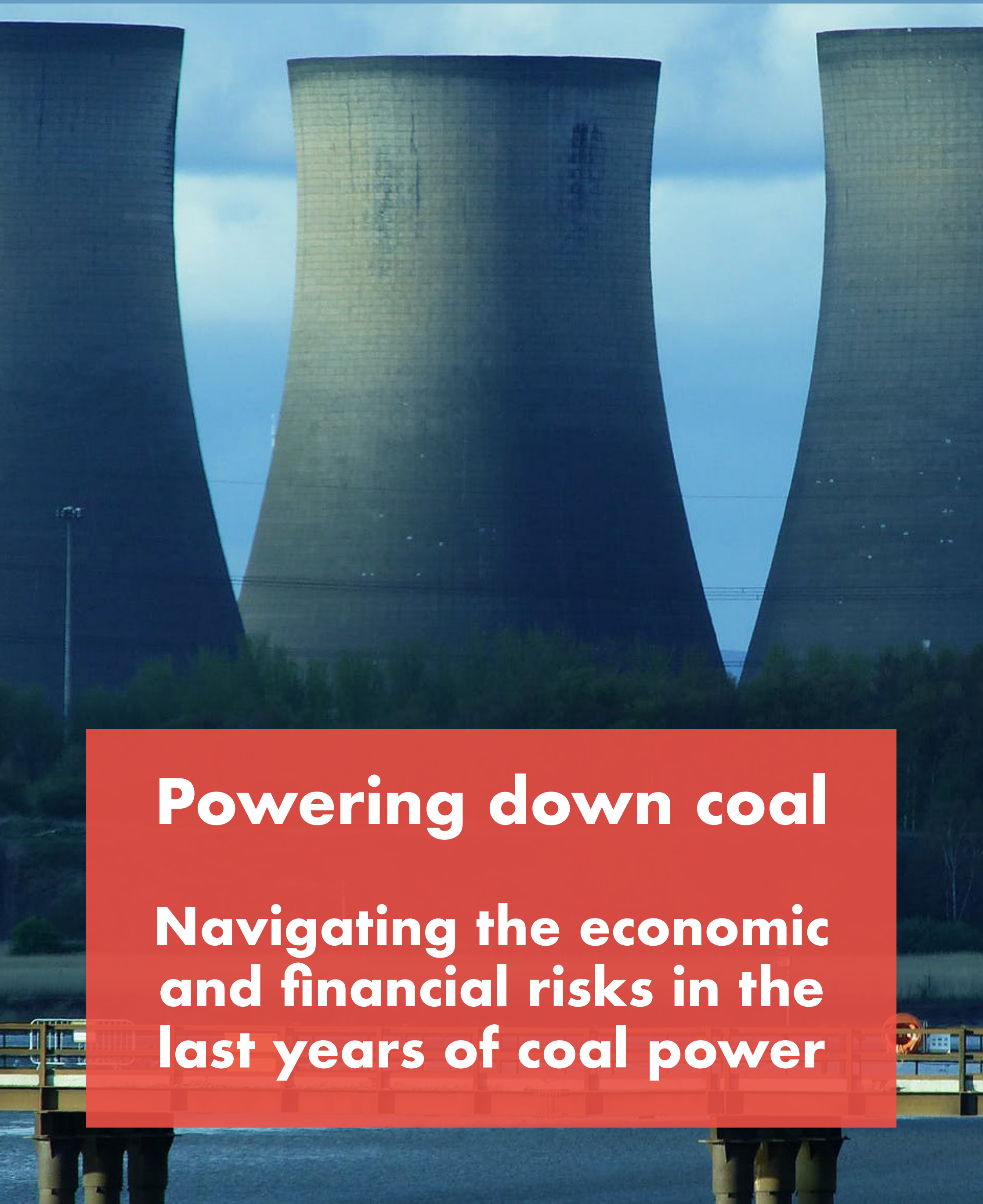
Carbon Tracker Initiative



Powering down coal

Navigating the economic and financial risks in the last years of coal power

November 2018

About Carbon Tracker

The Carbon Tracker Initiative is a team of financial specialists making climate risk real in today's financial markets. Our research to date on unburnable carbon and stranded assets has started a new debate on how to align the financial system in the transition to a low carbon economy.

www.carbontracker.org

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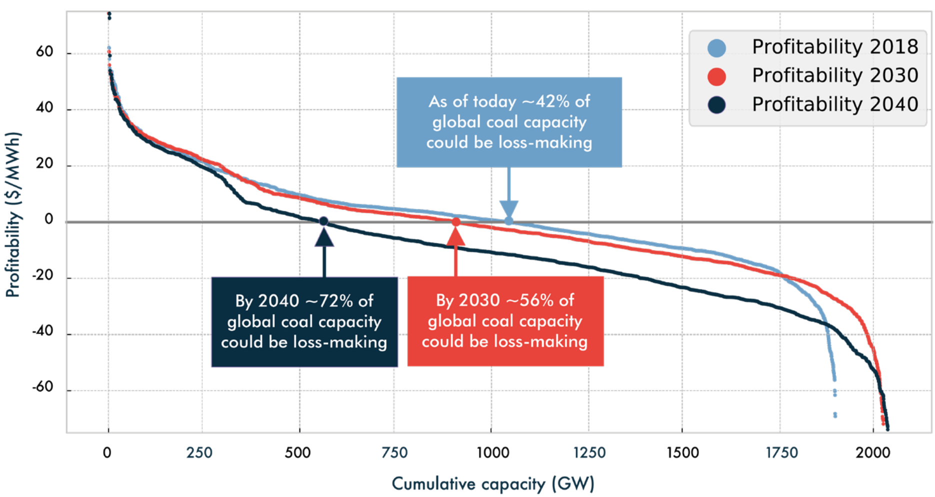
Executive Summary

This report presents the results of Carbon Tracker's coal power economics portal, an online tool that tracks the economic and financial risks of coal power at the asset-level throughout the world. The portal covers 6,685 coal units which represent ~95% (1,900 GW) of global operating capacity and ~90% (220 GW) of capacity under-construction. The portal provides current and forward-looking estimates of the (short and long-run) operating cost, gross profitability, relative competitiveness, phase-out year and stranded asset risk in a below 2°C scenario. Access to our portal and methodology document is available at www.carbontracker.com/reports/coal-portal.

Death spiral goes global – 42% of global operating fleet unprofitable in 2018 and 72% by 2040 independent of additional climate or air pollution policy

Where profitability is defined as revenues minus long-run operating costs, our analysis finds that due to high fuel costs 42% of coal capacity operating today could be losing money. From 2019 onwards, we expect a combination of renewable energy costs, air pollution regulation and carbon pricing to result in further cost pressures and make 72% of the fleet cashflow negative by 2040. This scenario assumes fuel costs will fall over 10% (on average) after 2018 and only includes existing climate and air pollution policies. This will likely prove too conservative, especially due to the continued politicisation of air pollution.

Global gross profitability curve of coal capacity existing and under construction



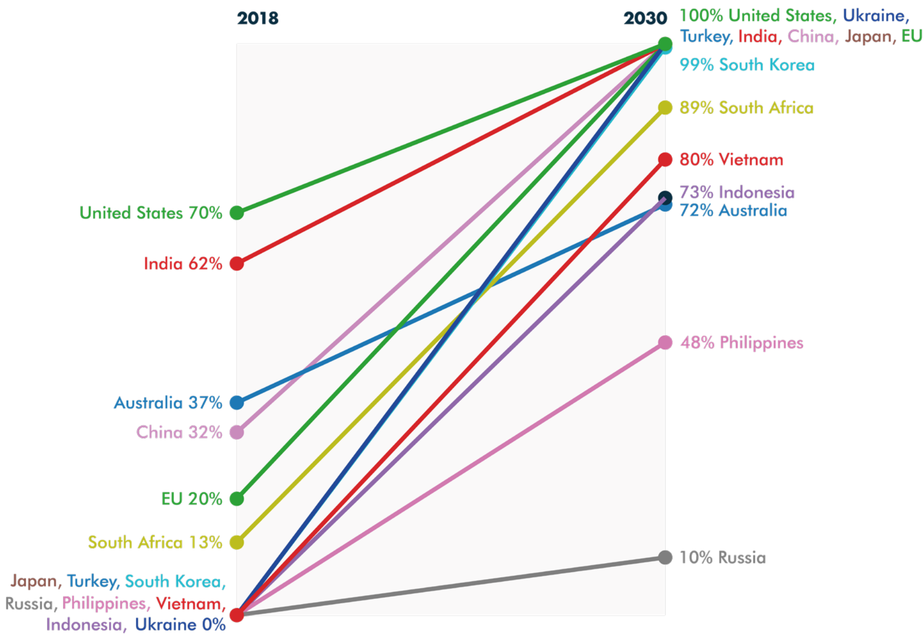
Source: Carbon Tracker analysis. See the report for further information.

In liberalised markets where power generators are subject to competition, coal capacity will be forced to shut if out-of-market payments cannot be secured or environmental regulations are not reduced or delayed. In regulated markets where governments typically approve and pass on the cost of generation to consumers, politicians have four options: close high-cost coal, subsidise coal generation, increase power prices to make coal viable, or subsidise power prices. Over the long-term coal power will become a net-liability and those politicians in regulated markets who remain wedded to high-cost coal will be forced to choose between subsidising coal generation and power prices (which will impact the fiscal health of the state) or increase power prices (which will hurt consumers and undermine competitiveness).

The myth of cheap coal– 35% of coal capacity costs more to run than building new renewables in 2018, increasing to 96% by 2030

There are three economic inflection points that policymakers and investors need to track to provide the least-cost power and avoid stranded assets: when new renewables and gas outcompete new coal; when new renewables and gas outcompete operating existing coal; and when new firm (or dispatchable) renewables and gas outcompete operating existing coal. Regarding the first inflection point, by 2025 at the latest, renewables will beat coal in all markets. This estimate will likely prove too conservative as policymakers introduce transparent auctions which will intensify

Percentage of operating and under-construction coal capacity with higher long-run operating cost than renewables in 2018 and 2030



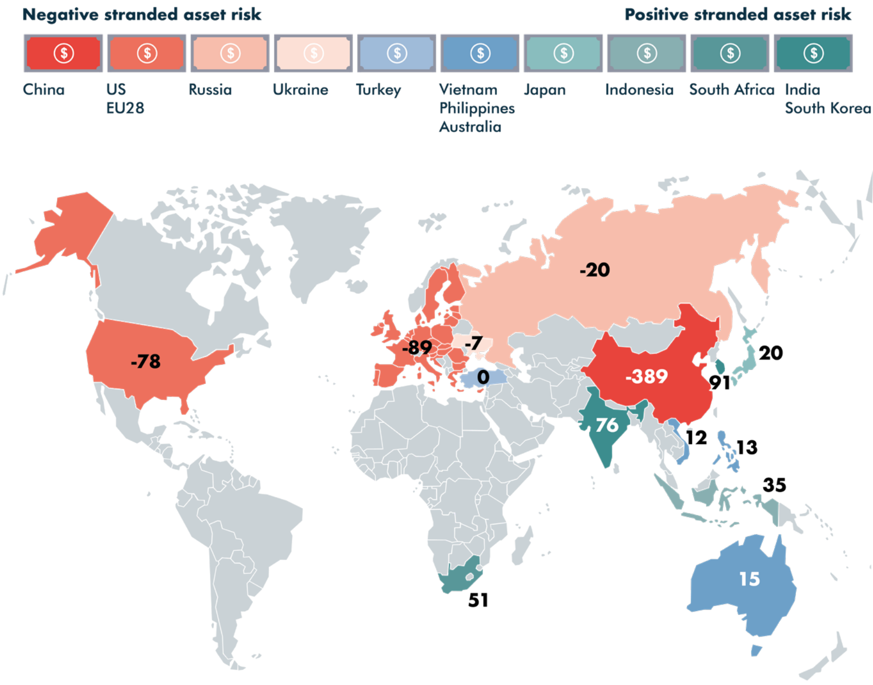
Source: Carbon Tracker analysis
Notes: Based on country averages. See the report for further details.

the deflationary trend of renewables in emerging markets. The second inflection point is where coal will face an existential crisis, as originators in liberalised markets will arbitrage the delta between the wholesale power price (which is typically set by dispatchable gas and coal generators) and the cost of new investments in renewable energy. Our analysis shows that as of today 35% of capacity could have a higher operating cost than new renewables and this may increase to 96% by 2030. This disruptive dynamic is problematic for policymakers who focus on the all-in cost for the end consumer. Inflection point three is clearly outside the scope of this analysis and will likely form part of future research with local partners. The challenge for policymakers at this point is no longer whether renewable energy will be the least-cost option, but rather how to integrate wind and solar to maximise system value.

Below 2°C scenario – coal owners could avoid $267 bn in stranded asset risk by phasing-out coal

We define stranded asset risk as the difference between cash flows in a business-as-usual (BAU) scenario (which acknowledges existing and ratified air pollution and carbon pricing policies as well as announced retirements in company reports) and cash flows in a below 2°C scenario (which sees coal power phased-out globally by 2040). A positive stranded asset risk value means, based on existing market structures, investors and governments could lose money in the below 2°C scenario as coal capacity is cash-flow positive. A negative stranded asset risk figure means, based on existing market structures, investors and governments could avoid

Below 2°C Stranded Asset Risk ($bn)



Source: Carbon Tracker analysis
Notes: Our modelling methodology for the US has changed from previous analysis. Please see the full report and methodology document for further information.

losses in the 2°C scenario as coal capacity is cash-flow negative. Our below 2°C scenario finds around -$267bn of stranded asset risk globally. In our business-as-usual scenario, major coal markets such as China, the US and the EU become ever more cash-flow negative and thus stranded asset risk is negative. This more than offsets those regions where risk is positive, meaning the premature closure of coal consistent with the Paris Agreement is the least-cost option compared to our BAU scenario. This analysis highlights a power sector mega trend: with or without climate policy coal power is increasingly a high-cost option.

A government problem with investor implications

According to our analysis, 90% of operating and under construction capacity is either regulated or semi-regulated. In both liberalised and regulated markets, the economics of power generation will continue to change much more quickly than expected and in favour of low-carbon technologies. This transition will expose governments and investors – both equity and debt – to material financial risk. Equally, governments and investors have opportunities to be agents of change and to ensure an ordered transition.

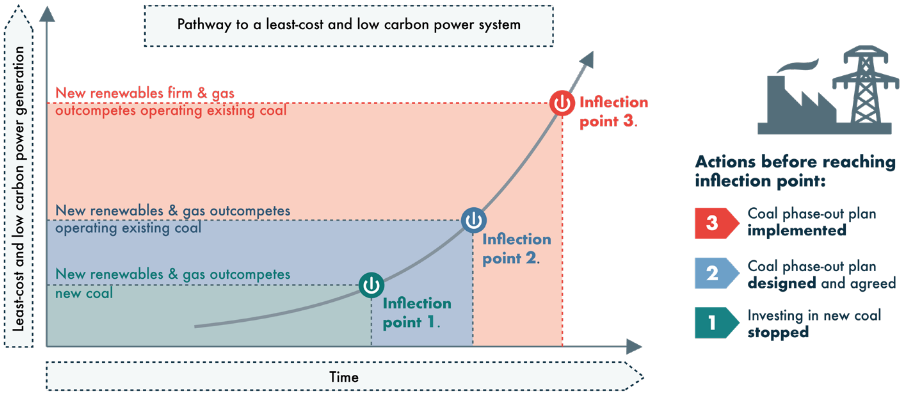
Regardless of the market structure, the continued downward trend for the costs of renewable energy will strengthen policymakers' ability to provide consumers access to secure, affordable, and clean energy. This is particularly important for those countries who face the challenge of stimulating economic development while reducing air pollution. Moreover, commitments to renewable power over the long-term will better position governments to attract the business of multinational corporations who have already begun to gravitate towards guarantors of renewable energy supply.

Policymakers in regulated markets will be more acutely conscious than those in liberalised markets of the financial risks that will materialise from a commitment to coal power, which over the long-term will become a net-liability. Governments will be forced to choose between subsidising coal generation and power prices (which will impact the fiscal health of the state) or increasing power prices (which will anger consumers and undermine competitiveness).

The impact upon – and role for – investors also differs depending upon the market context. In liberalised markets, utility shareholders are highly exposed to the kind of market volatility that has plagued European utilities' transition. Coal-heavy utilities in liberalised markets are at a strategic crossroads: continue to reinvest in existing coal capacity and hope governments ignore the overwhelming energy market trends and approve subsidies in the form of capacity and retirement payments; or divest and prepare for a low carbon future. Equity and bond investors of companies in regulated markets will also need to consider the extent to which they are insulated from cheap renewable power.

The orderliness of the transition away from coal power rests on policymaker and investors' willingness to prepare. In this regard, the establishment of the Powering Past Coal Alliance offers a mechanism for government and finance to work collectively. Utility investors, particularly those operating in liberalised markets, can play a critical role in engaging with their portfolio of companies. However, power markets are political constructs and, as such, governments will need to plan well ahead of time as low-carbon technologies accelerate through the three inflection points on their way to providing electricity.

Economic inflection points to a least-cost and low carbon power generation system



Source: Carbon Tracker analysis

If you're not embarrassed by the first version of your product, you've launched too late." – Reid Hoffman

The findings of this report are based on our coal power economics portal which is the product of a two-year modelling effort. This is the first time anyone has attempted global coverage of coal power at asset-level. While every effort was made to model capacity as comprehensively as possible, data and model anomalies are an inevitable result of the scale and scope of this project. Our objective here is simple: move first and iterate constantly. Future versions will include more accurate and comprehensive data and modelling as we undertake bespoke research in collaboration with our local partners.

Summary of the results for the top three companies by capacity within each country

Country	Region total and top three companies by capacity	Operating and under construction capacity (MW)	Capacity-weighted average long-run operating cost ($/MWh) (1)		Capacity-weighted average gross profitability ($/MWh) (2)		Year when new renewables will outcompete new coal (3)	Percentage of total coal capacity with a higher running cost than new renewables (%)		Avg. age at retirement under below 2°C scenario (years)	Stranded asset risk under below 2°C scenario ($/mn) (4)	Stranded asset risk as percentage of total assets (%) (5)
			2018	2030	2018	2030		2018	2030			
Australia	Total	24.842	48	52	17	13	Today	37%	72%	35	15.160	-
	AGL Energy	5.194	38	40	33	27		0%	89%	45	5.146	48%
	Origin Energy	2.880	53	56	18	10		100%	100%	38	1.570	9%
	CLP Group	2.880	48	56	12	7		0%	49%	29	2.705	9%
China	Total	1.036.987	49	64	-3	-9	Today	34%	100%	15	-388.775	-
	National Energy Investment Group	178.760	47	61	0	-5		24%	100%	19	-68.434	45%
	China Huaneng	123.851	46	61	1	-5		22%	100%	20	-40.163	25%
	China Datang	103.422	48	61	1	-5		25%	100%	21	-32.064	29%
EU	Total	155.301	60	100	-10	-32	Today	20%	100%	40	-89.013	-
	RWE	20.243	52	87	1	-15		9%	100%	35	-8.637	10%
	PGE	13.019	59	105	-5	-26		14%	100%	38	-8.640	42%
	EPH	12.196	59	105	-3	-31		21%	100%	37	-5.528	36%
India	Total	257.468	42	45	13	11	Today	62%	100%	15	76.174	-
	NTPC	61.075	36	45	9	12		56%	97%	19	11.009	26%
	MAHAGENCO	10.450	40	42	22	20		62%	100%	28	4.039	N/A
	Adani Group	10.440	35	36	28	26		13%	100%	19	6.799	78%
Indonesia	Total	41.126	35	44	21	24	2021	0%	73%	17	34.736	-
	PT PLN Persero	18.499	34	41	25	28		0%	91%	18	16.062	16%
	Sumitomo Corporation	2.640	39	41	28	26		0%	100%	19	3.068	4%
	Sumitomo	2.000	25	41	3	23		0%	0%	18	588	1%
Japan	Total	51.036	47	51	6	9	2025	0%	100%	24	20.370	-
	J-POWER	9.405	43	45	3	9		0%	100%	31	3.131	13%
	TEPCO	6.581	46	45	9	13		0%	100%	24	2.948	2%
	Chubu Electric Power	5.532	38	44	3	7		0%	100%	23	2.221	4%
Philippines	Total	11.163	45	46	9	17	2021	0%	46%	16	13.111	-
	San Miguel Corporation	3.113	48	44	12	24		0%	81%	20	3.351	12%
	Aboitiz Group	1.277	37	37	16	28		0%	16%	15	1.499	15%
	Ayala Corporation	1.069	43	43	8	22		0%	75%	13	695	3%

Russia	Total	48.690	44	44	-12	-11	2020	0%	10%	48	-19.930	-
	Gazprom	10.256	46	44	-17	-15		0%	6%	52	-5.751	2%
	SUEK	7.216	31	28	-7	-4		0%	0%	51	-1.327	13%
	Inter RAO	6.350	45	44	-18	-17		0%	7%	44	-4.104	38%
South Africa	Total	48.453	48	52	23	21	Today	2%	85%	45	51.276	-
	Eskom	47.481	34	41	29	32		8%	42%	35	50.377	81%
	Aldwych International	600	55	58	18	15		0%	100%	55	567	N/A
	Tshwane Electricity Division	300	57	61	16	12		0%	100%	53	240	N/A
South Korea	Total	43.096	50	51	14	23	2024	0%	99%	15	105.589	-
	KEPCO	38.751	49	48	20	28		0%	89%	19	97.752	57%
	KDB Infrastructure	777	59	61	23	21		0%	100%	4	1.450	44%
	SK Gas	693	-	43	-	31		0%	100%	11	1.660	N/A
Turkey	Total	18.469	47	46	2	4	2022	0%	100%	23	-153	-
	Eren Holding	2.790	43	38	0	5		0%	100%	18	151	N/A
	IC İÇTAŞ Enerji	2.340	50	47	-5	-2		0%	100%	18	-249	N/A
	EÜAŞ	1.760	50	52	4	2		0%	100%	19	77	N/A
Ukraine	Total	20.750	67	85	-5	-22	2020	0%	100%	57	-6.593	-
	DTEK	12.255	72	90	-8	-26		0%	100%	55	-4.653	99%
	Energy Company of Ukraine	4.825	74	114	-10	-66		0%	100%	54	-1.438	N/A
	Energoinvest Holding	3.010	61	66	3	-5		0%	100%	68	-155	N/A
United States	Total	261.972	45	47	-5	-7	Today	69%	100%	39	-78.435	-
	Duke Energy Corporation	18.821	55	58	-11	-14		100%	100%	52	-6.561	5%
	Vistra Energy Corp	15.438	41	43	-4	-6		78%	100%	49	-3.896	6%
	Southern Company	14.938	49	52	-9	-12		82%	100%	49	-7.474	7%
Vietnam	Total	24.406	37	46	1	8	2020	0%	40%	14	11.683	-
	EVN	11.247	46	44	3	11		0%	60%	13	6.513	85%
	Petrovietnam	4.800	20	44	0	11		0%	75%	11	1.534	56%
	Vinacomin	2.284	42	40	5	15		0%	24%	13	1.218	110%
Total	**-**	**2.043.759**	**48**	**60**	**0**	**-5**	**n/a**	**35%**	**96%**	**22**	**-267,415**	**n/a**

Source: Carbon Tracker analysis

Notes:
(1) Based on long-run operating costs, which includes: fuel, carbon (where applicable), variable O&M, fixed O&M and capital addition from meeting air pollution regulation.
(2) Based on in-market and out-of-market revenues minus long-run operating costs.
(3) Based on country averages.
(4) Our modelling methodology for the US has changed from previous analysis. Please see the full report and methodology document for further information.
(5) Total assets represent the final amount of all gross investments, cash and equivalents, receivables, and other assets as they are presented on the balance sheet.

2 Introduction

This report presents the main findings from Carbon Tracker's coal portal, a free-to-use online tool which tracks the economics of coal power for ~95% of existing coal capacity and ~90% of capacity under-construction[1]. The portal provides current and forward-looking estimates for the following metrics: the short-run and long-run operating cost[2]; gross profitability based on the long-run operating cost; the year when the levelised cost of onshore wind and solar photovoltaics (PV) will be lower than the long-run operating cost in a region; and cost-optimised retirement schedules and stranded asset risk in a below 2°C scenario. In doing so, the report's findings challenge the validity of going ahead with new coal investments and highlight how it will increasingly make economic and financial sense to retire coal capacity in a manner consistent with the temperature goal in the Paris Agreement.

Tracking economic inflection points to a least-cost and low-carbon power system

There are three inflection points to a least-cost and low-carbon power system: new renewables and gas outcompete new coal; new renewables and gas outcompete operating existing coal; and new firm renewables and gas outcompete operating existing coal. The first inflection point is already well under way in the EU, the US, Australia, India and parts of Latin America, where new investments in coal capacity have slowed or ground to a halt mostly because of fierce competition from wind, solar and, in the case of the US, natural gas. The second and third inflection points also appear imminent in both the EU and the US. Because of higher carbon and coal prices, onshore wind auctions in Germany this summer were lower than operating coal plants[3]. Moreover, earlier this year, median bids for wind plus storage in Colorado were $21/MWh – lower than the running cost of all coal plants currently in operation throughout that US state[4]. Our market scenario analysis aims to give policymakers, investors and civil society unprecedented granularity by tracking these inflection points at asset-level.

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1 According to CoalSwarm Global Coal Plant Tracker (July 2018 update) those plants with status 'Under Construction' and expected year for grid connection.

2 Short-Run marginal cost includes, also known as cash costs, includes fuel and variable operating and maintenance costs. Long-run marginal cost includes cash costs, fixed operating and maintenance costs and costs borne by environmental regulations.

3 Sandbag (2018). New Wind & Solar now competes even with existing coal and gas. Available: https://sandbag.org.uk/2018/08/22/new-wind-solar-vs-existing-fossil/

4 Carbon Tracker (2018). Colorado's renewables revolution gathers steam. Available: https://www.carbontracker.org/colorados-renewables-revolution/

Asset-level data is essential to avoid value destruction

Stabilising our climate will require a dramatic phase-out of coal-fired generation. For instance, to meet the temperature goal set out in the Paris Agreement one coal unit will need to close every day, or 100 GW every year, until 2040[5]. This contrasts to average annual retirements of 30 GW from 2010 to 2018. In short, there needs to be a threefold increase in the amount of capacity closed to meet the temperature goal of Paris. The average age of the existing global fleet is currently 22 years, compared with an expected life of 40 years, meaning we have a choice between runaway global warming and the premature closure of coal plants. Our below 2°C scenario analysis models the financial implications of the direction of travel (from fossil to clean, which is underlined by our market scenario analysis) and supports policymakers, investors and civil society who want to know how to phase-out coal in an economically rational manner.

Power market structures and the materialisation of asset stranding risk

We categorise power markets three ways: liberalised, semi-regulated and regulated. Liberalised power markets subject generators to greater competition, while regulated markets tend to be dominated by vertically integrated utilities that operate as regulated monopolies and cover the entire value chain with oversight from a public regulator. Market structure nuances are essential to understand how uneconomic coal and thus stranded asset risk materialises.

In the context of climate policy and technological disruption, most work to date presents stranded assets as a company impairment problem. Indeed, in liberalised markets the stranded asset risk is typically borne by publicly-listed companies. However, in regulated markets the risk often ends up with the state who ultimately underwrites investment risk. These are important distinctions for investors and policymakers to understand as coal power gradually becomes economically obsolete.

Future iterations and the role of local partners

This is the first time anyone has attempted global coverage of coal power economics at the asset-level. While every effort was made to model capacity as comprehensively as possible, data and model anomalies are an inevitable result of the scale and scope of this project. We intend to continue to collaborate with local partners for future data and modelling iterations.

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5 *Carbon Tracker (2018). Earth to Investors: Paris Agreement Requires One Coal Unit to Close Every Day Until 2040. Available: https://www.carbontracker.org/earth-to-investors/*

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Modelling methodology and assumptions

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This section gives a summary of the modelling methodology and assumptions used in this report. Our modelling covers 6,685 coal units which represent ~95% (1,900 GW) of all operating capacity and ~90% (220 GW) of all capacity under-construction in the markets listed in the table on the side.

A separate methodology document is available for an in-depth description of the overall approach and features of the model, as well as the main assumptions. At a high-level our modelling uses the following inputs: asset inventory data, technical, marketing and regulatory assumptions, and asset performance data. As detailed below and illustrated in Figure 1, these inputs are used to produce regional asset-level economic models that inform our market and below 2°C scenario.

Regions
Australia
China
EU28
India
Indonesia
Japan
Philippines
Russia
South Africa
South Korea
Turkey
Ukraine
United States
Vietnam

EU Member States
Austria
Bulgaria
Croatia
Czech Republic
Denmark
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Netherlands
Poland
Romania
Slovakia
Slovenia
Spain
Sweden
UK

Asset economic modelling

The asset-level economic models drive the outcomes in the market and below 2°C scenarios. We model the cost of each coal unit using a range of data sources. Our inventory data comes primarily from the Global Plant Coal Tracker database (CoalSwarm, 2018), the US Energy Information Administration (EIA, 2018), the Europe Beyond Coal European Coal Plant Database (EU Beyond Coal, 2018), the World Electric Power Plants database (Platts, 2018), as well as other national reports, statistics and databases, and inputs from local experts. Other inventory data includes pollution control technologies (Platts, 2018), fuel cost prices (Wood Mackenzie, 2018), coal products and tariffs. We also take into account national, regional or local policies governing environmental pollution, carbon prices, retirement schedules and market structures.

The asset-level model outputs are based on a series of reasonable assumptions about commodity prices (fuel, power and carbon), variable and fixed operations and maintenance costs (O&M) and policy outcomes (out-of-market revenues and control technologies costs, for example). Fuel costs include the expenses incurred in buying, transporting and preparing the coal. For the cost of coal for producers we use benchmarks from Wood Mackenzie and Bloomberg LP. Estimates for 2018 are based on monthly or daily price averages, while from 2019 onwards we take an annual average from 2014 to 2017.

Fuel costs also include a model which calculates the transport. This is a cost-optimised supply route algorithm, which computes the distance between a unit's demand and the nearest suitable coal mine, considering coal type, mode of transport and related costs and other charges, and available port, mine and import capacities.

Revenues comprise of in-market and out-of-market revenues a plant may receive. We assume carbon pricing only where a carbon price has been implemented or ratified and use conservative scenarios throughout the modelling horizon. In regions where stringent pollutant emission limits exist, we assume the installation of pollution control technologies and the relevant capital and operation costs across those plants that are non-compliant.

The main outputs from our asset economic modelling include gross profitability and both short-run and long-run operating cost. Gross profitability is defined as revenues from in-market (i.e. wholesale power markets) and out-of-market (i.e. ancillary and balancing services and capacity markets) minus long-run operating costs. Long-run operating costs include: fuel, carbon (where applicable), variable O&M, fixed O&M and any capital additions from meeting environmental regulations. Short-run operating cost only includes fuel, carbon (where applicable) and variable O&M.

Figure 1. *Diagram of the research methodology for coal power analysis*

Carbon Tracker's coal power analysis offering

Methodology

Carbon Tracker Initiative

INPUTS

Asset inventory data

- unit and plant name
- financial sponsor
- parent company
- nameplate capacity
- start year
- planned retirement year
- combustion technology
- coal type
- cooling technology

Technical, market and regulatory assumptions

- mine location and capacity
- coal type and transportation
- long-term coal contracts
- fixed and variable O&M
- environmental regulations
- electricity system structure
- power and carbon prices
- tariffs
- out-of-market revenues
- taxation and inflation

Asset performance data

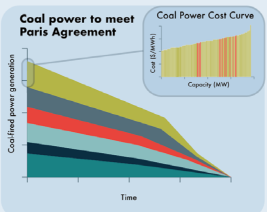
- heat rate
- capacity factor
- efficiency
- coal consumption
- calorific value of coal
- fuel cost**
- fixed and variable O&M cost
- capex and opex control tech
- in-market payments
- out-of-market payments***

***transport, tax, washing, etc.*
****capacity payments, ancillary services, etc.*

OUTPUTS

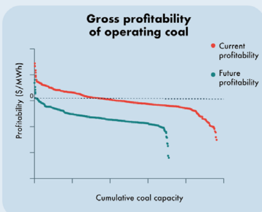
Below 2°C scenario analysis

- Cost-optimised retirement schedules
- Stranded asset risk
- Company and country ranking



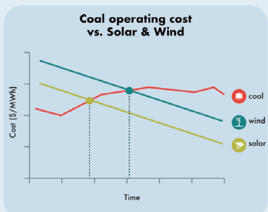
Asset economics modelling

- Current and future short-run operating cost, long-run operating cost and gross profitability
- Company and country ranking



Market scenario analysis

- Year when building new wind and solar is cheaper than operating coal
- Company and country ranking



Market scenario analysis

The market scenario analysis compares the long-run operating cost of coal with the levelised cost of energy (LCOE) of onshore wind and utility-scale solar PV[6]. LCOE is a standard analytical tool used to compare power generation technologies and is widely used in power market analysis and modelling. While the limitations of using generic LCOE analysis for understanding the economics of power generation have been well documented, it does provide a simple proxy for when new investments in coal power no longer make economic sense and when investors and policymakers should plan and implement a coal power phase-out[7]. The LCOE is simply the sum of all costs divided by the amount of generation. The costs include capital costs, the capital recovery factor, fixed O&M, variable O&M, fuel and carbon. 2018 LCOE estimates for onshore wind and solar PV are predominantly from Bloomberg NEF[8].

Below 2°C scenario analysis

The stranded asset risk in our 2°C scenario is defined as the difference between the net present value (NPV) of revenues in a BAU scenario and a scenario consistent with the temperature goal in the Paris Agreement. The retirement schedules are developed based on gross profitability, if a liberalised market, or long-run operating cost, if a regulated market. Underlying this analysis is the logic that in the context of efforts to reduce carbon emissions and demand for coal power, the least economically-efficient will be retired first. The modelling approach involves three steps.

Firstly, we identify the amount of capacity required to fill the generation requirement in the IEA's beyond 2-degree scenario (B2DS). Under the B2DS coal generation without carbon capture and storage (CCS) is phased-out globally by 2040. Our analysis assumes CCS will not be available to extend the lifetimes of coal capacity, as the costs will likely be prohibitively expensive[9]. Regions have different phase-out dates. For instance, the EU, US and India phase-out coal by 2030, 2035 and 2040, respectively.

Secondly, we rank the coal-fired generation units to develop a retirement schedule. We develop the retirement schedules based on the authority, region or grid responsible for maintaining security of supply. Here the analysis differs slightly depending on whether the units operate in a liberalised or regulated market. In regulated markets, for example, we rank the units based on the long-run operating cost, while in liberalised markets we phase-out units based on gross profitability. This nuance aims to either replicate a rank from the perspective of a regulator who is interested in providing cost-optimised generation or a merchant utility who is interested in maximising

6 *While we recognise that other renewable options for power generation may be appropriate in some regions, utility-scale solar-PV and onshore wind have been chosen for comparability and simplicity.*

7 *LCOE analysis is a limited metric as it does not consider revenues from generation and the system value of wind and solar. For more information, see: IEA (2016). Next-generation wind and solar power: From cost to value. Available: https://www.iea.org/publications/freepublications/publication/NextGenerationWindandSolarPower.pdf*

8 *See the methodology document for more information.*

9 *There is currently one CCS-equipped coal-fired power plant operating in the world today (Boundary Dam in Canada) and 12 plants in development. The last coal plant to start construction in the US is the Kemper County integrated gasification combined cycle (IGCC) project. The cost of the 600 MW Kemper plant is projected to increase from $2.2 bn to $6.66 bn, or over four times of the capex cost of an unabated IGCC plant in a similar location. In 2015, the US Department of Energy withdrew support for the 200 MW CCS project in Illinois, which has since been cancelled. Due to limited progress to date and the new build and retrofit costs compared to other decarbonisation options, this report assumes that CCS will only be viable in niche applications over the lifetimes of the fossil fuel plants analysed, and thus is not included in this study which focuses on global averages without subsidies. For more information see: Carbon Tracker (2016). End of the load for coal and gas? Available: https://www.carbontracker.org/reports/the-end-of-the-load-for-coal-and-gas/*

profitability. As mentioned above, we define cost as the long-run operating cost. The coal units that are most costly or least profitable are phased-out until the aggregated asset level generation reaches the limits set out in the B2DS.

Thirdly, we calculate the cash flow of every operating and under-construction unit in both the B2DS and BAU outcomes to understand stranded asset risk. Stranded asset risk under the B2DS is defined as the difference between the NPV of cash flow in the B2DS (which phases-out all coal power by 2040) and the NPV of cash flow in the BAU scenario (which is based on retirements announced in company reports).

Risks and limitations

Our analysis cannot capture unforeseen changes to commodity prices, environmental policies, market structures and technology costs. For a full breakdown of our commodity, policy regulatory and technology assumptions, please refer to the methodology document.

Results

This section presents the results of our asset-level modelling which provides current and forward-looking estimates of the (short and long-run) operating cost, gross profitability, relative competitiveness, and phase-out year and stranded asset risk in a below 2°C scenario. Market structures are rarely homogenous and vary from region to region depending on numerous technical, political and economic factors. These differences are essential for interpreting the results of this analysis as the asset stranding risk from high-cost and unprofitable coal capacity materialises differently depending on market structures. These nuances are briefly detailed in Table 1 below.

Table 1. *Interpreting the results depending on market type*

Market structure	Interpreting impact on gross profitability	Interpreting impact on stranded asset risk
Liberalised	• Gross profitability equals revenues received from in-the-market and out-of-the-market minus long-run operating costs. • If gross profitability remains negative for an extended period the unit will be closed unless the owner decides to stay open for the following reasons: optionality, such as future expectations around capacity market payments, premature retirement payments and market conditions; clean-up costs; and shareholder or government resistance.	• Stranded asset risk is often low or negative as coal generators operating in liberalised markets are cashflow negative due to suppressed wholesale power prices from renewable energy which increasingly have a lower levelised cost than wholesale power prices. Stranded asset risk typically materialises with the shareholders of utilities. Additional costs from compliance to pollution limits as well as carbon prices apply further stress to coal-fired power.
Semi-regulated	• Gross profitability equals revenues from both in-market and out-of-market mechanisms minus long-run operating costs. • If gross profitability remains negative for an extended period, the unit will not necessarily close as costs can be partially or fully passed on the energy consumer or tax payer.	• Stranded asset risk is often high or positive as coal generators get a fixed rate of return regardless of market conditions. Stranded asset risk can materialise with both shareholders and the state. The state can either subsidise the cost of power (in which case the tax payer bears the stranded asset risk) or pass the risk on to the end consumer by increasing power prices.
Regulated	• Gross profitability equals revenues from predominantly out-of-market mechanisms minus long-run operating costs. • If gross profitability remains negative for an extended period, the unit will not necessarily close as costs can be passed onto the energy consumer or tax payer.	• Stranded asset risk is often high or positive as coal generators get a fixed rate of return regardless of market conditions. Stranded asset risk materialises with the state through either higher tax rates, greater debt levels or increased power prices.

Source: Carbon Tracker analysis
Notes: According to our analysis, 90% of operating and under construction capacity is either regulated or semi-regulated. For further information on these nuances and their implications for investors and policymakers we recommend readers refer to the Appendix for brief summaries of each market we have modelled.

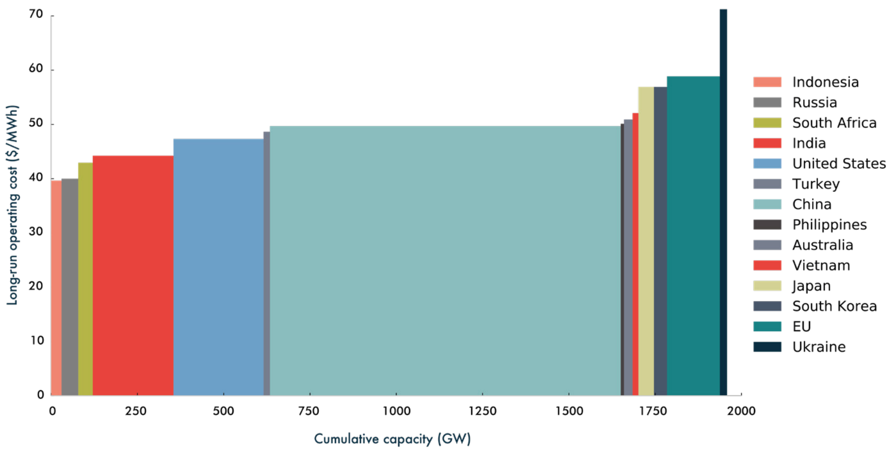
Asset-level economics

Global cost curve

Replace with: "Power markets are not global in nature and thus Figure 2 below is provided for illustrative purposes only. Moreover, high-cost units may still be highly profitable due to market structures or policy support. We recommend readers refer to the Appendix for brief summaries of each market that we have modelled. The operating cost of a unit is influenced by fuel costs, O&M and environmental policies. Units operating in coal producing regions tend to have lower fuel costs, although this is often due to long-term contracts. O&M is influenced heavily by unit size and technology. Larger units have lower O&M costs per kW, while advanced technologies (such as super and ultra-supercritical) have high costs per kW.

As a rule of thumb, due to competitive pressures, coal units operating in liberalised markets typically have lower operating costs than those in regulated markets. China is the exception to this rule. To prevent a situation where a lack of power infrastructure stifles economic growth, a central goal of China's energy policy over the last decade has been to reduce price volatility. As such, to incentivise large-scale capital investments in power infrastructure, power prices have remained stable. China deregulated coal prices in 2003, but tariffs for power are still heavily regulated. As a consequence, the size of China's coal power value chain has driven a paradigm shift in the capital and O&M costs of coal power relative to other regions."

Figure 2. *Global long-run operating cost curve of coal capacity existing and under construction*



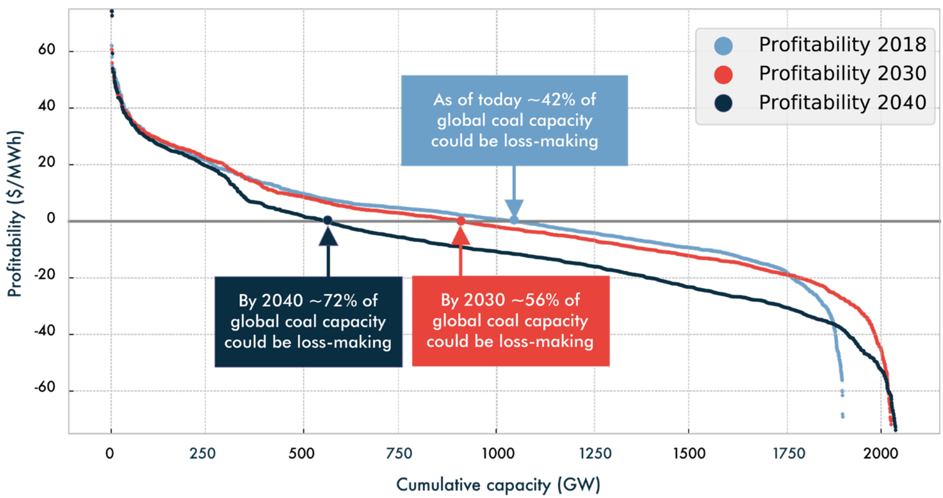
Source: Carbon Tracker analysis
Notes: long-run operating costs include fuel, carbon where applicable, variable O&M, fixed O&M and any capital additions from meeting environmental regulations. 2018 fuel costs are based on monthly or daily price averages, while from 2019 onwards we take an annual average from 2014 to 2017.

Global profitability curve

Per our definition, profitability is only a valuable metric in liberalised markets where generators are subject to profit and loss. This is not because the regulation can change and therefore make generators more or less profitable. Power markets – whether liberalised or regulated – are political constructs and therefore will create outcomes based on political motives. In liberalised markets merchant generators are principally interested in maximising profitability, whereas in regulated markets regulators typically have a mandate to provide the least-cost generation to the end consumer. To reduce the cost to the consumer many regulated markets have subsidised prices which do not reflect the cost of production. As a consequence, profitability in regulated markets is of limited use for understanding the economics of coal capacity.

Across the globe, the unprofitable units are predominantly in the EU, the US and China. In the EU rising carbon prices are currently undermining generator margins. This is expected to increase as EU ETS reforms take hold and forthcoming air pollution regulation increases both short- and long-run operating costs. In US markets, such as ERCOT, coal generators are being disrupted by ultra-low-cost wind has led to low wholesale power prices and load following from coal generation, which decreases revenues and increases costs respectively. The Chinese government has implemented policies to manage both mining and generation overcapacity and profitability. These measures aim to keep coal prices in a zone of Rmb500-575/t. Intervention is expected if prices go above Rmb600/t (to manage generator margins) or below Rmb470/t (to manage miner margins). Coal prices in 2018 have been relatively high, which is the biggest contributor to unprofitability in China.

Figure 3. *Global gross profitability curve of coal capacity existing and under construction*



Source: Carbon Tracker analysis
Notes: gross profitability is defined as revenues from in-market (i.e. wholesale power markets) and out-of-market (i.e. ancillary and balancing services and capacity markets) minus long-run operating costs.

Over time we expect a combination of carbon pricing and air pollution regulation to undermine the profitability of coal generators.

Market scenario analysis

There are three economic inflection points that policymakers and investors need to track to provide the least-cost power and avoid stranded assets: when new renewables and gas outcompete new coal; when new renewables and gas outcompete operating existing coal; and when new firm (or dispatchable) renewables and gas outcompete operating existing coal.

Inflection point 1

Regarding the first inflection point, by 2025 at the latest, renewables will beat coal in all markets. This estimate will likely prove too conservative as (i) policymakers introduce transparent auctions which will intensify the deflationary trend of renewables in emerging markets; and (ii) LCOE analysis typically fails to predict trends which have recently occurred. For example, Bloomberg NEF's LCOE estimate for solar PV in the Philippines is $85/MWh[10], while a recent power purchase agreement (PPA) was signed for $44/MWh[11].

Table 2. *Year when new renewables will be cheaper than new coal*

Country or region	Year when new renewables will be cheaper than new coal
Australia	Today
China	Today
EU	Today
India	Today
Indonesia	2021
Japan	2025
Philippines	2021
Russia	2020
South Africa	Today
South Korea	2024
Turkey	2022
Ukraine	2020
United States	Today
Vietnam	2020

Source: Carbon Tracker analysis

10 *Bloomberg NEF (2018), Historic LCOE Benchmark. Unavailable without subscription.*
11 *PV Magazine (2018). Philippine utility Meralco receives Southeast Asia's lowest solar bid. Available:* *https://www.pv-magazine.com/2018/08/13/philippine-utility-meralco-receives-southeast-asias-lowest-solar-bid/*

Inflection point 2

Our analysis shows that as of today 35% of capacity could have a higher operating cost than new renewables and this may increase to 96% by 2030. This inflection point is reached at different times for different reasons. Those regions with competitive auctions for power capacity see renewable energy outcompeting coal more quickly. The second inflection point is where coal will face an existential crisis. As renewable energy becomes cheaper, rates of deployment will increase. Making coal highly dispatchable to accommodate increased amounts of low-cost variable renewable energy increases O&M costs, exacerbating its economic disadvantage. Moreover, originators in liberalised markets will arbitrage the delta between the wholesale power price (which is typically set by dispatchable gas and coal generators) and the cost of new investments in renewable energy. This disruptive dynamic is problematic for policymakers who focus on the all-in cost for the end consumer. Policymakers in regulated markets who continue to support coal will come under increasing scrutiny from tax payers and energy consumers, where power prices are unsubsidised.

Table 3. *Percentage of operating and under-construction coal capacity with higher long-run operating cost than renewables in 2018 and 2030*

Country or region	Percentage of operating and under-construction coal capacity with higher long-run operating cost than renewables in 2018	Percentage of operating and under-construction coal capacity with higher long-run operating cost than renewables in 2030	Year when coal has a higher operating cost than new renewables based on a capacty-weighted average
Australia	37%	72%	2021
China	32%	100%	2021
EU	20%	100%	2019
India	62%	100%	Today
Indonesia	0%	73%	2028
Japan	0%	100%	2025
Philippines	0%	48%	2029
Russia	0%	10%	2035-40
South Africa	13%	89%	2023
South Korea	0%	99%	2027
Turkey	0%	100%	2023
Ukraine	0%	100%	2024
United States	70%	100%	Today
Vietnam	0%	80%	2028

Source: Carbon Tracker analysis
Note: There is considerable uncertainty around the cost of renewable energy due to market transparency and maturity. Please refer to methodology for more information.

Inflection point 3

Inflection point 3 is clearly outside the scope of this analysis and will likely form part of future iterations with local partners. The challenge for policymakers is no longer whether renewable energy will be the least-cost option, but rather how to integrate wind and solar to maximise system value and lower the cost to the overall system. Grid operators need to manage the spatial and temporal nature of power generation by matching the supply and demand in real time. This is particularly important with solar and wind, which can account for a much larger share in power generation than annual averages suggest. For example, on the 3rd of November 2013 wind power generation in Denmark exceeded the level of power consumption, while the share of all renewable energy in consumption for 2013 on average was only 27%[12,13].

When the penetration of wind and solar remains small (i.e. a few percentage points of the annual power mix) their integration has a limited impact on grid stability and market functionality[14]. However, with increased levels of wind and solar their integration becomes crucially important to minimise system costs and maximise the value of power from wind and solar[15]. According to the IEA, the best way to integrate wind and solar is to transform the overall power system through system-friendly deployment, improved operating strategies and investment in additional flexible resources. Flexible resources include better located generation, grid infrastructure, storage and demand side integration. As identified by IEA analysis, by maximising system value policymakers can significantly reduce integration costs and ensure electricity security.


Xcel Energy's Sherburne County (Sherco) Generating Station, Minnesota | photo by Tony Webster

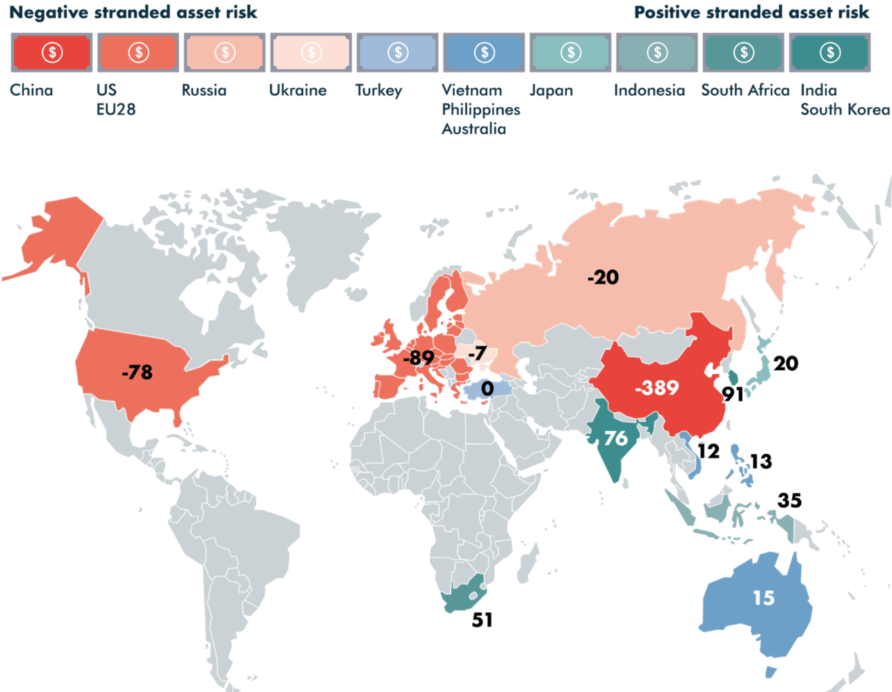
12 Morris, C (2013), Denmark surpasses 100% wind power. Available: https://energytransition.org/2013/11/denmark-surpasses-100-percent-wind-power/
13 Eurostat (2016), Share of energy from renewable sources [nrg_ind_335a]. Luxembourg, Eurostat. Available: http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_from_renewable_sources
14 IEA (2014), The Power of Transformation. Available: https://www.iea.org/publications/freepublications/publication/the-power-of-transformation---wind-sun-and-the-economics-of-flexible-power-systems.html
15 IEA (2016), Next-generation wind and solar power: From cost to value. Available: https://www.iea.org/publications/freepublications/publication/NextGenerationWindandSolarPower.pdf

Below 2°C scenario analysis

Stranded asset risk is defined as the delta between the cash flows derived at the plant in a BAU scenario and the cash flow in a below 2°C scenario consistent with the temperature limit set in the Paris Agreement. A BAU scenario assumes no changes to policy or market structures but does acknowledge existing and ratified air pollution and carbon pricing policies, as well as announced retirements in company reports.

On the other hand, the below 2°C scenario incorporates a cost-optimised retirement schedule where unabated coal is to a large extent phased-out globally by 2040. A positive stranded asset risk value means investors and governments could lose money in the below 2°C scenario as coal capacity is cash-flow positiv, based on existing market structures. In contrast, a negative stranded asset risk figure means investors and governments could avoid losses in the below 2°C scenario as coal capacity is cash-flow negative.

Figure 4. *Below 2°C stranded asset risk by country*



Source: Carbon Tracker analysis

Our below 2°C scenario finds -$267bn of stranded asset risk globally. In our business-as-usual scenario, major coal capacity markets such as China, the US, and the EU become ever more cash-flow negative and thus the stranded asset risk is negative. This more than offsets those regions where risk is positive, meaning the premature closure of coal power consistent with the Paris Agreement is the least-cost. This analysis highlights a power sector megatrend: with or without climate policy coal power is increasingly a high-cost option.

Summary data table

Table 4. *Summary of the results for the top three companies by capacity within each country*

Country	Region total and top three companies by capacity	Operating and under construction capacity (MW)	Capacity-weighted average long-run operating cost ($/MWh) (1)		Capacity-weighted average gross profitability ($/MWh) (2)		Year when new renewables will outcompete new coal (3)	Percentage of total coal capacity with a higher running cost than new renewables (%)		Avg. age at retirement under below 2°C scenario (years)	Stranded asset risk under below 2°C scenario ($/mn) (4)	Stranded asset risk as percentage of total assets (%) (5)
			2018	2030	2018	2030		2018	2030			
Australia	Total	24.842	48	52	17	13	Today	37%	72%	35	15.160	-
	AGL Energy	5.194	38	40	33	27		0%	89%	45	5.146	48%
	Origin Energy	2.880	53	56	18	10		100%	100%	38	1.570	9%
	CLP Group	2.880	48	56	12	7		0%	49%	29	2.705	9%
China	Total	1.036.987	49	64	-3	-9	Today	34%	100%	15	-388.775	-
	National Energy Investment Group	178.760	47	61	0	-5		24%	100%	19	-68.434	45%
	China Huaneng	123.851	46	61	1	-5		22%	100%	20	-40.163	25%
	China Datang	103.422	48	61	1	-5		25%	100%	21	-32.064	29%
EU	Total	155.301	60	100	-10	-32	Today	20%	100%	40	-89.013	-
	RWE	20.243	52	87	1	-15		9%	100%	35	-8.637	10%
	PGE	13.019	59	105	-5	-26		14%	100%	38	-8.640	42%
	EPH	12.196	59	105	-3	-31		21%	100%	37	-5.528	36%
India	Total	257.468	42	45	13	11	Today	62%	100%	15	76.174	-
	NTPC	61.075	36	45	9	12		56%	97%	19	11.009	26%
	MAHAGENCO	10.450	40	42	22	20		62%	100%	28	4.039	N/A
	Adani Group	10.440	35	36	28	26		13%	100%	19	6.799	78%
Indonesia	Total	41.126	35	44	21	24	2021	0%	73%	17	34.736	-
	PT PLN Persero	18.499	34	41	25	28		0%	91%	18	16.062	16%
	Sumitomo Corporation	2.640	39	41	28	26		0%	100%	19	3.068	4%
	Sumitomo	2.000	25	41	3	23		0%	0%	18	588	1%
Japan	Total	51.036	47	51	6	9	2025	0%	100%	24	20.370	-
	J-POWER	9.405	43	45	3	9		0%	100%	31	3.131	13%
	TEPCO	6.581	46	45	9	13		0%	100%	24	2.948	2%
	Chubu Electric Power	5.532	38	44	3	7		0%	100%	23	2.221	4%

Philippines	Total	11.163	45	46	9	17	2021	0%	46%	16	13.111	-
	San Miguel Corporation	3.113	48	44	12	24		0%	81%	20	3.351	12%
	Aboitiz Group	1.277	37	37	16	28		0%	16%	15	1.499	15%
	Ayala Corpo-ration	1.069	43	43	8	22		0%	75%	13	695	3%
Russia	Total	48.690	44	44	-12	-11	2020	0%	10%	48	-19.930	-
	Gazprom	10.256	46	44	-17	-15		0%	6%	52	-5.751	2%
	SUEK	7.216	31	28	-7	-4		0%	0%	51	-1.327	13%
	Inter RAO	6.350	45	44	-18	-17		0%	7%	44	-4.104	38%
South Africa	Total	48.453	48	52	23	21	Today	2%	85%	45	51.276	-
	Eskom	47.481	34	41	29	32		8%	42%	35	50.377	81%
	Aldwych International	600	55	58	18	15		0%	100%	55	567	N/A
	Tshwane Electricity Division	300	57	61	16	12		0%	100%	53	240	N/A
South Korea	Total	43.096	50	51	14	23	2024	0%	99%	15	105.589	-
	KEPCO	38.751	49	48	20	28		0%	89%	19	97.752	57%
	KDB Infra-structure	777	59	61	23	21		0%	100%	4	1.450	44%
	SK Gas	693	-	43	-	31		0%	100%	11	1.660	N/A
Turkey	Total	18.469	47	46	2	4	2022	0%	100%	23	-153	-
	Eren Holding	2.790	43	38	0	5		0%	100%	18	151	N/A
	IC İÇTAŞ Enerji	2.340	50	47	-5	-2		0%	100%	18	-249	N/A
	EÜAŞ	1.760	50	52	4	2		0%	100%	19	77	N/A
Ukraine	Total	20.750	67	85	-5	-22	2020	0%	100%	57	-6.593	-
	DTEK	12.255	72	90	-8	-26		0%	100%	55	-4.653	99%
	Energy Company of Ukraine	4.825	74	114	-10	-66		0%	100%	54	-1.438	N/A
	Energoinvest Holding	3.010	61	66	3	-5		0%	100%	68	-155	N/A
United States	Total	261.972	45	47	-5	-7	Today	69%	100%	39	-78.435	-
	Duke Energy Corporation	18.821	55	58	-11	-14		100%	100%	52	-6.561	5%
	Vistra Energy Corp	15.438	41	43	-4	-6		78%	100%	49	-3.896	6%
	Southern Company	14.938	49	52	-9	-12		82%	100%	49	-7.474	7%
Vietnam	Total	24.406	37	46	1	8	2020	0%	40%	14	11.683	-
	EVN	11.247	46	44	3	11		0%	60%	13	6.513	85%
	Petrovietnam	4.800	20	44	0	11		0%	75%	11	1.534	56%
	Vinacomin	2.284	42	40	5	15		0%	24%	13	1.218	110%
Total	**-**	**2.043.759**	**48**	**60**	**0**	**-5**	**n/a**	**35%**	**96%**	**22**	**-267,415**	**N/A**

Source: Carbon Tracker analysis

Notes:
(1) Based on long-run operating costs, which includes: fuel, carbon (where applicable), variable O&M, fixed O&M and capital addition from meeting air pollution regulation.
(2) Based on in-market and out-of-market revenues minus long-run operating costs.
(3) Based on country averages.
(4) Our modelling methodology for the US has changed from previous analysis. Please see the full report and methodology document for further information.
(5) Total assets represent the final amount of all gross investments, cash and equivalents, receivables, and other assets as they are

Kohlekraftwerk Scholven, Germany | photo by Sebastian Schlüter

Implications for policymakers and investors

According to our analysis, 90% of operating and under construction capacity is either regulated or semi-regulated. Ultra-low-cost renewable energy, battery storage and demand response are energy sector megatrends that will change power systems throughout the world. Governments and investors in both liberalised and regulated markets will need to be agents of change that ensure an orderly transition. Failure to plan accordingly may result in a rapid and disordered transition that presents material financial risk.

Policy opportunities – and concerns

Priorities for those policymakers designing a power system are typically to ensure that it is least-cost, safe, and secure. Increasingly, a secondary concern is limiting air pollution and health costs. Regardless of the market structure, trends in power generation economics overwhelmingly indicate that greater penetration of renewable energy will help to meet each of these priorities. For some, low-cost renewable energy has already proven this; but for all countries, within the decade the economics of renewable energy will ensure that this opportunity can be realised.

'Hard' and 'soft' economic pragmatism

This analysis also implies some 'soft' and 'hard' options for policymakers. An example of the former is corporate renewable energy initiatives. Multi-national corporations will increasingly demand renewable energy for their businesses and supply chains. Facebook, for instance, recently put their Southeast Asian data server in Singapore because it was the only market that could guarantee renewable energy[16]. 'Harder' decisions will

16 *Fortune (2018). Facebook to Build $1 Billion Data Center in Singapore. Available: http://fortune.*

materialise in regulated power markets (Southeast Asia and China) that for the foreseeable future will be dependent on their manufacturing bases to drive economic growth. Industrial power consumers have one priority: cost. This, coupled with retail consumers using their vote to demand cheap power, drives the political focus on least-cost power regardless of externalities. Once the inflection point is reached whereby it is cheaper to build new renewables than to run coal, coal will quickly become a net liability to the energy consumer and tax payer.

Stranded assets as a fiscal concern

Herein lies a significant and common misconception with stranded asset theory in the power sector, that stranded assets is predominantly a company impairment problem. Indeed, in liberalised markets the stranding risk is typically borne by utilities. However, in semi and highly regulated markets the risk ends up with governments that underwrite the PPAs. Regulated markets, and particularly in Southeast Asia, politicians have two levers to manipulate the economics of power generation. As coal loses its economic footing, those committed to it will face a dilemma: subsidise coal generators to maintain their financial viability or keep tariffs artificially low to shelter consumers from higher costs. Both outcomes are patently unsustainable for fiscal health reasons. Thus, there is a choice between taking the blue pill – decrease subsidies which will undermine utility returns – or the red pill – increase tariffs which will anger voters and reduce competitiveness.

Creating the right market environment for least-cost power

In addition to the fiscal implications of this power market transition, policymakers will need to consider the extent to which existing markets structures will both effectively promote the continued cost deflation of renewable energy and absorb additional penetration that materialises.

In regulated markets, renewable energy investments are typically incentivised by out-of-market policies. This makes regulated markets vulnerable to over and under subsidisation of power generation infrastructure, which is perhaps acceptable in some markets where power demand is growing rapidly and a failure to build generation infrastructure undermines economic development[17]. However, to ensure the cost-effective build out of renewable energy, transparent reverse auctions will assist policymakers in driving down the cost of wind and solar.

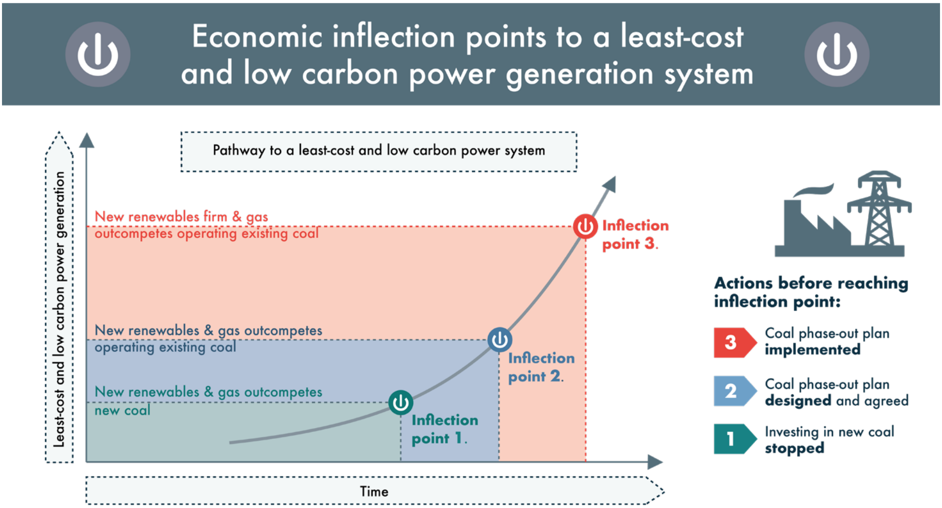
Renewable energy developers in liberalised markets are increasingly taking advantage of the delta between the wholesale power price (which is typically set by dispatchable gas and coal generators and from which renewable developers derive their revenue) and the unsubsidised levelised cost of these technologies. This is problematic for policymakers who are rightfully focused on system value and the all-in cost for the end consumer. This is one of the reason why wind and solar generators are rapidly driving coal retirements in the EU and the US, despite the IEA claiming the system value of existing coal and gas generation is higher than wind and solar generation for the foreseeable future[18].

com/2018/09/06/facebook-data-center-singapore/

17 From 1980 to 2010 the Chinese economy grew on average 10% per year. After suffering from blackouts in the early 2000s, the Chinese government offered generous subsidies to ensure power generation infrastructure investments kept pace with economic growth. See: Kroeber, (2016). China's Economy: What Everyone Needs to Know? Available: https://www.amazon.co.uk/Chinas-Economy-What-Everyone-Needs/dp/0190239034

18 In the 2018 World Energy Outlook, the IEA developed a new metric for competitiveness called the value-adjusted levelised cost of electricity (VALCOE) which attempts to do just this. The VALCOE combines the projected levelised costs of electricity with simulated energy value, flexibility value and capacity value by technology. See: IEA

Figure 5. *The intersection between the economic inflection points and the policymaking process for a least-cost power system*



Source: Carbon Tracker analysis

We question the sustainability of the merchant generator model for renewable energy until storage becomes cost-competitive and market structures reward flexible resources[19].

Lay the foundations for an orderly transition

In both liberalised and regulated markets, policymakers need to send long-term investment signals to market participants based on the inflection points mentioned above. When new renewables and gas cost less than coal, policymakers should prohibit new investments in coal. As new renewables and gas cost less than running coal, policymakers need to plan for a coal phase-out. Finally, when dispatchable new renewables and gas outcompete operating coal, policymakers need to implement a coal phase-out. The time to implement a phase-out will depend on a region's unique circumstances, but it is important to note two points: first, that planning for these inflection points should occur years in advance of their arrival; and second, that examples exist of policies that support the smooth phase-out of coal power. The, establishment of the Powering Past Coal Alliance by the UK and Canada offers a mechanism for all relevant actors to work collectively.

(2018). World Energy Outlook. Available: https://www.iea.org/weo/

19 For more information which supports this statement, please see: Grubb (2016). Planetary Economics: Energy, climate change and the three domains of sustainable development, 1st Edition. Available: https://www.routledge.com/Planetary-Economics-Energy-climate-change-and-the-three-domains-of-sustainable/Grubb-Hourcade-Neuhoff/p/book/9780415518826

The transition from high- to low-carbon power, driven by economic pragmatism, will present multiple challenges for governments. While this report focuses on financial implications, we recognise the growing attention rightfully being paid to broader social impacts, such as job losses and local-scale economic activity.

Investors remain exposed but can engage

The impact upon – and role for – investors also differs depending upon the market context. In markets where power generation is liberalised and thus subject to market forces, utility shareholders are highly exposed to stranded asset risk. In liberalised markets coal-heavy utilities are at a strategic crossroads: continue to reinvest in coal power and hope governments will approve subsidies in the form of capacity and retirement payments or divest and prepare for a low carbon future.

This crossroad is already materialising in Europe. A pro-coal strategy is dependent on lobbying strategies to avoid regulations and secure support payments. We believe this is a risky strategy that could lead to additional value destruction over the long-term. In the EU, for example, air pollution and carbon pricing reforms highlight the risk of a pro-coal strategy and could prove to be the final straw which phases-out coal power across the continent. Those utilities in liberalised markets who expect to operate their coal units beyond 2030 are putting their assets on a collision course with the power generation trends highlighted by this report. Moreover, utilities should prepare for the reality that compensation may not get paid for early closure, as has been recently observed in the Netherlands.

The asset-level approach developed for this analysis provides an important tool for investors to adjust the valuation ascribed to coal generation assets held by utilities. Its granularity can also be of value to investor engagement initiatives, such as the Climate Action 100+ (CA100+). Supported by investors with collectively more than $32 trillion of assets under management, the CA100+ is the apotheosis of recent engagement efforts by shareholders who are concerned about the risks to their investment portfolios from climate change. Equity and bond investors of companies in regulated markets will also need to consider the extent to which they are insulated from possible changes to governments' energy policy that may result from the increasing attractiveness of cheap renewable power.

Elektrownia Rybnik coal power plant | photo by CEE Bankwatch Network

Conclusion

In this report we presented the findings of our coal power economics portal to showcase how a confluence of factors are disrupting coal's pre-eminence as a least-cost option for power generation. Renewable energy, air pollution regulation and carbon pricing are already undermining the economics of coal power in ways previously unimaginable. As competition from renewable energy intensifies, and air pollution regulations and carbon pricing increase running costs, coal generators in liberalised markets will be forced to shut if out-of-market payments cannot be secured or environmental regulations are not reduced or delayed. Coal generators in regulated markets will increasingly be viewed as high-cost and thus should fall out of favour with policymakers.

Those policymakers in regulated markets who remain committed to coal over the long-term will be forced to choose between subsidising coal generation and power prices (which will impact the fiscal health of the state) or increase power prices (which will hurt consumers and undermine competitiveness). The rate at which coal becomes economically obsolete will vary depending on the unique circumstances of each market, but it is inevitable with or without climate policy that coal will become a high-cost form of power generation. Policymakers and investors need to carefully track the economics of coal power to ensure new investments cease as soon as possible and retirement schedules are implemented when coal becomes a net-liability to the power system.

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Appendix 1– interpreting the modelling results

Modelling confidence levels by region

Power markets are inherently complex for technical, economic and political reasons. While every effort was made to model capacity as comprehensively as possible, data and model anomalies are likely to occur due to the scale and scope of this project. We expect anomalies to arise in regulated markets where asset-level data is often unavailable and detail about market structures is limited. Table 5 below provides detail on our modelling confidence levels by the regions analysed in this report.

Table 5. *Modelling confidence levels of regions analysed*

Region	Confidence level	Comments
China		The reform to the Chinese power market provides some uncertainty around revenues. Further granularity on generation and costs borne by environment control technologies would benefit analysis.
US		n/a
India		Further granularity in fuel costs, more recent plant-level revenues and local operating and maintenance costs would benefit the analysis.
EU		n/a
Indonesia		Granularity around plant-level revenues and local operating and maintenance costs would benefit the analysis.
Japan		Granularity around regulated tariffs, plant level generation, local operation and maintenance costs and costs borne by environmental control technologies would benefit the analysis.
South Africa		Further granularity around plant-level generation and tariffs would benefit the analysis.
South Korea		n/a
Turkey		Further granularity on plant-level revenues, local operation and maintenance costs and local lignite prices would benefit the analysis.

Russia	Red	Statistics on revenues at asset-level for power market and electricity sales for both price zone areas and regulated zones would benefit the analysis. Other areas include: generation at the asset level and local O&M costs.
Ukraine	Teal	N/A (although some uncertainty from the conflict in the east)
Vietnam	Yellow	Some difficulty in capturing revenues as the market structure transitions to a competitive wholesale market. More recent data on plant-level generation and local O&M costs would benefit the analysis.
Philippines	Orange	Granularity on plant-level generation data and further transparency on plant-level revenues across islands and local O&M costs would benefit the analysis.

	Confidence level	Detail
Teal	**Excellent** (80-90%)	Deep in-house sector expertise and/or significant interaction with regional experts.
Yellow	**Good** (60-80%)	Some in-house sector expertise and/or some interaction with regional experts.
Orange	**Average** (40-60%)	Limited in-house sector expertise and/or limited interaction with regional experts.
Red	**Poor** (20-40%)	Little in-house sector expertise and/or little interaction with regional experts.

Power market structures

Power market structures are rarely homogenous and vary from region to region depending on numerous technical, political and economic factors. These differences are essential for interpreting the results of this analysis as the asset stranding risk from high-cost and unprofitable coal capacity materialises differently depending on market structures. As detailed below and in Table 2, we categorise markets in three ways: liberalised, semi-regulated and regulated.

Liberalised markets

Definition:
Subject to a competitive wholesale power market where generation activities are completely separated from the rest of the value chain.

Implications for interpreting results:

- Gross profitability equals revenues received from in-the-market and out-of-the-market minus long-run operating costs.
- If gross profitability remains negative for an extended period the unit will be closed unless the owner decides to stay open for the following reasons: optionality, such as future expectations

around capacity market payments, premature retirement payments and market conditions; clean-up costs; and shareholder or government resistance.

- Stranded asset risk is often low or negative as coal generators operating in liberalised markets are cashflow negative due to suppressed wholesale power prices from out-of-market renewable energy and unsubsidised renewables which increasingly have a lower levelised cost than wholesale power prices. Stranded asset risk typically materialises with the shareholders of utilities.

Semi-regulated markets

Definition:
Partially subject to a competitive wholesale power market where generation activities are partially separated from the rest of the value chain.

Implications for interpreting results:

- Gross profitability equals revenues from both in-market and out-of-market mechanisms minus long-run operating costs.

- If gross profitability remains negative for an extended period, the unit will not necessarily close as costs can be partially or fully passed on the energy consumer or tax payer.

- Stranded asset risk is often high or positive as coal generators get a fixed rate of return regardless of market conditions. Stranded asset risk can materialise with both shareholders and the state. The state can either subsidise the cost of power (in which case the tax payer bears the stranded asset risk) or pass the risk on to the end consumer by increasing power prices.

Regulated markets

Definition:
Not subject to the competitive wholesale power market where generation activities are integrated into the rest of the value chain under the ownership of a vertically integrated utility.

Implications for interpreting results:

- Gross profitability equals revenues from predominantly out-of-market mechanisms minus long-run operating costs.

- If gross profitability remains negative for an extended period, the unit will not necessarily close as costs can be passed onto the energy consumer or tax payer.

- Stranded asset risk is often high or positive as coal generators get a fixed rate of return regardless of market conditions. Stranded asset risk materialises with the state through either higher tax rates, greater debt levels or increased power prices.

Table 6. *Market structures of the regions analysed*

Liberalised markets	Semi-regulated markets	Regulated markets
Australia	Czech Republic	Bulgaria
Austria	Hungary	Croatia
Denmark	Italy	Greece
Finland	Poland	Romania
Portugal	Russia	India
France	Slovakia	China
Germany	Spain	US
Slovenia	US	South Korea
Ireland	The Philippines	Indonesia
Netherlands		South Africa
Sweden		Turkey
UK		Vietnam
US		Ukraine
		Japan

Source: Carbon Tracker analysis
Notes: The authors acknowledge that various regions are undertaking liberalisation pilots. These pilots are not considered in our categorisation.

Appendix 2 – region backgrounds

Australia

Australia is heavily reliant on coal mining and coal for power generation. It is the world's largest coal exporter, accounting for roughly one-third of global coal exports[1]. Currently, coal accounts for two-thirds of Australia's power generation and a little more than one-third of the country's installed power capacity[2]. While the share of renewables in power generation has increased by 63% since 2010, Australia's power system remains carbon intensive due to reliance on old and inefficient coal technologies[3]. Coal power contributes to 88% of the emissions from electricity, and 30% of the total emissions of Australia[4].

Australia has fully liberalised its power market and unbundled generation, distribution, and retail sectors[5]. The power system is fragmented, and energy policy devolved to state-level. The National Electricity Market covers East and South Australia, accounting for 89% of the total capacity[6]. Power market reforms have put the energy system under stress, resulting in higher prices for consumers and poor reliability[7]. Following the power outages in South Australia in September 2016, the government has taken steps to review energy policy. Dramatic cost reductions in solar and wind with battery storage are increasingly pushing out coal power in South Australia, and 1 GW of contracted demand-side management is expected to provide flexibility to the grid[8].

China

China is the largest power producer in the world, representing one-third of global power generation[9]. Its 993 GW of operating capacity represents one half of the world's total, with another 259 GW – a size similar to the United States' operating fleet – under construction[10]. While China's investment in new coal-fired plants dropped by 55% in 2017, in response to slowing power demand and overcapacity concerns[11], recent satellite imagery suggests China's recent

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1 IEA (2017). *Coal Information 2017: Overview*. Available: https://www.iea.org/publications/freepublications/publication/CoalInformation2017Overview.pdf

2 Bloomberg NEF (2018). *Generation*. Unavailable without subscription.

3 Bloomberg NEF (2018). *Demise of the Australian Coal: Detailed Plant Analysis*. Unavailable without subscription.

4 Climate Change Authority, *Policy Options for Australia's Electricity Supply Sector: Special Review Research Report*. Available: http://climatechangeauthority.gov.au/sites/prod.climatechangeauthority.gov.au/files/files/SR%20Electricity%20research%20report/Electricity%20research%20report%20-%20for%20publication.pdf

5 OECD (2016). *Australia Country Brief*. Available: http://stats.oecd.org/wbos/fileview2.aspx?IDFile=3a9e9066-f0cd-4f49-97ff-534cf2c16cfa

6 PWC (2014). *Australian Electricity Market Reforms and Business Cases*. Available: https://www.pwc.com/jp/ja/japan-service/electricity-system-reform/assets/pdf/energy-market-in-australia-e1406.pdf

7 IEA (2018). *Australia 2018 Review*. Available: https://www.iea.org/publications/freepublications/publication/EnergyPoliciesofIEACountriesAustralia2018Review.pdf

8 IEEFA (2018). *Power-Industry Transition, Here and Now Wind and Solar Won't Break the Grid: Nine Case Studies*. Available: http://ieefa.org/wp-content/uploads/2018/02/Power-Industry-Transition-Here-and-Now_February-2018.pdf

9 IEA (2017). *World Energy Outlook*. Available: https://www.iea.org/weo2017/

10 CoalSwarm (2018). *Tsunami Warning: China's Central Authorities Stop a Massive Surge in New Coal Plants Caused by Provincial Overpermitting?* Available: https://endcoal.org/wp-content/uploads/2018/09/TsunamiWarningEnglish.pdf

11 IEA (2018). *World Energy Investment*. Available: https://webstore.iea.org/download/direct/1242?filename=wei2018.pdf

credit stimulus has restarted investment[12].

The Chinese government has focused on diversifying their power generation mix over the last decade, due to fuel import costs and air pollution concerns. As such, the share of coal in power generation declined from 81% in 2007 to 66% in 2017[13]. As detailed by Carbon Tracker, the Chinese government's power market reforms have consistently been constrained due to the financial impact they would have on state-owned enterprises[14].

EU

Significant low-carbon investments have been made over the last decade, but the EU remains the world's fourth largest producer of coal power, with Germany and Poland responsible for the majority share[15]. European utilities have experienced the financial consequences of a turbulent low-carbon transition. From 2008 to 2013, five European utilities lost 37% of their value due to failure to understand changing policy, technology costs and business models[16]. Several utilities have since separated or re-focused their portfolio to adjust to the changing landscape. A combination of deflationary renewable energy costs, air pollution regulations and increasing carbon prices continue to compromise the economics of the EU's coal power fleet, which is projected to be entirely loss-making by 2030[17]. A growing number of the EU countries are phasing out coal power, including: France (2022), Denmark (2025), Italy (2025), the UK (2025), Netherlands (2030), Portugal (2030), and Spain (2030), while Belgium has been coal-free since 2016[18].

India

India has rapidly become the world's third largest power producer, adding 157 GW of coal capacity since 2006 to bring its 2018 fleet size to 219 GW[19,20]. Coal was responsible for three-quarters of the 1,323 TWh of electricity produced in 2017[21]. India is developing its renewable energy industry with similar zeal. Renewable cost deflation underpins India's ambition to build 275 GW of renewable energy capacity by 2027[22]. Indeed, for the fiscal year 2017, India installed more renewable capacity than coal and gas capacity[23]. These dynamics, plus a failure to pay generators, has placed significant stress on India's coal assets[24]. The Power Ministry currently considers 30 GW of coal capacity to be distressed assets and a further 10 GW to be unviable[25].

12 *CoalSwarm (2018).*

13 *IEA (2018). Power Sector Reform in China: An International Perspective. Available: https://webstore.iea.org/download/direct/2367?fileName=Insights_Series_2018_Power_Sector_Reform_in_China.pdf*

14 *Carbon Tracker (2018). Chasing the Dragon: China's coal overcapacity crisis and what it means for investors. Available: https://www.carbontracker.org/reports/chasing-the-dragon-china-coal-power-plants-stranded-assets-five-year-plan/*

15 *Bloomberg NEF (2018). Capacity and Generation. Unavailable without subscription.*

16 *Carbon Tracker (2015). Coal: Caught in the EU Utility Death Spiral. Available: https://www.carbontracker.org/reports/eu_utilities/*

17 *Carbon Tracker (2017). Lignite of the Living Dead: Below 20C Scenario and Strategy Analysis for EU Coal Power Investors. Available: https://www.carbontracker.org/reports/lignite-living-dead/*

18 *Europe Beyond Coal (2017). Overview: National Coal Phase-Out Announcements in Europe. Available: https://beyond-coal.eu/wp-content/uploads/2017/12/National-phase-out-overview-171219.pdf*

19 *CoalSwarm (2018). Global Plant Tracker July Update. Available: https://endcoal.org/global-coal-plant-tracker/*

20 *CoalSwarm, Sierra Club, and Greenpeace (2018). Boom and Bust 2018: Tracking Global Coal Plant Pipeline. Available: https://endcoal.org/wp-content/uploads/2018/03/BoomAndBust_2018_r6.pdf*

21 *Bloomberg NEF (2018). New Energy Outlook. Unavailable without subscription.*

22 *India Central Electricity Authority (2018). National Electricity Plan. Available: http://www.cea.nic.in/reports/committee/nep/nep_jan_2018.pdf*

23 *Bloomberg NEF (2017). Accelerating India's Clean Energy Transition. Available: https://about.bnef.com/blog/accelerating-indias-clean-energy-transition/*

24 *Carbon Tracker (2018). From Stressed to Unviable: India's Renewables Revolution is Pushing Coal Off the Debt Cliff. Available: https://www.carbontracker.org/from-stressed-to-unviable/*

25 *Bloomberg Quint (2018). RBI Not in Favour of Forbearance for Stressed Power Assets, Says Power Sectary. Available: https://www.bloombergquint.com/business/nearly-10000-mw-coal-based-capacity-remains-unviable-power-secretary-says*

As more coal plants are retired and renewable energy increases, the share of coal in total capacity could fall from 58% in 2017 to 43% in 2027[26].

Indonesia

Indonesia is the world's fourth-largest coal miner, its second largest coal exporter and has a substantial fleet of coal-fired power plants[27]. In 2017, coal accounted for 58% of total power generation and 49% of installed capacity, equal to 147 TWh and 31 GW, respectively[28]. Despite recent downward revisions to plans to expand Indonesia's coal fleet (due to sluggish energy demand), coal looks set to remain the cornerstone of Indonesia's energy policy, with plans in the 2018-2027 Electricity Power Supply Plan (2018 RUPTL) to build 21 GW of new capacity[29, 30].

State-owned Perusahan Listrik Negara (PLN) controls the majority of power generation and has a regulated monopoly on transmission and distribution. The Electricity Law No. 30 of 2009 introduced a more significant role for the private players in power generation[31]. PLN controlled 78% of generation capacity in 2008, and by 2022 it is expected to deliver 41% of generation, transmission, and distribution capacity[32, 33]. Indonesia Power and PT Pembangkitan Jawa-Bali are the most significant two subsidiaries of PLN, accounting for 22% of coal generation assets. PLN uses capacity payments to incentivise private investment in new coal power capacity. A study by IEEFA showed the 2017 RUPTL could oblige PLN to pay $16.2 bn for idle capacity (5.1 GW)[34].

Japan

Japan has the world's sixth largest coal fleet, with 50 GW of operating capacity and plans to expand this by roughly one third[35,36]. Following the Fukushima nuclear disaster, the share of coal in generation has increased from 25% in 2011 to 31% in 2017, or equivalent to 332 TWh[37]. Sluggish economic growth and an increasing share of renewables have recently slowed down post-Fukushima plans to expand coal generation, and many of the 13 GW planned capacity might not reach the construction phase[38]. While Bloomberg NEF estimate absolute coal generation to marginally increase

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26 IEEFA (2018). New National Electricity Plan Reinforces Intent Toward 275 Gigawatts of Renewables-Generated Electricity by 2027. Available: http://ieefa.org/ieefa-india-new-national-electricity-plan-reinforces-intent-toward-275-gigawatts-of-renewables-generated-electricity-by-2027/
27 IEA, (2018). Indonesia. Available: https://www.iea.org/countries/indonesia/
28 Bloomberg NEF, (2018). New Energy Outlook 2018. Unavailable without subscription.
29 Policymakers target the majority of coal expansion in the western islands. Micro-grid or off-grid renewables are seen an attractive option in eastern islands with lower electrification rates. See NREL, (2015). Sustainable Energy in Remote Indonesian Grids: Accelerating Project Development. Available: https://www.nrel.gov/docs/fy15osti/64018.pdf
30 PWC, (2018). Alternating Currents: Indonesian Power Industry Survey 2018. Available: https://www.pwc.com/id/en/publications/assets/eumpublications/utilities/power-survey-2018.pdf
31 IEA, (2009). Electricity Law (No.30/2009). Available: https://www.iea.org/policiesandmeasures/pams/indonesia/name-140166-en.php
32 World Bank, (2013). Power Market Structure. Available: http://documents.worldbank.org/curated/en/795791468314701057/pdf/761790PUB0EPI00LIC00pubdate03014013.pdf
33 IEA, (2015). Indonesia 2015. Available: https://www.iea.org/publications/freepublications/publication/Indonesia_IDR.pdf
34 IEEFA, (2017). Overpaid and Underutilized: How Capacity Payments to Coal-Fired Power Plants Could Lock Indonesia into a High-Cost Electricity Future. Available: http://ieefa.org/wp-content/uploads/2017/08/Overpaid-and-Underutilized_How-Capacity-Payments-to-Coal-Fired-Power-Plants-Could-Lock-Indonesia-into-a-High-Cost-Electricity-Future-_August2017.pdf
35 CoalSwarm (2018). Global Plant Tracker July Update. Available: https://endcoal.org/global-coal-plant-tracker/
36 CoalSwarm, Sierra Club, and Greenpeace (2018). Boom and Bust 2018: Tracking Global Coal Plant Pipeline. Available: https://endcoal.org/wp-content/uploads/2018/03/BoomAndBust_2018_r6.pdf
37 Bloomberg NEF (2018). Generation. Unavailable without subscription.
38 IEEFA (2017). Japan: Greater Energy Security Through Renewables: Electricity Transformation in A Post-Nuclear Economy. Available: http://ieefa.org/wp-content/uploads/2017/03/Japan_-Greater-Energy-Security-Through-Renewables-_March-2017.pdf

over the short-term, it estimates renewable energy to produce three-quarters of Japan's power by 2050[39].

Japan's electricity system is composed of ten grid regions that have been historically monopolised by ten vertically-integrated electric power companies (EPCOs). While the Japanese government introduced a three-step market reform in 2013, EPCOs are still the dominant players in generation, transmission and distribution[40]. The introduction of full retail market liberalisation in 2016 has increased competition, but as of 2018 EPCOs retain majority share in the wholesale market[41].

The Philippines

Coal constitutes almost half of the Philippines' power generation, with its absolute total more than doubling from 2010 to 47 TWh in 2017[42]. Despite this, renewable cost deflation and heavy dependence on imported coal underscore the planned increase of renewable capacity set out in the Philippine Energy Plan 2012-2030 from 7 GW in 2017 to 9.5 GW by 2030[43,44].

The Philippines was the first ASEAN county to adopt power market reforms. The Electricity Power Industry Reform Act (EPIRA) of 2001 accelerated market liberalisation and unbundled generation, wholesale and distribution markets[45,46]. The National Power Corporation (NPC) monopolised generation until 2001, but by 2017 almost 90% of the Philippines' power generation assets were owned by independent power producers[47]. Aboitiz, Alcantara, Ayala, San Miguel, and Filinvest are major conglomerates involved in coal plant construction in the Philippines[48].

Power purchase agreements are offered to investors that secure a return on capital for a period of 20 years. These agreements have the potential to create asset stranding risk if policymakers and investors overestimate power demand and underestimate the competitiveness of renewable energy. Lower capacity factors would increase the operating costs as fixed operating costs are spread across fewer operating hours. These higher operating costs would be passed on to consumers. The coal fleet presently has a lower operating cost than wind and solar, but the levelised cost of solar PV plummeted 138% over the last four years[49,50].

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39 *Bloomberg NEF (2018). New Energy Outlook. Unavailable without subscription.*
40 *Renewable Energy Institute (2017). The Ways Forward for Japan EPCOs in the New Energy Paradigm. Available: https://www.renewable-ei.org/en/activities/reports/img/20171006/REI_EPCOs_Report_EN_171006_FINAL.PDF*
41 *Bloomberg NEF (2017). Power Market Design Series 4: Japan. Unavailable without subscription.*
42 *Department of Energy (DOE), (2018). Power Statistics. Available: https://www.doe.gov.ph/sites/default/files/pdf/energy_statistics/01_2017_power_statistics_as_of_30_april_2018_summary_05092018.pdf*
43 *DOE, (2018). Power Statistics. Available: https://www.doe.gov.ph/sites/default/files/pdf/energy_statistics/01_2017_power_statistics_as_of_30_april_2018_summary_05092018.pdf*
44 *DOE, (2012) Philippine Energy Plan 2012-2030. Available: https://www.doe.gov.ph/sites/default/files/pdf/pep/2012-2030_pep.pdf*
45 *The Electricity Power Industry Reform Act (2001). Available: https://www.doe.gov.ph/sites/default/files/pdf/issuances/20010608-ra-09136-gma.pdf*
46 *IEA, (2015). Development Prospects of the ASEAN Power Sector: Towards an Integrated Electricity Market. Available: https://www.iea.org/publications/freepublications/publication/Partnercountry_DevelopmentProspectsoftheASEANPowerSector.pdf*
47 *DOE, (2017). Gross Power Generation by Ownership. Available: https://www.doe.gov.ph/sites/default/files/pdf/energy_statistics/06_2017_power_statistics_as_of_30_april_2018_6.gen_per_ownership.pdf*
48 *IEEFA and ICSC. (2017). Carving out Coal in the Philippines: Stranded Coal Assets and the Energy Transition. Available: http://ieefa.org/wp-content/uploads/2017/10/Carving-out-Coal-in-the-Philippines_IEEFAICSC_ONLINE_12Oct2017.pdf*
49 *LCOE estimates for solar PV and onshore wind are based on Bloomberg NEF's 1H 2018 data. See BNEF, (2018). Levelised Cost of Electricity (LCOE) by country. Available: https://www.bnef.com/core/data-hubs/5/27?tab=Current%20LCOE%20by%20Country*
50 *Bloomberg NEF (2018). LCOE Historical Benchmark 1H 2018. Unavailable without subscription.*

Russia

Russia has the world's fifth largest coal fleet, with a capacity in 2018 of 47 GW. Coal produced 169 TWh of electricity in 2017, or 16% of the total, with gas by far the dominant source of power[51]. Renewable power remains nascent; the Russian government has committed to increase its share to 4.5% by 2020[52]. Russia has recently liberalised the power sector, which was previously dominated by the state-owned RAO UES. 80% of installed capacity is controlled by just ten companies and state-owned companies control over half of capacity[53]. Russia's electricity system is divided into competitive and non-competitive regions, and coal powers the Southern Siberia region. Even though coal prices are low and unregulated, the operational cost of coal power is high due to high coal transport costs and the capital costs of inefficient coal technologies[54].

South Africa

South Africa has the world's seventh largest coal fleet, with 42 GW of operating coal capacity in 2018, accounting for more than four-fifths of total power generation[55,56]. The South African government aims to reduce coal's share of total capacity from almost 80% in 2017 to 46% by 2030[57]. The country's power sector is dominated by the state-owned utility Eskom. While the government introduced a managed liberalisation and set a target for 30% of the generation to be produced by by independent power producers (IPPs)[58], independent generators and 137 municipal power companies currently capture only one third of that target[59]. In April 2018, the South African government ended the policy uncertainty over renewable energy by signing PPAs for 2.4 GW of renewable projects[60]. The government also announced new plans to quadruple renewable energy's share of capacity to 36% in 2030.

South Korea

South Korea is heavily dependent on coal. Its 38 GW of operating coal-fired capacity, which the government plans to expand, is the dominant source of electricity in the country and produced 44% of the 585 TWh in 2017[61]. 10 GW of additional coal capacity has been commissioned since 2016[62,63]. The Korean government aims to reduce its reliance on coal and phase-out nuclear by

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51 Bloomberg NEF (2018). Generation. Unavailable without subscription.
52 IEEFA (2016). The New Development Bank: Its Role in Achieving BRICS Renewable Energy Targets. Available: http://ieefa.org/wp-content/uploads/2016/10/New-Development-Bank-and-Role-in-BRICS-Renewable-Energy-Targets-October-2016.pdf
53 OEIS (2018). Market Liberalisation and Decarbonisation of The Russian Electricity Industry: Perpetuum Pendulum. Available: https://www.oxfordenergy.org/wpcms/wp-content/uploads/2018/05/Market-liberalization-and-decarbonization-of-the-Russian-electricity-industry-perpetuum-pendulum-Comment.pdf
54 OEIS (2018). The Development of Natural Gas Demand in the Russian Electricity and Heat Sectors. Available: https://www.oxfordenergy.org/wpcms/wp-content/uploads/2018/08/The-Development-of-Natural-Gas-Demand-in-the-Russian-Electricity-and-Heat-Sector-NG-136.pdf
55 CoalSwarm (2018). Global Plant Tracker July Update. Available: https://endcoal.org/global-coal-plant-tracker/
56 Bloomberg NEF (2018). Generation in South Africa. Unavailable without subscription.
57 Bloomberg NEF (2018). South Africa to Quintuple Renewables, Sextuple Gas by 2030. Unavailable without subscription. Also see Bloomberg (2018). South Africa Drops Nuclear, Adds Renewables in Energy Plan. Available: https://www.bloomberg.com/news/articles/2018-08-27/south-africa-drops-nuclear-power-in-new-energy-capacity-plans
58 Vagliasindi M and Besant-Jones J (2013). Power Market Structure: Revisiting Policy Options. Available: https://openknowledge.worldbank.org/handle/10986/13115
59 RECP (2018). South Africa Energy Sector. Available: https://www.africa-eu-renewables.org/market-information/south-africa/energy-sector/
60 Bloomberg NEF (2018). South Africa Ends Renewables Stalemate. Unavailable without subscription.
61 Bloomberg NEF (2018). Generation. Unavailable without subscription.
62 CoalSwarm (2018). Global Plant Tracker July Update. Available: https://endcoal.org/global-coal-plant-tracker/
63 CoalSwarm, Sierra Club, and Greenpeace (2018). Boom and Bust 2018: Tracking Global Coal Plant Pipeline. Available: https://endcoal.org/wp-content/uploads/2018/03/BoomAndBust_2018_r6.pdf

increasing its share of renewables to 20% of total generation by 2030[64]. Indeed, South Chungcheong Province, which possesses half of South Korea's coal capacity, joined the international coalition Powering Past Coal Alliance, agreeing to hasten the closure of its coal plants[65]. Solar and wind power continue to grow rapidly, but retained a fractional 2% share of total generation in 2017[66]. Although the government has initiated the restructuring of the power sector, the state-owned Korea Electric Power Corporation (KEPCO)'s five subsidiaries still supply 85% of the generation assets[67]. KEPCO has some competition from IPPs in the generation, controls transmission and distribution, and leads the execution of the clean energy transition[68].

Turkey

Turkey has 19 GW of operating coal capacity in 2018 and 1.3 GW under construction[69]. The government plans to expand coal-fired generation and prioritise domestic lignite resources to reduce reliance on imported gas from Russia. Coal is currently responsible for a third of total generation, and planned addition of 42 GW of coal capacity will increase the coal generation by nearly 150%[70]. The majority of new capacity has been submitted by private companies and is likely to be supplied by imported coal[71]. Turkey has started an ambitious liberalisation and privatisation of the power sector, allowing private companies to enter into bilateral contracts for generation and distribution. Turkey's plan to significantly expand coal capacity is at odds with its renewable potential. According to Bloomberg NEF, solar and wind capacity has almost doubled since 2010 and is estimated to be nearly 70% of the total by 2050[72]. Given the rapid growth of solar and wind power, investing in renewable capacity is financially less-risky than expanding coal power in Turkey[73].

Ukraine

Ukraine has 22 GW of installed coal capacity, which account for 40% of the total capacity and 27% of total power generation, second only to nuclear in 2018[74,75]. The preponderance of coal power in Ukraine is on a downward trend: its share of total power generation more than halved between 2010 and 2017; the annexation of Crimea limited the access to coal mines in Donbass, leading to a decline in thermal coal power generation[76]; and coal-fired capacity has decreased by 45% since 2010. In the meantime, subsidised utility solar and onshore wind capacity has doubled, accounting for 1 GW and 474 MW in 2017, respectively[77].

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64 Energiewende (2018). South Korea's Move Towards Renewables. Available: https://energytransition.org/2018/06/south-koreas-move-towards-renewable-energy/

65 Powering Past Coal Alliance (2018). Press release. Available: https://poweringpastcoal.org/assets/docs/news/Press_Release_-_South_Chungcheong_Province_joins_Powering_Past_Coal_Alliance_-_2_October_2018_-_Final.pdf

66 Bloomberg NEF (2018). Generation. Unavailable without subscription.

67 Bloomberg NEF (2018). South Korea Power Market Structure. Unavailable without subscription.

68 IEEFA (2018). Korea's Clean Energy Challenge – Time for A Check Up. Available: http://ieefa.org/wp-content/uploads/2018/09/Korea-Energy-Challenge_September2018.pdf

69 CoalSwarm (2018). Global Plant Tracker July Update. Available: https://endcoal.org/global-coal-plant-tracker/

70 Bloomberg NEF (2014). Turkey's Changing Power Markets. Available: https://about.bnef.com/blog/turkeys-changing-power-markets/

71 EIA (2018). Countries in and around the Middle East are Adding Coal-fired Power Plants. Available: https://www.eia.gov/todayinenergy/detail.php?id=36172

72 Bloomberg NEF (2018). Turkey Long-Term Power Market Outlook. Unavailable without subscription.

73 IEEFA (2016). Turkey at a Crossroads: Invest in the Old Energy Economy or the New? Available: http://ieefa.org/wp-content/uploads/2016/09/Turkey-Crossroads-Invest-in-the-Old-Energy-Economy-or-the-New_June-2016-v2.pdf

74 CoalSwarm (2018). Global Plant Tracker July Update. Available: https://endcoal.org/global-coal-plant-tracker/

75 Bloomberg NEF (2018). Generation. Unavailable without subscription.

76 Reuters (2017). Ukraine Faces Energy Crisis After Blockade Cuts Off Coal Supply. Available: https://www.reuters.com/article/ukraine-crisis-blockade-idUSL8N1G15LA

77 Bloomberg NEF (2018). Capacity. Unavailable without subscription.

The share of renewable power could grow to 91% by 2050 under the revolutionary scenario, according to IEF[78]. Ukraine has recently introduced power market reforms to transition from a single buyer model to a more liberalised model outlined in the Third Energy Package of the EU[79]. It also targets a full integration of the electricity system with the European Network of Transmission System Operators (ENTSO-E) by 2025. These reforms will accelerate the deployment of renewables in Ukraine, while its thermal coal fleet will be uncompetitive in the EU power markets after 2025[80].

US

The US is the world's second largest power producer with 250 GW of coal capacity generating 1,269 TWh, or 31% of its total, in 2017[81]. Coal power generation has declined by 28% from 2012 to 2017, with 45 GW of coal retired[82]. A further 17 GW of coal capacity is expected to be shut down by the end of 2018[83]. Despite the Trump Administration's attempts to support coal power, it widely agreed that new coal capacity will likely be uncompetitive[84]. According to Bloomberg NEF, solar and wind power will replace coal and gas over the next 30 years, with the share of solar and wind in power generation increasing from 8% in 2017 to 21% by 2030 and 47% by 2050[85].

The US power generation assets operate under a mix of liberalised, semi-regulated and regulated markets. California independent system operator (CAISO), Midcontinent (MISO), New England (ISO-NE), New York (NYSIO), PJM interconnection, Texas (ERCOT) and Southwest power pool (SPP) operate under competitive wholesale markets[86]. Southeast and Northwest of the US are regulated markets with integrated utilities and federal system own the generation, transmission, and distribution systems. Nearly 190 GW, or two-thirds, of the operating coal capacity are regulated units, and their costs are largely passed through to consumers[87]. The remaining third (90 GW) operates under competitive wholesale markets, predominantly in PJM and MISO.

Vietnam

Coal is the second largest source of power generation in Vietnam, responsible for 34% of electricity generated in 2017[88]. Electricity production from coal-fired plants surged by 72% from 2010 to 67.5 TWh in 2017, as did capacity, increasing by 84% to 17 GW over the same period. Onshore wind and solar PV take a minute share of total capacity with 0.4%. According to the revised Power Development Plan VII (PDP 7), the share of coal capacity is expected to be 42.6% by 2030, equivalent to 43 GW of new coal

78 Institute for Economics and Forecasting (2018). The Transition of Ukraine to the Renewable Energy by 2050. Available: https://ua.boell.org/sites/default/files/transition_of_ukraine_to_the_renewable_energy_by_2050_1.pdf
79 EU4Energy Initiative (2018). Electricity Market Reform in Ukraine: Will We Make It in Time? Available: https://www.euneighbours.eu/sites/default/files/publications/2018-04/Power-Reforms-Hurry-up-Holikova-ENG.pdf
80 Clean Technica (2018). Ukraine's Power Sector is Set for A Major Transition. Available: https://cleantechnica.com/2018/07/10/ep-ukraines-power-sector-is-set-for-a-major-transition/
81 Bloomberg NEF (2018). New Energy Outlook. Unavailable without subscription.
82 Bloomberg NEF (2018). New Energy Outlook. Unavailable without subscription.
83 Bloomberg NEF (2018). US Coal Retirements Near All-Time High. Available: https://about.bnef.com/blog/u-s-coal-plant-retirements-near-all-time-high/
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plants[89]. However, the government targets the deployment of 18 GW of onshore wind and solar PV by 2030[90].

Vietnam has reformed its power sector towards a more competitive system[91]. Before 2012, Vietnam Electricity (EVN) had a monopoly over generation, transmission, and distribution. The Electricity Law of 2004 initiated the restructuring of EVN to encourage private players' participation[92].

With the establishment of the Vietnam Competitive Generation Market (VCGM) in 2012, EVN's affiliate power generation companies (Gencos) and IPPs began selling power to a single-buyer, the Electricity Power Trading Company (EPTC)[93]. EVN owns 60% of power generation assets, the remaining being held by PetroVietnam (13%), Vinacomin (4%) and IPPs[94]. A fully competitive retail market will be in working order by 2023[95].

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92 *The Electricity Law, (2004). Available: http://www.tracuuphapluat.info/2010/06/toan-van-luat-ien-luc-nam-2004.html*

93 *EPTC is a subsidiary of EVN and responsible for regulating the price of electricity in the competitive power pool.*

94 *Bloomberg NEF (2017). Vietnam Power Market: Opportunities and Risks. Unavailable without subscription.*

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