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Retirement of Existing Coal Fleet in India for Alternative Decarbonization Pathways:

Analysis of Stranded Costs

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Contents

1 Context

The Indian power system has one of the largest coal fleets comprising 209 GW, nearly half of which has been built over the past decade, that generate over 1000 TWh and account for over a billion tonne of annual CO2 emissions. Any energy transition in the country therefore critically hinges on displacement of coal-based generation over the next two decades with renewables including solar, wind and hydro among other options. Coal-fired power generation is in structural decline, and its role in the global energy mix will continue to diminish, primarily due to climate change concerns as well its economics. The erosion will be driven predominantly by inexpensive renewables, and the costs associated with complying with environmental regulations that seek to reduce air pollution and address climate change.

IEA 2021, for instance, postulates that India's coal-based generation (including generation from new coal plants that are under construction and planned additions) will need to reduce below 200 TWh by 2040 for an 'Accelerated Decarbonization" ("IEA AD") pathway.[1] This is in sharp contrast with a Business-as-Usual scenario that would increase coal-based generation to over 1300 TWh by the same year. The difference translates into a very significant part of the existing fleet that will need to shut down over the next two decades including close to 100 GW of capacity that is at present barely 10-year-old. There is an economic rationale in several of these cases as the costs of solar and wind power in India have been plummeting over the last five years and these resources are available for less than Rs 2.5/kWh at the wholesale level making them competitive against coal. The wholesale electricity market in the country also reflects the relatively surplus state in the thermal sector with spot prices hovering around Rs 2.5 - 3/kWh for most part of last few years, albeit on a small volume under 10 GW.

While a low cost clean power alternative would make a resounding case for retirement of part of the coal fleet, a wiping out the rest of the fleet over the next two decades also increases the likelihood of widespread stranded assets that may in some cases have to forego significant profit and incur capital destruction. The issue of stranded cost of coal plants, upstream mines, social issues around jobs, etc. suggest a set of difficult exit barriers that will need to be addressed in an orderly manner. The older and inefficient part of the coal fleet pose less of a challenge. The sentiments for retirement of the current capacity have been echoed from various quarters. At present, around 25 GW (or 12%) of the existing capacity has been earmarked for retirement by the Central Electricity Authority (CEA) in the near term. The Ministry of Power has indicated that the retired capacity will be replaced by renewables. Discoms too have shown a reluctance to sign new coal PPAs or extend incumbent PPAs when they expire.

Several studies have estimated the benefits to the Discoms due to retirement of coal capacity by proposing shutting down of inefficient old or expensive coal plants. A study [2]conducted across 11 states indicated that an accelerated shut down of plants 20 years or older can yield savings to the tune of INR 53,000 crores (USD 71.3 bn) over five years through savings from avoided retrofit costs (INR 18,000 crores or USD 24.2 bn) and replacement of generation from cheaper renewables (INR 7,000 crores or USD 9.4 bn per annum). Further analysis[3] has highlighted that many of the older stations have lower variable costs and thus higher utilization. The recommendations for accelerated retirements are also mostly drawn based on annual average values and do not consider the variation in demand and supply. A pure age-based retirement strategy may be counter-intuitive and that a more detailed analysis considering the various technical, economic and operating characteristics of stations would shed better light on the subject.

The issue of stranded cost is likely to be a major issue as one gets to the deeper end of coal retirement. This is as much as global issue – for instance, Rocky Mountain Institute had estimated the global stranded asset cost of coal by 2030 will reach $255 billion.[4] The fact that most of the coal plants including almost all of the older plants have PPAs with Discoms and concomitant upstream coal supply linkages, that suggest there is a definitive value at risk associated with these plants. There is therefore a legitimate concern on coal generation being wiped out too quickly and a case for continuing with coal until the policies are streamlined to support accelerated retirement of coal. [5]A stumbling block for the more expensive and/or older fleet of coal plant is indeed in the form of the legacy PPA contracts signed by DISCOMs and generation companies that in many cases extend for 25 years. These contracts have onerous take-or-pay conditions and also a "fixed cost" payment obligations that would render many of these plants commercially available, even if the renewable economics, and a small but competitive electricity spot market would suggest otherwise. This dichotomy raises difficult questions on closure of coal plants at least until the legacy PPA contracts collectively

[1] IEA, *India Energy Outlook 2021*, Flagship Report, February 2021. https://www.iea.org/reports/india-energy-outlook-2021
[2] Ashish Fernandes & Harshit Sharma. *The 3Rs of Discom Recovery: Retirement, Renewables & Rationalisation*. Climate Risk Horizons. August 2020.
[3] Maria Chirayil & Ashok Sreenivas. *Early Age-based Retirement of Coal Power Plants: Misplaced emphasis?* Prayas (Energy Group). May 2021.
[4] A. Benn et al, *Managing the Coal Capital Transition,* Rocky Mountain Institute, 2018.
[5] Samantha Gross, *Coal is King in India and will Likely Remain So*, Brookings Institution, March 8, 2019.
https://www.brookings.edu/blog/planetpolicy/2019/03/08/coal-is-king-in-india-and-will-likely-remain-so/

expire. It should be noted that the great majority of stranded value would occur in regulated markets like India because of these legacy PPAs with offtake guarantee in the form of payment of fixed charges. The story is markedly different in some of the liberalized markets, where uneconomic plants are fully exposed to market forces. Critical questions like what would be the compensation that the coal asset owners should be compensated if India were to follow an accelerated decarbonization pathway – be it the IEA trajectory or a less steep one are being contemplated and discussed by policymakers. There are also related questions on details, namely, the order in which the existing plants should be retired to reduce coal-based generation to minimize the overall cost to the system. Although the commercial realities around existing PPA cannot be ignored, it is also imperative to explore a competitive benchmark under which coal plants compete on a level playing field in the spot market that should result in a lower level of compensation that the generation companies may reasonably expect.

It is important to acknowledge at the outset that the early retirement of coal plants is a complex and controversial topic with strong views from various stakeholders. There is a myriad of economic, commercial, security of supply, social and environmental issues. The objective of this analysis is not to provide a holistic assessment of all of these, but it is an objective assessment of the stranded cost of existing coal assets using best available data and assumptions. The study is an attempt to assess the economic and financial costs of the stranded assets under various energy transition scenarios and identify the coal assets that are prospective candidates for retirement in each of these scenarios – often ahead of their technical life for the deeper decarbonization scenarios including the IEA AD scenario.

In this context, the World Bank Group has appointed Deloitte Touche Tohmatsu India LLP as their Consultant to develop a framework and a model to determine the stranded cost of coal assets under various energy transition scenarios.

A key factor underlying the purpose of this report is the concept of stranded assets. The term has been used to refer coal-fired assets that reach end of their economic life, i.e. are no longer able to earn an economic return because of changes associated with the energy". A related and important figure to consider in the context of coal phaseout is stranded value, which, when defined broadly, is the difference in expected and actual financial outcomes. This has been explained further in the pursuant section of the report.

The present analysis focuses on the questions raised regarding the coal retirement strategy. An optimization model is developed which considers various technical and cost related parameters. The Coal Retirement Model is used to develop a preliminary estimate of the total compensation for stranded coal plants. The model considers the fixed cost payment obligation associated with most of these PPAs in the optimization objective. In addition to the Business as Usual (BAU) and Accelerated Decarbonization (AD) scenarios, the study also considers three additional intermediate scenarios of coal generation requirements.

The analysis for all five decarbonization scenarios is performed to show how coal retirement and compensation costs will change across the scenarios. The scenarios were run for two regimes, namely (a) the PPA regime that reflects the fixed and variable cost compensation and take-or-pay obligations; and (b) the Market spot price regime that is a proxy for an economic scenario in which the coal plants are dispatched strictly against the (competitive cost based) market price at their variable costs (VC) only. While the former regime best reflects the current realities, there are major policies currently under consideration that would require all generators in the system to be governed by a "Market Based Economic Dispatch" or MBED model. The latter market regime is an attempt to reflect the longer term goal to remove the distortions in the dispatch by the legacy PPA contracts. The Coal retirement profile and the compensation payable across different scenarios have also been analyzed for different sub-regions, vintage and cost categories to understand how retirement of coal plants under aggressive decarbonization strategies is affected by location, age and variable/fixed costs.

2 Methodology

The methodology adopted for undertaking the analysis has been developed following the best practices adopted by other similar studies conducted for India and globally. An optimization model has been developed to assess the stranded costs under various scenarios. Details about the model and the scenarios are explained below.

2.1 Stranded Cost Compensation

Stranded Cost Compensation, as referred to in this study, is defined as the difference in plant revenue, especially the foregone revenue of plants that reach the end of their economic life in the reduced carbonization scenarios, relative to the BAU scenario:

- In the PPA regime, the revenue is the total fixed cost earned by the operating generators according to their year on year generation levels; and
- In the Market Price regime, the revenue is the total earnings in the market, net off the variable cost. For each of the scenarios under both price regimes, the present value of the revenue is calculated and is compared with the BAU as a measure of compensation for stranded coal plants.

2.1.1 Overview of the Price Regimes Analyzed

We look at two price regimes, one where the legacy PPAs are kept sacrosanct and another where all the generators participate in the market under the Market Based Economic Dispatch (MBED) mechanism and earn the market spot price.

The PPA scenario considers that the existing PPAs will be continued and once expired, PPAs will be renegotiated between respective Discoms and generators at the same rate, without the mandatory capacity payment. With both Discoms and generators looking to hedge their positions, this is likely to happen for generators with relatively low variable costs.

The Ministry of Power recently released the discussion paper on the implementation of MBED, which will shift the day ahead scheduling of electricity in the country to the market.[6] This change aims to reduce the overall power procurement cost which are currently prevalent due to self-scheduling by discoms from their contracted generators. MBED will also provide a uniform pricing framework and facilitate the increased VRE integration. The proposed Phase – I of MBED will start from April 2022, with only the NTPC thermal generators participating in the market.

With the imminent shift of a significant share of the power procurement in the country to the market, it is important to understand how the coal retirement and compensation will change. As per the discussion paper, the Bilateral Contract Settlement (BCS) applicable for generators under a PPA to ensure fixed cost settlement will be outside the market framework and is thus is treated as outside the confines of the model for this study.

2.1.2 Overview of the scenarios

The projections in IEA's Indian Energy Outlook 2021 are used as a guideline while designing the scenarios. The Stated Policy Scenario pathway is used to formulate the Business as Usual Scenario (BAU) in this exercise. This scenario incorporates IEA's assessment of the policy targets announced by the Indian government while also considering the real-life constraints that must be faced to implement the policies. The Accelerated Decarbonization (AD) scenario in our study uses the targets set by IEA's Sustainable Development Scenario (SDS). The SDS sets ambitious targets to meet the UN Sustainable Development Goals (SGGs) – to hold the rise in global average temperature "*well below 2°C … and pursuing efforts to limit to 1.5°C*" as set out in the Paris Agreement.

Using the Business as Usual Scenario and the Accelerated Decarbonization scenarios as two extreme cases, three intermediary scenarios are developed with generation targets in between these two to analyze the impact of a progressively deeper decarbonization target from BAU to AD. The scenarios have been designed such the reduction in total coal generation targets when compared to the BAU scenario is 25%, 50% and 75% of the difference between the BAU and AD total coal generation targets for Intermediary Scenario 1 (IS 1), Intermediary Scenario 2 (IS 2) and Intermediary Scenario 3 (IS 3) respectively. The intermediary scenarios also consider future coal capacity addition as per the current status of under construction projects.

[6] CERC, *Discussion Paper on Market Based Economic Dispatch of Electricity: Re-designing of Day-ahead Market (DAM) in India*, 2018. https://cercind.gov.in/2018/draft_reg/DP31.pdf

2.1.3 Coal Retirement Model

An optimization model (or 'Model') for the existing coal plants in India has been developed that considers commissioning year of each plant, total TWh of coal generation needed according to the scenarios, costs and marginal revenue to decide which plants should contribute to meet the total (coal) generation requirement. The Model is run for the two price regimes, with the coal generation targets and assumptions for each of the five scenarios.

2.1.3.1 Objective Function

The objective function used in the Model is a system wide net revenue maximization function. The Model optimizes the generation such that the discounted net revenue, which is aggregated for all the twenty years (2021 – 2040), is maximized.

> **Objective function for PPA Regime:** In the PPA regime, the net revenue used in the objective function is the present value of the summation of the PPA price (Fixed Cost per unit plus Variable Cost per unit) over the total generation minus the cost of generation and the mandatory capacity charge (Annual Fixed Costs) over the twenty years. The BAU and IS scenarios deduct the mandatory capacity charge for the entire original PPA period (25 years since the commissioning of the plant), irrespective of plant retirement, whereas in the AD scenario, mandatory capacity charge is deducted only up to the project lifetime (no capacity charge payment if the plant is retired before the end of its PPA tenure).
>
> **Objective function for Market Price Regime:** In the market price regime, the mandatory capacity payment is not considered for any scenario, with the present value of the earnings from MCP minus the generation cost for the twenty years making up the net revenue function.

2.1.3.2 Model inputs, decision variables and constraints

The Model is run for the existing fleet of coal generators, for which their capacities, costs (both fixed costs and variable costs) and the year of commissioning have been collected. The variable costs are escalated year on year according to the vintage of the plants. The time periods in a year are broken into distinct time blocks representing peak, shoulder, and off-peak periods, each, with an associated duration and an associated market price.[7] The total generation from all the plants for all the time blocks in a year is aggregated to meet the generation targets. One of the key decisions in the Model is also to shut down plants that do not have economic contribution to meet generation. Each generator is required to meet a minimum Plant Load Factor (PLF) condition, which is calculated by summing up its generation over the ten time-blocks of the year, below which it is considered uneconomical to run and hence is retired. An additional constraint on the load factor is applied for each year to ensure that adequate capacity is operational to match the profile of load that varies considerably across the time blocks.

Model Inputs
Generator inputs: • Capacity (in MW) • Variable Costs (VC in USD/MWh) along with cost escalation factor • Annual Fixed Costs for the original PPA period (initial 25 years since station COD) (AFC in USD/MW) • PPA cost – Fixed Cost per unit plus the Variable Cost per unit (in USD/MWh) • Year of Commissioning
Market Inputs: • Duration of the 10 time-blocks as percentage of hours in the year • Average Market Prices for each of the time-blocks to be used for 2021 – 2040 (in USD/MWh)
Generation targets: • Annual generation targets for 2021 – 2040 for the 5 scenarios (in TWh)
Other inputs: • Model years (2021 – 2040) • Discount rate (in %) • Maximum station life (in years) • Minimum and Maximum Plant Load Factor (PLF) for each station (in %) • Average load factor (in %)
Decision Variables
Positive Variables • Capacity for each station over the model years – becomes 0 after retirement

[7] Wholesale electricity spot prices for India is approximated using 2019/20 actual prices in the Day Ahead Market (DAM) of the Indian Energy Exchange (IEX). Further details are provided in 3.1.8

Model Inputs
• Generation from each station for each time-block over the model years
Binary Variables: • Retirement decision – retire station if its past its life or PLF falls persistently below minimum PLF target for all subsequent years (set to 1 for the year when the station is retired)
Continuous Variables: • Total discounted net revenue – used in the objective function
Constraints
Total Generation Target: • Aggregated annual generation of all generators for each year should meet the annual generation target for the scenario

Individual Station Constraints:
• Annual Generation
    o Annual generation for a station is the aggregated generation for all the time-blocks weighted according to the duration of the respective time-block
• PLF of each operation station should be:
    o greater than or equal to the Minimum PLF target, and
    o less than or equal to the Maximum PLF target
• Year on year Capacity constraints:
    o Capacity for the year is set to the previous year capacity unless the station is retired in the current year in which case it is set to 0

Minimum Capacity Constraint: • The minimum operation capacity for each year should be greater than or equal to the capacity required to meet the generation target for the year at the Average load factor

2.1.3.3 Model outputs

The model is run for each of the scenarios independently and gives the following outputs:

- The year on year capacity required to meet annual targets
- Station-wise generation for each year
- Annual revenue for each generator.

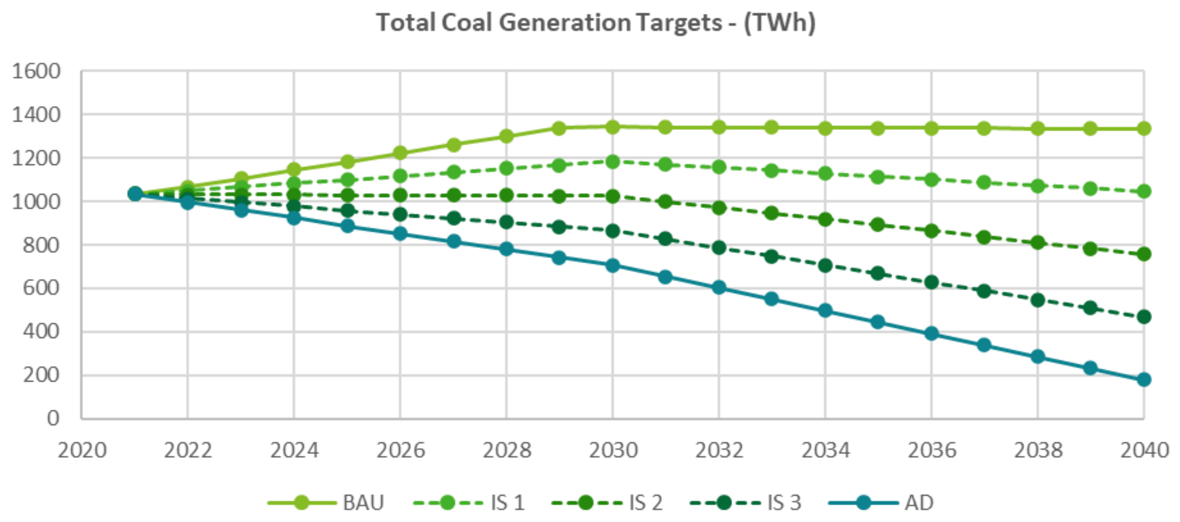
The annual revenue is used to calculate the stranded cost compensation for each scenario. The capacity and generation results are also used to further analyze the retirement strategies across the different scenarios and price regimes.

3 Data and Assumptions

The data and assumptions used in the analysis for each scenario are discussed in this section. The underlying data of the generation plants would remain the same across the scenarios, but the input variables and constraints used in the optimization model are varied across the scenarios. This has been further elaborated in the sections below.

3.1 Scenarios

Two baseline scenarios, Business as Usual (BAU) and Accelerated Decarbonization (AD), have been developed from IEA's generation targets for 2030 and 2040. Generation targets for the intermediate years are derived using linear interpolation. The actual coal generation during FY 2020-21 is considered as the 1033 TWh. Three intermediate scenarios for a sensitivity analysis have been created between BAU and AD. The total coal generation targets (from existing as well as planned coal generators) from 2021-2040 for all the scenarios are shown below:[8]



Further inputs and assumptions under each scenario are presented below.

3.1.1 Business as Usual (BAU):

The total coal capacity in 2030 for the BAU as per the IEA report is 269 GW. CEA's NEP 2018 and Optimal Generation Capacity Mix 2029-30 states that 25 GW is due for decommissioning before 2030. The total new capacity addition by 2030 is thus 85 GW. This capacity is taken to have an average capacity factor of 70%, and the balance generation will be met by the existing fleet of plants.

Year	**Total Coal Generation Target (TWh)**	New Capacity (GW)	Capacity Factor of New Capacity	Generation from New Capacity (TWh)	**Existing Fleet Coal Generation Target (TWh)**
2021	**1033**	-	-	-	**1033**
2030	**1343**	85	70%	523	**820**
2040	**1334**	85	70%	523	**811**

[8] The residual generation from the existing fleet only is presented in a later part of this section.

3.1.2 Accelerated Decarbonization (AD):

The total coal capacity in 2030 for the AD scenario as per the IEA report is 221 GW. Considering decommissioning to the tune of 25 GW as per CEA's NEP 2018 and Optimal Generation Capacity Mix 2029-30, the total new capacity addition by 2030 is 37 GW. This capacity is taken to have an average capacity factor of 70% up to 2030 and 50% beyond 2030. The balance generation will be met by the existing fleet of plants.

Year	Total Coal Generation Target (TWh)	New Capacity (GW)	Capacity Factor of New Capacity	Generation from New Capacity (TWh)	Existing Fleet Coal Generation Target (TWh)
2021	1033	-	-	-	1033
2030	708	37	70%	229	479
2040	181	37	50%	163	18

3.1.3 Intermediate Scenarios

For the intermediary scenarios, the new coal capacity addition as per CEA's latest Thermal Broad Status report have been considered. Around 33 GW of new thermal capacity under various stages of construction are likely to be commissioned within the next 4 years

Year	2021-22	2022-23	2023-24	2024-25
Capacity Addition	11 GW	12 GW	7 GW	3 GW

3.1.4 Intermediate Scenario 1 (IS 1)

A capacity factor of 80% is assumed for the new capacity in this scenario, with the balance generation being met by the existing fleet.

Year	Total Coal Generation Target (TWh)	New Capacity (GW)	Capacity Factor of New Capacity	Generation from New Capacity (TWh)	Existing Fleet Coal Generation Target (TWh)
2021	1033	-	-	-	1033
2030	1184	33	80%	226	958
2040	1046	33	80%	226	819

3.1.5 Intermediate Scenario 2 (IS 2)

This scenario considers the addition of 33 GW of new capacity within the next 4 years, as per CEA's latest Thermal Broad Status reports. A capacity factor of 70% is assumed for the new capacity in this scenario, with the balance generation being met by the existing fleet.

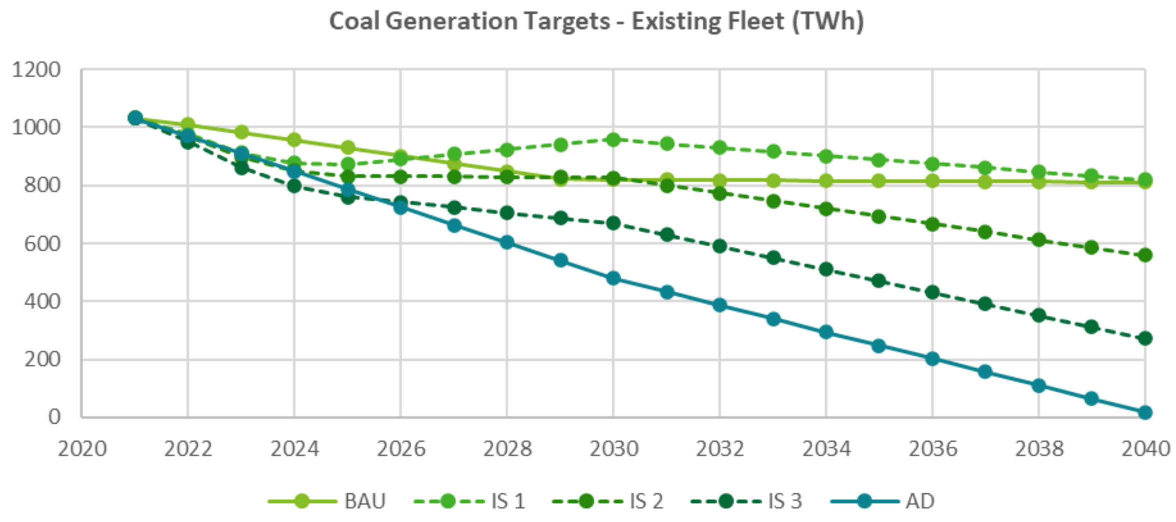
Year	Total Coal Generation Target (TWh)	New Capacity (GW)	Capacity Factor of New Capacity	Generation from New Capacity (TWh)	Existing Fleet Coal Generation Target (TWh)
2021	1033	-	-	-	1033
2030	1026	33	70%	198	828
2040	758	33	70%	198	560

3.1.6 Intermediate Scenario 3 (IS 3)

This scenario considers the addition of 33 GW of new capacity within the next 4 years, as per CEA's latest Thermal Broad Status reports. A capacity factor of 70% is assumed for the new capacity in this scenario, with the balance generation being met by the existing fleet.

Year	Total Coal Generation Target (TWh)	New Capacity (GW)	Capacity Factor of New Capacity	Generation from New Capacity (TWh)	Existing Fleet Coal Generation Target (TWh)
2021	1033	-	-	-	1033
2030	867	33	70%	198	669
2040	469	33	70%	198	271

The total coal generation targets for the existing fleet of coal generators on a year on year basis are shown below

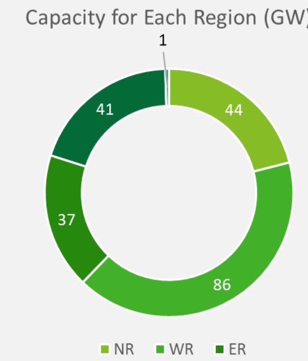


3.1.7 Data for the Current Coal Fleet

The total installed capacity of the current fleet is 209 GW, consisting of 196 stations in total. The fixed costs and variable costs for each of the stations have been collected from their respective tariff orders of the states or from Merit India [9]– which publishes the monthly fixed cost per unit and variable cost. The PPA price for each of the plants is taken as the fixed cost plus the variable cost on a per unit basis. The maximum life for each plant is taken as 40 years. The variable costs for the plants are escalated as per the vintage of the plant:

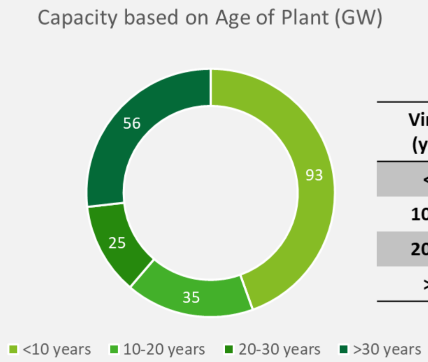
- 0.5% for Plants commissioned within the last 10 years,
- 1% for Plants commissioned between 10-30 years from the present, and
- 1.5% if the Plant was commissioned 30 years prior.

[9] MERIT (Merit Order Despatch of Electricity for Rejuvenation of Income and Transparency) website by the Ministry of Power http://meritindia.in/



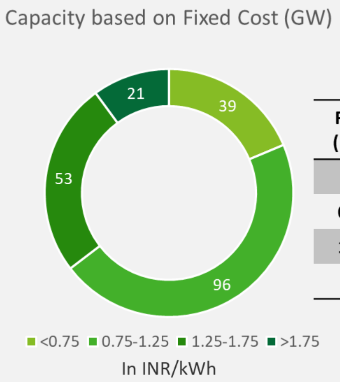
In INR/kWh

Region	WA FC	WA VC
NR	1.09	2.65
WR	1.07	2.36
SR	1.22	3.09
ER	1.32	2.40
NER	2.77	2.97



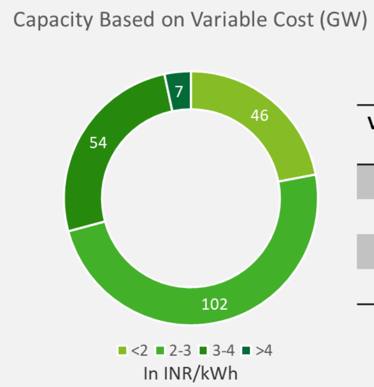
In INR/kWh

Vintage (years)	WA FC	WA VC
< 10	1.21	2.48
10 – 20	1.18	2.69
20 – 30	1.22	2.84
> 30	0.96	2.64



In INR/kWh

Fixed Cost (INR/kWh)	WA FC	WA VC
< 0.75	0.53	2.53
0.75-1.25	1.00	2.61
1.25-1.75	1.46	2.67
>1.75	2.23	2.40



In INR/kWh

Variable Cost (INR/kWh)	WA FC	WA VC
<2	1.03	1.48
2-3	1.22	2.54
3-4	1.09	3.40
>4	1.28	4.23

3.1.8 Data for Market Prices and time blocks

Each year is divided into 10 blocks, representing peak periods, shoulder periods and off-peak periods. Historic spot prices of 2019-20 were collected and the average market price for each of the time-blocks were calculated. The average market price for each of these periods is used when computing the revenue in the Market Price regime. The market prices are kept constant over the model years without considering any escalation factor. This has been substantiated with separate modeling efforts that the prices discovered in the market in future would be largely remaining the same, barring few hours of the day, when the prices can further go south depending on the extent of RE addition and success of agricultural load shift. The market price as well as the time duration for each of the blocks are shown below:

Block	Peak 1	Peak 2	Peak 3	Shoulder 1	Shoulder 2	Shoulder 3	Shoulder 4	Shoulder 5	Off-peak 1	Off-peak 2
Duration of hours in the year	2%	3%	4%	5%	5%	5%	31%	15%	15%	15%
2021 – 2040 (USD/MWh) *	91.28	67.35	58.27	53.36	49.81	47.27	42.18	37.85	34.38	28.11

** Prices calculated as per values in IEX DAM for 2019-20 [1 USD = Rs 72]*

3.1.9 Other Assumptions

- The Discount rate used to calculate the present value of the revenue is assumed to be 6%.
- Maximum and minimum PLF targets are 25% and 85% respectively for each plant. The model will choose to the retire plant if PLF falls persistently below 25% for all subsequent years.
- An average load factor of 75% is used to determine the minim capacity requirement for all the years.

4 Results

The table below summarizes the key findings including the coal capacity, generation and discounted net revenue for 2021-2040 for the PPA and Market regimes across BAU, IS 1-3 and the IEA AD scenarios. As discussed before, the key metric of stranded cost for each decarbonization scenario (IS1-3 and AD) is calculated relative to the BAU as the reduction in discounted revenue.

	SCENARIO				
Particulars	BAU	IS 1	IS 2	IS 3	AD
❶ PPA Regime					
Operational Capacity among the existing fleet by 2040 (GW)	124	125	87	43	3
Total Retired Capacity (GW)	85	84	122	166	206
Coal Generation met by existing fleet in 2040 (TWh)	811	819	560	271	18
Wt. Avg. FC – Existing 2040 Capacity (Rs/kWh)*	*2.44*	*2.41*	*2.80*	*3.32*	*4.45*
Wt. Avg. VC (2021#) – Existing 2040 Capacity (Rs/kWh)*	*4.90*	*4.79*	*4.89*	*4.96*	*5.30*
Total Discounted Revenue (USD bn)	**207**	**209**	**196**	**173**	**126**
Stranded Cost Compensation (USD bn)	-	-	*11*	*33*	*81*
❷ Market Regime					
Operational Capacity among the existing fleet by 2040 (GW)	125	125	94	55	8
Total Retired Capacity (GW)	85	84	115	154	201
Coal Generation met by existing fleet in 2040 (TWh)	811	819	560	271	18
Wt. Avg. FC – Existing 2040 Capacity (Rs/kWh)*	*2.37*	*2.39*	*2.41*	*2.33*	*0.92*
Wt. Avg. VC (2021#) – Existing 2040 Capacity (Rs/kWh)*	*4.78*	*4.87*	*4.36*	*3.67*	*2.41*
Total Discounted Revenue (USD bn)	**140**	**137**	**141**	**138**	**104**
Stranded Cost Compensation (USD bn)	-	*3*	-	*2*	*36*

- *The weighted average FC and VC are calculated for the operational capacity among the existing fleet in 2040*

\# *The weighted average VC is calculated using non-escalated 2021 values*

The salient points from the table are as follows:

1. The stranded cost under the PPA regime ranges from USD 11 bn to USD 81 bn depending on the extent of decarbonization. These compensation figures reduce significantly under the market regime, ranging from USD 2 bn to USD 36 bn. In other words, if a MBED regime is introduced and all generators compete on the basis of their costs ignoring the take-or-pay obligations or fixed costs under the PPA regime, a large part of the coal fleet would be deemed unprofitable and as such the compensation requirements drop by at least a factor of 2 even under the most stringent AD scenario. This is indeed a significant finding and corroborates several reports and news items that have been published of late suggesting unprofitability of several coal plants.
2. The IS-2 and IS-3 scenarios present modest to reasonably deep decarbonization pathways with 37 GW and 81 GW of coal capacity being decommissioned, respectively under a PPA regime at relatively modest stranded costs of $11b and $33b, respectively. This clearly shows that it may be far cheaper to target the most expensive group of 37 GW generators at a relatively modest stranded cost of $11b or $0.3m/MW on average. As increasingly more profitable units are shut down, the compensation payable to the PPA-holder generators would quickly rise to $0.5m/MW for the next lot of (81-37=) 44 GW capacity. In fact, the stranded cost will be much higher at $81b under the AD scenario which equates to an incremental cost of $1.2m/MW to move from IS-3 to AD.[10] While this analysis is focused solely on PPA price and costs and

[10] An additional 40 GW retired with a foregone (discounted) net revenue of $48 billion.

hence ignores a number of other attributes relevant to plant decommissioning, stranded cost and compensation associated with it is often a critical factor. These findings are important to prioritize projects that may be good candidates for accelerated coal transition, subject to meeting other preconditions including a prudent way of managing social issues.

3. Although we do not explicitly look at associated reduction in CO_2 and local pollutants, it is worth noting that IS-2, IS-3 and AD scenarios all represent a massive reduction in coal based generation of 251 TWh, 532 TWh, and 793 TWh, respectively, by 2040, relative to the BAU generation of 811 TWh in the same year. Even if we consider the higher end of stranded cost and assume the compensation will fully offset the generators at that level, the implied *average* cost of CO_2 reduction for IS-2, IS-3 and AD works out to be approximately \$10/t, \$14/t and \$22/t, respectively.[11] As IS-3 and AD in particular represent deep decarbonation pathways, these average cost of carbon reduction is quite remarkable and indicate that even at the high end of this range, around 7 billion tons of CO_2 (in the AD scenario in cumulative terms over 2021-2040) is achievable at a (discounted) cost of \$81b. The Market/MBEB scenario, of course, presents a far cheaper solution with practically zero cost for IS-3 and at \$36b for AD. While this calls for sweeping reform of the PPA regime to bring all of the generation in the country to be cleared through the market, it also shows the rich reward that such measures entail not only to enhance cost efficiency, but the tremendous potential for a market based mechanism to deliver decarbonization through accelerated retirement of coal.
4. While the capacities are similar in both BAU and IS-1 scenarios, the operational capacity for the scenarios with more aggressive decarbonization is higher in the market regime. It appears that the variability of market prices constraints the stations to operate at lower PLFs. This is also reflected in the total revenue for both the price regimes - the revenue in the market is significantly lower since a section of the capacity will be operating under a loss for certain years.
5. A look at the weighted average FC per unit and VC per unit (2021 values) also gives insight into how the two regimes optimizes the operational capacity. The PPA regime prefers to incentivize stations with higher FC per unit while remaining indifferent to the VC, whereas the Market Regime tries to incentivize stations with the lowest VC.[12] It must be noted that the capacities and the weighted average costs in the BAU and IS 1 scenarios are not too dissimilar – this is because almost all the retirement is due to the age of the stations as the generation targets were the highest in these scenarios.

4.1 Analysis of results

A deeper dive into the results is presented in the following section. Coal plant retirement schedule is analyzed from three different perspectives: Region-wise analysis, vintage-wise analysis and cost-based analysis. For each of these categories, three parameters, namely the Capacity, Generation and the net revenue are presented for 2021, 2030 and 2040. As the FC per unit is the driving factor in the PPA regime, the cost-based analysis considers the FC based categories whereas in the Market regime, the analysis is based on VC. The vintage-wise category is further broken down into four sub-categories:

- < 10 years: plants commissioned within 10 years prior to 2021
- 10 – 20 years: plants commissioned between 10 to 20 years prior to 2021
- 20 – 30 years: plants commissioned between 20 to 30 years prior to 2021
- 30+ years: plants commissioned at least 30 years prior to 2021

4.1.1 PPA Regime

A closer inspection of the outputs is conducted for each scenario to analyze the behavior of the coal assets. A capacity analysis (GW) is complemented by generation analysis (TWh) to derive insights and is followed by a stranded cost analysis.

4.1.1.1 Capacity (GW) analysis

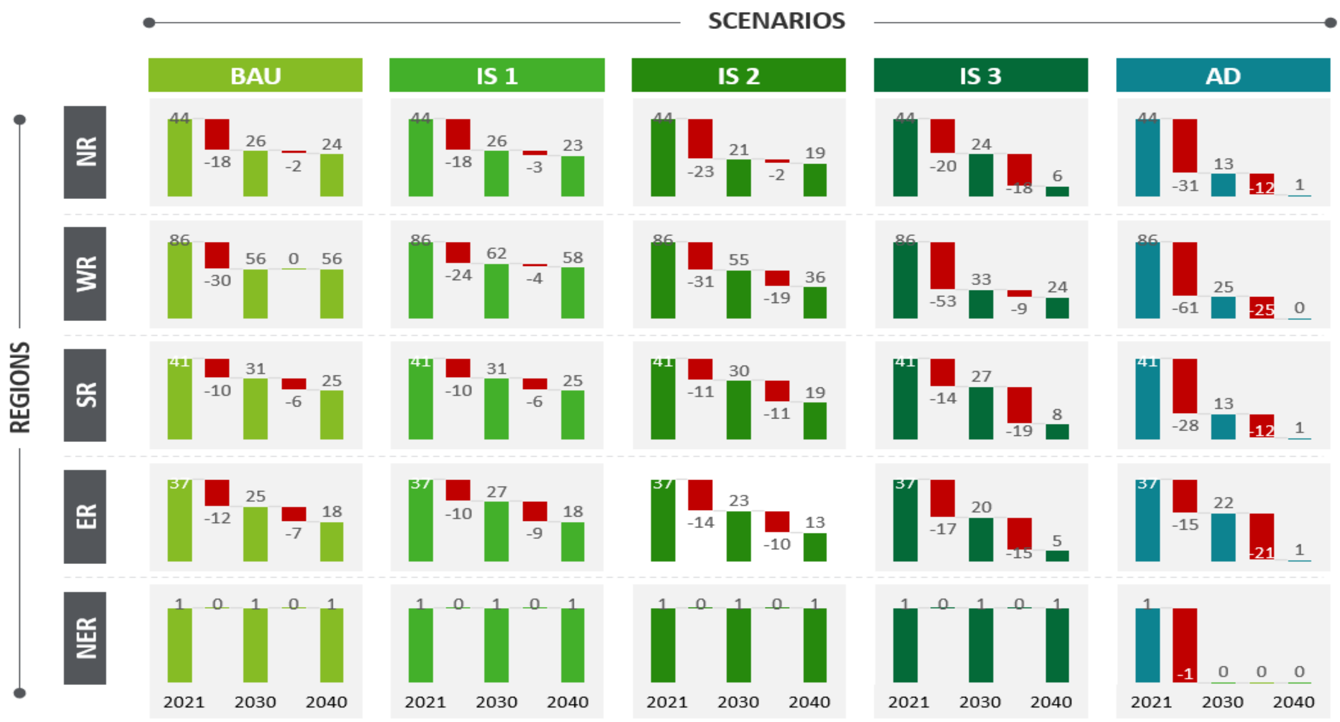
The installed capacity of coal assets, how it fares under each scenario on region-wise, vintage basis and cost basis has been further analyzed to identify any patterns emerging from the retirement of coal assets.

4.1.1.1.1 Region-wise

The figure below projects the region-wise installed capacity base and retirement capacity under these 5 scenarios for each of the years (2021, 2030 and 2040),

[11] This is a simplified calculation done using the output of the Model assuming an average 0.9t/MWh of emission intensity for all plants and a linear trajectory of generation reduction over 2021-2040.

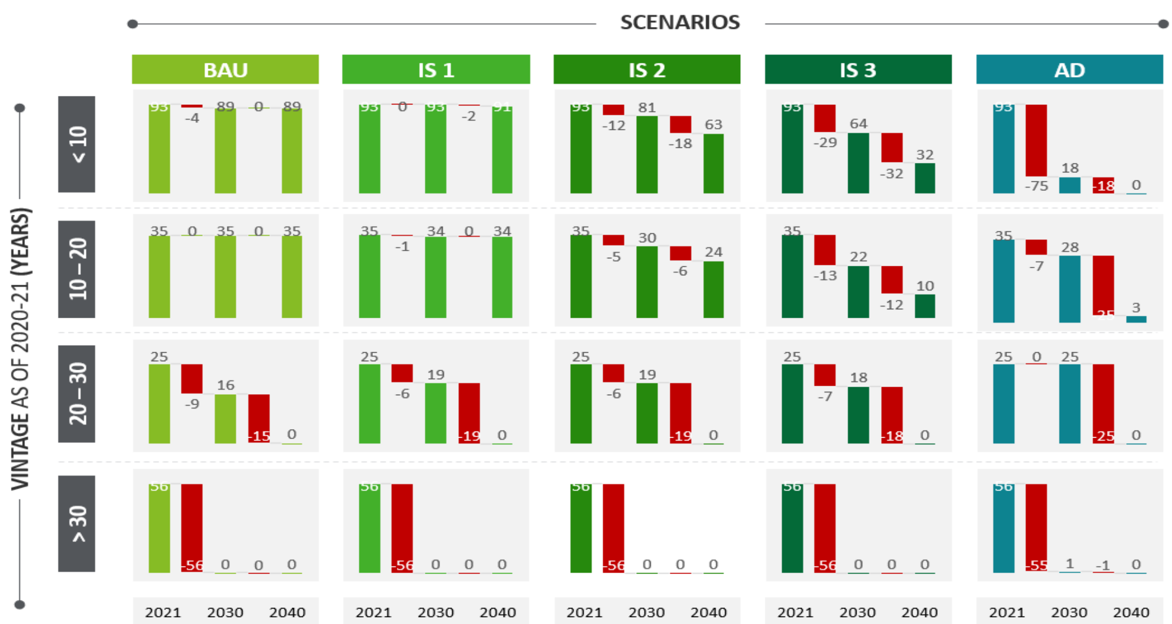
[12] While the weighted average VC in IS 1 is higher in the market regime, it must be noted that the numbers mentioned in the table above are the 2021 values for VC. The vintages of the capacity in both the regimes are slightly different and thus after factoring in vintage based cost escalation, the weighted average VC in the market regime will be slightly lesser than that of the PPA regime



- The Western region which has the highest installed coal capacity as of 2021 sees the steepest decline in capacity. The reason for this sharp decline is explained further in the following sections.
- In the AD scenario, the entire existing coal fleet in the western region and the north-eastern region will be shut down, with only 1 GW operating in Northern, Eastern and Southern regions each, i.e., total ~3 GW to meet the residual 18 TWh of generation requirement from the existing fleet in 2040.
- There is negligible reduction in the latter decade when compared to 2030's across all regions in the BAU and IS1 scenarios.

4.1.1.1.2 Vintage-wise

Similarly, a vintage-wise timeline of capacity retirement is presented below followed by a summary of the insights derived from the analysis.

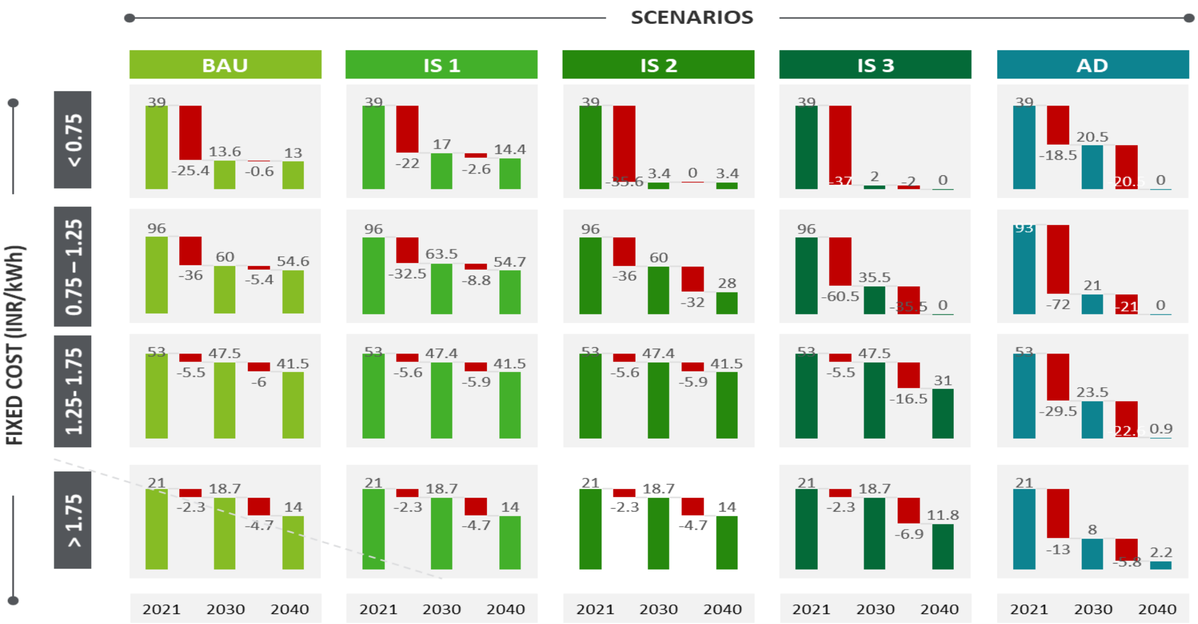


- All the plants with vintage greater than 20 years are retiring by 2040 across all scenarios – as they complete their maximum useful life of 40 years.

- In BAU and IS 1, hardly any capacity among plants with vintage below 20 years are retired.
- However, in IS-2 and IS-3, 12 and 29 GW of new plants (<10 years old in 2021) are retired by 2030 and these are higher figures compared to the older generators (10-30 years old) in both cases. It garners some support to the Prayas study[13] that also noted a strictly age-based retirement policy may not be effective.
- In fact, in the AD scenario, all the plants with vintage less than 10 years are retired, with a small capacity (3 GW) of plants between 10 – 20 years of current age still operational by 2040.

4.1.1.1.3 Cost-based

A cost wise (FC) segregation of coal assets and their retirement (in GW) has been depicted below, followed by a summary of the insights generated from the analysis



- In the most scenarios except AD, lower FC plants are predominantly retiring due to lower payoff costs
- In the BAU scenario, the drop in capacity in first decade is significantly higher than the second decade.

4.1.1.1.4 Key Observations

A summary of the key observations and insights from the above analysis is presented below as key takeaways.

- In the BAU and IS-1 scenarios, retirement is almost exclusively within capacity commissioned 20 years prior to 2021. In the AD scenario however, retirement is heavily skewed towards the newer capacity (commissioned within 10 years of 2021). This is because of the objective function of the model is slightly different in that the mandatory capacity payment deduction in the net revenue is only applicable until the plant is retired. Thus, there is aggressive retirement of newer capacity who have more years left in its original PPA tenure across all regions (nearly 75 GW of retirement by 2030 out of 93 GW). This is also the reason why the IS 3 scenario retirement is different from AD even though the coal generation targets are similar, since the BAU and IS scenarios deduct the capacity payment irrespective of whether the plant has retired.
- With SR and NR having higher cost stations, it is almost counter-intuitive to see that a larger capacity is being retired in the WR. An analysis of the break-up of the capacities show that in the BAU scenario only plants older than 30 years (as of 2021) are being retired in SR and NR whereas plants older than 20 years and some plants younger than 10 years are being retired in WR. The model In the PPA regime essentially tries to maximize the FC per unit payment – and plants with higher FC will be incentivized to stay on. As highlighted in the data and assumptions section, the weighted average FC is lower in WR and thus more capacity is retired in WR.
- In the AD the scenario, the 3 GW operational in 2040 is spread across NR, SR and ER. This is because these stations have higher FC per unit. All the operational capacity is also commissioned between 10 to 20 years before 2021. This is

[13] Maria Chirayil & Ashok Sreenivas. *Early Age-based Retirement of Coal Power Plants: Misplaced emphasis?* Prayas (Energy Group). May 2021.

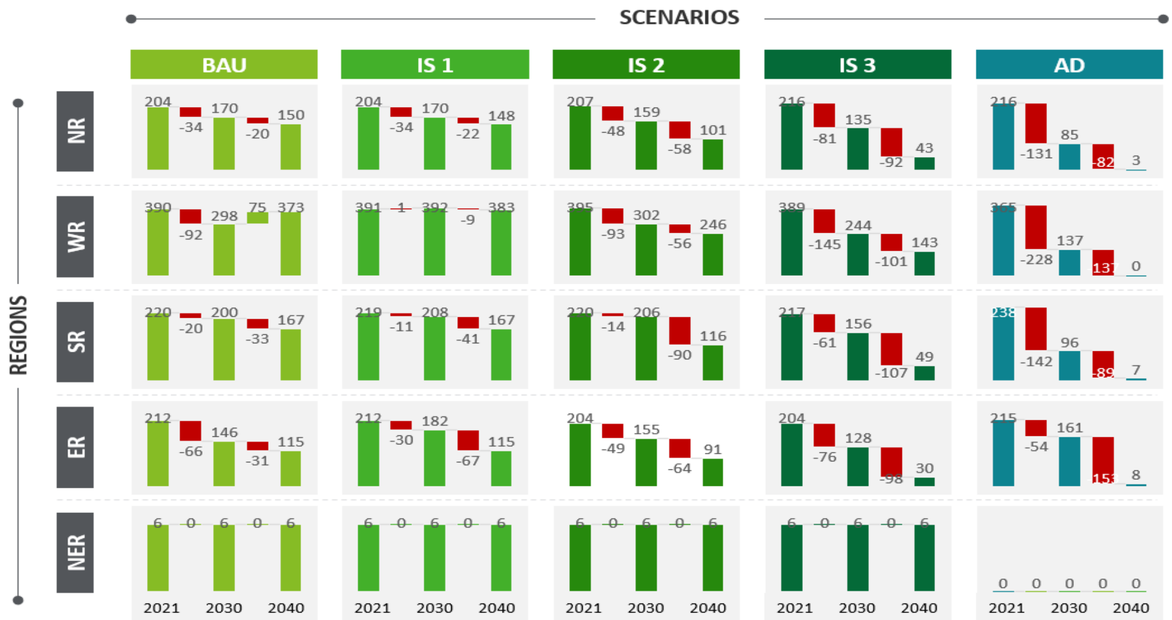
because, as mentioned in the first point, in the AD scenario, the model tries to retire capacities with longer initial PPA periods.

4.1.1.2 Generation (TWh) analysis

The generation of electricity in BU from the coal assets and how it changes across the years under each scenario on region-wise, vintage basis and cost basis has been further analysed to identify any patterns emerging from the retirement of coal assets.

4.1.1.2.1 Region-wise

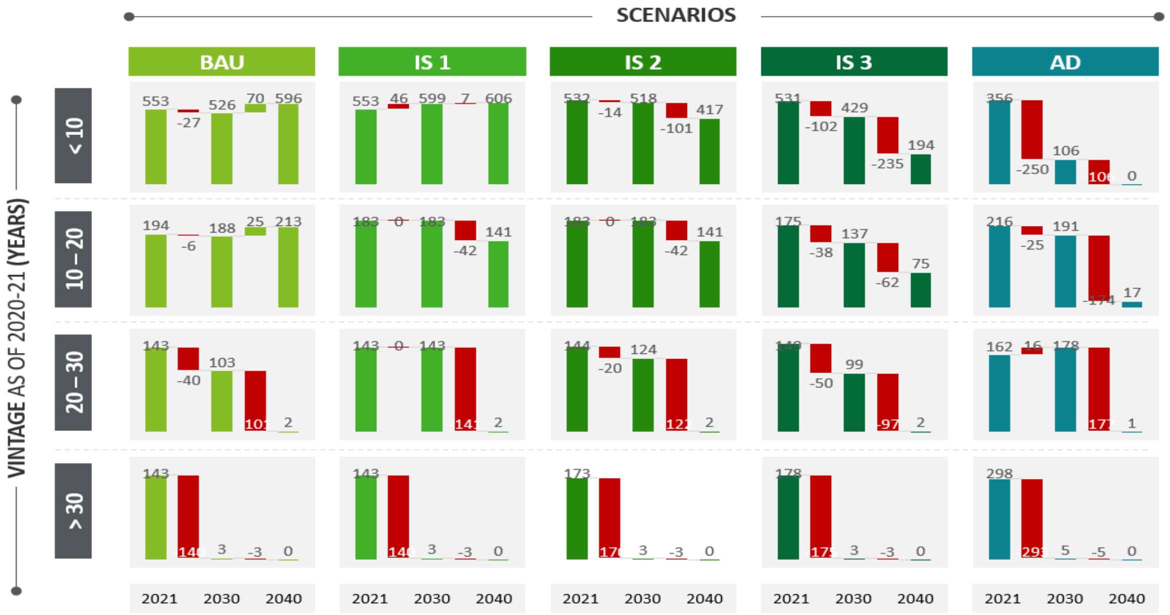
The depiction below projects the region-wise generation from coal assets and retirement of generation under these 5 scenarios for each of the years (2021, 2030 and 2040),



- An increase in the PLFs of plants from the Western region are observed in the BAU scenario between 2030 and 2040.
- In the AD scenario, there is a significant decrease in the generation in the first decade for NR, WR and SR, whereas ER sees a significant decrease in generation in the second decade

4.1.1.2.2 Vintage-wise

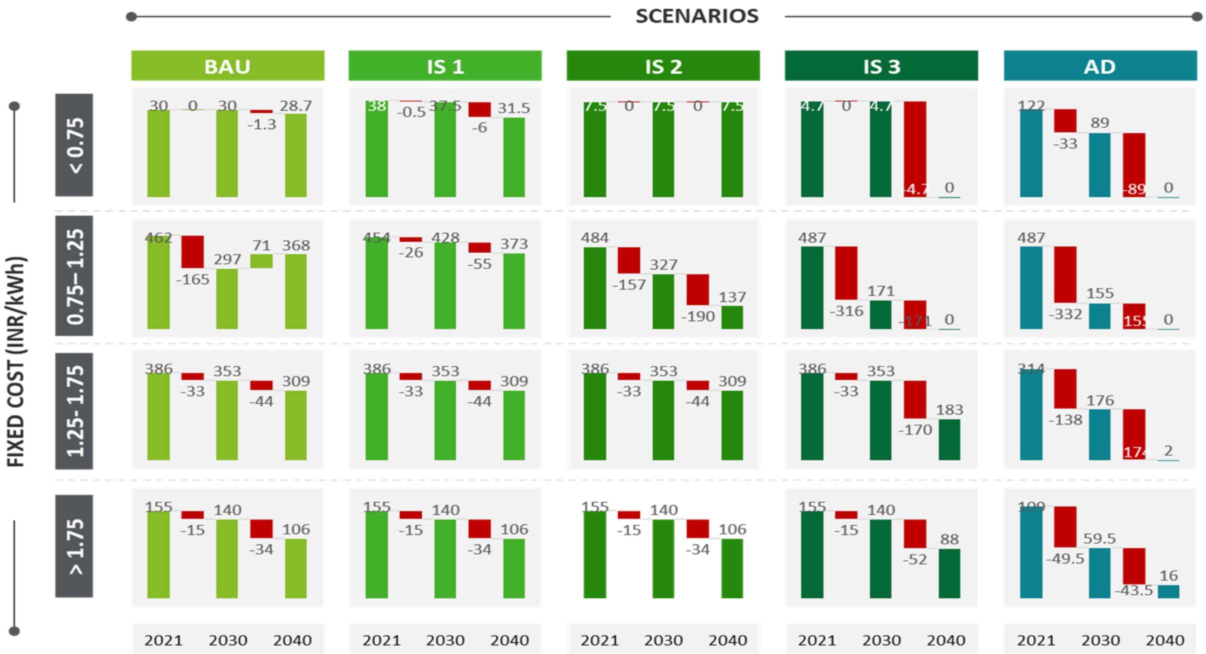
Similarly, a vintage-wise depiction is presented below followed by a summary of the insights generated from the analysis.



- The BAU scenario sees an increase in generation between 2030 and 2040 from plants with a vintage below 20 years which are not retiring any capacity in 2040.
- On the other hand, in the AD scenario, both the <10-year-old plants and >30-year-old plants go through a rapid reduction in generation in the first decade. Plants in the other two vintage classes undergo a similar rapid reduction post 2030.

4.1.1.2.3 Cost-based

A cost wise (FC) segregation of coal assets and their retirement (in TWh) has been depicted below followed by a summary of the insights generated from the analysis.



- There is a minimal drop in generation from low FC plants across most scenarios other than AD across the years. However, the PLF of these stations is at the minimum level of 25% and but for this constraint, some of them probably would have been retired; and
- In both AD and IS-3 scenario, plants with a higher FC are operation in 2040 while all other plants are shut down.

4.1.1.2.4 Key Observations

A summary of the key observations and insights from the above analysis is presented below as key takeaways.

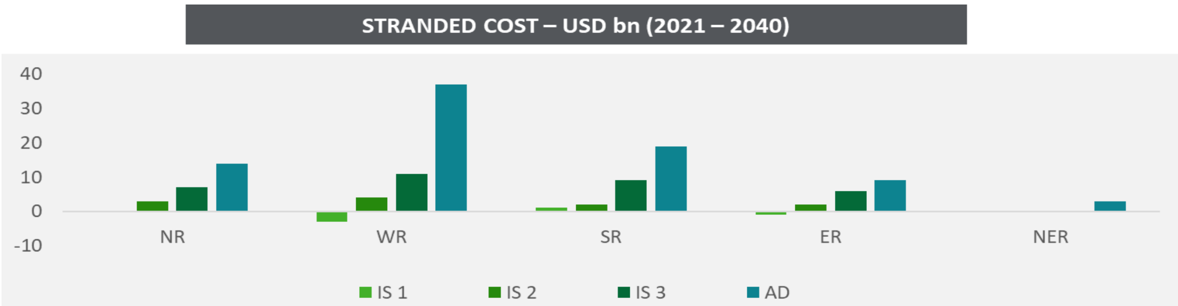
- The cost structure of the underlying PPAs has a profound impact on which plants lose dispatch most rather than vintage. This is also observed for capacity retirement and as such the capacity and generation trends are similar. It is optimal to retire plants with high FC under a deep decarbonization scenarios, and retain plants with low FC even if they are needed at the minimum PLF; and
- In the BAU scenario, there is an increase in the generation in 2040 from stations in WR which have been commissioned within the last 20 years. These stations have their FC in the range of INR 0.75 – 1.25 /kWh. The generation from stations with higher fixed cost has reduced due to age-related retirements and the operating capacities in these categories are generating at the maximum PLF limit.

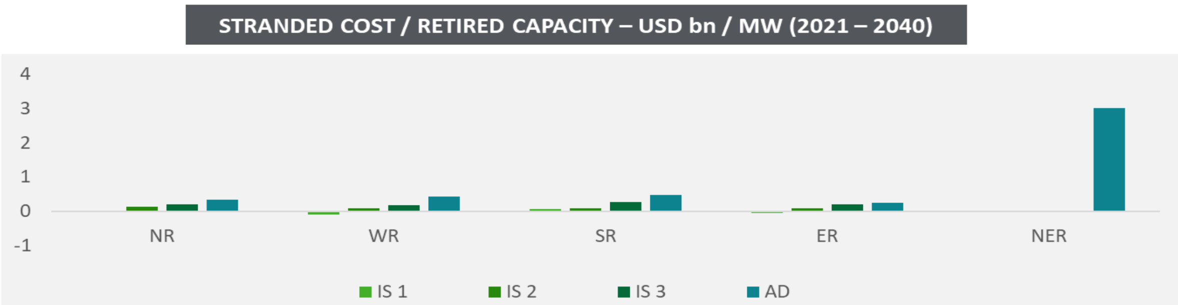
4.1.1.3 Stranded Cost (USD bn) analysis

The estimated stranded cost under each scenario on region-wise, vintage basis and cost basis has been further analyzed to identify any patterns emerging from the retirement of coal assets.

4.1.1.3.1 Region-wise

The figure below estimates the region-wise stranded cost under each scenario. This is further been estimated on a per MW basis of stranded capacity.



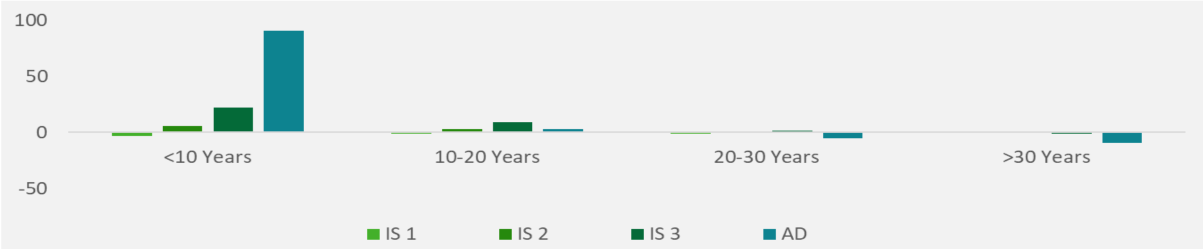


- In all the scenarios, the total stranded is highest in WR, followed by SR, ER, NR and NER. However, in the AD scenario the average stranded cost per MW of retired capacity is higher in SR compared to WR. This is because WR has significantly higher capacity which retires in AD.
- The stranded cost is negative for WR and ER in IS 1 indicating that the revenue earned by the generators in these regions is higher in this scenario compared to BAU. This is due to the different trajectories of coal generation targets due to lower capacity addition in IS 1.

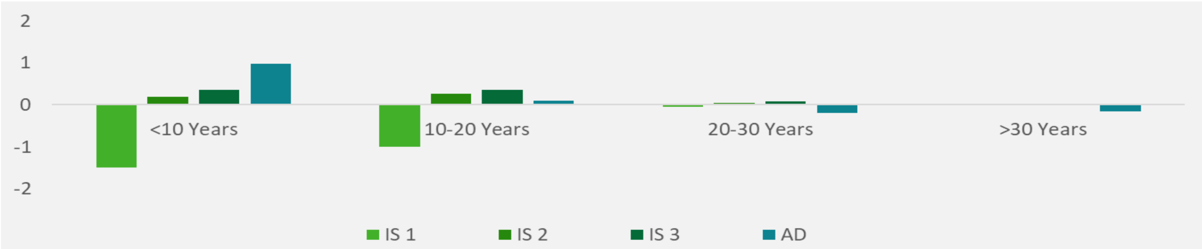
4.1.1.3.2 Vintage-wise

The figure below shows the vintage-wise stranded cost under each scenario. This is also expressed on a per MW basis of stranded capacity.

STRANDED COST – USD bn (2021 – 2040)



STRANDED COST / RETIRED CAPACITY – USD bn / MW (2021 – 2040)

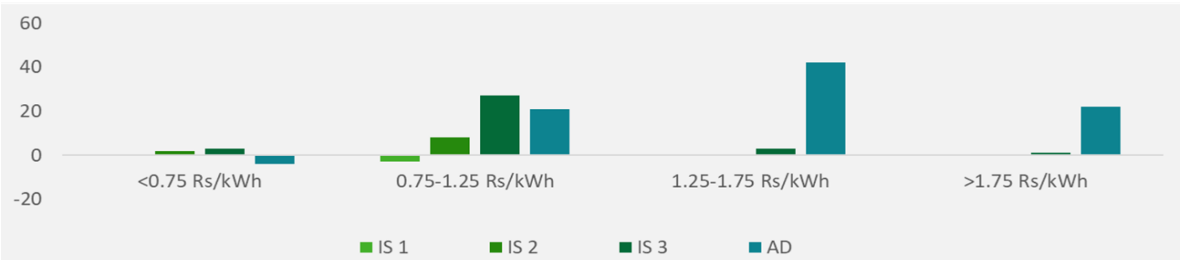


- The stranded cost for stations commissioned in the last 10 years are the highest in the AD scenario. This is because of the aggressive close-down of newer stations in AD. However, the stranded cost among stations commissioned between 10 – 20 years before 2021 is the highest in IS-3. Similarly, the stranded cost in AD for the other categories are negative. The high retirement of new capacity in the AD scenario has increased the generation for other categories and thus increasing their revenue.
- The revenue earned by the newer capacities is higher in IS-1 compared to BAU indicated by negative stranded cost.

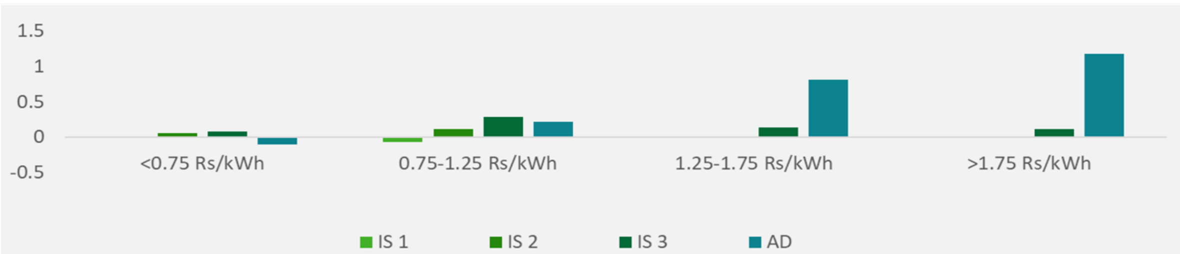
4.1.1.3.3 Cost based

The depiction below estimates the cost based stranded cost under each scenario. This is also expressed on a per MW basis of stranded capacity.

STRANDED COST – USD bn (2021 – 2040)



STRANDED COST / RETIRED CAPACITY – USD bn / MW (2021 – 2040)



- The stranded cost is highest in the AD scenario for the two high FC brackets but is lower for the lower FC brackets, this is due to the high retirement of new capacities which typically tend to have higher fixed costs.
- The stranded cost present in the lower FC brackets for the IS scenarios are due to aggressive retirement of these plants.

4.1.1.3.4 Key Observations

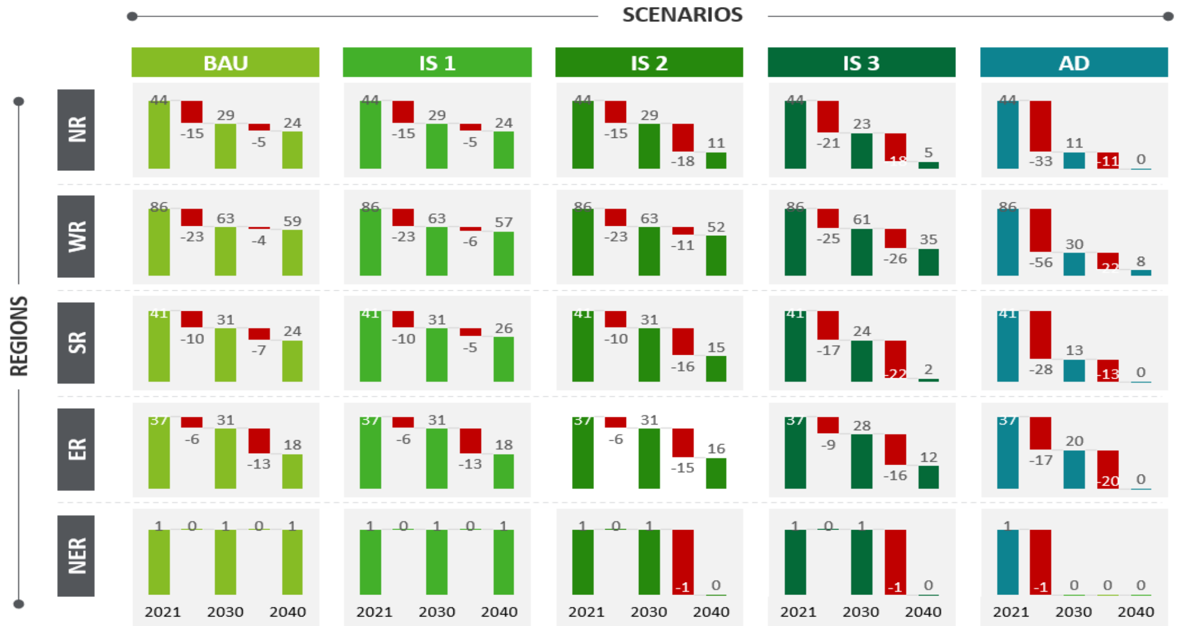
- The AD scenario sees significant stranded costs due to the aggressive retirement of newer capacities which also have higher FC, thus reducing the revenue for the scenario. This also results in the increase in generation of lower FC stations, thus reducing their stranded costs.

4.1.2 Market Regime

A similar analysis has been undertaken considering a market regime, where the capacity prices and variable costs are recovered by a plant solely through the MBED market mechanisms. The results of such analysis are markedly different from the ones in the PPA regime as discussed below.

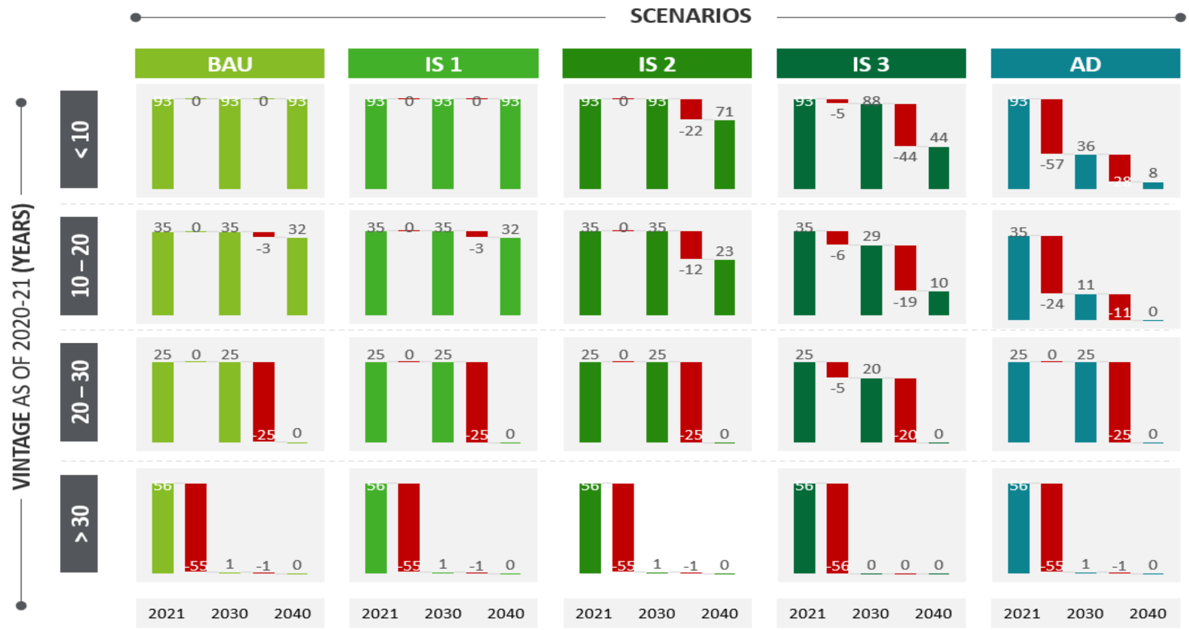
4.1.2.1 Capacity (GW) analysis

4.1.2.1.1 Region-wise



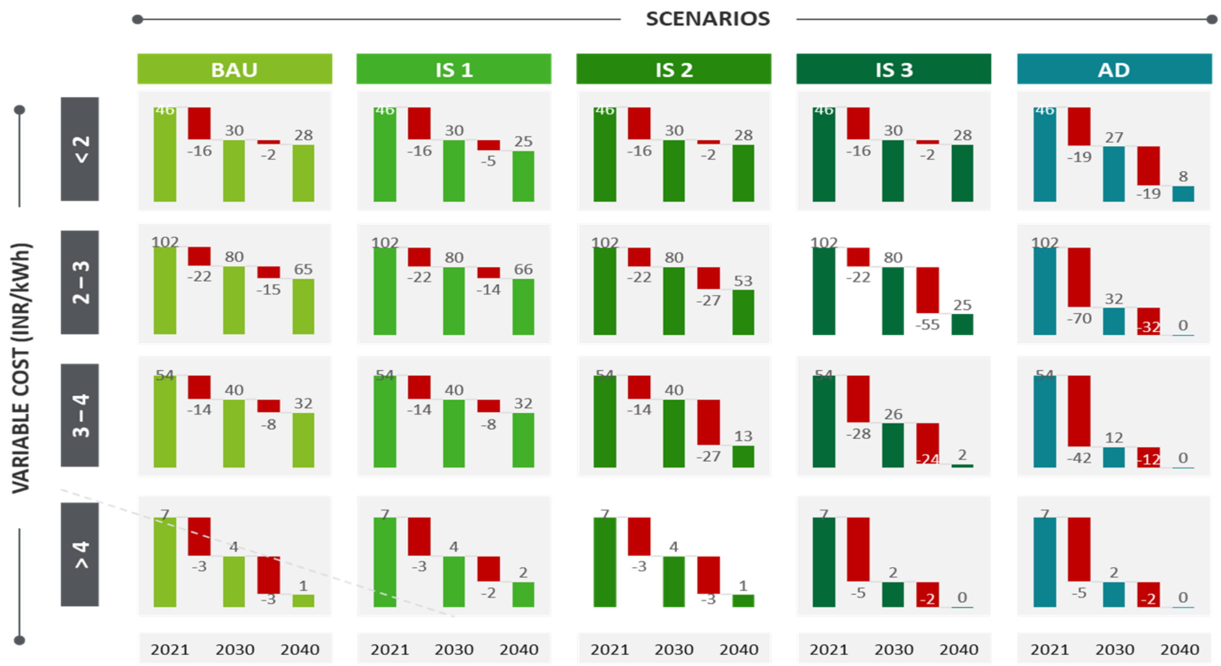
- The BAU scenario sees retirement to the extent of 27 GW in WR, 20 GW in NR, 19 GW in ER and 17 GW in SR over the next 20 years.
- In the AD scenario, the entire existing coal fleet except for 8 GW capacity in the Western region is shut down over the next two decades.
- Across all scenarios, the capacities in the market regime are higher than those in the PPA regime, but operate at lower PLFs. Absent a FC, there is less of an economic justification to shut down plants.

4.1.2.1.2 Vintage-wise



- All plants older than 20 years by 2021, are retired by 2040 across all the scenarios – as they complete their maximum useful life of 40 years.
- In the AD scenario, only plants with vintage less than 10 years are operational in 2040.
- Nearly no capacity with vintage younger than 20 years have been retired in BAU as well IS 1.

4.1.2.1.3 Cost-based



- The BAU scenario sees retirement of plants with cheaper production costs even though plants with higher production costs still survive. This is because a lot of the cheaper plants are older and have come to end of their life cycles.
- In the AD scenario, the biggest reduction in capacity comes across for the 2-3 INR/kWh segment totalling 70 GW in the first decade.

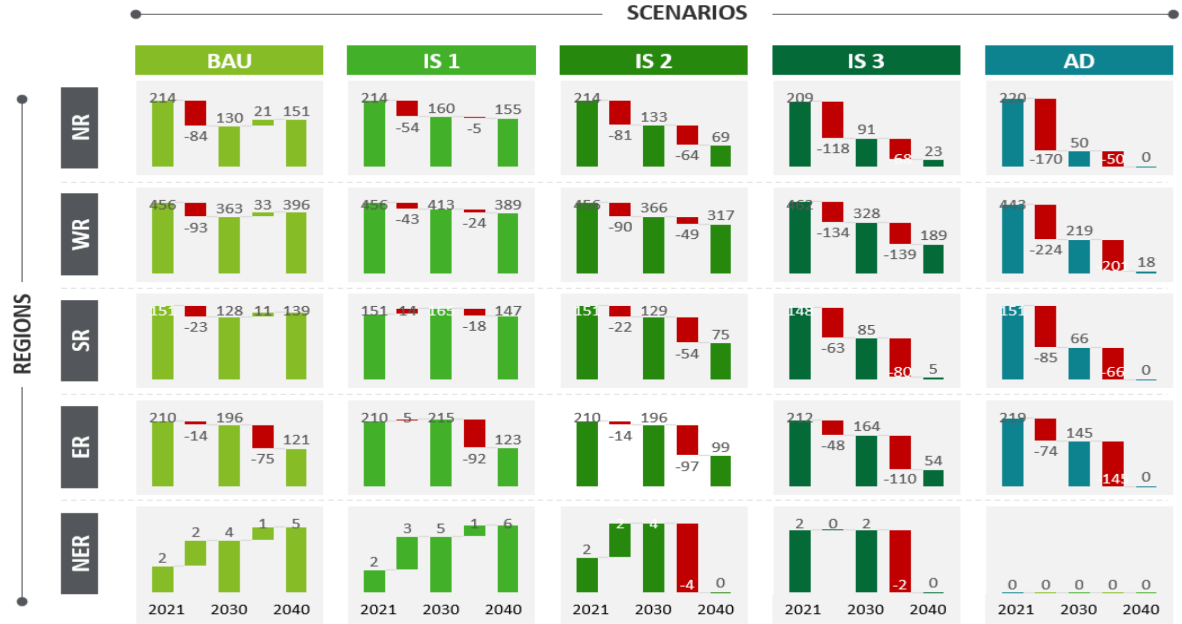
4.1.2.1.4 Key Observations

Compared to the PPA regime, there are a few differences which are highlighted below

- In the AD scenario , retirement is less skewed towards the newer capacity (commissioned after 2011) – 75 GW of retirement by 2030 in PPA regime compared to 57 GW in the market regime. This is because there is no longer any mandatory capacity payment deduction and the driver for the optimization is the variable cost. The only operational capacity by 2040 is also commissioned within the last 10 years since these stations have the lowest VC.
- Compared to the PPA scenario, lesser capacity is retired between 2021 and 2030 and more capacity is retired between 2030 and 2040. This has to do with the reduction in revenue in the later years due to the escalation of variable costs.
- Unlike in the PPA scenario which had some capacity with lower FC retired by 2030, in the market regime, the only retirement up to 2030 in BAU, IS 1 and IS 2 are due to the end of life of the stations.

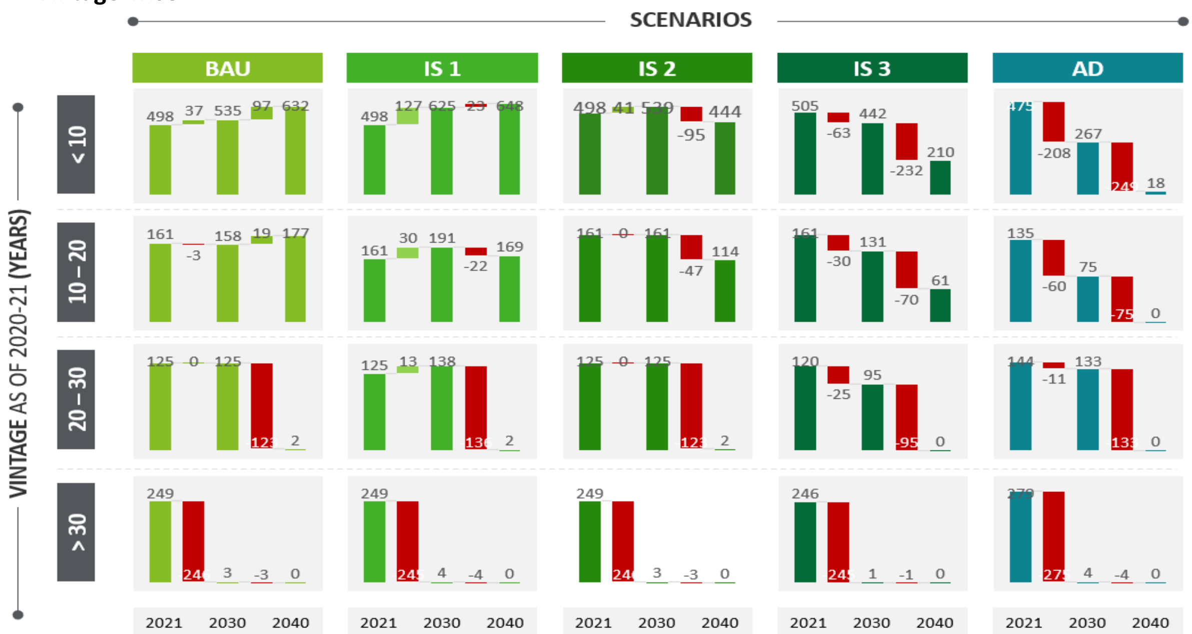
4.1.2.2 Generation (GWh) analysis

4.1.2.2.1 Region-wise



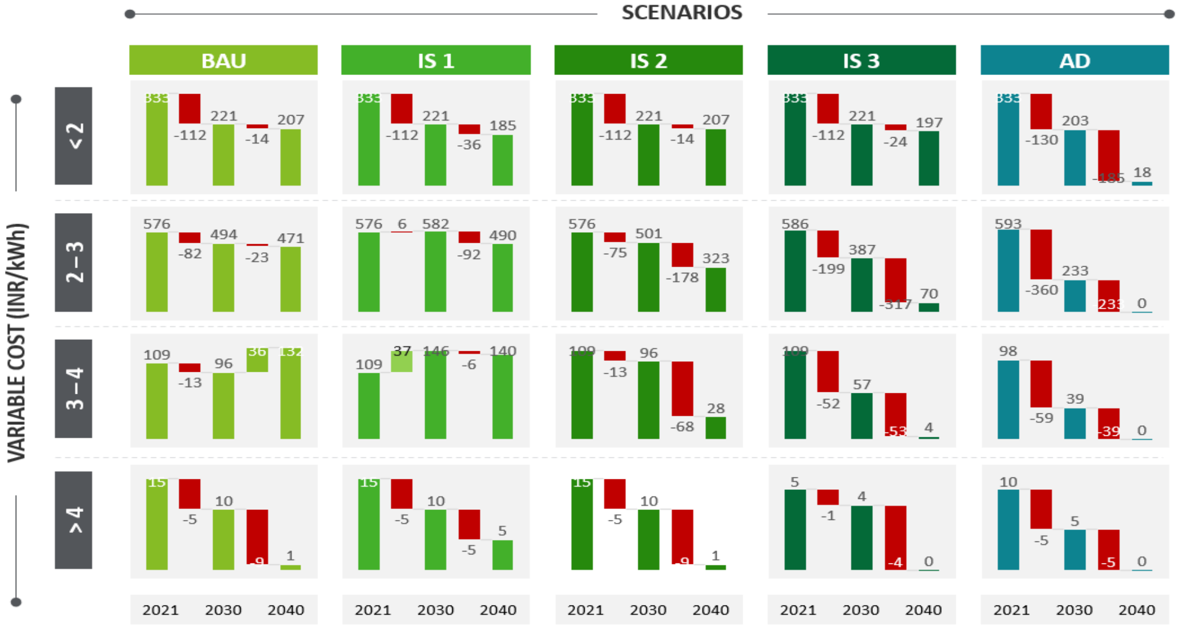
- The BAU scenario sees reduction in generation to the extent of 17 GW in WR, 63 GW in NR, 89 GW in ER and 12 GW in SR over the next 20 years. However, there is an increase in generation in NR, WR and SR between 2030 and 2040
- NER witnesses a rise in generation across the years in certain scenarios. However, the region has lower generation when compared to the PPA Regime.

4.1.2.2.2 Vintage-wise



- All the scenarios tend to aggressively reduce the generation through older plants due to the end of their life cycle.
- The generation from the newer plants is increasing for IS1-2 scenarios to make up for the lost capacities of the older plants.

4.1.2.2.3 Cost-based



- The PPA Regime saw a much higher reduction in capacities for plants producing at rates between 2-4 INR/kWh as compared to the Market Regime.
- Plants in the range of 3-4 INR/kWh are even seeing an increase in generation in the BAU and IS1 scenarios due to their age.

4.1.2.2.4 Key Observations

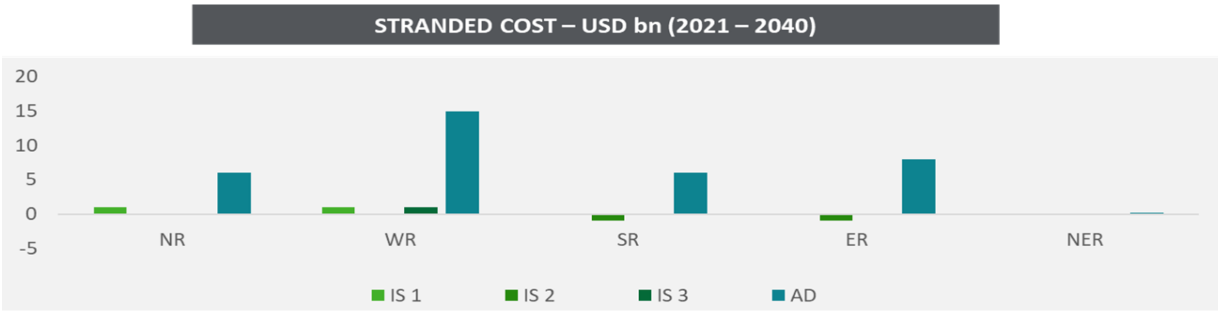
- As expected, the generation trend generally follows the capacity trend also for the Market regime.
- In the BAU and IS-1 scenarios, there is an increase in the generation from stations in various regions with a VC between INR 3 – 4 /kWh. This is because generation from stations with lower VC has reduced due to age-related retirements as indicated by the increase in generation from plants commissioned with the past two decades.

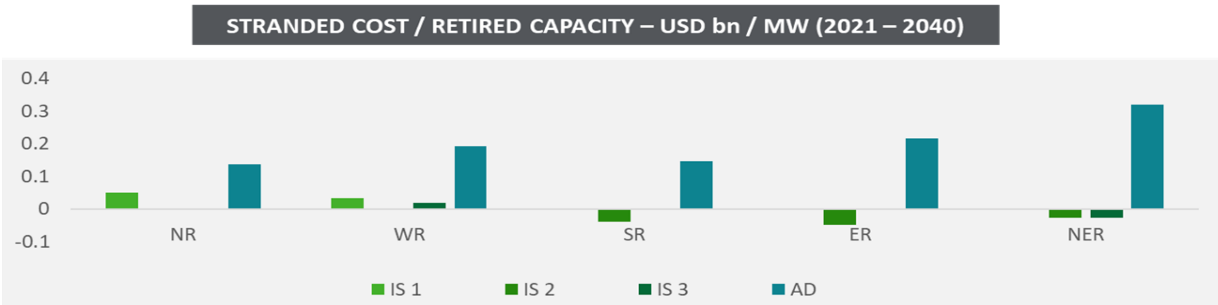
4.1.2.3 Stranded Cost (USD bn) analysis

The estimated stranded cost under each scenario on region-wise, vintage basis and cost basis has been further analyzed to identify any patterns emerging from the retirement of coal assets.

4.1.2.3.1 Region-wise

The depiction below estimates the region-wise stranded cost under each scenario. This is further been estimated on a per MW basis of stranded capacity.

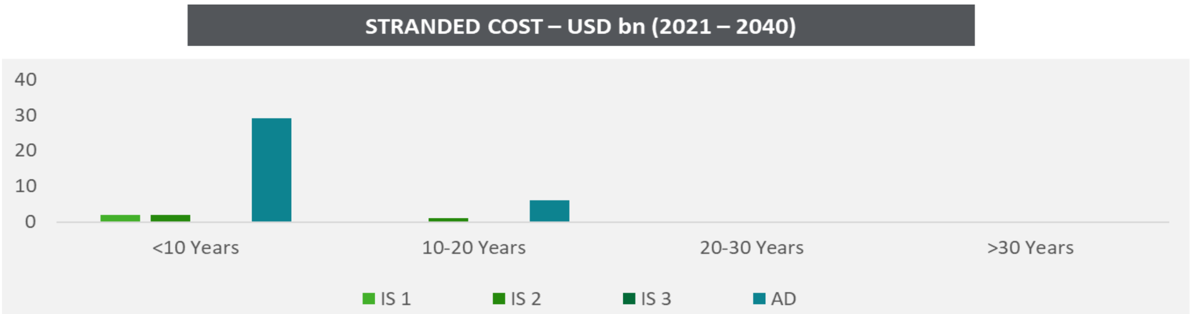


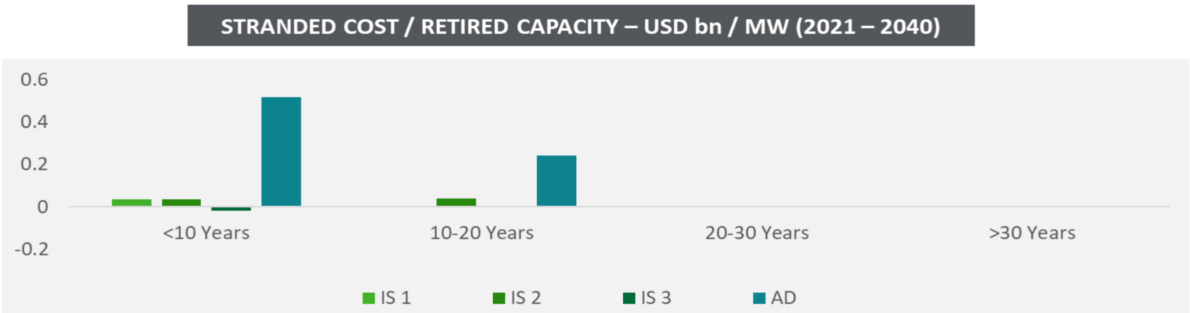


- The highest stranded cost in the AD scenario is in WR. Similarly, the average stranded cost over the retired capacity is highest in WR and ER indicating the loss of revenue for lower cost stations in these regions.

4.1.2.3.2 Vintage-wise

The figure below shows the vintage-wise stranded cost under each scenario. This is further been estimated on a per MW basis of stranded capacity.

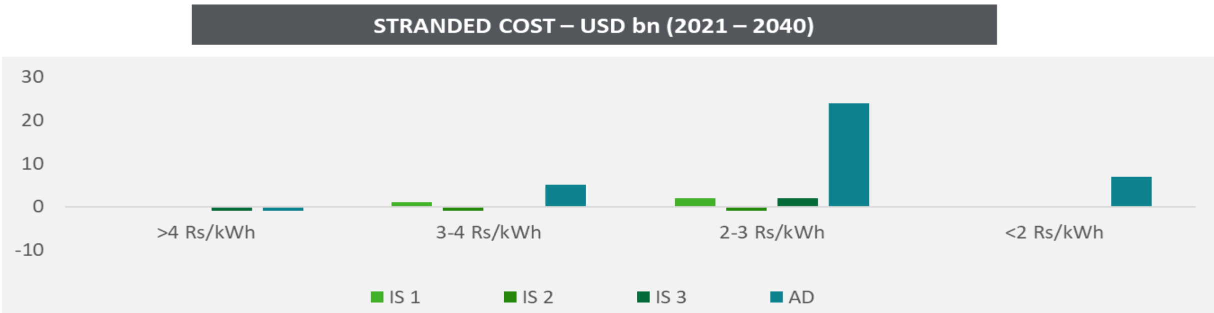


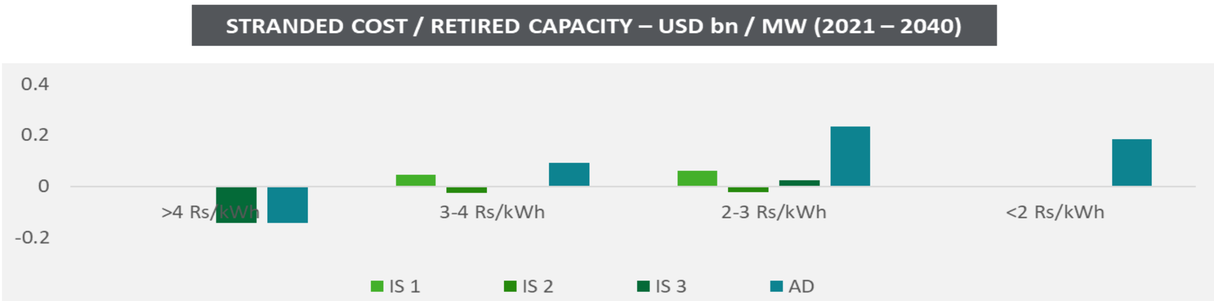


- The revenues for older plants (>20 years) tend to be similar across all the scenarios due to similar trajectories of plant closure, thus the stranded cost for these plants is virtually none.
- The stranded costs are higher in the newer stations as they stand to lose higher revenue due to aggressive decarbonization.

4.1.2.3.3 Cost based

The depiction below estimates the cost based stranded cost under each scenario. This is further been estimated on a per MW basis of stranded capacity.





- The stranded cost is highest in the AD scenario is the highest for the INR 2- 3 /kWh bracket because of significant retirement of stations in this VC range. The stranded cost in the lowest VC bracket is not very high due to similar levels of generation in all scenarios.
- The high VC generators are operating at a loss in the higher coal generation scenarios due to more requirement. Thus, the revenues for the high VC stations appear to be higher in the more aggressive decarbonization scenarios and the stranded cost is negative.

4.1.2.3.4 Key Observations

- As expected, the stranded cost is highest in WR and ER as the loss of revenue is higher in these regions with lower variable costs. The stranded cost is also the highest for newer stations which are in the INR 2 – 3 /kWh bracket due to higher levels of retirement to meet the aggressive decarbonization goals. The high cost stations are also observed to be operating at a loss (more details given in Annexure 1), and hence eligible for a lower stranded cost based compensation.

4.2 Concluding Remarks

Massive retirement of existing coal stations is essential if India wants to meet the net zero carbon emission goal by 2040 following IEA's Accelerated Decarbonization regime. This will effectively call for decommissioning over 200 GW of the existing fleet at an unprecedented rate globally with far reaching consequences not merely in financial terms for the asset owners, but also implications for secure operation of the system, job losses and the wider economic impact. First and foremost, there needs to be a clear view on how a coal retirement strategy should be shaped including plausible candidates by location/region, vintage and cost of generation. It is also important to understand the implications of a less stringent but potentially far less disruptive coal generation reduction pathway. This study has a modest objective to derive a ballpark estimate of the stranded cost of coal assets under alternative coal generation reduction pathways. More specifically, the study performs an optimization analysis to derive some insights on the order in which existing coal fleet should be retired to match the generation trajectory estimated in the IEA AD scenario as well a few other less aggressive reduction in coal generation. The study also then quantifies the compensation payable to the capacity which would be left stranded due to more aggressive decarbonization relative to a Business-as-usual scenario also considered in the IEA report. While other studies have looked at the benefits of coal retirement, this study tries to identify the capacity which should be retired based on cost, operational and technical parameters instead of just the vintage. The compensation payable for stranded assets also depend heavily on the pricing regime, namely whether the plants operate under a PPA which is by and large the current norm ("PPA regime"), or if they participate in a wholesale electricity market as is envisaged in the proposed Market Based Economic Dispatch ("Market regime"). If the stranded cost is high, this in itself is a significant exit barrier for coal even before we consider the difficult social and political ones. Understanding these stranded costs for different decarbonization targets under alternative pricing (i.e., PPA vs market) regimes may be a useful starting point to form a strategy and prioritize the assets that can realistically form an initial portfolio of candidates that warrant a deeper dialogue around other issues.

The key findings of the study are as follows:

- If India continues as per the Business-as-Usual scenario or a far less aggressive decarbonization route, the coal fleet retirements are almost entirely driven by age/ vintage of the plants. In the more aggressive decarbonization pathway, the retirements are driven by the age as well as the cost of the stations, with the fixed cost being the driver in the PPA regime and the variable cost being the driver in the market price regime.
- The stranded cost under the PPA regime ranges from USD 11 bn to USD 81 bn depending on the extent to which coal generation needs to be curtailed from the existing fleet by 2040. The high end of $81 billion represents the IEA AD scenario that virtually reduces generation from the existing coal fleet to close to zero by 2040 and retires more than 200 GW of coal capacity. These compensation figures however reduce significantly under the market regime, ranging from USD 2 bn to USD 36 billion for the same set of decarbonization scenarios. The fact that a market-oriented dispatch which obviously has other attractions to provide a clear and transparent signal to market participants, can therefore be a critical part of the decarbonization strategy.
- It is also worth noting the fact that a lesser ambition to reduce coal based generation than the IEA AD scenario can be achieved at a disproportionately lower cost, and yet still see formidable reduction of coal capacity/generation. The IS-2 (30% reduction in generation from BAU by 2040) and IS-3 (67% reduction in coal generation from BAU by 2040) scenarios present modest to reasonably deep decarbonization pathways with 37 GW and 81 GW of coal capacity being decommissioned, respectively under a PPA regime at relatively modest stranded costs of $11b and $33b, respectively. This clearly shows that it may be far cheaper to target the most expensive group of 37 GW generators at a relatively modest stranded cost of $11b or $0.3m/MW on average.
- Reduction of generation from existing coal fleet can present an economically attractive way to reduce carbon emissions. Even if we consider the higher end of stranded cost and assume the compensation will fully offset the generators at that level, the implied *average* cost of CO_2 reduction for IS-2, IS-3 and AD works out to be approximately $10/t, $14/t and $22/t, respectively. As IS-3 and AD in particular represent deep decarbonation pathways, these average cost of carbon reduction is quite remarkable and indicate that even at the high end of this range, around 7 billion tons of CO_2 (in the AD scenario in cumulative terms over 2021-2040) is achievable at a (discounted) cost of $81b. The Market/MBEB scenario, of course, presents a far cheaper solution with practically zero cost for IS-3 and at $36b for AD. While this calls for sweeping reform of the PPA regime to bring all of the generation in the country to be cleared through the market, it also shows the rich reward that such measures entail not only to enhance cost efficiency, but the tremendous potential for a market based mechanism to deliver decarbonization through accelerated retirement of coal.

There are major policy implications of the findings. The introduction of MBED (with future capacities linked to market prices) would help achieve decarbonization in a more cost-efficient manner that provides an additional impetus to implement the new market regime. This in turn also suggests that Discoms should not renegotiate expiring PPAs and instead rely more on the market to reduce their procurement costs. The market scenario also optimizes the procurement costs and therefore presents the best possible outcomes for the overall system. The significantly lower stranded costs also suggest that the market would help better integrate more renewables.

While the analysis has been done for the PPA regime and the Market Regime independently, it is unlikely that only one of these regimes would prevail over the next two decades. It is more likely that we will see a more hybrid regime, with the market penetration slowly increasing over the next decade while some capacity, especially the state generation companies, remaining under the PPA regime for a longer.

The present analysis does not look at the issue of the settlement of fixed costs for the retired capacity. Fixed costs were treated as sunk costs and were thus outside the scope of the optimization. With a significant capacity currently stranded and with 24 GW of the upcoming 57 GW of new capacity unlikely to be commissioned, it is possible that generators and Discoms would be willing to renegotiate existing PPAs.

While discussing the retirement of coal capacity, it should also be noted that some of the capacity identified as part of the optimal retirement strategy, could operate during high demand periods or for ancillary services which is becoming more crucial with the increasing share of renewables. An analysis of the ancillary demand and the possible prices in a potential ancillary market would help cast light on benefits of keeping some of this capacity operational. This is essentially a resource adequacy assessment that will need to be performed to critically evaluate the role of existing coal fleet to complement and refine the findings of this study.

5 Annexure 1: List of Loss-Making Stations

The following plants are operating under loss in the Market Price regime.

5.1.1 Business as Usual (BAU)

Plant Name	Region	Vintage	Year since plant is operating under loss	Retirement Year
BELLARY	SR	10 - 20	2021	2040
METTUR	SR	> 30	2021	2028
SURATGARH	NR	20 - 30	2021	2039
TROMBAY	WR	> 30	2021	2025
DURGAPUR DPL	ER	10 - 20	2021	-
TITAGARH	ER	> 30	2021	2024
GANDHINAGAR	WR	> 30	2024	2031
RAYALASEEMA	SR	20 - 30	2027	2035
RAJIV GANDHI (HISAR)	NR	10 - 20	2032	-
GURU HARGOBIND	NR	20 - 30	2033	2038
UDUPI	SR	10 - 20	2033	-
KHARAGPRASAD	ER	10 - 20	2036	-
NEYVELI ZERO	SR	10 - 20	2036	-
PANIPAT	NR	10 - 20	2037	-
PALONCHA PLANT	SR	20 - 30	2037	2038
KUDGI	SR	< 10	2037	-
PARLI	WR	10 - 20	2037	-
MUNDRA ADANI	WR	10 - 20	2037	-

Plant Name	Region	Vintage	Year since plant is operating under loss	Retirement Year
BARKHERA IPP	NR	< 10	2038	-
UTRAULA	NR	< 10	2038	-
SURAT	WR	20 - 30	2038	-
KUNDARKI IPP	NR	< 10	2039	-
MAHATMA GANDHI	NR	< 10	2039	-
GUMMIDIPOONDI CAUVERY	SR	< 10	2039	-
PARADIP ESSAR	ER	< 10	2039	-
KHAMBERKHERA IPP	NR	< 10	2039	-
AMRAVATI	WR	< 10	2039	-
GOINDWAL SAHIB	NR	< 10	2040	-
NASIK SINNAR	WR	< 10	2040	-
INDIRA GANDHI	NR	< 10	2040	-
VADINAR POWER	WR	< 10	2040	-
SIKKA	WR	< 10	2040	-
LALITPUR	NR	< 10	2040	-
THOOTHUKKUDI IBPGL	SR	10 - 20	2040	-
BHAVNAGAR PADVA	WR	< 10	2040	-
ROSA POWER	NR	10 - 20	2040	-

5.1.2 Intermediate Scenario 1 (IS 1)

Plant Name	Region	Vintage	Year since plant is operating under loss	Retirement Year
BELLARY	SR	10 - 20	2021	-
METTUR	SR	> 30	2021	2028
SURATGARH	NR	20 - 30	2021	2039
TROMBAY	WR	> 30	2021	2025
DURGAPUR DPL	ER	10 - 20	2021	-

Plant Name	Region	Vintage	Year since plant is operating under loss	Retirement Year
PARLI	WR	10 - 20	2037	-
KOTHAGUDEM	SR	20 - 30	2037	2038
MUNDRA ADANI	WR	10 - 20	2037	-
BARKHERA IPP	NR	< 10	2038	-
GOINDWAL SAHIB	NR	< 10	2038	-

Plant Name	Region	Vintage	Year since plant is operating under loss	Retirement Year
TITAGARH	ER	> 30	2021	2024
GANDHINAGAR	WR	> 30	2024	2031
RAYALASEEMA	SR	20 - 30	2027	2035
AMRAVATI	WR	< 10	2030	-
RAJIV GANDHI (HISAR)	NR	10 - 20	2032	-
UTRAULA	NR	< 10	2032	-
INDIRA GANDHI	NR	< 10	2033	-
GURU HARGOBIND	NR	20 - 30	2033	2038
UDUPI	SR	10 - 20	2033	-
SIMHADRI	SR	10 - 20	2033	-
KUDGI	SR	< 10	2034	-
KHARAGPRASAD	ER	10 - 20	2036	-
ROSA POWER	NR	10 - 20	2036	-
NEYVELI ZERO	SR	10 - 20	2036	-
RAIKHEDA	WR	< 10	2036	-
NASIK SINNAR	WR	< 10	2037	-
VADINAR POWER	WR	< 10	2037	-
GUMMIDIPOONDI CAUVERY	SR	< 10	2037	-
PANIPAT	NR	10 - 20	2037	-
PALONCHA PLANT	SR	20 - 30	2037	2038
PARADIP ESSAR	ER	< 10	2037	-
SIKKA	WR	< 10	2037	-

Plant Name	Region	Vintage	Year since plant is operating under loss	Retirement Year
BONGAIGAON NTPC	NER	< 10	2038	-
MAHANADI	WR	< 10	2038	-
KAKATIYA	SR	10 - 20	2038	-
BHAVNAGAR PADVA	WR	< 10	2038	-
SURAT	WR	20 - 30	2038	2040
MOUDA	WR	< 10	2038	-
MAITHON RB POWER	ER	< 10	2038	-
SOLAPUR	WR	< 10	2038	-
KUNDARKI IPP	NR	< 10	2039	-
MAHATMA GANDHI	NR	< 10	2039	-
KHAMBERKHERA IPP	NR	< 10	2039	-
RATNAGIRI	WR	10 - 20	2040	-
MUTIARA	SR	< 10	2040	-
KUTCH OPG	WR	< 10	2040	-
SRI DAMODARAM SANJEEVAIAH	SR	< 10	2040	-
MAADURGA TANGI	ER	< 10	2040	-
LALITPUR	NR	< 10	2040	-
THOOTHUKKUDI IBPGL	SR	10 - 20	2040	-
BINA	WR	< 10	2040	-
HAZIRA-2	WR	< 10	2040	-
BOKAROA	ER	< 10	2040	-

5.1.3 Intermediate Scenario 2 (IS 2)

Plant Name	Region	Vintage	Year since plant is operating under loss	Retirement Year
BELLARY	SR	10 - 20	2021	2040
METTUR	SR	> 30	2021	2028
SURATGARH	NR	20 - 30	2021	2039
TROMBAY	WR	> 30	2021	2025
DURGAPUR DPL	ER	10 - 20	2021	-
TITAGARH	ER	> 30	2021	2023
GANDHINAGAR	WR	> 30	2024	2031
RAYALASEEMA	SR	20 - 30	2027	2035

Plant Name	Region	Vintage	Year since plant is operating under loss	Retirement Year
UDUPI	SR	10 - 20	2033	-
KHARAGPRASAD	ER	10 - 20	2036	2040
NEYVELI ZERO	SR	10 - 20	2036	-
PANIPAT	NR	10 - 20	2037	2040
PALONCHA PLANT	SR	20 - 30	2037	2038
PARLI	WR	10 - 20	2037	2040
BARKHERA IPP	NR	< 10	2038	2040
SURAT	WR	20 - 30	2038	2040

Plant Name	Region	Vintage	Year since plant is operating under loss	Retirement Year
RAJIV GANDHI (HISAR)	NR	10 - 20	2032	2040
GURU HARGOBIND	NR	20 - 30	2033	2038

Plant Name	Region	Vintage	Year since plant is operating under loss	Retirement Year
KHAMBERKHERA IPP	NR	< 10	2039	2040

5.1.4 Intermediate Scenario 3 (IS 3)

Plant Name	Region	Vintage	Year since plant is operating under loss	Retirement Year
BELLARY	SR	10 - 20	2021	2040

Plant Name	Region	Vintage	Year since plant is operating under loss	Retirement Year
DURGAPUR DPL	ER	10 - 20	2021	2022

5.1.5 Accelerated Decarbonization (AD)

Plant Name	Region	Vintage	Year since plant is operating under loss	Retirement Year
METTUR	SR	> 30	2021	2028
SURATGARH	NR	20 - 30	2021	2031
TROMBAY	WR	> 30	2021	2025

Plant Name	Region	Vintage	Year since plant is operating under loss	Retirement Year
GANDHINAGAR	WR	> 30	2024	2031
RAYALASEEMA	SR	20 - 30	2027	2034
GURU HARGOBIND	NR	20 - 30	2033	2035