Carbon Tracker Initiative

BROWN IS THE NEW GREEN

Will South Korea's commitment to coal power undermine its low carbon strategy?

Analyst Note

March, 2019

About Carbon Tracker

The Carbon Tracker Initiative is a team of financial specialists making climate risk real in today's capital 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 | hello@carbontracker.org

About this note

Lead authors: Matt Gray (mgray@carbontracker.org) and Durand D'souza (ddsouza@carbontracker.org)

The note benefited from insights from Joojin Kim, Soyoung Lee and Jeehye Park from Solutions for Our Climate.

The data and analytics from this note are drawn from a techno-economic simulation model, which covers ~95% of global operating capacity and ~90% of capacity under-construction. This model was developed by the power and utilities team from 2016 to 2018 and provides current and forward-looking estimates of the (short and long-run) marginal cost, gross profitability, relative competitiveness, phase-out year and stranded asset risk in a below 2°C scenario. More information on this data and analytics is available at Carbon Tracker's coal power portal.

About the power and utilities team

Matt Gray – Head of Power and Utilities

Matt is an energy investment expert and leads Carbon Tracker's work on power and utilities. Matt was previously an analyst at Jefferies, an American investment bank, where he was the head of European carbon and power research. More recently, Matt was a consultant analyst at the International Energy Agency and has also worked on emissions trading at Credit Suisse and energy efficiency at the UK's DECC. He has a Bachelor of Applied Science from the University of Otago and a Master of Science from the University of Manchester where he was awarded a Rotary Foundation ambassadorial scholarship. In 2017, Matt received a Google scholarship to attend Singularity University's Global Solutions Program at the NASA Ames Research Center in California.

Laurence Watson – Data Scientist

Laurence is a data scientist at Carbon Tracker with broad experience in energy and climate change. Laurence was previously head of technology at Sandbag, an NGO focused on carbon markets. More recently he was a climate and energy policy researcher for Barry Gardiner MP, and senior parliamentary assistant for Gill Furniss MP supporting their work across a range of policy briefs in Westminster. He has also worked at the Alvin Weinberg Foundation, a charity advocating the development of next-generation nuclear technology and interned with Lord Dubs and the British Embassy, Prague. He has a Bachelor of Arts in physics from the University of Cambridge.

Durand D'souza – Data Scientist

Durand is a data scientist at Carbon Tracker with experience across a wide range of domains. Prior to joining Carbon Tracker, he was a freelance data journalist producing interactive visual stories, winning an Information Is Beautiful award along the way. He also worked on a PhD in computational stellar astrophysics at the Max Planck Institute for Astrophysics in Germany, until his lifelong obsession with climate & energy policy prevailed. He is interested in how machine learning can be used for social good and to bring about a just transition. Durand holds a Masters in Physics with Astrophysics from the University of Leeds.

Magali Joseph – Energy Analyst

Magali is an energy analyst with a background in the power industry. Prior to joining Carbon Tracker, she worked as a market analyst for the French utility ENGIE, focusing on long-term resource planning and power price forecasting. More recently, she worked for Energy Exemplar, a power modelling software company, helping clients use the product and implement their models. She holds a Bachelor in Business Administration from HEC Montreal and a Master of Economics from Uppsala University. During her academic studies and professional experience, Magali developed a strong interest in climate change and the risks and opportunities associated with the energy transition to a low carbon economy.

Aurore Le Galiot – Policy Associate

Aurore joined Carbon Tracker in 2018 as an intern, supporting the activities of the regulatory and policy team. She has now joined the team as a Junior Associate. Prior to joining Carbon Tracker, Aurore completed two internships at HSBC Paris, focusing on business analysis and development. Aurore holds a BSc degree in International Management and Chinese language from SOAS University and continued further studies at Beijing Normal University and Shanghai University of Finance and Economics, learning Mandarin and focusing on the political and economic context in China.

Richard Folland – Senior Policy and Government Affairs Adviser

Richard has been an Adviser to Carbon Tracker since 2014, advising on the organisation's interactions with governments and multilateral institutions, especially where it concerns the intersection between climate and finance issues. Richard has worked on climate and energy policy – in government and the financial sector – for nearly 15 years. A long-time British diplomat, he headed UK international policy at the Foreign Office from 2004-2007. He has since then been JPMorgan's European Climate Change and Energy Policy Adviser.

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1 Key Findings

In this note we present the results of Carbon Tracker's coal power analysis for South Korea to understand stranded asset risk and relative economic competitiveness. The note has four key findings.

South Korea has the highest stranded asset risk in the world due to market structures.

Our below 2°C scenario finds South Korea has $106 billion of stranded asset risk – the highest of the 34 countries modelled. The $106 billion represents the difference between the cash flow utilities may receive under the current South Korean power market and what they would receive in a below 2°C scenario, which sees capacity closed prematurely to meet the temperature goal in the Paris Agreement. This is due to regulatory structures which effectively guarantee coal generators' high returns. These policy measures include: merit order being based solely on fuel costs; large capacity market payments; and compensation for carbon exposure and transmission restrictions. All together, these measures provide coal generators with cash flows larger than that which they would receive in other markets throughout the world.

South Korea risks losing the low carbon technology race by remaining committed to coal.

South Korea has 5.4 GW of coal under construction and 2.1 GW planned, as well as several retrofits in various stages of planning. The nation's low carbon strategy, which aims to stimulate the economy and secure energy independence, risks being derailed by a continued focus on coal power. Independent of additional climate or air pollution policy, our analysis shows it will be cheaper for South Korea to build new solar PV than to operate existing coal plants by 2027, calling into question not only planned coal investments but also the economic viability of the current operating fleet.

Planned retrofits to cost $3.6 bn which will accelerate the competitiveness of renewables and could impact KEPCO's finances.

Our analysis of South Korea's coal retrofits, which is based on publicly-available data in company reports, shows these investments will, on average, increase the long-run marginal cost (LRMC) by 18%, and thus will further improve the relative competitiveness of renewables. For example, if these retrofits go ahead the LRMC could, on average, be higher than building new solar PV by 2025 rather than 2028.

South Korea should stop investing in new coal and develop a retirement schedule.

If South Korean policymakers remain committed to coal power the nation will face a dilemma: continue to subsidise coal generators either directly (through higher tariffs) or indirectly (through out-of-market payments) to maintain their financial viability; or keep tariffs artificially low to shelter consumers from higher costs. Both outcomes could prove financially and economically unsustainable, as subsidising coal generation will either anger taxpayers or energy consumers, while artificially low tariffs for consumers will impact fiscal resources. Thus, South Korea needs to stop new investments (both new build and retrofits) and develop a cost-optimised retirement schedule.

2 Executive Summary

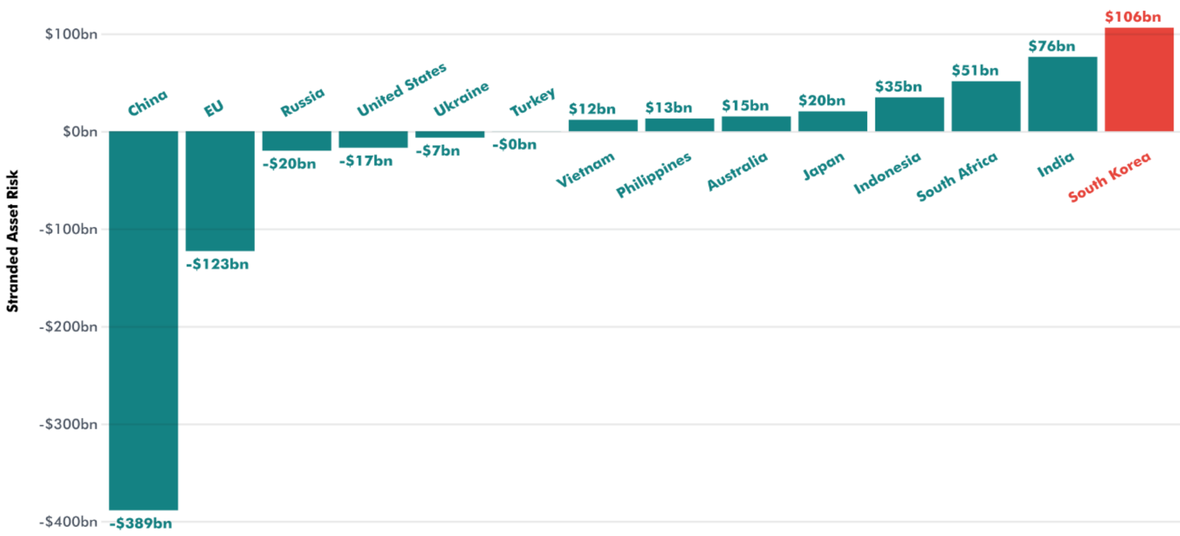
In this note we present the results of Carbon Tracker's coal power analysis for South Korea to understand stranded asset risk and relative economic competitiveness. Carbon Tracker has created a techno-economic simulation model to track key economic and financial metrics of coal power at the asset-level throughout the world. These metrics include: the operating cost, gross profitability, relative competitiveness, phase-out year, and stranded asset risk in a below 2°C scenario.

South Korea has the highest stranded asset risk in the world due to market structures

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 in South Korea by 2040 in accordance with the Paris agreement). 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 losses in the 2°C scenario as coal capacity is cash-flow negative.

Our below 2°C scenario finds South Korea has $106 billion of stranded asset risk – the highest of the 34 countries modelled. The figure represents the difference between the cash flow utilities (i.e. Korea Electric Power Corporation's (KEPCO) generation companies and private generators) may receive under the current South Korean power market and what they would receive in a below 2°C scenario, which sees capacity closed prematurely to meet the temperature goal in the Paris Agreement. This is due to regulatory structures which effectively guarantee coal generators' high returns. The policies include: the merit order being based solely on fuel costs; large capacity market payments; and compensation for carbon exposure and transmission restrictions. These measures provide coal generators with cash flows larger than that which they would receive in other markets throughout the world. For example, our analysis finds that major coal power markets, such as China, the US, and the EU, are cash-flow negative in our BAU scenario, and thus have negative stranded asset risk.

FIGURE 1 STRANDED ASSET RISK OF OPERATING COAL CAPACITY AND CAPACITY UNDER-CONSTRUCTION BY COUNTRY OR REGION

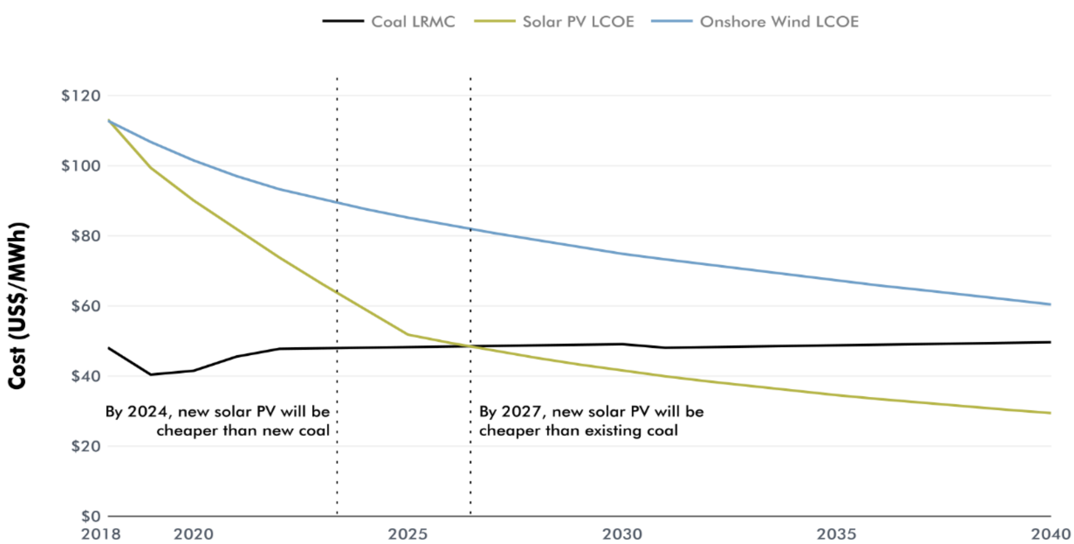


Source: Carbon Tracker analysis. Notes: for more information on the methodology see the main body of this note.

South Korea risks losing the low carbon technology race by remaining committed to coal

Independent of additional climate or air pollution policy, our analysis shows it will be cheaper for South Korea to build new solar PV than to operate existing coal plants by 2027, calling into question not only planned coal investments, but also the economic viability of the current operating fleet. This highlights a power sector mega trend: with or without climate policy coal power will likely become a high-cost option.

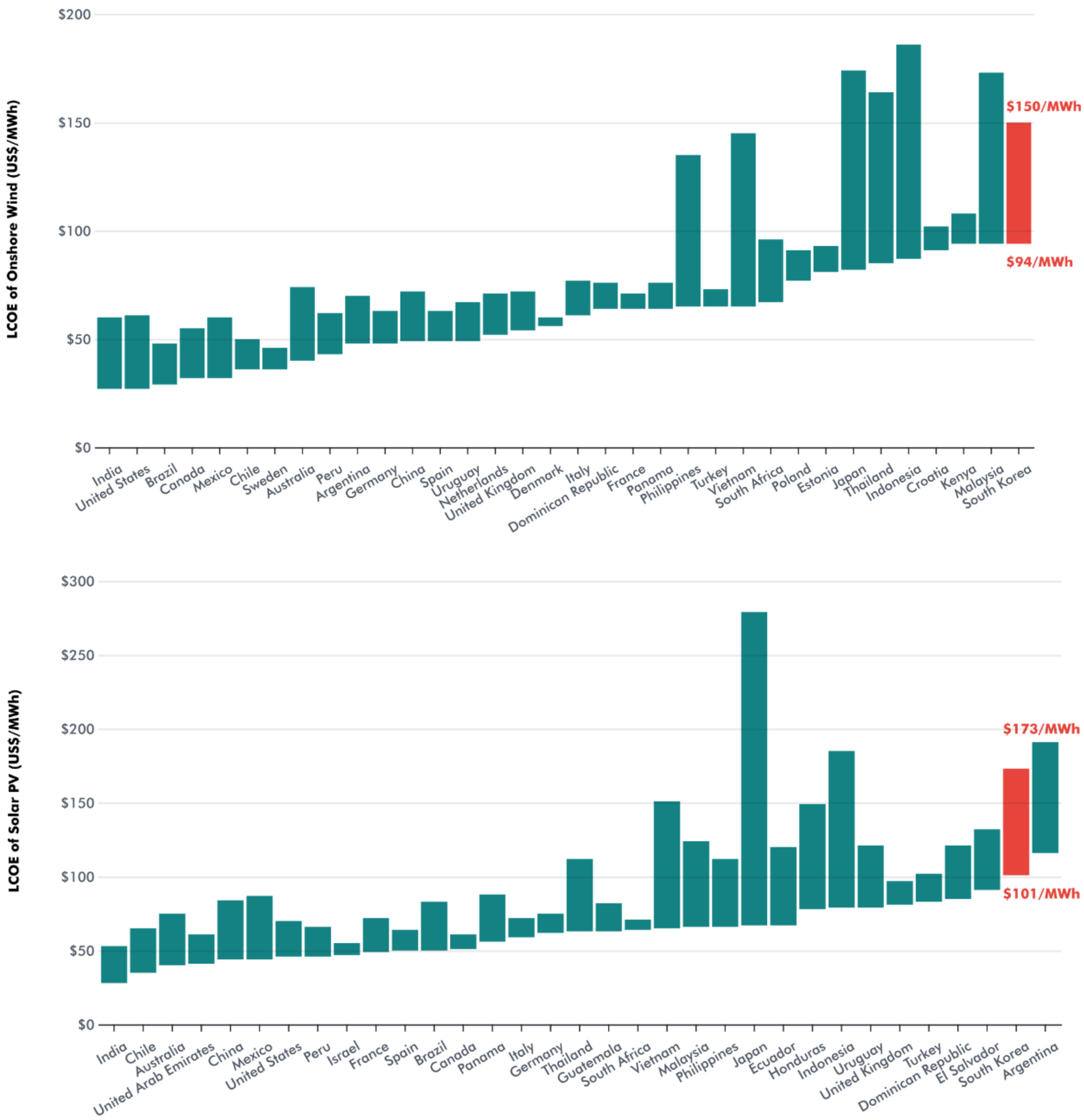
FIGURE 2 LONG-RUN MARGINAL COST OF SOUTH KOREA'S COAL CAPACITY VS THE LEVELIZED-COST OF ONSHORE WIND AND SOLAR PV FROM 2018 TO 2040



Source: Bloomber NEF (2018), Carbon Tracker analysis. Notes: for more information on the methodology see the main body of this note.

President Moon Jae-in, has clarified his willingness to move away from coal by announcing plans to decommission several operating coal power plants and cancelling construction plans for two units. Despite ongoing efforts towards a cleaner power mix, coal is the dominant source of electricity in South Korea producing 43% of total gross generation in 2017. South Korea has 5.4 GW of coal under construction and 2.1 GW planned, as well as several retrofits in various stages of planning. The country's low carbon strategy, which aims to stimulate the economy and secure energy independence, risks being derailed by a continued focus on coal power. For example, according to Bloomberg NEF, South Korea currently has the second highest solar PV costs and the highest onshore wind costs worldwide.

FIGURE 3 LEVELIZED COST OF ONSHORE WIND AND SOLAR PV FOR SELECT COUNTRIES IN 2018



Source: Bloomberg NEF (2018)

Planned retrofits costing $3.6 bn will accelerate the competitiveness of renewables and could impact KEPCO's finances

The government plans to retrofit a number of coal units to improve performance and reduce air pollution. Our analysis of these retrofits, which is based on publicly-available data in company reports, shows these investments will, on average, increase the LRMC by 18%, and thus will further improve the relative competitiveness of renewables. For example, if these retrofits go ahead the LRMC could, on average, be higher than building new solar PV by 2025 rather than 2028. While analysing the impact of these retrofits for the end power user is beyond the scope of this note, these investments are capital intensive and should be scrutinised by policymakers before proceeding. Whereas the $106 billion stranded asset risk discussed above is based on the existing power market structure, this analysis is neutral of such market structures and focuses on the operating cost of each source of energy. In a power market like South Korea's – where consumer power prices are regulated and KEPCO is the only entity authorised to sell electricity – relying on least-cost competitive sources of generation may directly impact KEPCO's finances. For example, the analysis below shows amounts that KEPCO may lose if expensive retrofitting is not avoided.

TABLE 1 THE COST OF PLANNED COAL UNIT RETROFITS FOR PERFORMANCE IMPROVEMENTS AND ENVIRONMENTAL CONTROL TECHNOLOGIES

UNIT	PARENT COMPANY	CAPACITY (MW)	RETROFIT COST ($/MN)	LONG-RUN MARGINAL COST ($/MWH)		YEAR WHEN RENEWABLES ARE CHEAPER (YEAR)	
				Before	After	Before	After
Dangjin power station Unit 1	KEPCO	500	343	48.55	60.61	2027	2024
Dangjin power station Unit 2	KEPCO	500	343	48.27	59.62	2027	2024
Dangjin power station Unit 3	KEPCO	500	343	49.08	62.95	2027	2024
Dangjin power station Unit 4	KEPCO	500	343	47.88	59.13	2027	2024
Samchonpo power station Unit 5	KEPCO	500	92	45.57	49.64	2028	2026
Samchonpo power station Unit 6	KEPCO	500	92	45.03	48.84	2029	2027
Boryeong power station Unit 3	KEPCO	500	270	46.61	55.74	2028	2025
Boryeong power station Unit 4	KEPCO	500	289	46.22	55.03	2028	2025
Boryeong power station Unit 5	KEPCO	500	289	46.64	56.39	2028	2025

Boryeong power station Unit 6	KEPCO	500	289	46.06	54.92	2028	2025
Taean power station Unit 3	KEPCO	500	326	48.14	57.87	2027	2025
Taean power station Unit 4	KEPCO	500	326	48.46	58.94	2027	2024
Yeongheung power station Unit 1	KEPCO	800	145	47.24	51.4	2027	2026
Yeongheung power station Unit 2	KEPCO	800	145	46.73	50.52	2028	2026
Total or average	**n/a**	**7,600**	**3,635**	**47.18**	**55.83**	**2028**	**2025**

Source: Carbon Tracker analysis. Notes: LRMC estimates are based on a 10-year payback period. For more information on the methodology used see the main body of this note.

Policy recommendations

If policymakers fail to implement these recommendations and remain committed to coal power, the nation will face a dilemma: continue to subsidise coal generators either directly (through higher tariffs) or indirectly (through out-of-market payments) to maintain their financial viability; or keep tariffs artificially low to shelter consumers from higher costs. Both outcomes could prove financially and economically unsustainable, as subsidising coal generation will either anger taxpayers or energy consumers, while artificially low tariffs for consumers will impact fiscal resources. In the context of this analysis, Carbon Tracker offers three recommendations for policymakers.

1. Stop investing in new coal (both new build and retrofits).

   New investments in coal capacity – both new build and retrofits – will unlikely be a least-cost solution over the capital recovery period. This period is typically 15-20 years for new coal capacity and 5-10 years for retrofits relating to performance enhancements or control technolgy installations. Our analysis highlights how coal power is losing its economic footing independent of additional climate change and air pollution policies. By 2024 at the latest, new solar PV investments will beat new coal investments based on LCOE analysis, and by 2027 it will be cheaper on average to build new solar PV than continue to run coal.

2. Develop a cost-optimised retirement schedule for the operating fleet.

   South Korean policymakers should develop retirement schedules based on the LRMC of individual units. This analysis will allow policymakers to close the higher cost units first and lower cost units last, which should help ensure the end consumer receives the lowest cost electricity possible. Alternative retirement schedules, particularly those based on emission intensity targets, may not result in a least-cost outcome and thus could impact economic competitiveness.

3. Subject the retirement schedule to resource planning analysis to understand the system value of units.

   Once policymakers have developed a cost-optimised retirement schedule at asset level, they should then undertake a systems planning analysis to take into consideration the system value of individual assets. Understanding system value is outside the scope of this analysis. Carbon Tracker intends to conduct this analysis with local partners and make this research publicly available.

3 Background

This note analyses the asset economics and relative competitiveness of South Korea's coal power capacity. In doing so, the note not only challenges the validity of planned coal investments but also the long-term viability of the existing fleet.

Despite ongoing effort towards a cleaner power mix, South Korea is heavily dependent on coal. Its 37 GW of operating coal-fired capacity, which the government plans to expand, is the dominant source of electricity and produced around 43% of total gross generation in 2017[1]. According to CoalSwarm, 10 GW of additional coal capacity has been commissioned since 2016[2,3]. The South Korean government aims to reduce its reliance on coal and phase-out nuclear by increasing its share of renewables to 20% of total generation by 2030[4]. Indeed, South Chungcheong Province, which possesses half of the nation's coal capacity, joined the international coalition Powering Past Coal Alliance, agreeing to hasten the closure of its existing coal plants[5]. Solar and wind power continue to grow rapidly, but retained a fractional 2% share of total generation in 2017[6]. Although the government has initiated the restructuring of the power sector, the state-owned KEPCO's five subsidiaries still supply 85% of the generation assets[7]. KEPCO has some competition from Independent Power Producers (IPPs) in power generation, but totally controls transmission and distribution[8].

An important feature of KEPCO is that its management has little control over influencing future cashflow. Tariffs are regulated and it has limited ability choosing the sources it purchases power from. It also cannot appoint heads of generation companies it owns outright, as these decisions are made by the Korean government. More specifically, 90% of the power KEPCO purchases from generation companies are procured on a spot basis and the merit order is determined only by fuel cost. Capital, pollution and carbon costs, for instance, are not reflected in merit order. Capital, pollution and carbon costs are separately compensated by KEPCO. This situation puts nuclear and coal at an economic advantage. It also means KEPCO takes the risk on capital-intensive investments. This institutional and regulatory backdrop is also one of the reasons why South Korea has a preponderance of coal generation and little solar and wind.

[1] *Capacity figure is based on CoalSwarm (2018). Global Plant Tracker July Update. Available:* https://endcoal.org/global-coal-planttracker/
Generation statistic is based on KEPCO (2017). Statistics of Electric Power in Korea. Available: http://epsis.kpx.or.kr/epsisnew/selectEkccIntroEn.do?menuId=110100
[2] *CoalSwarm (2018). Global Plant Tracker July Update. Available:* https://endcoal.org/global-coal-planttracker/
[3] *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
[4] *Ministry of Trade, Industry and Energy (2017). Renewable Energy 3020 Implementation Plan. Available:* http://www.motie.go.kr/motiee/presse/press2/bbs/bbsView.do?bbs_seq_n=159996&bbs_cd_n=81
[5] *Powering Past Coal Alliance (2018). Press release. Available:* https://poweringpastcoal.org/news/PPCA-news/South-Chungcheong-Province-South-Korea-coal-Powering-Past-Coal-Alliance
[6] *Bloomberg NEF (2018). Generation. Unavailable without subscription.*
[7] *Bloomberg NEF (2018). South Korea Power Market Structure. Unavailable without subscription.*
[8] *IEEFA (2018). Korea's Clean Energy Challenge – Time for A Check Up. Available:* http://ieefa.org/wpcontent/uploads/2018/09/Korea-Energy-Challenge_September2018.pdf

This note follows previous analysis by Carbon Tracker on the financial risks and relative competitiveness of coal power globally titled *Powering Down Coal* which found the following:

1. 42% of the global operating fleet was unprofitable in 2018 and 72% will be so by 2040 independent of additional climate or air pollution policy;
2. 35% of coal capacity cost more to run than building new renewables in 2018, increasing to 96% by 2030; and
3. coal owners could avoid $267 bn in stranded asset risk by phasing-out coal capacity[9].

We use reasonable assumptions to analyse the financial risks associated with new and existing coal power, as well as the significant economic opportunities related to the pursuit of low carbon alternatives. Consequently, this note highlights how South Korea's long-term commitment to coal power could burden the state with either higher tax rates, greater debt levels or increased power prices, as well as hinder the development of least-cost and low carbon technologies.

[9] *Carbon Tracker (2018). Powering down coal: Navigating the economic and financial risks in the last years of coal power. Available:* https://www.carbontracker.org/reports/coal-portal/

4 Data sources, key assumptions and modelling methodology

This section gives a summary of the data sources, key assumptions, and modelling methodology used in this note. We also detail the key risks and limitations associated with this analysis.

4.1 Data sources and key assumptions

The asset-level model outputs in this analysis are based on a number 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). These data sources and assumptions are detailed in Table 2. For the technical definitions used in this note see Box 1.

TABLE 2 DATASETS AND KEY ASSUMPTIONS USED IN THIS ANALYSIS

PARAMETER	COMMENT	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organisation, sponsor organisation, combustion technology type, coal type, heat rate, and emissions factor.	CoalSwarm (2018) and Solutions for Our Climate analysis
Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide, sulphur dioxide and particulate matter, as well as the type of cooling technology.	Platts (2018) and Solutions for Our Climate analysis
Fixed operations & maintenance (FOM) costs	The fixed cost assumptions depend on the combustion technology of the boiler: \$7.79/kW for subcritical technologies; \$10.39/kW for supercritical technologies; \$11.87/kW for ultra-supercritical technologies; \$18.37/kW for integrated gasification combined cycle technologies; and \$10.39/kW for circulating fluidised bed technologies.	IEA (2016)
Non-fuel variable operations and maintenance (VOM) costs	The variable costs we used depend on the installed capacity of the unit: \$4.49/MWh for units 0 to 100 MW; \$3.59/MWh for units 100 to 300 MW and \$3.37/MWh for units 300 MW or more.	North America Electric Reliability Corporation (2010)
Utilisation rate	Realised annual capacity factors at the asset level for existing coal-fired power capacity from 2016.	KEPCO (2017)
Fuel type, cost and transport	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 of coal. This is a cost-optimised supply route algorithm, which computes the distance between a unit's location 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. We assume	Bloomberg (2018), UN Comtrade (2018), WoodMackenzie (2018), Mining Atlas (2018), CoalSwarm (2018), Ports.com (2018) and Carbon Tracker analysis

	anthracite, bituminous and sub-bituminous coal is imported from Australia, Indonesia and Russia via seaborne and then land routes to plant. See fuel transport model description in the Appendix.	
Carbon price	Carbon pricing is incorporated using flat assumption of KRW 22,000, adjusting for the reduction in free allocation over the three planned phases: Phase 2 (2018-2020): 3% auctioned; and Phase 3 (2021-2025) 10% auctioned.	ICAP (2018) and Carbon Tracker estimates
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age.	IEA (2016), Carbon Tracker analysis
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA (2018)
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kw per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA (2018)
Unabated coal-fired power generation pathway for below 2°C scenario	Electricity transmission and distribution integrated nationally and wholly operated and owned by KEPCO. Thus, phase-out is national rather than regional. We assume OECD decline rates in the IEA's beyond 2°C scenario (B2DS) for South Korea generation.	IEA (2017)
Pollution limit regulations and associated capital and operational costs	Air pollution regulation is assumed to apply only to those units in Incheon or Gyeonggi province.	Solutions for Our Climate analysis and Carbon Tracker analysis
Plant revenues	In-market and out-of-market payments are incorporated in the form of scheduled energy payment, constrained-on energy payment, trading period capacity payment, constrained-off energy payment, renewable portfolio standard payment, emission trading payment, local resources tax payment and operation cost of preventive facilities.	Solutions for Our Climate and Carbon Tracker analysis

Sources: see above and references.

Notes: Revenue data was obtained from the South Korean government's Environment and Labor Committee and the plant revenues data was obtained from the Trade, Industry and Energy Committee.

Box 1. Metric definitions

This note includes several metric definitions which inform our economic and financial analysis of coal capacity. These definitions are detailed below.

Short-run marginal cost. The short-run marginal cost (SRMC) of a coal unit includes fuel, carbon (where applicable) and variable O&M cost. Fuel costs include the cost of buying, transporting, and preparing the coal. There are different types of coal which vary in cost depending on the energy content. The transportation costs depend on whether the coal is imported from the seaborne market or purchased domestically from a nearby mine. Variable O&M costs vary with the use of the unit. These costs include, but are not limited to, purchasing water, power and chemicals, lubricants, and other supplies, as well as disposing of waste. The short-run operating cost tends to impact dispatch decisions in liberalised markets where units enter competitive markets for the right to sell power to consumers. Liberalised markets operate in the following way:

1. The grid operator forecasts power demand ahead of time.
2. The grid operator asks for bids to supply quantity of power required to meet the forecast. Power generators typically bid at SRMC of producing the next unit of power.
3. The grid operator starts purchasing the power offered by the lowest bid operators until they add up to the required power in the forecast. This is called the uniform clearing price.
4. The grid operator pays all suppliers the same uniform clearing price regardless of what they bid. In regulated markets the way coal plants are dispatched varies depending on market structures.

LRMC. LRMC includes SRMC plus fixed O&M and any capital additions from meeting environmental regulations. Fixed costs include the expenses incurred at a power plant that do not vary significantly with generation and include staffing, equipment, administrative expenses, maintenance and operating fees, as well as installing and operating control technologies to meet regulations. While the SRMC governs dispatch decisions, the LRMC impacts the bottom-line[1].

Relative competitiveness. The year when the levelized cost of electricity (LCOE) of either onshore wind or solar PV is lower than the LRMC of coal capacity.

Gross profitability. Revenues from in-market (i.e. wholesale power markets) and out-of-market (i.e. ancillary and balancing services and capacity markets) sources minus the LRMC.

Below 2°C scenario retirement year. The year when the unit should be retired to be consistent with the temperature goal in the Paris Agreement. The retirement schedule is determined based on the long run marginal cost or gross profitability. See the modelling methodology for more information.

Below 2°C scenario stranded asset risk. The potential revenues lost from shutting the unit prematurely in accordance with the retirement year mentioned above. See the modelling methodology for more information.

4.2 Modelling methodology

The asset-level models drive the outcomes in the market and below 2°C scenarios. These scenarios are described below.

4.2.1 Market scenario model

The market scenario analysis compares the LRMC of coal with the LCOE of onshore wind and utility-scale solar PV[10]. 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[11]. 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 taxes. 2018 LCOE estimates for onshore wind and solar PV are adopted from Bloomberg NEF.

4.2.2 Below 2°C scenario model

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 LRMC, if a regulated market (as is the case for South Korea). 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 that is 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[12]. Regions have different phase-out

[10] 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.
[11] 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
[12] 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/

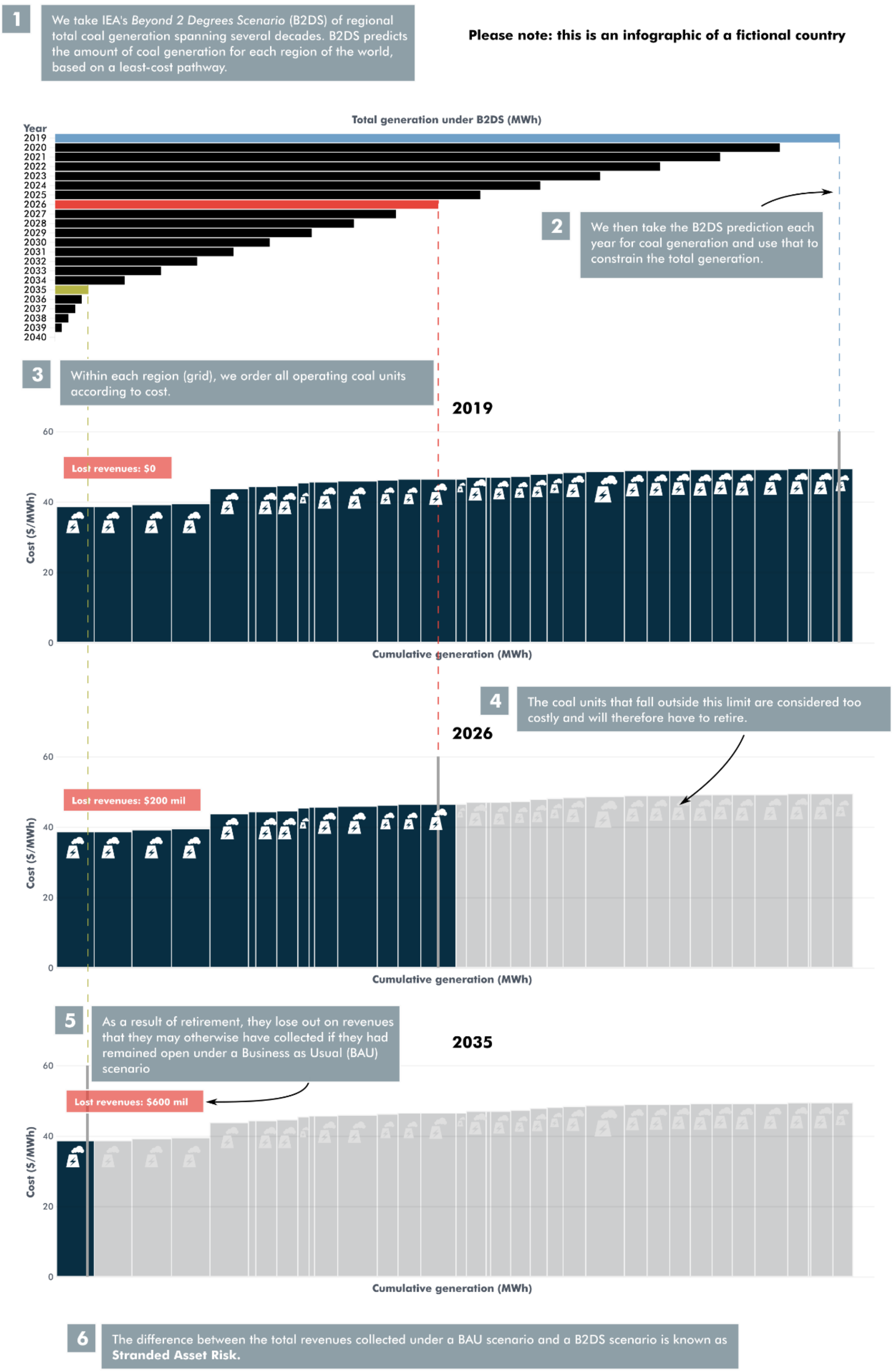
dates. For South Korea, we assume a phase-out date of 2040 which is broadly consistent with other Organisation for Economic Co-operation and Development countries[13].

Secondly, we rank the coal-fired generation units to develop a retirement schedule, 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, such as South Korea, we rank the units based on the LRMC, while in liberalised markets we phase-out units based on gross profitability. This nuance aims to either replicate a phase-out from the perspective of a regulator who is interested in providing cost-optimised generation or a merchant utility who is interested in maximising profitability. 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 flows in the B2DS (which phases-out all coal power by 2040) and the NPV of cash flows in the BAU scenario (which includes announced retirements in company reports).

[13] *For more information see: IEA (2017). Energy Technology Perspectives (ETP) 2017. Available:* https://www.iea.org/etp/

FIGURE 4 SCHEMATIC ILLUSTRATION OF THE MODELLING METHODOLOGY



5 Results and discussion

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. South Korea's power market is regulated and therefore two interpretations should be made:

1. The gross profitability of coal in regulated markets is often predetermined by market structures, meaning coal generators are either subsidised to operate at a profit or run at a loss to cross-subsidise other sectors of the economy.
2. Stranded asset risk is often high or positive in regulated markets as coal generators often get a fixed rate of return and thus risk materialises with the state through either increased tax rates, greater debt levels, or higher power prices.

5.1 Highest stranded asset risk in the world due to market structures

Stranded asset risk is defined as the difference between the cash flow derived in a BAU scenario and the cash flow in a below 2°C scenario consistent with the temperature limit set in the Paris Agreement.

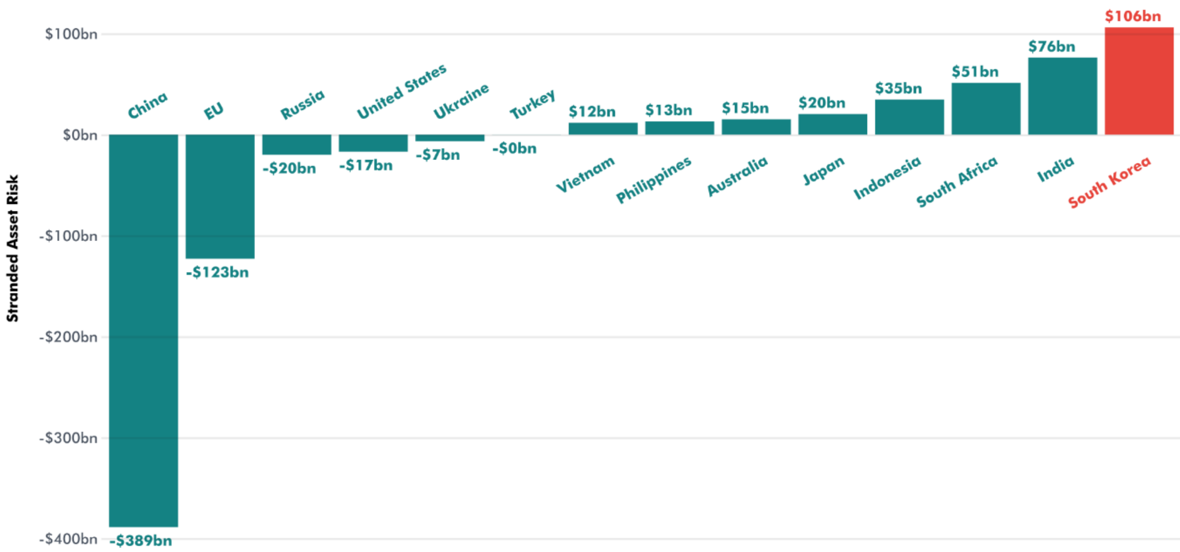
The BAU scenario assumes no changes to policy or market structures but does acknowledge existing and ratified air pollution and carbon pricing policies, as well as announced retirements in company reports. The below 2°C scenario incorporates a cost-optimised retirement schedule where unabated coal is phased-out in South Korea by 2040. A positive stranded asset risk value means investors and the South Korean government could lose money in the below 2°C scenario as coal capacity is cash-flow positive, based on existing market structures. In contrast, a negative stranded asset risk figure means investors and the South Korean government could avoid losses in the below 2°C scenario as coal capacity is cash-flow negative.

Our below 2°C scenario finds -$267 billion of stranded asset risk globally. In our BAU 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 option. Regarding South Korea, our below 2°C scenario finds $106 billion of stranded asset risk – the highest of the 34 countries modelled. The $106 billion represents the difference between the cash flow utilities (i.e. KEPCO's generation companies and private generators) may receive under the current South Korean power market and what they would receive in a below 2°C scenario, which sees capacity closed prematurely to meet the temperature goal in the Paris Agreement[14]. This is due to regulatory structures which effectively guarantee coal

[14] *This analysis includes "unit-level" in-market and out-of-market revenue data (e.g., unit-level scheduled energy payments, constrained-on energy payments, trading period capacity payments, constrained-off energy payments, renewable portfolio standard payments, emission trading payments,*

generators' high returns. These policy measures include: the merit order being based solely on fuel costs; large capacity market payments; and compensation utilities for carbon exposure and transmission restrictions. These measures provide coal generators with cash flows larger than that which they would receive in other markets throughout the world. For example, our analysis finds major coal power markets, such as China, the US and the EU, are cash-flow negative in our BAU scenario, and thus have negative stranded asset risk.

FIGURE 5 STRANDED ASSET RISK OF OPERATING COAL CAPACITY AND CAPACITY UNDER-CONSTRUCTION BY COUNTRY OR REGION



Source: Carbon Tracker analysis

5.2 At risk of losing the low carbon technology race by remaining committed to coal power

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.

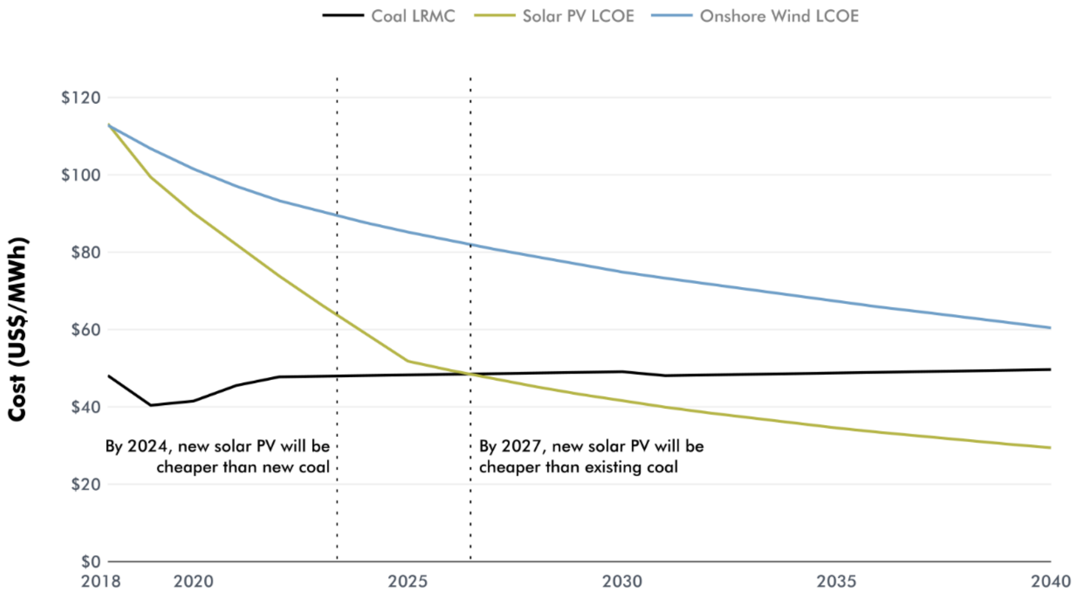
Regarding the first inflection point, by 2024 at the latest, new solar PV investments will beat new coal investments based on LCOE analysis[15]. The second inflection point is where coal will face an existential crisis. Independent of additional climate or air pollution policy, our analysis shows it will be cheaper for South Korea to build new solar PV than to operate existing coal plants by 2027. As renewable energy becomes cheaper, rates of deployment will increase. Making coal highly dispatchable to

local resources tax payments and the operation cost of preventative facilities) when projecting the cash flow of each unit under the business-as-usual scenario. The retirement schedule is cost-optimised, meaning units are retired based on their LRMC. See the full report for more information.

[15] *This finding is broadly consistent with government forecasts. For example, Chinho Park, managing director of the energy industry, Ministry of Trade, Industry and Energy said in a recent interview that he expects the industry to become subsidy free between 2022 and 2025. Bloomberg NEF (2018). South Korea Sees Solar Subsidy-Free as Early as 2022: BNEF Q&A. Unavailable without subscription.*

accommodate increased amounts of low-cost variable renewable energy increases O&M costs, exacerbating its economic disadvantage[16]. If policymakers in South Korea continue to support coal, they could come under increasing scrutiny from taxpayers and energy consumers.

FIGURE 6 LONG-RUN MARGINAL COST OF SOUTH KOREA'S COAL CAPACITY VS THE LEVELIZED-COST OF ONSHORE WIND AND SOLAR PV



Source: Bloomberg NEF (2018), Carbon Tracker analysis

Inflection point 3 is outside the scope of this analysis. The challenge for policymakers today 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. The IEA notes that it is possible to get to 15% solar and wind by simply upgrading some operational practices, such as better grid codes, better forecasting, better scheduling and so on, which are not capital intensive[17].

Moreover, South Korea risks losing the low carbon technology race to those nations who are opening up their power markets to competitive forces which accelerate the deflationary trends of renewable energy. For instance, according to Bloomberg NEF, South Korea currently has the second highest solar PV costs and the highest onshore wind costs (see Figure 7). This reality conflicts with South Korea's recent ambition to increase renewable energy generation to 20% by 2030. This ambition was further emphasised by the 8th Basic Plan for Electricity Supply and Demand in 2017.

FIGURE 7 LEVELIZED COST OF ONSHORE WIND AND SOLAR PV FOR SELECT COUNTRIES

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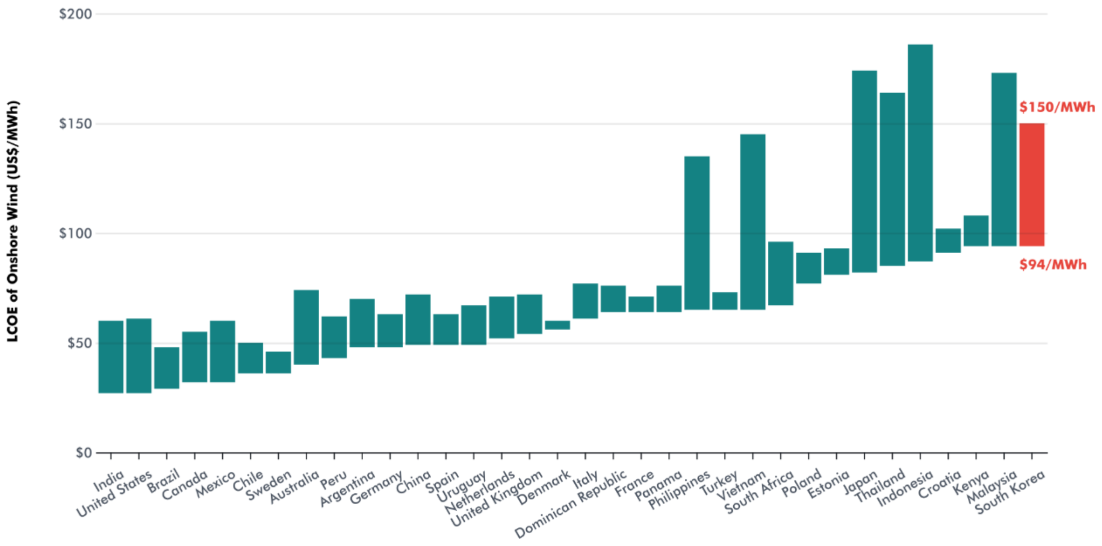
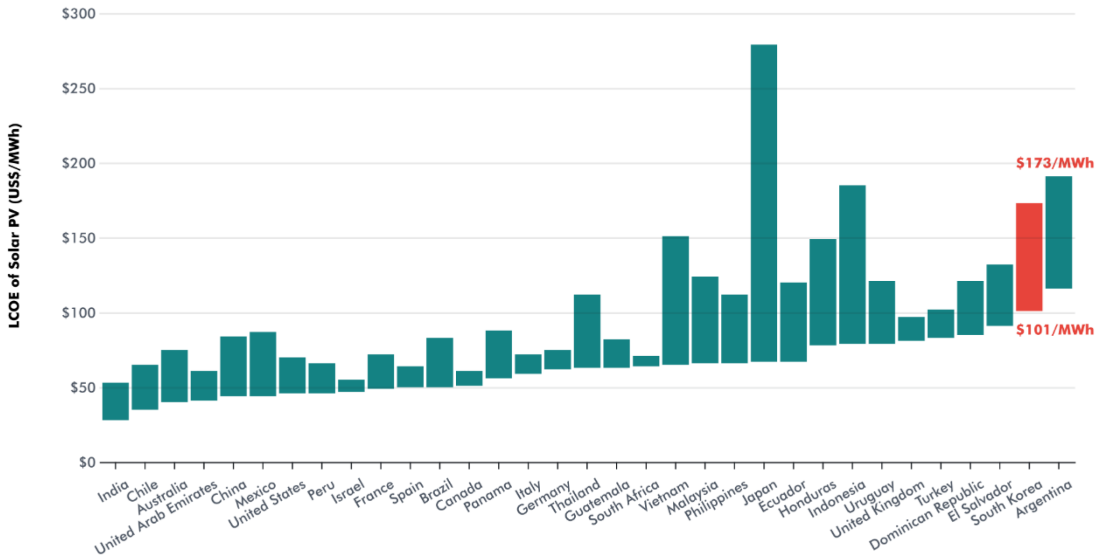
[16] *The IEA Clean Coal Centre estimated these costs. Hot, warm and cold starting a 500 MW coal unit could cost $94,000, $116,000 and $174,000, respectively. Load cycling a 500 MW coal unit down to 180 MW could cost $13,000. IEA Clean Coal Centre (2016). Levelling the intermittency of renewables with coal. Available:*
https://www.usea.org/sites/default/files/Leveling%20the%20intermittency%20of%20renewables%20with%20coal%20-%20ccc268-1.pdf

[17] *IEA (2017). Getting wind and sun onto the grid. Available:*
https://www.iea.org/newsroom/news/2017/march/getting-wind-and-sun-onto-the-grid.html





Source: Bloomberg NEF (2018)

5.3 Planned retrofits costing $3.6 bn will accelerate the competitiveness of renewables and could impact KEPCO's finances

The South Korean government plans to retrofit a number of coal units to improve performance and reduce air pollution. According to the government, South Korea will close seven units by 2022, and retrofit the remaining 39 units[18]. Our analysis of these retrofits, which is based on publicly-available data in company disclosures on the South Korean Financial Supervisory Service website or preliminary feasibility studies prepared by the South Korea Development Institute, shows that these investments will, on average, increase the LRMC by 18%, and thus will further increase the relative competitiveness of renewables. If these retrofits go ahead the LRMC could be higher than building new renewables in 2025 instead of 2028. While analysing the impact of these retrofits for the end power user is beyond the scope of this note, these investments are capital intensive

[18] *Prime Minister's Office et al. (2017). Fine Dust Management Comprehensive Plan. Available:* http://www.me.go.kr/home/file/readDownloadFile.do?fileId=152146&fileSeq=1

and should be scrutinised by policymakers before proceeding. Whereas the $106 billion stranded asset risk discussed above is based on the existing power market structure, this analysis is neutral of such market structures and focuses on the operating cost of each unit. In a power market like South Korea's – where consumer power prices are regulated and KEPCO is the only entity authorised to sell electricity – relying on least-cost competitive sources of generation may directly impact KEPCO's finances. For example, the analysis below shows the amount that KEPCO may lose if expensive retrofitting is not avoided.

TABLE 3 THE COST OF PLANNED COAL UNIT RETROFITS FOR PERFORMANCE IMPROVEMENTS AND ENVIRONMENTAL CONTROL TECHNOLOGIES

UNIT	PARENT COMPANY	CAPACITY (MW)	RETROFIT COST ($/MN)	LONG-RUN MARGINAL COST ($/MWH)		YEAR WHEN RENEWABLES ARE CHEAPER	
				Before	After	Before	After
Dangjin power station Unit 1	KEPCO	500	343	48.55	60.61	2027	2024
Dangjin power station Unit 2	KEPCO	500	343	48.27	59.62	2027	2024
Dangjin power station Unit 3	KEPCO	500	343	49.08	62.95	2027	2024
Dangjin power station Unit 4	KEPCO	500	343	47.88	59.13	2027	2024
Samchonpo power station Unit 5	KEPCO	500	92	45.57	49.64	2028	2026
Samchonpo power station Unit 6	KEPCO	500	92	45.03	48.84	2029	2027
Boryeong power station Unit 3	KEPCO	500	270	46.61	55.74	2028	2025
Boryeong power station Unit 4	KEPCO	500	289	46.22	55.03	2028	2025
Boryeong power station Unit 5	KEPCO	500	289	46.64	56.39	2028	2025
Boryeong power station Unit 6	KEPCO	500	289	46.06	54.92	2028	2025
Taean power station Unit 3	KEPCO	500	326	48.14	57.87	2027	2025
Taean power station Unit 4	KEPCO	500	326	48.46	58.94	2027	2024
Yeongheung power station Unit 1	KEPCO	800	145	47.24	51.4	2027	2026
Yeongheung power station Unit 2	KEPCO	800	145	46.73	50.52	2028	2026
Total or average	**n/a**	**7,600**	**3,635**	**47.18**	**55.83**	**2028**	**2025**

Source: Carbon Tracker analysis. Notes: LRMC estimates are based on a 10-year payback period.

6 Policy recommendations

If South Korean policymakers remain committed to coal power the nation will face a dilemma: continue to subsidise coal generators either directly (through higher tariffs) or indirectly (through out-of-market payments) to maintain their financial viability; or keep tariffs artificially low to shelter consumers from higher costs. Both outcomes could prove financially and economically unsustainable, as subsidising coal generation will either anger taxpayers or energy consumers, while artificially low tariffs for consumers will impact fiscal resources. In the context of this analysis, Carbon Tracker offers three recommendations for policymakers.

1. Stop investing in new coal capacity and scrutinise retrofitting investments.

   New investments in coal capacity – both new build and retrofitting – will unlikely be a least-cost solution over the capital recovery period. This period is typically 15-20 years for new coal capacity and 5-10 years for retrofits relating to performance enhancements or control technolgy installations. Our analysis highlights how coal power is losing its economic footing, independent of additional climate change and air pollution policies. By 2024 at the latest, new solar PV investments will beat new coal investments based on LCOE analysis and by 2027 it will be cheaper on average to build new solar PV than continue to run coal.

2. Develop a cost-optimised retirement schedule for the operating fleet.

   South Korean policymakers should develop retirement schedules based on the LRMC of individual units. This analysis will allow policymakers to close the higher cost units first and lower cost units last, which should help ensure the end consumer receives the lowest cost electricity possible. Alternative retirement schedules, particularly those based on emission intensity targets, may not result in a least-cost outcome and thus could impact economic competitiveness.

3. Subject the retirement schedule to resource planning analysis to understand system value of units.

   Once policymakers have developed a cost-optimised retirement schedule at asset level, they should then undertake a systems planning analysis to take into consideration the system value of individual assets. Understanding system value is outside the scope of this analysis. Carbon Tracker intends to conduct this analysis with local partners and make this research publicly-available.

7 Conclusions

In this note we presented the findings of our coal power economics analysis for South Korea to understand the potential for asset stranding and relative competitiveness of renewable energy. Coal has long been considered the least-cost option for power in South Korea. However, that is quickly changing as a confluence of factors are disrupting coal's pre-eminence. As competition from ultra-low-cost renewable energy intensifies, and air pollution regulations and carbon pricing increase running costs, coal generators will increasingly be viewed as high-cost and thus should fall out of favour with policymakers. If the country remains committed to coal over the long-term, it 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). South Korean policymakers 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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9 Appendix – the cost of coal and fuel transport model

Calculating the delivery cost for coal at the unit level varies widely and depends on a number of criteria, including local infrastructure, cost of labour, cost of commodities, distance of travel and capacity of the mode of transport. The cost of coal and its transportation can have a large impact on a coal-fired power plant's cost profile. Coal can be transported in a host of different ways depending on imports, location and capacity of mines, available modes of transport, transport infrastructure throughout the supply chain and the contractual and pricing structures for delivery.

Fuel costs include the expenses incurred in buying, transporting and preparing the coal. For the cost of coal for producers we use the FOB[19] benchmark price indices 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. For the transportation of coal, a distance-optimised route algorithm has been developed, which calculates the distance between a unit and the nearest suitable coal mine (or port if imported), considering coal type, mode of transport and related costs and other charges, and available port, mine and import capacities.

For regions that have abundant thermal coal resources which can satisfy demand domestically, plants generally pay less for the transportation of coal compared to those regions who are import dependent. While there are countries that have enough to satisfy domestic thermal demand and those that rely entirely on imports, for some regions this represents more of a mixed picture, depending on the coal quality, availability of mining and transport infrastructure and locations of key transport hubs.

International coal balances and supply routes are incorporated to reflect the volume of trade between countries and regions for different thermal coal products. These nodes are incorporated into the distance-optimised algorithm for each region. Inputs to the cost-optimised algorithm are as follows:

- International coal balances: the model incorporates the balances for countries of thermal coal by coal grade according to national statistics or reputable international energy data sources. Assessments of coal trade routes between countries and/or regions are made in addition to corroborate findings. This can be broken down into three types:
  - Import only: coal product export price indices from Wood Mackenzie from main export regions are used;
  - Consumption of domestic coal: coal product domestic price indices from Wood Mackenzie are used;
  - Consumes domestic and imported coal: the split between imported/domestic (per coal product) is incorporated and weighted export and domestic price by product is used.

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[19] *Free on-board (FOB) price. FOB is usually indicated at the port of origin. It means that the buyer will pay for transportation to the destination port and assume the risks in transit. For more information, refer to* https://webstore.iea.org/medium-term-coal-market-report-2013

- Infrastructure of coal logistics: the location of export and import terminals for various regions are incorporated for seaborne transportation, if applicable. Cross-boundary rail transportation is also included, where applicable.
- Transportation costs: cost assumptions are used on a tonne-kilometre (tkm) basis for seaborne freight, rail and truck freight. Routes are optimised using either intermodal or multimodal transportation routes. For example, in Russia, the marginal cost of the transportation of coal by rail can vary from less than $0.01/tkm to $0.07/tkm, depending on distance alone. We take a universal rail and road freight price assumption of $0.02/tkm and $0.002/tkm for ocean freight.
- Distance - Distances are calculated between the point of supply (mine or port) and point of delivery (plant), considering export and import terminals, if relevant.

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