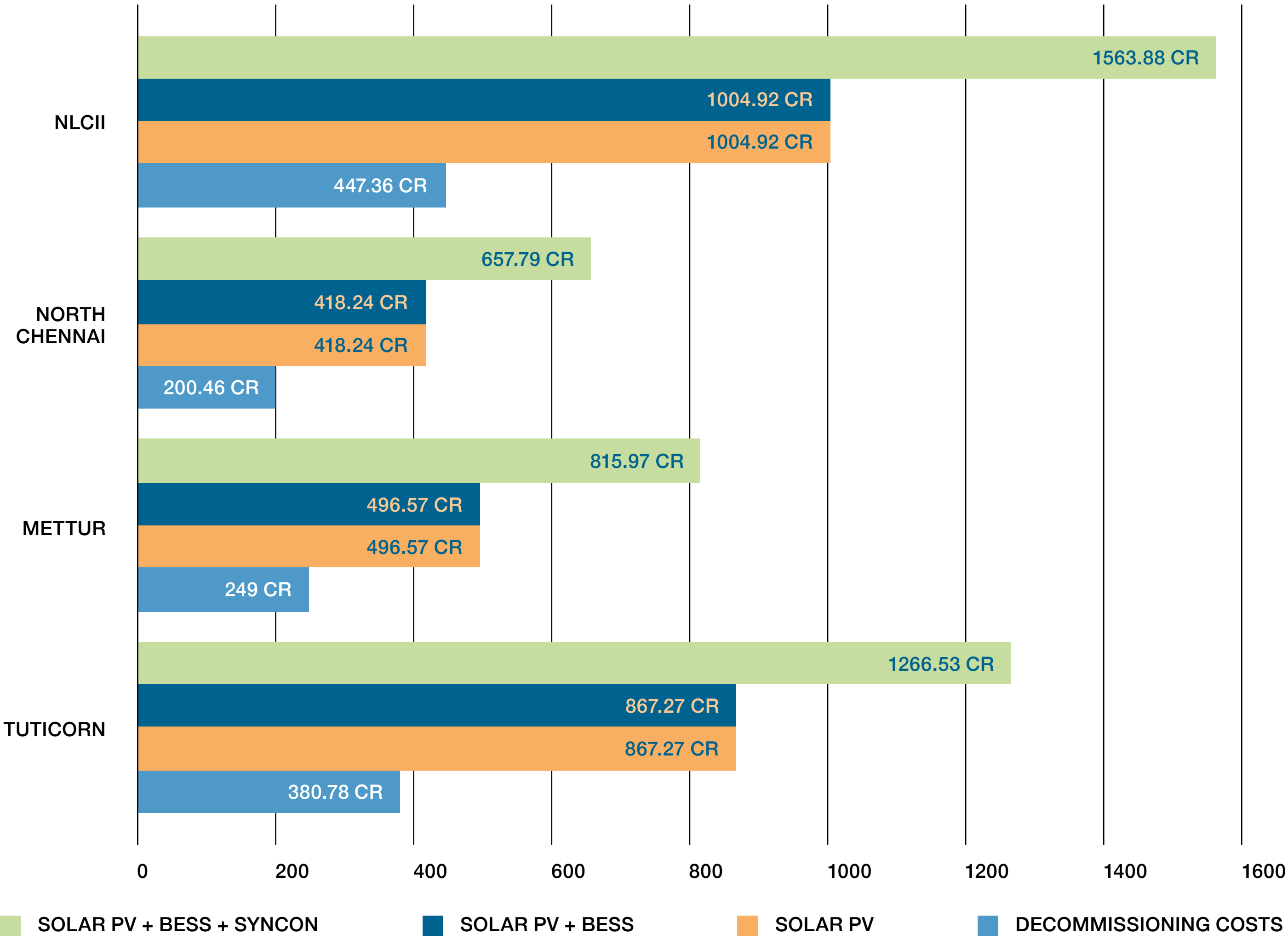
With entire plant of NLC TPS II Stage I and II is considered for repurposing, the net benefit with solar PV as well as with solar PV plus BESS is pegged at ₹1004.92 CR. As expected, majority of the repurposing benefits are realized from scrap value, which turns out to be higher than other plants in this analysis because of higher installed capacity. With the addition of system balancing with SynCON, the overall benefits accrues to ₹1563.88 CR (refer Table 16). Similar to the result for repurposing with Ash pond, repurposing with entire coal plant land also reveals the same order of benefits for the four plants with NLC TPS II showing highest benefits (refer Figure 7).

TABLE 16: BENEFITS OF REPURPOSING OPTIONS (ENTIRE COAL PLANT LAND) NLC TPS II, STAGE I & II

Sl. No.	Item	NLC TPS II (Stage I & II): 1470 MW			
		Million $		INR CR	
		One time	Lifetime	One time	Lifetime
1	**Scrap value**	96.52		675.61	
2	**Land utilization**	6.90		48.31	
3	**Equipment (switchyard, substation)**	21.84		152.90	
4	**Remediation benefits**	6.15		43.07	
5	**Transmission and interconnection evacuation**	12.15		85.03	
Direct (plant-specific) benefits: solar PV		**143.56**		**1004.92**	
Direct (plant-specific) benefits: solar PV + BESS		**143.56**		**1004.92**	
6	**System balancing (reactive power) benefits (net)**		79.85		558.95
Direct (plant-specific) benefits: Solar PV + BESS + SynCON			**223.41**		**1563.88**

Source: Compiled by the authors

FIGURE 7: REPURPOSING BENEFITS FOR FOUR TN COAL PLANTS (ENTIRE COAL PLANT LAND)



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Repurposing Benefits as a Percentage of CAPEX Repurposing Option

We now compute the benefits[7] as a percentage of CAPEX repurposing option for each plant location. We have computed the benefits both including and excluding scrap value of the old thermal plant.

FIGURE 8: TUTICORIN–REPURPOSING BENEFITS AS PERCENTAGE OF CAPEX OF REPURPOSING OPTION

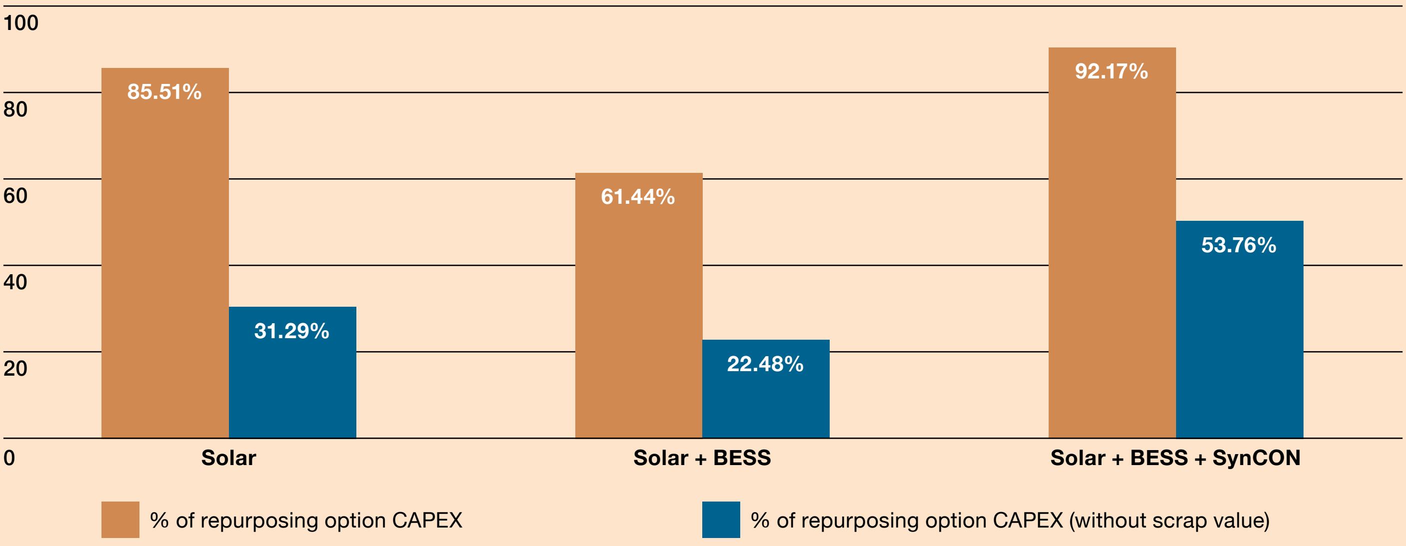


FIGURE 9: METTUR–REPURPOSING BENEFITS AS PERCENTAGE OF CAPEX OF REPURPOSING OPTION

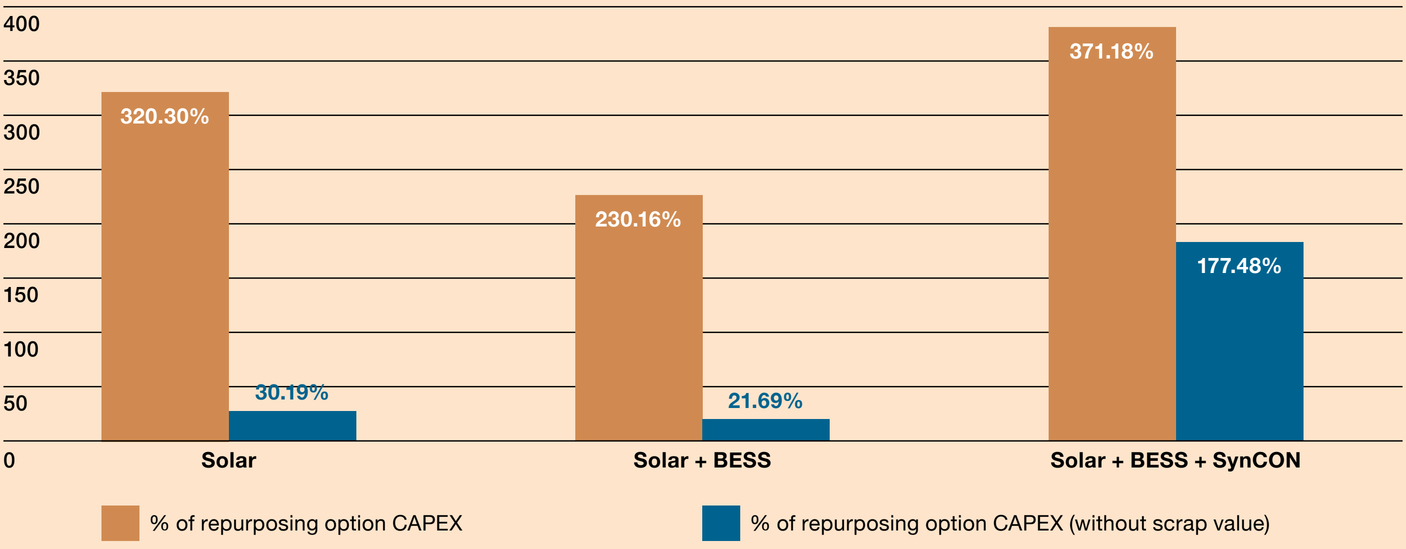


FIGURE 10: NORTH CHENNAI–REPURPOSING BENEFITS AS PERCENTAGE OF CAPEX OF REPURPOSING OPTION

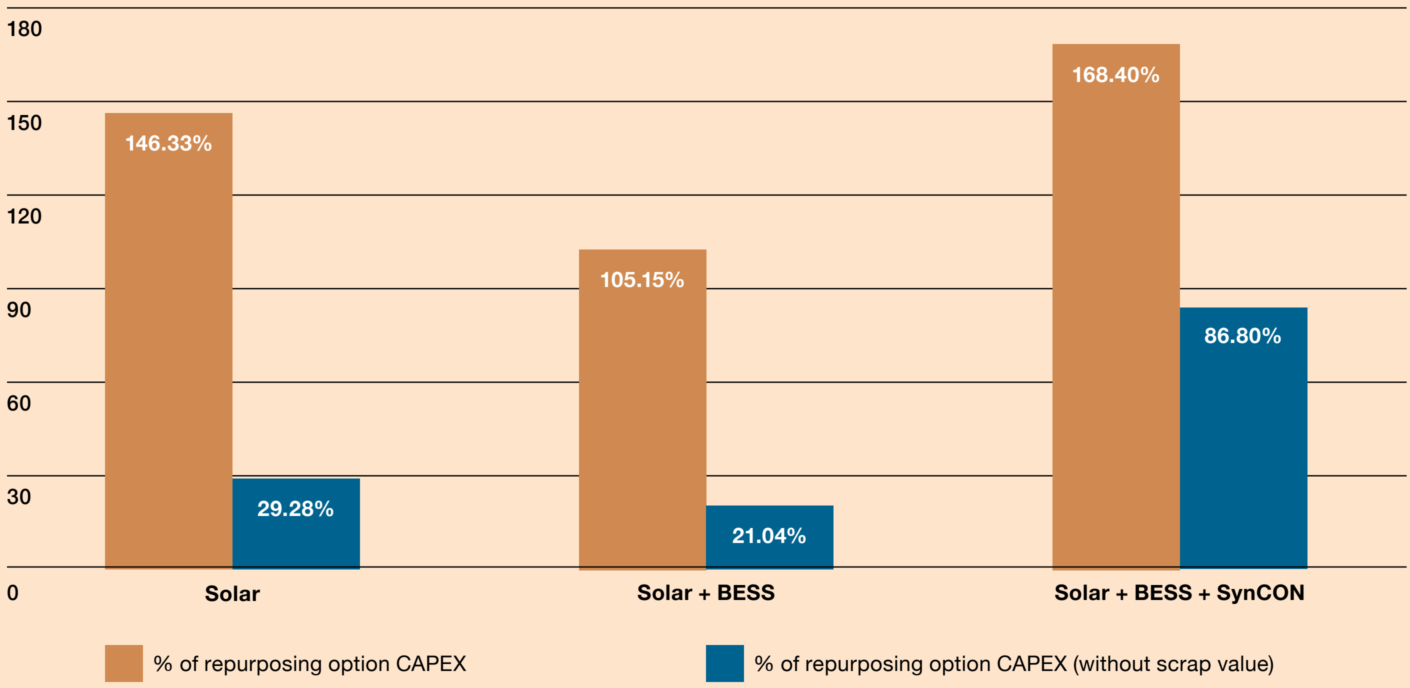
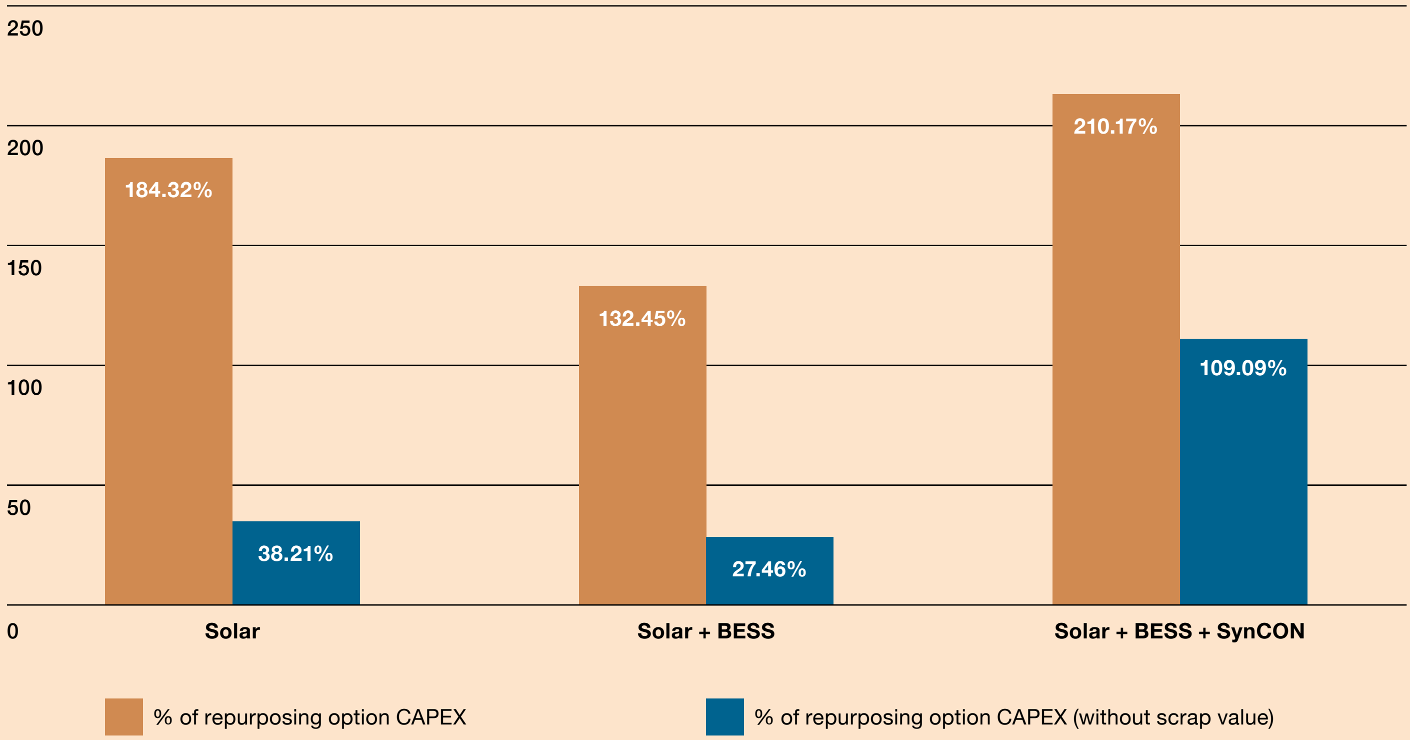


FIGURE 11: NEYVELI–REPURPOSING BENEFITS AS PERCENTAGE OF CAPEX OF REPURPOSING OPTION



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Regarding the scrap value benefits, it is important to note that the scrap value benefits would accrue to the parent coal plant owner whereas other repurposing benefits would accrue to the upcoming RE utility. Howecver, in the case of the plants under discussion, it is feasible that the two entities are one and the same, i.e. TANGEDCO and NLC could operate RE+Bess+SynCon plants in place of their decommissioned thermal assets. In any event, both scrap value benefits and other repurposing benefits would be beneficial for the entire power system.

In general, the repurposing benefits with Solar +BESS+SynCON are the highest because SynCON benefits have been considered over the remaining life time period (i.e., 10 years). It is noteworthy that, in case of Mettur and Neyveli plants, repurposing benefits with SynCON have exceeded 100% CAPEX repurposing option suggesting that the use of Solar+BESS+SynCON at a coal plant location would easily cover entire CAPEX of Solar, BESS and SynCON put together. Using repurposing benefits as a % of CAPEX, we now try to compute the generic savings in Levelized cost of energy (LCOE) for the repurposing options. It is interesting to note that after accounting for these benefits, the LCOE for a new solar PV plant reduces by nearly 48.5% and the LCOE for a new Solar PV plus BESS plant reduces by about 40.4% assuming both these are put up at repurposed coal plant site. To illustrate, for instance, for a new solar PV and a new Solar PV plus BESS (i.e., co-located battery storage) set up at any location,[8] the LCOE values would be ₹2.76/KWh and ₹3.90/KWh respectively which would reduce to ₹1.42/KWh and ₹2.33/KWh respectively with repurposing existing coal plant in favour of a solar PV and solar PV plus BESS at the coal plant site.

07 Comparative analysis: costs and benefits

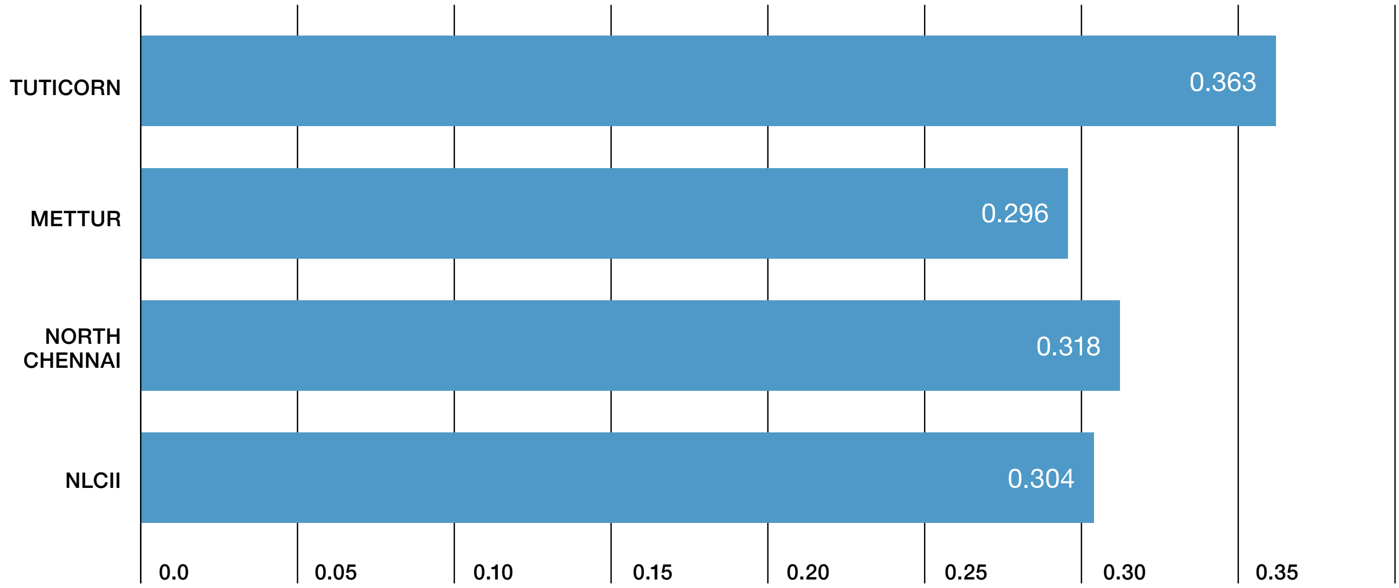
In the previous section, we estimated the decommissioning costs and intended benefits for a combination of three repurposing options for four thermal power plants of Tamil Nadu, all of which had completed their useful economic life.

Further, to enable policy makers and utility managers to take an informed decision on the decommissioning related aspects of the thermal power units under discussion and the benefits of repurposing over plain decommissioning, we present a comparative analysis in the table below of all four TPS under consideration. The comparative analysis has been done on a per MW basis for each TPS under consideration for the sake of uniformity.

Figure 12 plots the decommissioning cost estimates of plants in ₹ CR/MW allowing decision makers to compare these. Clearly, Tuticorin and Mettur plants have the highest and lowest decommissioning costs respectively. However, in absolute terms, NLC TPS II exhibit the highest decommissioning costs and North Chennai TPS shows the lowest (see Figure 5).

Our analysis reveals that two significant factors drive the differences in decommissioning costs: first, the installed capacity (i.e., size of the plant) and second, the area (i.e., layout of the plant) in terms of the ash dyke land, coal bearing area land which has a direct bearing on the environmental remediation expenses incurred on land areas exposed to ash, coal, asbestos etc. The former affects the decommissioning costs mentioned at Sl. No. 1 (i), (ii) and (iii) and 3 and the latter impacts the decommissioning costs mentioned at Sl. No. 2, 4 & 5 in Tables 5, 8, 11 & 14 presented earlier.

FIGURE 12: COMPARATIVE ANALYSIS OF DECOMMISSIONING COSTS (₹ CR/MW)



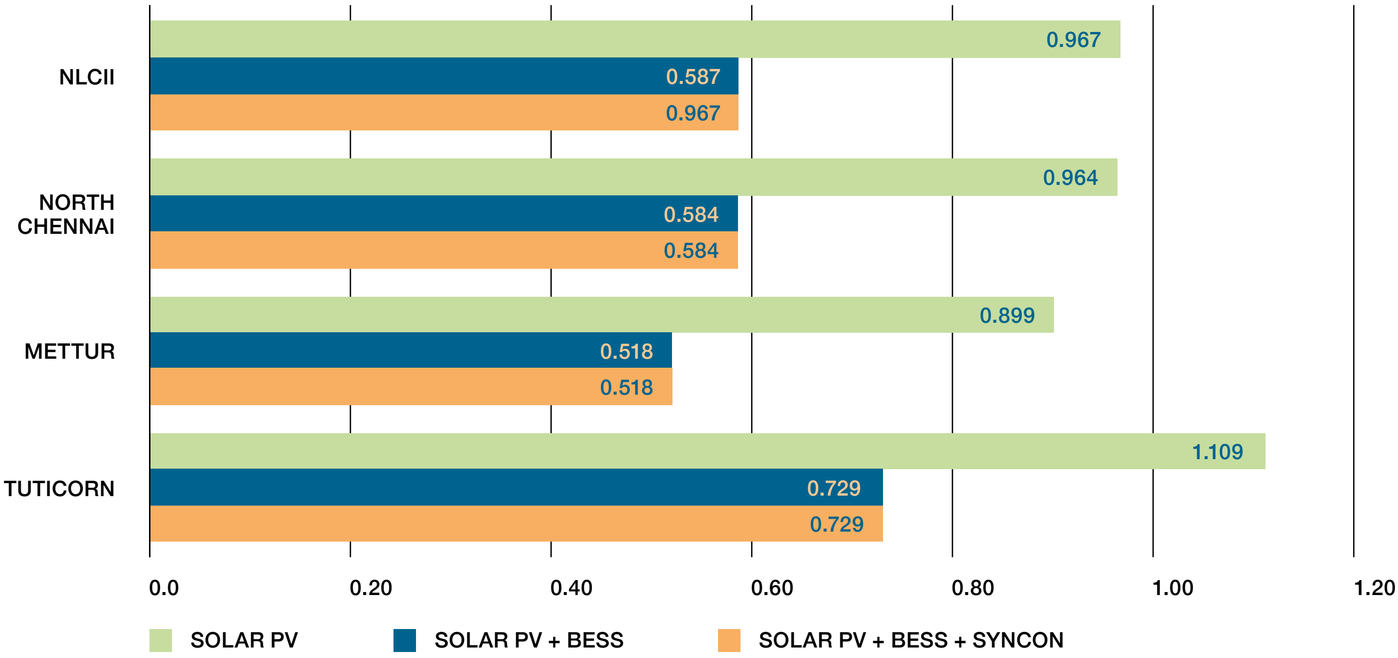
Source: Created by authors

We now compare the benefits of repurposing across the four TPPs. We find that Tuticorin plant gives the maximum benefits for each of the three repurposing options i.e., (i) solar PV, (ii) solar PV plus BESS, and (iii) solar PV plus BESS plus SynCON both when repurposing is carried out on ash pond land alone as well as on entire coal plant land area. Repurposing benefits follow the order: Tuticorin>NLC II> North Chennai> Mettur TPS for all repurposing options and under both scenarios (see Figures 13 & 14).

Our analysis reveals that three significant factors drive the differences in repurposing benefits among plants. First, the installed capacity (i.e., size of the plant) which relates to equipment (i.e., switchyard etc) and transmission and interconnection benefits. Second factor is the area (i.e., layout of the plant) in terms of the ash dyke land, coal bearing area land, entire coal plant land which has a direct bearing on the land available for repurposing options and yields land reutilization benefits as well as remediation benefits. The third and most significant factor is the CAPEX of the plant and its useful economic life in years which determines the salvage value (i.e., scrap value) of the plant. Clearly, plants with higher installed capacity and greater land available for repurposing would yield higher repurposing benefits.

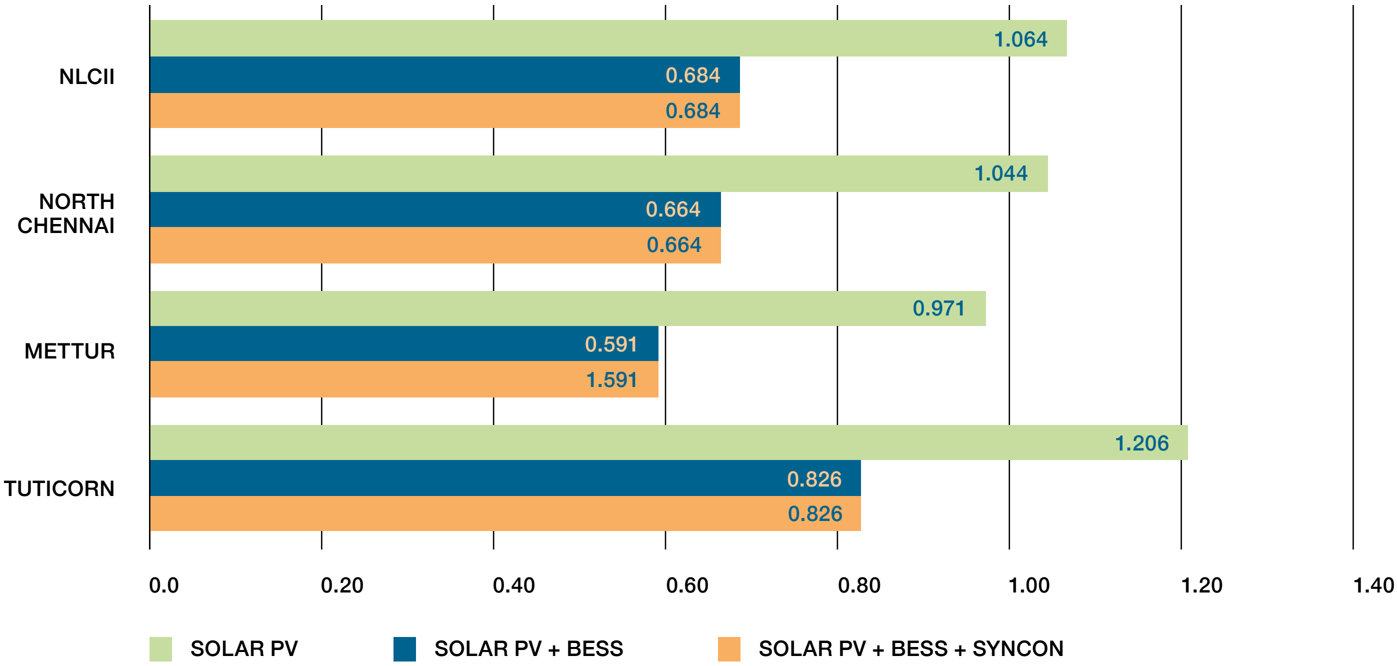
Tuticorin plant gives the maximum benefits for each of the three repurposing options, followed by NLC II, North Chennai and Mettur

FIGURE 13: COMPARATIVE ANALYSIS OF REPURPOSING BENEFITS—ASH POND LAND ONLY (IN INR CR/MW)



Source: Created by authors

FIGURE 14: COMPARATIVE ANALYSIS OF REPURPOSING BENEFITS—ENTIRE COAL PLANT LAND (IN INR CR/MW)



Source: Created by authors

We now mention the PV capacity/BESS capacity for each plant getting repurposed as under (see Table 17):

TABLE 17: REPURPOSED CAPACITY OPTION—SOLAR PV/BESS

Plant	Installed coal capacity	Capacity	
		Solar PV	BESS
Tuticorin Stage I II & III	1050 MW	178 MW	18 MW/72 MWh
Mettur Stage I & II	840 MW	27 MW	3 MW/12 MWh
North Chennai Stage I	630 MW	50 MW	5 MW/20 MWh
Neyveli II Stage I & II	1470 MW	93 MW	10 MW/40 MWh

08 Conclusion

Tamil Nadu has significant coal capacities with low capacity utilization levels as many of these plants are old, unprofitable to utilities and uneconomical to customers. Repurposing such plants for RE sources could provide a solution to overcome some of these challenges. While repurposing coal plants looks beneficial, it may encounter resistance due to the costs involved, system flexibility considerations and impact on communities and livelihoods. To overcome this we have tried to establish the utility of repurposing over plain decommissioning for four coal plants in Tamil Nadu in favor of a combination of repurposing options such as solar, BESS and SynCON.

Clearly, this analysis reveals that direct benefits of repurposing outweigh the direct costs of decommissioning. The benefits would easily cover a significant portion of CAPEX of repurposing option and would be an incentivize for RE utilities and developers. The benefits of repurposing look lucrative when carried out in ash pond land area only as the repurposing benefits realized from using entire plant area does not considerably enhance the monetary value of repurposing benefits in linear terms. However, there is no constraint in using entire plant area for repurposing if need be; albeit there may be instances where power plants located in urban areas have higher land rates and the land utilization benefits may not overweigh these rates in case of entire plant area repurposing.

The direct benefits of repurposing outweigh the direct costs of decommissioning and would easily cover a significant portion of CAPEX of the repurposing option

Repurposing these coal plants which have already exceeded their useful economic lives will not only help Tamil Nadu augment RE in its energy mix portfolio but will also see other indirect benefits in the form of avoided carbon emissions, elimination of ash residues along with other societal benefits which have not been considered in our empirical analysis. The analysis doesn't factor in these indirect benefits due to their limited monetization in a developing country like India, but if monetized these will add further value and make the case stronger for moving towards repurposing options.

09 References & Endnotes

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Endnotes

1. *https://indianexpress.com/article/india/union-budget-old-polluting-coal-power-stations-to-be-closed-says-fm-6246629/*

2. G.S.R 243(E), Notification of Amendment to Environment (Protection) Rules *dated March 31, 2021*

3. *http://www.tnbudget.tn.gov.in/tnweb_files/white_paper_2021_english.pdf*

4. *https://climateriskhorizons.com/research/TANGEDCOs-Recipe-for-Recovery.pdf*

5. The Central Electricity Authority of India (CEA) is a statutory organization which advises the Indian government on policy matters and formulates plans for the development of electricity systems.

6. For this analysis, one time benefits represent benefits accrued in a year and lifetime benefits represent benefits accrued in a span of 10 years.

7. All the repurposing benefits are undiscounted.

8. Other than the repurposed coal plant site.

Repurposing coal plants for the energy transition

Methodology

climate
risk
horizons

Introduction

The Rationale

Globally, countries are phasing out coal plants due to their ageing fleet, reduced profitability and growing environmental concerns. In developed countries, coal power unit retirement is hardly new. A vast number of smaller, less efficient units have already been retired globally. Over the next 30 years, an accelerated phase out of approx. 1200GW of coal plants is expected (RMI, 2016). Developed countries with significant coal capacities such as Australia, Canada, Germany, UK and US; are taking different approaches to wean themselves off coal. 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).

Straight out retiring of coal plants comes with its own sets of social, political, economic, and technical challenges. These range from issues like loss of employment opportunities to system flexibility considerations. Decommissioning power plants entails significant costs (Raimi, 2017); including dismantling, remediation, restoration, etc.; and making it suitable for reuse for development of an industrial facility.

Coal plant sites, their proximity to water, transportation, their connections to the power grid, associated human resources, their local community holds significant value. As old and polluting coal-fired power plants become uneconomical and ready for shutdown, their infrastructure could be reused for other productive purposes.

The 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

FIGURE 1: CONVERSION OF AN OLD AND UNPROFITABLE COAL PLANT INTO A RE + FLEX CENTER (CHATTOPADHYAY, ET AL., 2019)

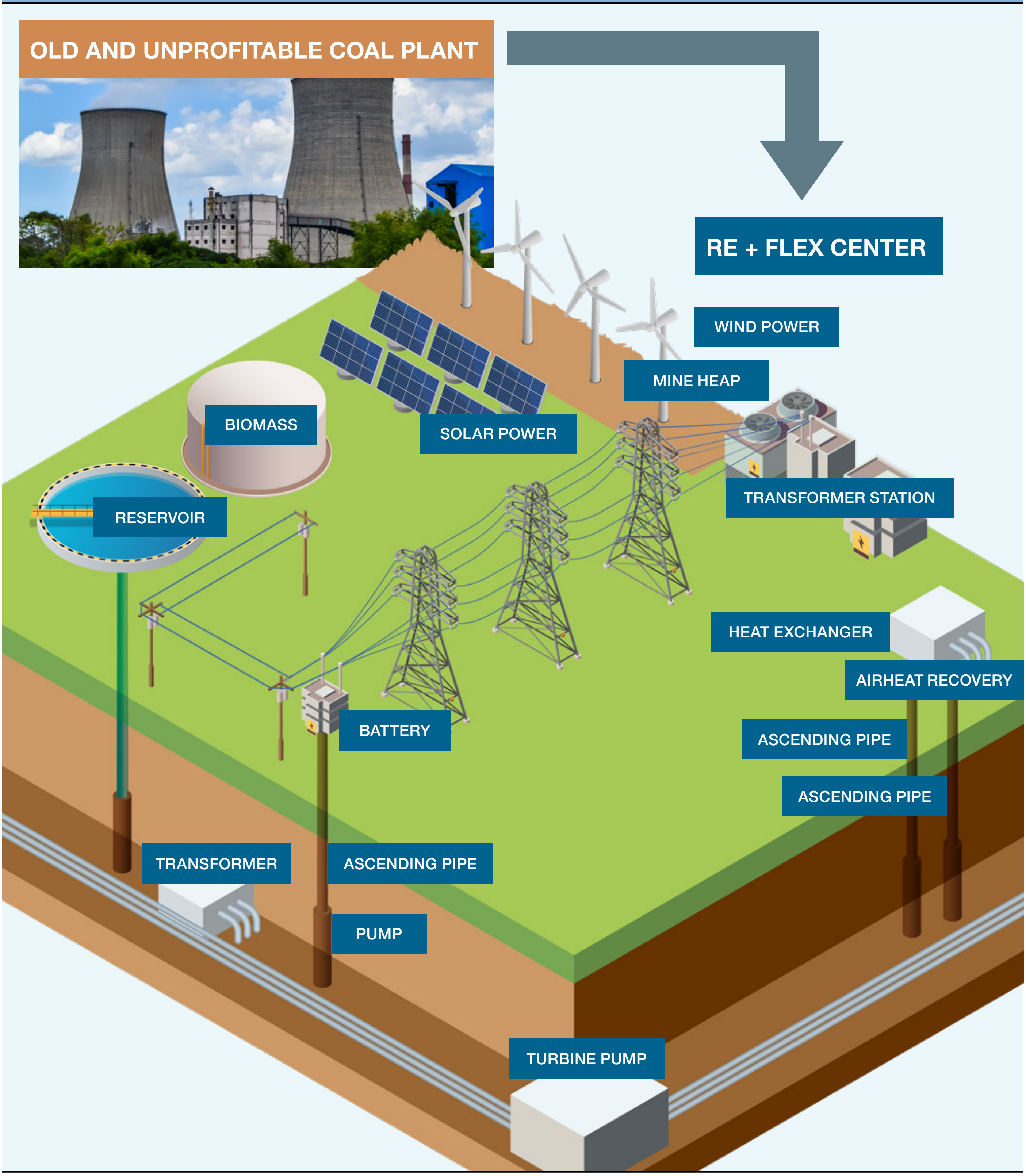


FIGURE 2: OVERVIEW OF THE DIRECT PLANT BENEFITS TO COAL PLANT REPURPOSING

DECOMISSIONING COSTS	IMPETUS TO RE	ECONOMIC DIVERSIFICATION	EXIT STRATEGY
Reduces decommissioning costs: Partially avoid remediation requirements and allow re-use part of the existing assets such as generators and substations	Reduces the cost of commissioning greenfield RE capacity at the same site	For coal plants located in urban and semi-urban areas, repurposing manifests in a multiple end uses leading to economic diversification benefiting local economies	Provides a lucrative exit strategy for stranded and stressed coal plants

Repurposing an old coal plant for energy services allows for reusing a coal plant to continue some of the functions including power generation and ancillary services. For example, coal plant retirement provides an opportunity for enhancing renewable capacity addition as well as adding energy storage and repurposing coal plant components for grid stability services (Chattopadhyay et al, 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 hydro or battery storage for providing frequency control ancillary services, energy storage and capacity; and synchronous condensers for delivering reactive power and inertia.

Repurposing allows for early retirement of old, polluting and unprofitable coal plants, while capturing value by reusing part of the assets such as substation, generator, turbine, etc. 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 lowering 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 plant specific cost benefits, coal plant decommissioning and repurposing provides environmental, social, and grid stability benefits.

On the environmental front, the benefits include near elimination of power plant emissions namely CO_2, SOx, NOx, and particulate matter; as well as substantial savings on water usage. Additionally, repurposing a coal plant site reduces the costs needed for environmental remediation, associated with sustained use of coal and its combustion residuals i.e., fly ash generated.

On the grid stability front, repurposing coal plants may offer significant benefits over decommissioning (Chattopadhyay et al, 2019). For instance, repurposing coal plant equipment (e.g., the turbo-generator) into a synchronous condenser (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.

On the social front, repurposing helps in mitigating 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 makeup a significant portion of revenue for local government 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 (WB, 2018); this would partly ameliorate the socioeconomic impact of potential layoffs (Raimi, 2017). Like the original coal plant, the repurposed plant would also continue to support local economies and the surrounding communities by providing jobs, enabling economic activities and their wellbeing in the long run.

FIGURE 3: ENVIRONMENTAL, GRID STABILITY AND SOCIAL BENEFITS TO COAL PLANT REPURPOSING

ENVIRONMENTAL	GRID STABILITY	SOCIAL
• Near elimination of power plant emissions namely CO_2, SOx, NOx, and particulate matter • Substantial savings on water usage • Reduces the costs needed for environmental remediation	• Reactive power service for voltage control using SyCON • BESS for essential frequency control ancillary services	• Reduce local fiscal implications like reduced revenues for local governments • Reskilling and retaining part of the workforce for an upcoming RE or storage project at the same site

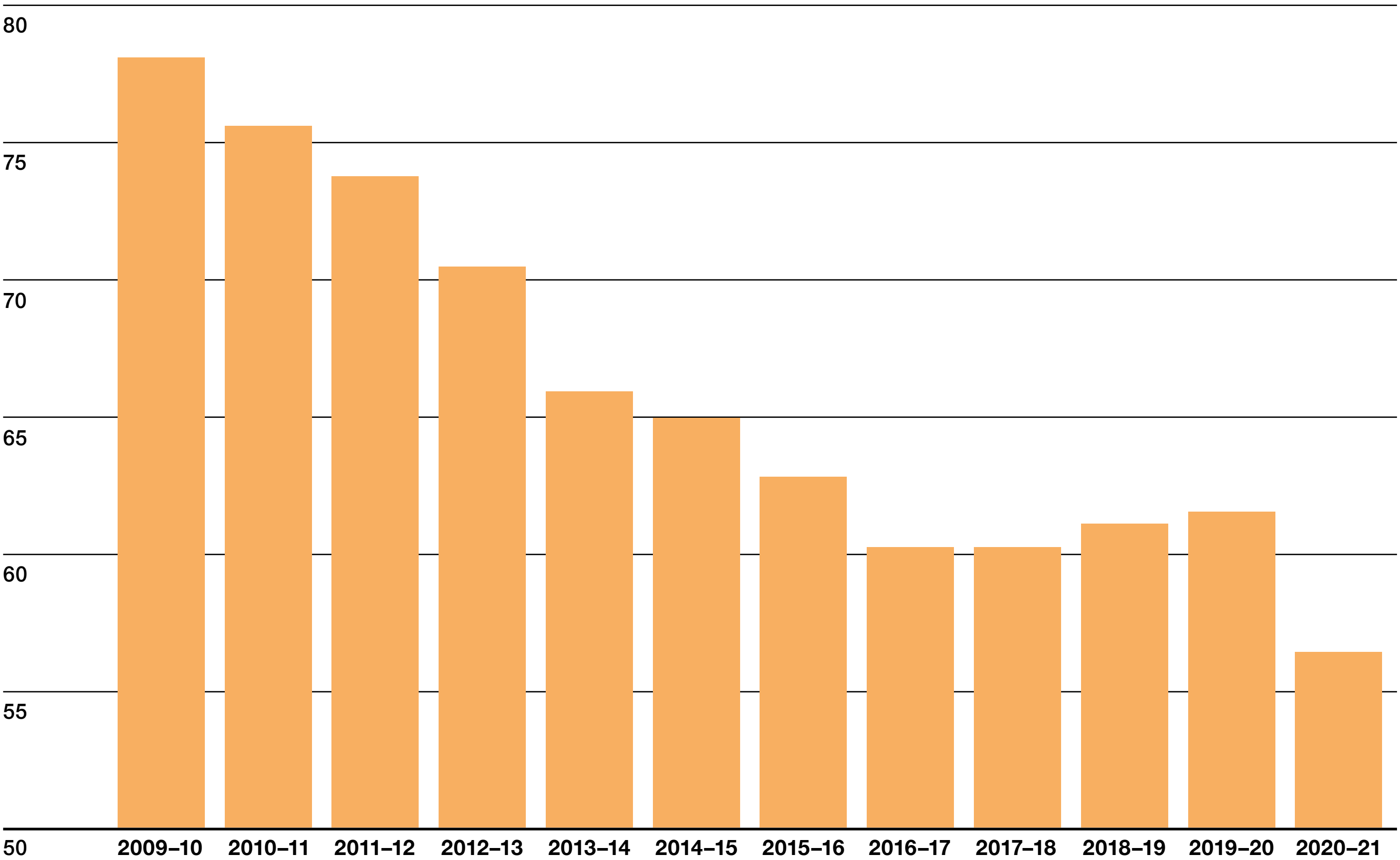
Indian context

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 with 175 GW RE capacity addition by 2022 and 50% generation capacity from non-fossil fuel sources by 2030. There is an overwhelming dominance of fossil fuels in power generation, with 50–55% of total installed generation capacity under coal plants producing more than 65% of total electricity generated.

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 2009–2019; however, the average plant load factor (PLF) of coal-fired plants, an indicator of capacity utilization, has seen a steady decline from 77.5% in 2009 to 53.37% in 2021 (MOP, 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 RE.

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.

FIGURE 4: AVERAGE PLANT LOAD FACTOR (PLF) OF COAL-FIRED PLANTS, AN INDICATOR OF CAPACITY UTILIZATION, HAS SEEN A STEADY DECLINE FROM 77.5% IN 2009 TO 53.37% IN 2021



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) identified approximately 9000 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 un-economic 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.

As per the revised environmental norms notified by MoEFCC in 2015, Coal plants are required to install Pollution Control Equipment (PCE) like FGD, NeNox Systems. This additional capital expenditure is a concern, especially for older plants, since they may find it difficult to recoup the investments. The tariff impact due to the installation of PCE is estimated to be around ₹0.25–0.75/kWh (Srinivasan, et al., 2018). A more recent order has been issued by MoEFCC on April 1, 2021 according to which older plants close to retirement can continue to operate without installing PCE by paying a penalty, applicable on generation beyond their specified date of retirement.

Scope of study

Coal plant closures can be better rationalized with clear empirical estimation of costs and benefits incurred in decommissioning plants vis-à-vis repurposing them. While repurposing coal plants in favor of RE looks beneficial, it may encounter resistance stemming from several factors including cheaper power, 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 synchronous condenser. In this context, the study addresses the following key questions:

1. *What are the costs of decommissioning old coal plants?*
2. *What the benefits of repurposing decommissioned coal plants as a combination of solar, battery storage, and synchronous condenser?*
3. *What proportion of capital expenditure (CAPEX) of repurposing option(s) are covered by the benefits of repurposing?*

Based on the above questions, the study aims to propose a business case for repurposing of coal power plant in favour of three potential alternatives namely, Solar PV, Solar PV plus BESS and SynCON. Although the proposition of coal plant phase out is gaining traction worldwide, there is pushback from some quarters due to social and economic concerns associated with the closure of coal plant. Our analysis makes a profitable case for coal plant utilities and addresses some of the barriers associated with the exit of coal plants.

In addition to the evident environmental benefits, we demonstrate that the repurposing benefits far outweigh the costs of both decommissioning as well as repurposing, which would prove to be a gainful proposition for the owners of these plants.

This work is novel on two counts. First, the report can be considered as an empirical application of the methodology discussed in Shrimali and Jindal (2021). Second, in the latter part, we suggest the corresponding solar PV and battery storage capacity that could be installed at coal plant site if the ash pond land is utilized for repurposing.

While in Shrimali and Jindal (2021), the authors used data on a model plant and estimated costs-benefits of repurposing, for this report, actual data on each plant is collected such as age, CAPEX, land, etc., and costs-benefits of repurposing are estimated for each plant. This would help us understand which plant makes an appropriate economic case for repurposing given its specific characteristics such as ash dyke land, total plant land, age etc. Among a set of existing coal plants, this would help the policy makers undertake decisions about prioritizing one plant over the other for repurposing.

Methodology

The Scenarios

Three scenarios have been developed to illustrate the repurposing options of coal plants.

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 getting decommissioned even while solar and BESS capacity addition continues in a usual manner. 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.

FIGURE 5: SCENARIOS FOR ILLUSTRATION OF COST AND BENEFITS OF A COAL PLANT

SCENARIO 1
BUSINESS AS USUAL

Coal plant continues to stay operational

SCENARIO 2
INTERMEDIATE

Coal plant is decommissioned and new solar, battery energy storage system (BESS) comes up elsewhere

SCENARIO 3
GOAL

Coal plant is repurposed for combination of solar, BESS, and synchronous condenser (SynCON)

Selection of Plants

The identification of thermal plants is a complex function influenced by many technical, social and political factors. The shortlisted plants, indicated below, conform to various factors like age, variable costs, PLF% as identified and analyzed in Shrimali and Jindal (2021) and at the outset qualifies for consideration towards repurposing. This set was analyzed after individual plant level data collection.

INDIVIDUAL PLANT LEVEL DATA COLLECTION					
TAMIL NADU					
SL. NO.	**NAME OF PLANT**	**CAPACITY (MW)**	**ECR (₹/KWH)**	**AGE (YEARS)**	**PLF (%)**
1	Tuticorin TPS	1050	4.44	29–42	55.9%
2	Mettur TPS	840	4.07	31–34	62.6%
3	North Chennai TPS	630	3.33	25–27	59.53%
4	NLC TS II Stage 1	630	3.36	33–34	79.86%

MAHARASHTRA					
SL. NO.	**NAME OF PLANT**	**CAPACITY (MW)**	**ECR (₹/KWH)**	**AGE (YEARS)**	**PLF (%)**
5	Bhusawal TPS Unit 3	210	3.07	37	2.85%
6	Chandrapur Units 3–4	420	2.31	33–24	61.64%
7	Chandrapur Units 5–7	1500	2.31	22–28	51.62%
8	Khaparkheda TPP Units 1–4	840	2.73	18–30	52.18%
9	Koradi TPS Unit 6	210	2.26	36	13.93%
10	Koradi TPS Unit 7	210	2.26	37	13.93%
11	Nashik TPS Unit 3	210	3.27	40	34.88%
12	Nashik TPS Unit 4	210	3.27	39	48.41%
13	Nashik TPS Unit 5	210	3.27	38	

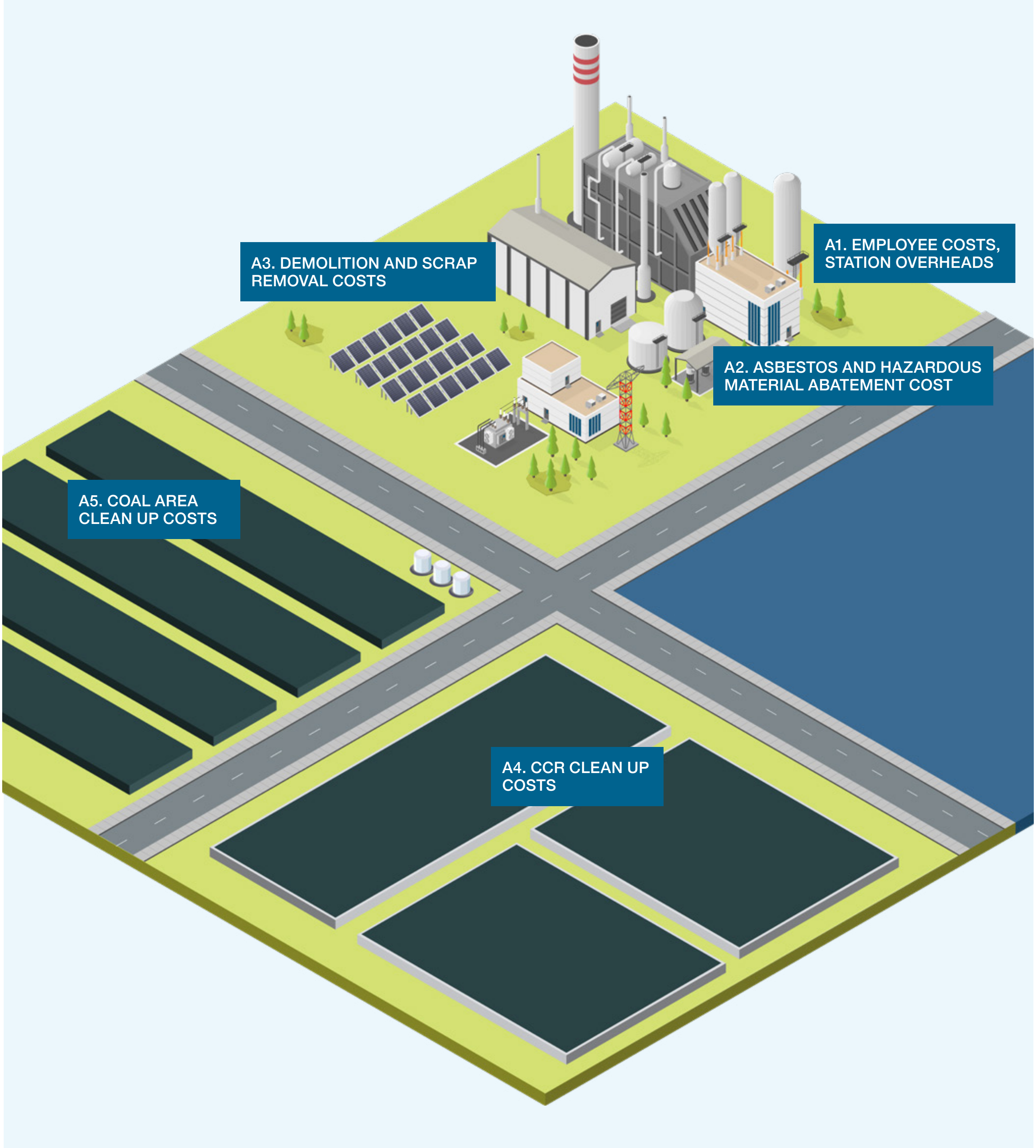
Costs

A comprehensive list of various costs and sub-costs is as below.

A. Plant-specific costs, including (as related to):	B. Environmental and social costs, including (as related to):	C. Additional repurposing costs, including (as related to):
1. Employee costs, station overheads as well as 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) clean up 5. Coal storage areas clean up	1. Contingency costs, such as unanticipated environmental costs 2. Lost local (city, state) tax revenue 3. Social costs, such as temporary income support for employee rehabilitation	1. Remaining capital expenditure (CAPEX) on the coal plant 2. Remaining operational expenditure (OPEX) margins on the coal plant

A. Plant-specific costs

FIGURE 6: A TYPICAL COAL POWER PLANT LAYOUT AND ASSOCIATED COSTS (HASNAT, 2017)



A1. Employee costs, station overheads and O&M expenses post retirement

Decommissioning a coal plant can take substantial time (1.5–2 years), involving employee costs, station overheads, and O&M expenses (A1). 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 Costs (a) + Liaising Costs (b) + Relocation Costs (c)*

Station Overheads *= Security Costs (a) + Power Costs (b) + Lease Costs (c) + Others (d)*

O&M Expenses *= Maintenance Costs (a) + Housekeeping Costs (b) + Firefighting Costs (c)*

FIGURE 7: COST FOR A REPRESENTATIVE 1000 MW PLANT; COMPONENTS AND SOURCES ARE INDICATED

$7.11M/GW
⁕ EMPLOYEE COST
⁜ NTPC, 2020

$24M/GW
⁕ STATION OVERHEADS
⁜ NTPC, 2020

$3.9M/GW
⁕ O&M EXPENSES
⁜ NTPC, 2020

A2. Environmental regulation, such as asbestos and hazardous material abatement costs

$0.09M/GW
⁕ ASBESTOS CLEAN UP COST
⁜ MRPL, 2020

Due to stringent environmental norms in developed countries, environmental remediation (A2) 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).

A3. Demolition and scrap removal costs

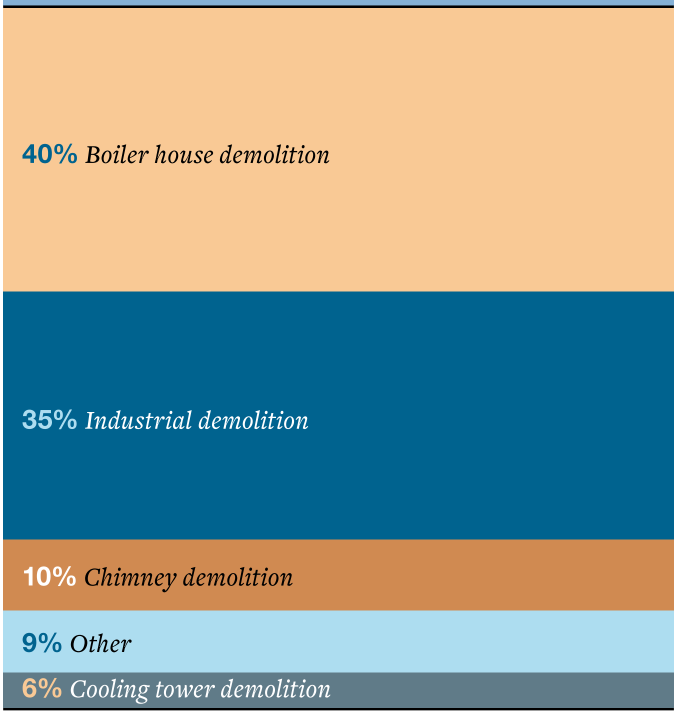
$4.05M/GW
⁕ DEMOLITION + SCRAP REMOVAL COST
⁜ NTPC, BADARPUR

Scrap removal costs are incurred in identification, removal and transportation of valuable or reused assets to a safe place before demolition actually begins. Demolition costs are a function of plant size as well as the safety norms followed for 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 in view of repurposing the coal plant, these costs are expected to be relatively low.

Demolition costs form a substantive component of decommissioning cost; however, it tends to be higher for plants sited at more urban locations, due to the additional requirement of dust mitigation. For this analysis, the demolition cost includes costs incurred towards scrap removal as well.

Demolition and salvage activities begin with the identification of componenets that can be reused or sold for scrap like copper. Depending on the kind of demolition contracts, plant owners may retain scrap revenues or share the proceeds from the resale of such material with the contractor. Once valuable components have been identified and removed, buildings, chimneys, cooling towers are demolished. The cost breakup of decommisioning activities are identified in figure.

FIGURE 8: COST BREAKUP OF KEY COMPONENTS IN DECOMMISSIONING OF THERMAL POWER UNITS—SHARE IN PERCENTAGE FOR A MW SIZE (SHEKHAR, 2020)



A4, A5. Coal combustion residuals and coal area clean up

Management of coal combustion residuals (CCR), i.e. ash disposal/pond cleanup and coal storage area cleanup (A4 and A5), is regarded as one of the costliest tasks associated with decommissioning. Management of CCRs for ash cleanup is critical because of the prevalence of strict environmental regulations to avoid contamination of ground water. 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. The calculations for ash pond cleanup cost and coal area cleanup cost are as follows:

$$\textit{Ash Pond\_Cleanup\_Cost} = \textit{Ash\_Area } (a) * \textit{Earth\_filling } (b) * \textit{Rate } (c)$$

$$\textit{Coal Area\_Cleanup\_Cost} = \textit{Coal Area } (a) * \textit{Earth\_Filling } (b) * \textit{Rate } (c)$$

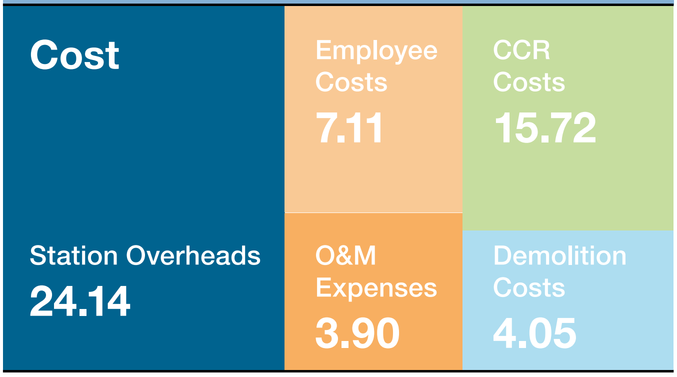
where,

- 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)

$15.72M/GW
- ASH POND CLEAN UP COST
- ASH DISPOSAL AREA—895 ACRES/GW, NTPC,BADARPUR (A)
- EARTH FILLING, 500MM, DSR 2016 (B)
- RATE FOR EARTH FILLING $6.11/M3, DSR 2016 (C)

$3.10M/GW
- COAL YARD CLEAN UP COST
- COAL YARD—1452 ACRES/GW NTPC, BADARPUR, 2020 (A)
- EARTH FILLING, 500MM, DSR 2016 (B)
- RATE FOR EARTH FILLING $6.11/M3, DSR 2016 (C)

FIGURE 9: AN OVERVIEW OF THE MAJOR PLANT SPECIFIC COSTS (IN MILLION $/MW)



B. Environmental and social costs

The various environmental and social costs related to decommissioning include:

1. Post-decommissioning expenditure towards monitoring and mitigation of the negative effects of coal plant towards soil, habitat, etc.; and meeting contingencies related to unanticipated damages in the future
2. Potential loss of revenue for local governments, especially in sparsely populated rural areas, which became reliant on coal plants for their revenue base (Raimi, 2017)
3. Social costs towards post-layoff (temporary income) support and rehabilitation of people dependent on coal plants for their livelihoods

Continuing with our assumption that the plant may have been used for another 10 years, while decommissioning takes approximately 1.5–2 years, the social costs would be calculated for the remaining 8–8.5 years.

In Indian context, coal plants can be divided into three categories based on ownership: State, Centre, and Private plants. Most of the coal plants beyond their economic life are either State or Centre. The employees at these plants can be relocated to other plants, which could prove useful for both the plants as well as the employees, thus avoiding significant social costs. Quantification of environmental, social costs is not part of this analysis.

C. Other costs

Scenario 3 may entail additional costs, remaining CAPEX and OPEX costs. These 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. In case 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.

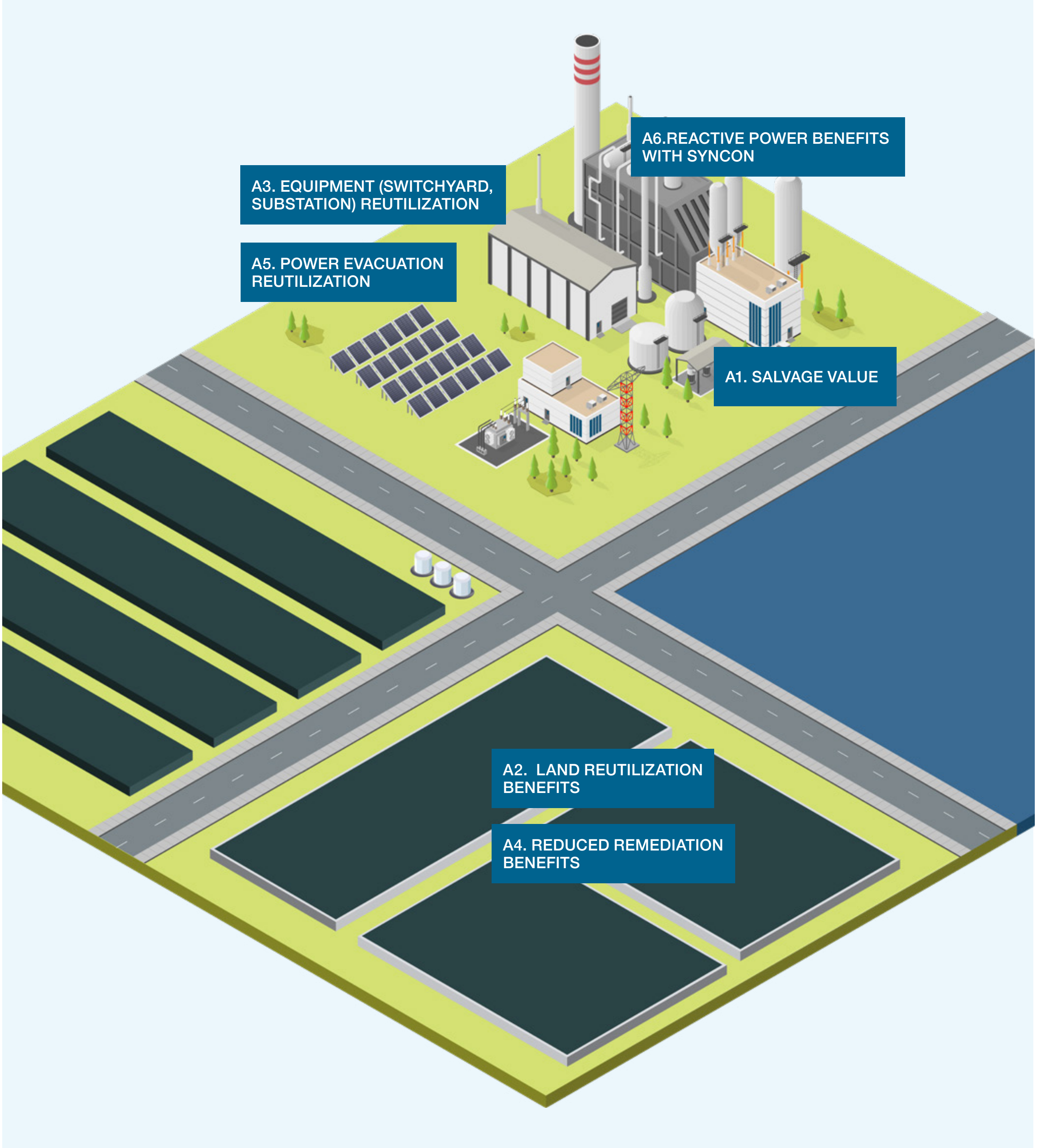
Benefits

Most of the benefits (including reductions in costs incurred while moving from Scenario 1 to Scenario 2) are from Scenario 2 to Scenario 3; however, some benefits are from Scenario 1 to Scenario 2 as well. Our ongoing assumption is that we are discussing the former (and therefore are implicit on the same), however we do explicitly mention the latter as appropriate. The plant specific benefits are in terms of monetary (and guaranteed) one-time benefits connected to coal plant decommissioning and repurposing, whereas the environmental and social benefits are additional, for a lifetime, and may either not be guaranteed or be subject to differing (and potentially subjective) opinions. A comprehensive list is as follows:

A. Plant-specific benefits, including (as related to):	B. Environmental and social benefits, including (as related to):
1. Salvage value/scrap value of coal plant machinery	1. Carbon benefits
2. Land reutilization	2. Health benefits
3. Equipment (i.e., switchyard, substation) reutilization	3. Water benefits
4. Remediation benefits i.e., reduced remediation costs	4. Reemployment benefits
5. Transmission and interconnection evacuation reutilization	
6. Reactive power benefits with SynCON by retaining system balancing services	

A. Plant-specific benefits

FIGURE 10: LAYOUT OF A TYPICAL POWER PLANT AND REPURPOSING BENEFITS



A1. Salvage value

*Salvage_Value = [CAPEX_Coal_Plant (a) - CAPEX_Repurpose_Equipment (b)] * Remaining_Depreciation (c)*

where,

- a = capital cost of the coal plant ($ million)
- b = capital cost of the repurposed equipment ($ million)
- c = remaining depreciation based on the remaining life of the plant (%)

$65.65M/GW
✱ SALVAGE VALUE
⁜ CAPEX (A)—INR 4.4M/MW, CERC 2012
⁜ REPURPOSED EQUIPMENT (B)—SEE A.3
⁜ DEPRECIATION(C)—10%, CERC 2019

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. 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.

A2. Land reutilization

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 ($/MW)

$9.07M/GW
✱ LAND REUTILIZATION
⁜ AREA (A)- ASH DYKE, 1270ACRES/GW, NTPC
⁜ % AVAILABLE FOR REPURPOSING(B)—100%
⁜ NORMATIVE LAND REQUIREMENT (C)—5MW/ACRE, CERC 2016A
⁜ NORMATIVE LAND RATE (D)—$0.036M/MW SAHOO, 2019

A3. Equipment (i.e., switchyard, substation) reutilization)

The repurpose option can reuse some of coal plant equipment such as switchyard, substation, turbo-generator etc.; 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 ($ million),
- b = proportional usage of the repurposed equipment

$16.40M/GW
⁕ EQUIPMENT REUTILIZATION
⁜ COST OF REPURPOSED EQUIP (A)–64.59M/GW, NLC, 2019
⁜ PROPORTIONAL USAGE (B)–SOLAR CAPACITY/ PLANT CAPACITY–0.254MW

In case the repurpose option is solar, this would be the ratio of solar capacity to coal capacity. For instance, for a 1000 MW coal plant repurposed as a 254 MW solar plant, this ratio would be 0.254.

A4. Remediation benefits i.e., reduced remediation costs

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.

$15.72M/GW
⁕ REMEDIATION BENEFITS
⁜ ASH DISPOSAL AREA–895 ACRES/GW, NTPC,BADARPUR (A)
⁜ EARTH FILLING, 500MM, DSR 2016 (B)
⁜ RATE FOR EARTH FILLING $6.11/M3, DSR 2016 (C)

A5. Transmission and interconnection evacuation reutilization

Power transmission and interconnection evacuation savings accrue due to reutilization of existing system capacity for evacuation of power from the repurpose option. 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 ($ million/ MW)

$15.96M/GW
⁕ TRANSMISSION AND INTERCONNECTION BENEFITS
⁜ CAPACITY OF SOLAR - 254MW (A)
⁜ NORMATIVE TRANSMISSION AND INTERCONNECTION CHARGES - $0.063M/MW, CERC 2016A (B)

A6. Reactive power benefits with SynCON

The above benefits (A.1.-A.5) accrue when repurposing is done via solar alone as well as solar and BESS. In addition to these (A.1-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). For the purpose of this report, we focus on providing reactive power support via repurposing a coal plant's turbo-generator into a synchronous condenser.

SynCON lifetime benefits are calculated over a 10-year horizon based on the rationale that the coal plant being repurposed could have run for another 10 years, beyond which point it would have needed additional capex towards renovation and modernization. In the Indian context, at present there is no market compensation mechanism to provide ancillary system balancing services (i.e., reactive power) through coal plants, following Shrimali and Jindal (2021) study, we have used the compensation rate for SynCON as INR 0.14/kVArh i.e. ¢0.002/kVArh (POSOCO, 2019).

The conversion to a synchronous condenser, while incurring some additional CAPEX, eventually provides net benefits due to gross benefits exceeding costs over the lifetime. The gross reactive power benefits under this conversion are calculated as follows:

$$\mathbf{Reactive\_Power\_benefits} = Coal\_plant\_capacity\ (a) * synchronous\_condenser\_rating\ (b) * hrs\ (c) * rate\ (d)$$

where,

- a = capacity of the coal plant (MW)
- b = rating of the synchronous condenser (MVAr/MW)
- c = operational time for synchronous condenser i.e., 8760 hrs
- d = compensation rate ($/MVArh)

FIGURE 11: AN OVERVIEW OF THE MAJOR PLANT SPECIFIC BENEFITS (IN MILLION $/MW)

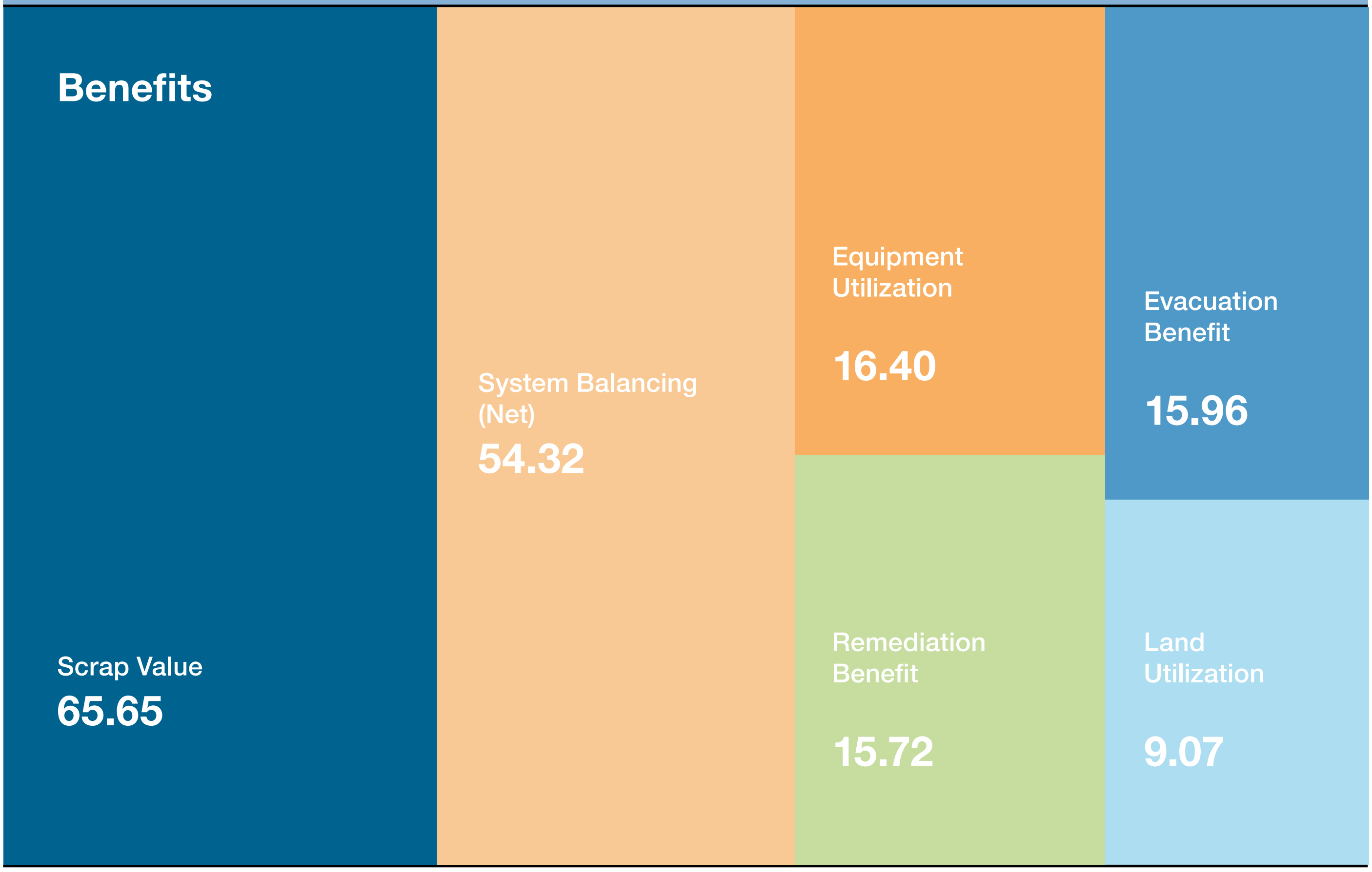
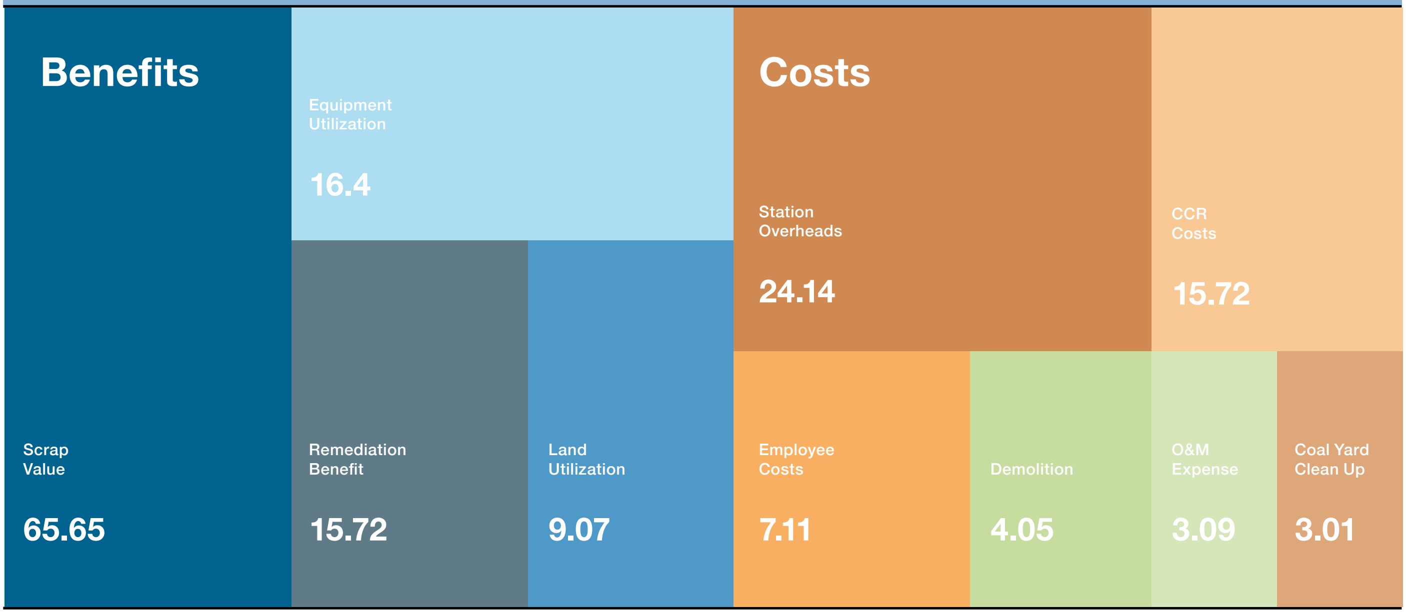


FIGURE 12: AN OVERVIEW OF THE MAJOR PLANT SPECIFIC COSTS AND BENEFITS (IN MILLION $/MW)



Data collection

For the identified plants, the following data is to be collected for calculation and the calculation of various cost and benefits.

Sl. No.	Data Point
1	Location
2	Company
3	Ownership
4	Source of Coal
5	Source of Water
6	Type of Units
7	Expansion
8	Capacity
8.1	Stage 1
8.2	Stage 2
8.3	Stage N
8.4	Total Capacity (MW)
8.5	No of Units
8.6	Maximum Rated Unit
9	**Commercial**
9.1	Year in Consideration
9.2	Fixed Cost (Rs/Unit)
9.3	Variable Cost (Rs/Unit)

9.4	Total Cost (Rs/Unit)
9.5	Merit Order for Disptach
9.6	Plant load factor (PLF)

10	**Area**
10.1	Main Plant
10.2	Ash Dyke Stage 1 (In hectares)
10.3	Ash Dyke Stage 2 (In hectares)
10.4	Coal Yard (StockPile+TPs)

11	**Project Cost (Crores Rs)**
11.1	Stage 1
11.2	Stage 2
11.3	Stage 3

12	**Commissioning Dates**
12.1	Unit 1
12.2	Unit 2
12.3	Unit 3
12.4	Unit 4
12.5	Unit 5
12.6	Max Age (In years)
12.7	Min Age (In years)
12.8	Average Age (In years)

Parameters

The various parameters considered for the calculation of costs and benefits along with the source are provided below (see Table 1).

Parameter	Value (Shrimali & Jindal, 2020)	Source (Shrimali & Jindal, 2020)	Value in INR	Units
Employee costs	$7.11 million	NTPC, 2020	49.77	Cr/GW
Station overheads costs	$24.14 million	NTPC, 2020	168.98	Cr/GW
O & M expenses	$3.90 million	NTPC, 2020	27.3	Cr/GW
Asbestos removal	$0.09 million	MRPL, 2020	0.63	Cr/GW
Demolition costs	$4.05 million	NTPC, 2020	28.35	Cr/GW

Parameter	Value (Shrimali & Jindal, 2020)	Source (Shrimali & Jindal, 2020)	Value in INR	Units
Earth filling for ash/coal area remediation	500 millimeters	DSR, 2016	500	mm
Rate of earth filling	$6.11/m^3	DSR, 2016	427.90	INR/m3
Remaining depreciation	10%	CERC, 2019	10%	%
Scrap value/Salvage value	10%	CERC, 2019	10%	%
Normative land rate for repurpose option	INR 2.5 million/MW	CERC, 2016a	0.25	Cr/MW
Standard land requirement for repurpose option	5 acre/MW	Sahoo, 2019	5	acre/MW
Normative transmission & Interconnection	INR 4.4 Million/MW	CERC, 2016a	0.44	Cr/GW
CAPEX solar	$182.45 million/ MW	CERC, 2016b	5.3	Cr/MW
Capacity utilization factor for solar	20%	SM, 2020	20%	
CAPEX solar and BESS	$253.90 million/MW	CEA, 2019a	7	Cr/MW
Storage duration (BESS)	4 hours	CEA, 2019a	4	hours
Efficiency (BESS)	85%	CEA, 2019a	85%	%
Compensation rate for SynCON	¢0.002 /kVArh	POSOCO, 2019	140	Rs/MVarh
SynCON rating	0.350 MVAr/MW of installed Capacity	Estimated	0.35	Mvar/MW

Assumptions

For this study, we have used actual data for each plant except decommissioning related expenses which have been drawn from Shrimali and Jindal (2021) and prorated for capacity for the respective plants. This is due to the fact that ex post estimation of decommissioning expenses for these plants individually would not be possible as these are operating and not yet decommissioned.

The table below provides key data assumptions utilized in this study.

Parameter	Impact	Assumption
Employee Costs, Station Overheads and O&M Expenses Post Retirement	**Decommissioning Costs**	Employee Costs, Station Overheads and O&M Expenses Post Retirement not calculated for each plant since this would depend on very specific inputs like security costs, Liaoning costs, Housekeeping costs incurred during the decommissioning period. These costs shall be drawn from Shrimali and Jindal (2021) and scaled as per installed capacity of plant under consideration.
Remaining Capex and Opex	**Decommissioning Costs**	Remaining capital expenditure (CAPEX) and operational expenditure (OPEX) margins on the coal plant. In general, the CAPEX gets fully recovered by the end of economic life of a plant and it is considered that the plants in consideration have completed their economic life of 25 years. OPEX margin here refers to the potential loss in notional efficiency gains when a profitable operating coal plant is repurposed. The same is debatable given the assumptions on levelized costs. Further, corresponding revenue from solar (at feed in tariff) has not been considered towards calculation of benefits.
Solar Capacity	**Benefits**	The potential solar capacity has been considered uniformly at 5MW/acres of repurposed land irrespective of the actual solar insolation available at the site.
Capex	**Benefits**	Towards calculation of scrap value, 10% of actual capex of plant wherever actual capex is available. Actual capex is considered in present value terms.

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