TransitionZero

Turning the Supertanker

Powering China's coal to clean transition with actionable analytics

April 2021

TransitionZero

TransitionZero combines financial and industry expertise with technology to help power a clear and timely transition to zero carbon in the power and heavy industry sectors. Using satellite imagery, machine learning and financial modelling, we gather real-time insights into the economic vulnerability of fossil fuel assets. We give key decision makers the solutions they need to reach their zero carbon targets.

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The experts above that contributed to this report are not responsible for any opinions or judgments it contains. All errors and omissions are solely the responsibility of TransitionZero.

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Foreword from Former U.S. Vice President Al Gore

The September 2020 announcement by President Xi Jinping of China's goals to reach peak carbon emissions before 2030 and achieve net-zero carbon emissions by 2060 was a watershed moment for our collective global efforts to solve the climate crisis. Coupled with even more ambitious commitments from the European Union, Japan, South Korea, and the United States, it signals that we are now finally beginning to take the steps needed to reach the goals of the Paris Agreement.

Moreover, China has often resisted setting goals until it feels certain it can meet them. So perhaps this goal will become more ambitious still as the nation develops momentum on its new trajectory. China is not only the world's largest emitter, but also one of the countries most threatened by the climate crisis. According to Munich Re, the most expensive climate-driven extreme weather event in the world in 2020 was the extraordinary summer flooding in China which resulted in $17 billion in damages. Moreover, a recent study from public health researchers found that fossil fuel pollution causes 2.4 million annual premature deaths in China.

In order to meet their stated goals, China will need to rapidly accelerate its climate action, including substantially reducing coal capacity this decade. China is already a world leader in the production, deployment, and financing of clean energy. Last year, China connected 72 gigawatts of wind and 48 gigawatts of solar to the grid, an increase that equates to more than three large wind turbines and five football fields of solar panels every hour. Unfortunately, last year China also added the equivalent of more than one large coal plant each week. Overall, China currently operates more than half of the world's total coal capacity.

The ground-breaking analysis in this new report by TransitionZero shows that not only can China meet their climate goals, the country and its leaders can accelerate them rapidly. The economic opportunity presented by a transition from coal to clean energy shows that climate action and economic growth go hand in hand. In China, because the costs of solar and wind are so much lower than coal, transitioning the vast majority of Chinese coal capacity to clean energy would save an astonishing $1.6 trillion. Ambitious Chinese action to shift from coal to clean energy can demonstrate the opportunity for a prosperous and sustainable future to the world.

The analysis in this report is driven by a new set of technological tools developed as part of the Climate TRACE (Tracking Real-time Atmospheric Carbon Emissions) coalition, which I have helped organize along with TransitionZero and a group of non-profit organizations and technology companies.

Our goal is to combine satellite data from existing constellations, artificial intelligence, and an array of other resources to produce an independent accounting of all significant sources of human-caused greenhouse gas emissions on the planet. We will release a new data tool for global emissions monitoring this summer, well ahead of the upcoming United Nations negotiations on climate change (COP26) in November 2021.

The purpose of Climate TRACE is to enable more ambitious climate action through better emissions data, and this report provides a powerful first example of how these data sets can become actionable information for decisionmakers. As China works to launch the world's largest carbon market, there is a need for new tools that can be used to strengthen this market to drive greater emissions reductions. New technologies like Climate TRACE represent a major breakthrough for crafting and implementing policies like this – and there are a multitude of other use cases that this new tool will unlock to help the world meet its goal of net-zero emissions as soon as possible.

I would like to thank every one of the many hard-working people who are part of the Climate TRACE coalition, in particular the team at TransitionZero, which is led by Matt Gray and Sriya Sundaresan. Their work plays a critical role in hastening our transition to a net-zero emissions future.

Al Gore

Al Gore was the 45th Vice President of the United States, is Chairman of the Climate Reality Project and is co-Founder and Chairman of Generation Investment Management, whose partners have donated funding for Climate TRACE.

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01 Key findings

About this report

In this report, we use our industrial production monitoring technology to:

- Provide coal plant emissions estimates and fundamental analysis of China's recently launched Emissions Trading System (ETS).
- Predict coal plant closures through a Risk Index System (RIS) to support the government's efforts to implement the net zero target.
- Recommend the closure, conversion or reserve capacity of China's coal plants in a manner consistent with the UN's Sustainable Development Goals (SDGs) via a net zero aligned coal phase out mechanism.

Context

We believe China will meet the net zero target ahead of time due to the country's track record of solving problems. The target will likely prove essential to China's economic growth prospects. It could buy policymakers time as the nation grapples with the socioeconomic implications of moving economic growth towards resource efficiency and domestic consumption.

Mind the (net zero) implementation gap

To date, the short term investment and policy signs regarding coal power have been inconsistent with China's net zero pledge. For example, the influential China Electricity Council (CEC) is lobbying to increase coal capacity to 1,300 GW by 2030, despite an average capacity factor of 49% in 2020.

A Chinese equivalent of our technology could reduce ETS enforcement costs

Our "offsite" continuous emissions monitoring system (CEMS), which is based on machine learning (ML) and satellite imagery, currently achieves a mean absolute error (MAE) of 14% at the plant level and 11% at the provincial level. To cost effectively regulate ETS companies, data checks could be based on an anomaly detection system. The Ministry of Ecology and Environment (MEE) is already using drones equipped with air pollution sensors. The use of satellite imagery and ML could be another powerful tool for enforcement of the ETS.

Without reform, the fair value of China's carbon allowances is zero

The ETS in its current form will likely have no impact reducing power generation emissions. According to our analysis, China's ETS is oversupplied by 1.56 billion tons from 2019 to 2020 – the equivalent of a year's worth of EU ETS emissions.

Coal to clean switch could save China $1.6 trillion or cost negative $20/tCO2

Our analysis shows that independent of water, air and climate concerns, the vast majority of China's coal fleet could be shut and replaced at a saving. Replacing China's coal fleet with clean energy alternatives could save $1.6 trillion or incur a net negative abatement cost of $20/tCO2. This analysis shows net zero alignment of China's power system is both technically feasible and economically beneficial.

Net zero alignment requires the carbon intensity of power generation to halve by 2030 from 672 g/CO2 today to 356 g/CO2

According to our net zero aligned phase out mechanism results, China would need to close, convert, or put into reserve capacity 364 GW of coal by 2030 to be consistent with their net zero pledge. This results in the carbon intensity of generation halving by 2030 from 672 gCO2/kWh in 2019 to 356 gCO2/kWh.

> **We believe China will meet the net zero target ahead of time due to the country's track record of solving problems. The target will likely prove essential to China's economic growth prospects.**

$1.6 trillion

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356 gCO2/kWh by 2030

Net zero alignment requires the carbon intensity of power generation to halve by 2030 from 672 gCO2/kWh today to 356 gCO2/kWh

1.56bn tons

China's ETS is oversupplied by 1.56 billion tons from 2019 to 2020 – the equivalent of a year's worth of EU ETS emissions.

02 Executive summary

Our research uses technology to empower investors, governments and civil society to align finance with a zero carbon economy. In this report, we use our technology to:

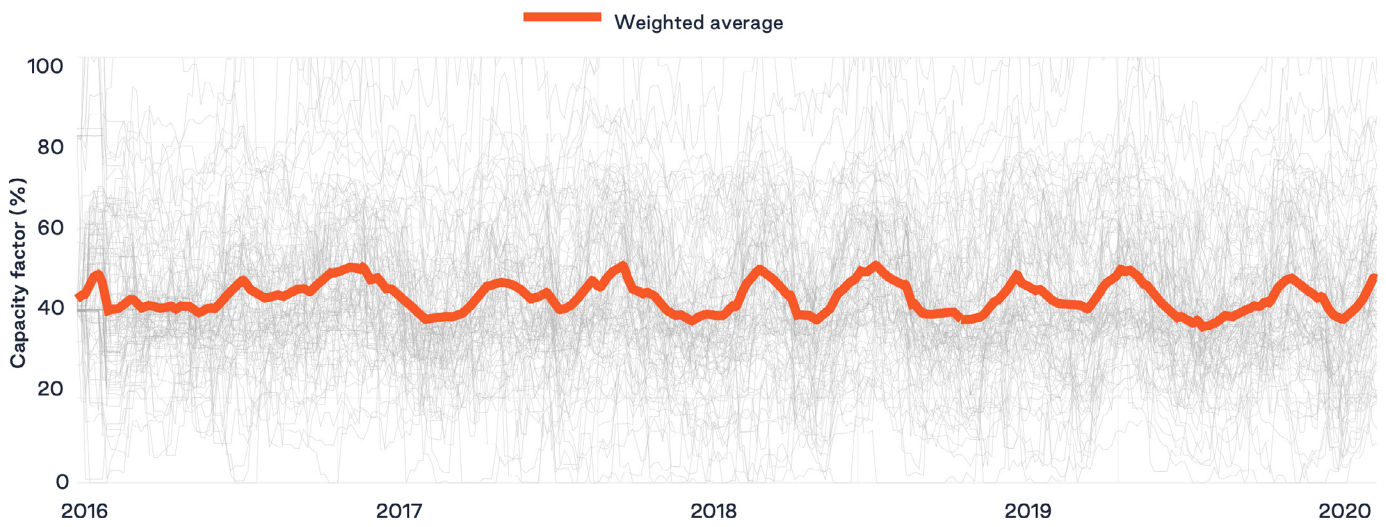
1. Provide coal plant emissions estimates and fundamental analysis of China's recently launched national ETS.
2. Predict coal plant closures through a RIS to support the government's efforts to bridge the gap between their net zero target and implementation on the ground.
3. Recommend the closure, conversion or reserve capacity of coal plants in a manner consistent with the UN's SDGs via a net zero aligned coal phase out mechanism.[1]

Our technology and its use cases

For this report, we use satellite imagery and ML to estimate production from coal power plants in China. We model 1 GW or bigger plants cooled by natural draft technologies (NDT). For these plants, our models currently achieve an MAE of 14% at the plant level based on data from the EU, the US and Australia and 11% at the provincial level based on disaggregated data from the Chinese government. We continue to improve model accuracy and coverage. For instance, training data suggests that including PlanetScope imagery will improve accuracy by several percentage points. This September, we plan to extend our modelling to cover 90% of the generation from coal, gas, and oil power plants globally. These will initially be published as annual country level estimates via Climate TRACE.[2]

Plant or asset level production estimates have the potential to spur a Cambrian explosion of use cases. For example, our production estimates — coupled with other analysis — give us the ability to estimate fuel consumption, carbon emissions, emissions intensity, water use, air pollution, operating costs, net profitability and abatement costs at the asset level. In the context of this report, these estimates inform our ETS analysis, RIS and net zero aligned coal plant phase out mechanism. We are releasing beta versions of these tools for testing before general use.

Figure 1. Monthly estimates of coal plant capacity factors in China



Source: TransitionZero analysis

1 Reserve capacity is available capacity for unexpected outages. A coal plant can be converted in several ways: zero carbon technologies, carbon capture, utilisation and storage (CCUS), gas and biomass.

2 TransitionZero is a founding member of Climate TRACE. The Climate TRACE coalition is building a tool that will use satellite image processing, ML, and other remote sensing technologies to monitor worldwide GHG emissions.

13 billion to zero

China emits 13.4 billion tons of greenhouse gases (GHGs) per year and dominates the consumption of fossil fuels globally.[3] The announcement by President Xi Jinping to the UN General Assembly last September that China would aim to be carbon neutral before 2060 represents one of the biggest changes to policy ever made by any country. Despite its ambition, we are optimistic China will meet this pledge ahead of time. Bets against China tend to ignore how good the country has been at solving problems. China's government has achieved close to four decades of economic growth, averaging around 10% since 1980. Only the East Asian Tigers come close to matching that. The rest of the developing world has not come close. Amongst this growth, China's policymakers have faced down the Asian financial crisis and the 2009 great financial crisis, recapitalised and listed major banks, halted two equity market routs, and stemmed capital outflows that threatened to trigger an emerging market crisis. If Chinese policymakers appear confident in their abilities, there is a reason for that.

Mind the (net zero) implementation gap

Since the reforms of the late 1970s, China's governance has been characterised by power dynamics between the central government, state owned enterprises (SOEs) and local governments. How China bridges the gap between the government's policies and their implementation on the ground will not only determine its success in delivering on its GHG neutrality target, but also the world's ability to meet the temperature goal in the Paris Agreement. To meet its net zero target, China will need to peak its GHG emissions well before 2030 to avoid a disorderly transition. The brunt of these emission reductions will need to come from electricity generation and the rationalisation of coal power. Thus far, local government and SOE decision makers appear to be defying the central government's net zero pledge. Recent examples include:

- Inner Mongolia recently approved power and industrial facilities with an estimated energy demand equivalent to 80 million tonnes of coal a year – the equivalent of Germany's total coal demand.[4]
- CEC are lobbying to increase coal capacity to 1,300 GW by 2030[5] despite an average capacity factor of 49% in 2020.[6]
- Recent black outs and brown outs caused by grid inflexibility are adding weight to CEC's request for coal additions.[7]

One reason for delay is consensus-based policymaking, which is reluctant to overturn entrenched industry interests. The central government appears to be signalling control may soon be tightened. For example, a recent audit of the National Energy Agency (NEA) by the Central Environmental Inspection Group (CEIG) provided a scathing assessment of the NEA and its failure to control coal capacity. The CEIG is seen as an important institution for the government to bridge the gap between the country's net zero pledge and implementation by local governments.

14th Five Year Plan risks stranded coal assets

In March, the Chinese government released a high level summary of the 14th Five Year Plan (FYP), which stated energy consumption and carbon emissions per unit of GDP will decline by 13.5% and 18%, respectively, by 2025.[8] The 13th FYP (2016-2020) highlighted China's ability to add renewable energy at breathtaking speed. For example, the 13th FYP targeted 210 GW of wind and 110 GW of solar by 2020. Based on preliminary data, China installed 282 GW of wind and 253 GW of solar over this period.[9] Last year alone, China connected 72 GW of wind and 48 GW of solar to the grid, which equates to more than 3 large wind turbines and 5 football fields of solar panels every hour.[10]

However, the 14th FYP summary contained language on "promoting the clean use of coal", which suggests a continuing trend of overcapacity from targeting low carbon development while also investing heavily in coal. According to Global Energy Monitor (GEM), in 2020, 31 GW of net coal capacity additions were operationalised, 37 GW was granted construction approval and 74 GW was given planning approval. This capacity has an overnight investment cost of $112 billion and will be entering an already oversupplied market.[11] The average capacity factor of China's coal fleet has declined from 57% in 2010 to 49% in 2020.[12] As mentioned above, stakeholder expectations for coal capacity in 2030 have been 1,300 GW or higher.[13] If this capacity is built and operated, the average capacity factor of the coal fleet could decline to 32% by 2030, assuming load growth is 4% per year.[14] Indeed, as detailed in Table 1, our analysis shows the average capacity factor of the fleet will decline significantly by 2030 if load growth is less than 6% per year.

3 Climate Action Tracker (2021).
4 Climate Home (2021).
5 China Dialogue (2020).
6 TransitionZero estimate.
7 South China Morning Post (2020).
8 NPC (2021).
9 China Energy Portal (2021).
10 China Energy Portal (2021) and TransitionZero analysis based on NREL (2020).
11 Based on an IEA (2020) estimate of $800/kW.
12 China Dialogue (2011) for 2010 and TransitionZero estimate for 2020.
13 China Dialogue (2020).
14 See the notes in Table 1 for more information.

Table 1. Coal capacity (GW) in 2030 based on existing plants as of 2020 under different coal plant capacity factors and power generation growth rates

Capacity factor (%)	Power demand (CAGR 2021–2030)			
	3%	4%	5%	6%
45%	−555	−326	−79	189
46%	−568	−344	−102	160
47%	−580	−360	−123	132
48%	−591	−377	−144	106
49%	−603	−392	−165	81
50%	−613	−407	−184	56
51%	−623	−421	−203	33
52%	−633	−435	−220	11
53%	−642	−448	−238	−11
54%	−652	−461	−254	−32
55%	−660	−473	−270	−52

Source: TransitionZero analysis
Notes: Assumes 446 GW, 7 GW, 202 GW, 120 GW, 94 GW, 900 GW and 900 GW of hydro, oil, gas, nuclear, wind and solar PV, respectively. Also assumes an average capacity factor of 35% for wind and 15% for solar PV.

Our analysis of projects in Henan, Inner Mongolia, Jiangsu and Shandong highlights how coal power investments are financially unviable. New coal projects in all of the provinces modelled deliver negative net present values (NPVs) from both a project and equity perspective. Moreover, none of the projects are able to service their debt requirements, yielding insufficient internal rate of returns (IRRs). The model results and a power price break even analysis are summarised in Table 2. This situation will likely intensify as deregulation reduces power prices below benchmark tariffs. For instance, market trading resulted in power price declines of 3% from 2019 to 2020.[15]

Table 2. Model results and a power price break even analysis based on a 800 MW coal project

Province	NPV (mm $)	IRR (%)	DSCR	Prevailing power price ($/MWh)	Break even power price ($/MWh)
Henan	−255	1.3%	0.47	58	75
Inner Mongolia	−591	−8.5%	0	42	68
Jiangsu	−66	6.2%	0.87	59	64
Shandong	−84	5.7%	0.83	61	67

Source: TransitionZero analysis
Notes: Based on the following assumptions: 800 MW unit, provincial average fuel price, no carbon price, FOM of ¥62/kW, VOM of ¥3.7/MWh (Zhang and Paltsev, 2016), cost of debt of 7% (2.25% higher than the prime loan rate), loan term of 15 years and discount rate of 8.6%. The debt to equity ratio is assumed to be 80/20. The capacity factors are based on market conditions and are derived from our technology. The prevailing power price is adjusted from the benchmark tariff to account for market trading. The Debt Service Coverage Ratio (DSCR) is a measurement of a project's available cash flow to pay current debt obligations. Inner Mongolia has two markets for domestic and East Coast demand. This analysis is based on Inner Mongolia's domestic market. See the report for more information.

15 Based on unpublished analysis obtained from Northeast Electric Power University.

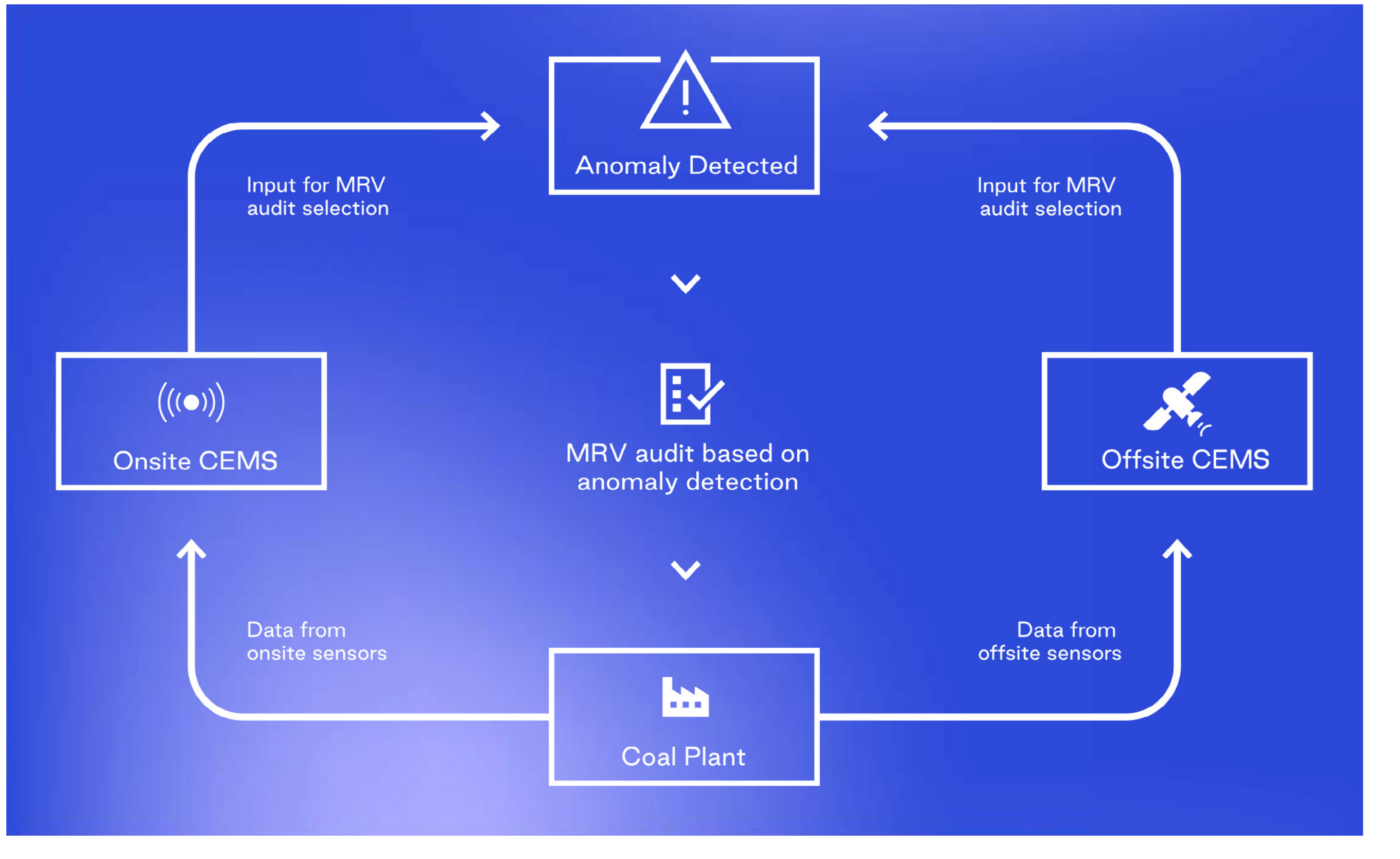
Near real time monitoring of ETS emissions

After years of pilots and delays, the MEE launched the trial phase of China's national ETS this January. According to the MEE, the first compliance cycle will run from January 1 to December 31, 2021 and will cover the emissions of 2,225 entities from 2019 and 2020. The ETS will initially cover fossil fuel power generation, which last year accounted for approximately 30% of China's total carbon emissions. Under the ETS, power generators must buy allowances if their plant exceeds carbon intensity benchmarks, giving them an incentive to improve efficiency. We used our technology to monitor carbon emissions and provide fundamental (supply and demand) analysis at the plant level for market regulators and participants.

Environmental governance 2.0: satellite imagery and machine learning can help reduce ETS enforcement costs

China currently uses Monitoring, Reporting and Verification (MRV) to regulate companies covered under the ETS. The MRV process requires regulated companies to submit an emissions report, which is verified by local governments every year, and determines the number of allowances to surrender to comply with the ETS. According to interviews with market experts, a number of local governments have argued they do not have adequate resources to undertake the MRV process comprehensively. As illustrated in Figure 2, to reduce ETS enforcement costs, the MRV process could be based on an anomaly detection system that uses CEMS data. CEMS are sensors installed on assets, automatically providing near real time estimates of emissions. We recommend coupling CEMS with "offsite" CEMS. The MEE already uses drones to monitor air pollution. The use of satellite imagery and ML could be another powerful tool to reduce ETS enforcement costs and discourage data falsification.

Figure 2. Illustration of an anomaly detection system to determine MRV audits for companies regulated by China's ETS



Source: TransitionZero analysis

Mistakes made, lessons unlearned: Without reform, the fair value of carbon is zero

In trading systems with an emissions cap, the fair value of carbon is a function of the highest cost of abatement in the future, discounted back in real terms. China's ETS is a carbon intensity system, with benchmarks, rather than an absolute cap. We estimate the ETS could have been oversupplied by 1.56 billion tons over the trial period (2019 to 2020). Put another way, cumulative oversupply over its first two years of operation is on track to be the equivalent of a year's worth of EU ETS emissions. Since supply is greater than demand and there is no indication that the benchmarks will be tightened, the fair value of allowances is zero. Without reform, we expect the price to crash, or remain close to zero, like Phase 1 of the EU's ETS. It is unclear to what extent the government plans to rely on market mechanisms to drive abatement in the future. If history is any guide, abatement will continue to come from direct interventions, which tend to reflect China's wider development priorities.

Risk index system for predicting coal plant vulnerability

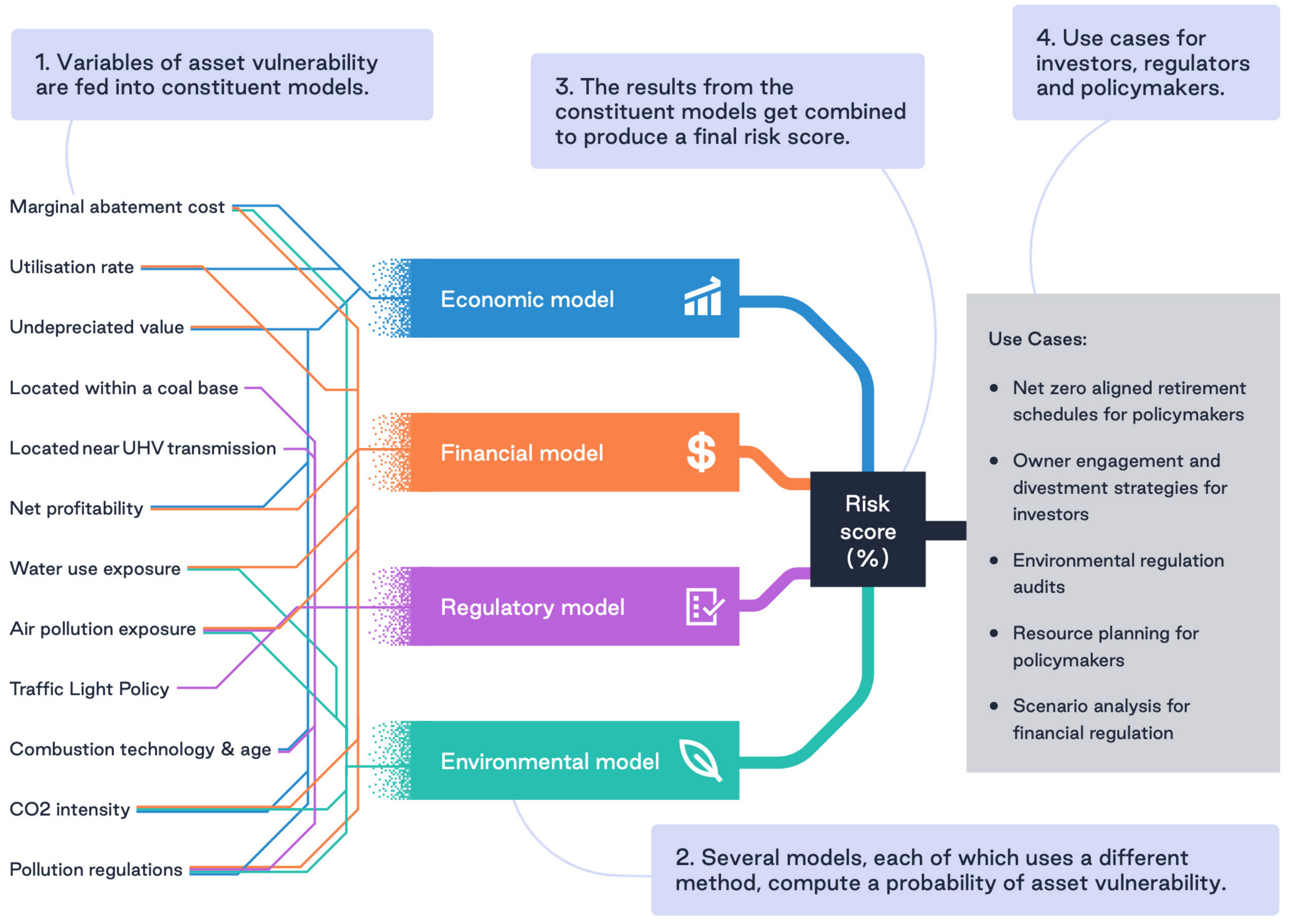
Our RIS is a tool for investors, policymakers, and regulators to prepare for the transition to a zero carbon economy. The core feature of our RIS is its ability to predict the vulnerability of fossil fuel assets based on metrics that capture SDG 3 (air pollution), SDG 6 (water use), SDG 8 (energy affordability) and SDG 13 (climate action). Predicting asset vulnerability requires complex analytical machinery. RIS is guided by our use of satellite imagery and ML to improve transparency in locations where data is unavailable, unreliable, or untimely. RIS is an ensemble model based on the following asset level metrics: abatement cost, net profitability, undepreciated value, carbon intensity, water use, air pollution and regulatory considerations. These metrics are fed into constituent models which give an overall (equal weight) risk score from 0 to 1, with 0 being low risk and 1 being high risk of closure due to the energy transition. Our RIS can be used for resource planning for policymakers, investor engagement and scenario analysis for financial regulation.

Table 3. Fundamental analysis of China's ETS from 2019 to 2020 (billion tCO2)

	2019	2020
Supply	5.19	5.32
Demand	4.45	4.49
Net balance	0.74	0.83
Cumulative balance	0.74	1.56

Source: TransitionZero analysis
Notes: See the report and appendix for more information on the methodology.

Figure 3. Inside our RIS tool from variables used to use cases for decision makers



Source: TransitionZero analysis
Notes: See the report for more information on the methodology.

The prize: Coal to clean switch could save China $1.6 trillion or cost negative $20/tCO2

In the context of this report, we use RIS to allow policymakers and investors to prepare for plant closures, as the government bridges the gap between its net zero ambition and implementation on the ground. RIS shows that independent of climate, water and air issues, the vast majority of China's coal fleet could be shut and replaced at a saving. We come to this conclusion by comparing the cost to replace the power generated from the coal plants with the lowest cost zero carbon alternative. The calculation is based on the value adjusted levelised cost of electricity (VALCOE) of either wind or solar, minus the long run marginal cost (LRMC) of coal over a 20 year period. The lowest cost clean energy alternatives in China are currently wind and solar, which are variable energy generation sources. To compensate for the variability of wind and solar we adjust the levelised cost based on the value it adds to the grid. VALCOE is a concept developed by the International Energy Agency (IEA) and aims to incorporate grid flexibility and capacity. Due to the intrinsically deflationary nature of wind and solar, we found replacing the coal fleet with clean energy could save China $1.6 trillion or cost negative $20/tCO2.

Table 4. Selected RIS variables, overall RIS score and high risk capacity by province

Province	Operating capacity (GW)	Abatement cost ($/tCO2)	Replacement saving (bn$)	Undepreciated value (bn$)	Net profit ($/MWh)	RIS score (0–1)	High risk capacity (GW)
Anhui	50.37	−15.85	62.17	17.44	−1.21	0.69	4.49
Chongqing	13.49	−21.30	17.63	5.11	−2.09	0.60	–
Fujian	26.87	−14.00	34.23	8.80	13.20	0.32	–
Gansu	18.10	−23.08	31.70	6.46	−12.83	0.63	1.20
Guangdong	61.88	−16.17	91.73	21.13	10.29	0.49	–
Guangxi	19.24	−15.48	24.36	7.10	12.66	0.37	–
Guizhou	32.57	−17.44	38.45	12.58	−6.74	0.65	0.60
Hainan	3.34	−14.81	4.74	1.18	11.55	0.39	–
Hebei	48.34	−24.63	105.98	17.07	−2.15	0.57	0.90
Heilongjiang	18.75	−24.97	41.07	5.80	−6.06	0.70	1.72
Henan	65.04	−17.33	64.93	23.23	−0.51	0.66	0.64
Hubei	27.59	−17.48	32.85	9.50	5.36	0.53	–
Hunan	18.89	−6.16	8.69	5.89	27.75	0.47	–
Inner Mongolia	86.28	−31.05	237.66	32.24	−23.23	0.63	2.16
Jiangsu	76.60	−19.45	125.62	24.68	0.91	0.70	4.08
Jiangxi	20.12	−18.16	33.51	7.10	7.52	0.51	–
Jilin	16.85	−26.77	35.89	5.73	−6.95	0.65	0.15
Liaoning	31.35	−13.61	32.02	10.18	7.47	0.41	–
Ningxia	28.77	−13.67	30.26	11.21	−6.22	0.43	–
Qinghai	3.16	−9.00	1.16	1.24	−1.35	0.35	–
Shaanxi	41.78	−23.51	76.51	16.21	−8.50	0.53	–
Shandong	101.02	−17.28	144.38	35.58	1.03	0.61	3.99
Shanghai	14.91	−15.59	19.00	3.23	2.88	0.69	0.80
Shanxi	61.27	−25.15	121.27	22.13	−10.72	0.53	0.81
Sichuan	11.16	−18.49	15.18	3.56	−5.36	0.68	1.96
Tianjin	11.83	−6.3	6.56	4.09	6.96	0.53	–
Xinjiang	59.79	−24.46	112.35	27.07	−16.38	0.51	0.22
Yunnan	11.39	−26.28	19.03	3.79	−15.69	0.78	2.34
Zhejiang	42.17	−14.72	61.20	12.92	8.00	0.56	–
Total	1,023	−19.80	1,630.13	362.25	−0.36	0.56	26.06

Source: TransitionZero analysis
Notes: Where applicable, variables are capacity weighted averages. The overall RIS score is from 0 to 1, with 0 being low risk and 1 being high risk of closure. High risk capacity has an RIS score of 0.85 or higher. This analysis assumes no carbon price due to structural oversupply. See the report and appendices for more information on the methodology.

Net zero coal plant phase out mechanism

We use RIS to rank and rationalise coal capacity to align with China's net zero pledge. Our net zero coal phase out mechanism involves three steps:

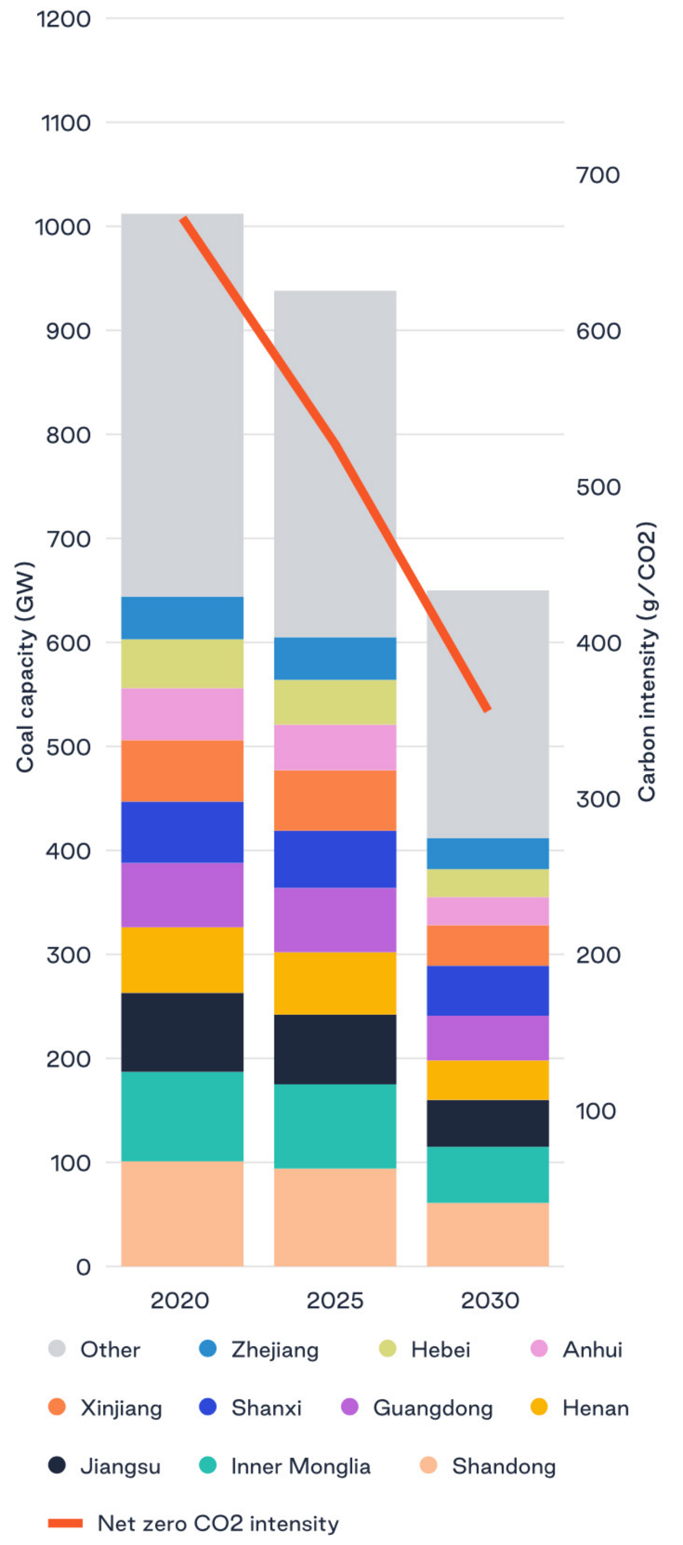
1. Identify a Paris aligned pathway. We use the IEA's Sustainable Development Scenario (SDS) as a demand constraint to align China's unabated coal fired capacity with the temperature goal in the Paris Agreement.

2. Rank assets based on RIS. The RIS score provides an overall risk score from 0 to 1, with 0 being low risk and 1 being high risk. To account for grid stability, we rank units by China's seven power grids.

3. Progressively close unabated capacity. Every year the units with the highest RIS score are progressively phased out to stay within the amount of coal generation in the IEA's SDS.

As detailed above, the debate amongst key stakeholders is currently centred around adding more coal capacity, not less. According to the results of our phase out mechanism, China would need to close, convert or put into reserve capacity 364 GW of unabated coal capacity by 2030 to be consistent with its net zero pledge. This results in the carbon intensity of power generation halving by 2030, from 672 gCO2/kWh in 2019 to 356 gCO2/kWh.[16] As of June 2020, there was 1,023 GW of coal capacity in operation in China.[17] According to the IEA's SDS, most unabated coal generation is either closed, converted or put into reserve capacity by 2040. This equates to between 2 and 3 coal units every week until 2040. Based on this analysis, we believe the closure of unabated coal capacity in China will not be linear across provinces due to water stress, air pollution and regional development priorities.

Figure 4. Unabated coal capacity under our coal phase out mechanism from 2020 to 2030



Source: TransitionZero analysis
Notes: See the report for more information on the methodology.

16 Based on the IEA's Sustainable Development Scenario. IEA (2020).

17 Based on GEM's Global Coal Plant Tracker, which excludes small units <30 MW. GEM (2020).

Policy recommendations

We offer the following high level recommendations to help stakeholders navigate risks and opportunities associated with China's power sector transition.

1 Cancel all new coal immediately and issue guidance on a net zero aligned phase out

Independent of climate policy, it makes sense for China to act on its coal overcapacity crisis. The changing power generation mix, the likely slowdown in load growth and existing overcapacity has an obvious policy implication: cancel all new coal immediately and indefinitely. A wider conversation with stakeholders is urgently required about how to gradually close, convert or put into reserve unabated coal capacity in a manner consistent with the net zero goal. Based on the IEA and Tsinghua University projections, unabated coal power is closed, converted or put into reserve capacity somewhere between 2040 and 2050.[18] We recommend that China phases out coal in a manner consistent with wider development objectives, such as those outlined in the UN's SDG framework.

2 Use satellite imagery and machine learning to help reduce ETS enforcement costs

In December 2020, China's MEE released a consultation document on GHG emissions accounting and report guidelines.[19] This document forms the basis of MRV for power generation facilities regulated by the ETS. Several provinces, including Hebei, are also piloting CEMS of carbon emissions from power plants.[20] As detailed above, we recommend that in the absence of additional resourcing for local governments, the MEE should explore introducing a system that uses a combination of onsite CEMS, offsite CEMS and selective MRV audits based on the likelihood of data misreporting.

3 Reform the ETS to create scarcity

If the government intends to rely on the ETS to drive abatement in the power sector, it needs to embrace the implications of deregulation. In non discriminatory deregulated markets, such as Western Europe, coal power struggles to compete as wind and solar result in lower power prices and often close coal ahead of schedule. Therefore, if China fully deregulates its power sector, coal generation assets will likely become unusable well before the end of their useful life. If the government intends to rely on the ETS to drive abatement, we recommend it overhauls the intensity benchmarks and replaces it with an absolute emissions cap (with a linear reduction factor) and a supply adjustment mechanism. A recent draft law by the MEE suggests there is an intention to set an emissions cap and auction allowances by the end of 2021.[21]

03 Modelling considerations

Production monitoring

- We use satellite imagery and ML to estimate generation from fossil fuel facilities and subsequently their emissions. These are indirect estimates and should not be misconstrued as direct measurements of generation or emissions.
- For this report we model 1 GW or bigger plants cooled by NDT. NDT plants represent around 30% of China's total operational coal capacity. By September 2021 we plan to extend our modelling to cover 90% of the generation from coal, gas, and oil power plants globally. These will initially be published as annual country level estimates via the Climate TRACE coalition.
- For these plants, our models currently achieve an MAE of 14% at the plant level and 11% at the provincial-level. The asset level estimates are based on data from the EU, the US and Australia where it is publicly available and therefore the MAE should not be misconstrued as results based on Chinese data. The provincial level estimates are based on aggregated data from the Chinese government, which do not disaggregate thermal generation and capacity into coal, gas, oil and biomass.

ETS fundamental analysis

- The ETS analysis is based on our interpretation of publicly available documents.

RIS metrics

- The metrics in RIS are estimates based on modelling of publicly available data and should not be misconstrued as company or government data. For key assumptions see the appendices. These metrics include: abatement cost, net profitability, undepreciated value, carbon intensity, water use, air pollution exposure and regulatory considerations.
- RIS considers economic, financial, health and environment issues, but does not systematically consider the safety and security of power supply. Future research will incorporate the spatial and temporal nature of power systems and its implications for specific assets.

Phase out mechanism

- The phase out mechanism is based on:
  - The RIS, which determines the ranking of the units to be closed, converted or put into reserve capacity; and
  - The IEA's SDSs which determines the demand constraint.
- The phase out mechanism should not, therefore, be misconstrued as modelling based on Chinese government policy, such as the 14 FYP.

18 Tsinghua University (2020) and IEA (2020).
19 MEE (2020).
20 Hebei Daily (2021).
21 China Securities Journal (2021).

04 Introduction

Despite COVID 19, China's economy and its policymakers still managed to impress in 2020. With a growth rate of 2.3%, China added the equivalent of the entire Danish economy to its GDP in 2020.[22] China's build out of renewable energy also surprised to the upside, with 72 GW of wind and 49 GW of utility scale solar in 2020.[23] That is the equivalent of China connecting more than 3 large wind turbines and 5 football fields of solar panels to the grid every hour in 2020.[24] The announcement before President Xi Jinping to the UN General Assembly last September that China would aim to be carbon neutral before 2060 represents one of the biggest changes to climate policy ever made by any country.

Despite the government's net zero pledge, the CEC suggested that coal capacity should expand to 1,300 GW by 2030.[25] Analysis by GEM and the Centre for Research on Energy and Clean Air (CREA), found that in China:

- 30 GW of net coal capacity additions were operationalised, while in the rest of the world net capacity decreased by 17 GW.
- 38 GW of coal capacity was granted construction approval, over three times the 12 GW greenlighted in the rest of the world.
- 74 GW of coal capacity was given planning approval, over five times the 14 GW granted approval in the rest of the world combined.

This report uses our technology – which applies satellite imagery and ML to estimate production and emissions from power generation and heavy industry facilities – to illustrate why it makes sense for China to deal with its coal overcapacity crisis and what government action could mean for asset owners. The report focuses on how technology can be used to help manage China's transition from coal to zero carbon power generation.

The report has three main sections. The first section details the genesis of China's coal overcapacity in the context of its net zero pledge. China is a huge, dynamic and decentralised country that makes complex political and economic decisions. This section describes the governance issues and market distortions that have contributed to the overinvestment in coal power and why coal capacity will have to be rationalised to avoid defaults.

The second section provides a fundamental analysis of China's recently launched national ETS to demonstrate how satellite imagery and ML could reduce the cost of enforcement and discourage misreporting. In doing so, our emissions estimates reveal structural flaws in the policy design of the ETS, which will likely result in prices close to zero. To avoid a situation like Phase 1 of the EU ETS – where prices crashed to zero due to an oversupply of allowances – China will need to overhaul the system to drive abatement.

The last section uses our RIS and net zero phase out mechanism to realign China's coal capacity with its net zero pledge. In emerging markets, such as China, the vulnerability of coal power capacity depends on a host of variables, such as cost competitiveness, profitability, air pollution, water use and other regulatory considerations. There is currently a yawning gap between the government's long term policy objectives and the short term investment decisions being made by local governments and SOEs. Without further reform, China's net zero pledge could face a credibility problem and undermine the competitiveness of its economy.

22 Nikkei Asia (2021).
23 China Energy Portal (2021).
24 TransitionZero analysis based on NREL (2020).
25 China Dialogue (2020).

05 Context

Net zero before 2060: technically achievable and economically desirable

The announcement by President Xi Jinping to the UN General Assembly last September that China would aim to be carbon neutral before 2060 represents a landmark change in climate policy and could help significantly slow down global warming. To realise President Xi's net zero announcement, huge challenges will need to be overcome. But there is already strong evidence that the target is achievable. In October last year, Tsinghua University presented their findings of a technical study on China's long term low carbon development strategy and pathway, which concluded that a net zero carbon economy was technically feasible before 2060.[26]

The net zero goal will likely prove essential to China's future economic growth prospects and could buy policymakers time as they grapple with the socioeconomic implications of moving economic growth towards resource efficiency and domestic consumption. It is difficult to overstate the implications of the net zero target for China's capital stock. We expect installed solar and wind capacity to reach 1,800 GW by 2030 – up from 535 GW at the end of 2020. This compares to a revised Nationally Determined Contribution (NDC) of 1,200 GW by 2030.[27] Of the 1,800 GW, we expect 900 GW to be wind and 900 GW to be solar, amounting to $1.4 trillion of capital investment. The required wind and solar additions mean adding an average of around 130 to 140 GW of wind and solar capacity every year. That is the equivalent of China installing 3 large wind turbines and 10 football fields solar panels, every hour, from 2021 to 2030.[28]

Mind the (net zero) implementation gap

The FYP process is a periodic planning tool to set goals for economic and social development. The 13th FYP, which ran from 2016 to 2020, showed China's ability to add renewable energy beyond the targets specified in the documentation. For example, the 13th FYP targeted 210 GW of wind and 110 GW of solar by 2020. Based on preliminary data, China installed 282 GW of wind and 253 GW of solar at the end of 2020.

The drafting of the 14th FYP started in 2019, with the Central Committee suggesting goals and guidelines in October 2020 for economic and social development from 2021 to 2025. In March, the Chinese government released a high level summary of the 14th FYP, which stated energy consumption and carbon emissions per unit of GDP will decline by 13.5% and 18%, respectively, by 2025. The 14th FYP summary also contained language on "promoting the clean use of coal", which suggests a continuing trend of overcapacity from targeting low carbon development while also investing heavily in coal. Despite the 14th FYP and President Xi's statements about carbon neutrality, China is considering adding another 200 GW of coal fired capacity by 2030.[31] As detailed in Table 5, our analysis shows the average capacity factor of the fleet will decline significantly by 2030 if load growth is less than 6%.

26 Tsinghua University (2020).
27 It should be noted, based on a consultation document on power generation mix targets, that China's wind and solar power capacity need to triple by 2030, reaching at least 1,500 GW and above the NDC target of 1,200 GW. See: Polaris Energy Storage Network (2021).
28 TransitionZero analysis based on NREL (2020).
29 China Energy Portal (2021).
30 NPC (2021).
31 China Dialogue (2020).

Table 5. Coal capacity (GW) in 2030 based on existing plants as of 2020 under different coal plant capacity factors and power generation growth rates

Capacity factor (%)	Power demand (CAGR 2021–2030)			
	3%	4%	5%	6%
45%	–555	–326	–79	189
46%	–568	–344	–102	160
47%	–580	–360	–123	132
48%	–591	–377	–144	106
49%	–603	–392	–165	81
50%	–613	–407	–184	56
51%	–623	–421	–203	33
52%	–633	–435	–220	11
53%	–642	–448	–238	–11
54%	–652	–461	–254	–32
55%	–660	–473	–270	–52

Source: *TransitionZero analysis*
Notes: *Assumes 446 GW, 7 GW, 202 GW, 120 GW, 94 GW, 900 GW and 900 GW of hydro, oil, gas, nuclear, wind and solar PV, respectively. Also assumes an average capacity factor of 35% for wind and 15% for solar PV.*

China's investments in coal mask an increasingly insolvent industry

Our analysis of projects in Henan, Inner Mongolia, Jiangsu and Shandong highlights the increasingly unviable nature of coal power in China. From a financial perspective, capital intensive power projects are only viable if certain criteria are met. Three key measures to assess project viability are the NPV, the IRR and the DSCR. The NPV is the present value of cash outflows over the life of the project. The IRR is the growth rate a project is expected to generate. The DSCR is a measurement of a project's available cash flow to pay debt obligations.

New coal projects in all the provinces modelled deliver negative NPVs from both a project and equity perspective. The DSCRs of the projects vary from 0 to 0.87, meaning none of the projects in the provinces modelled would be able to service their debt requirements. The results and a power price break even analysis are summarised in Table 6. As detailed below, power prices need to increase by from 8% to 62% depending on the province. Power prices are unlikely to rise in China and will likely decline, due to the deregulation agenda and increased levels of near zero marginal cost wind and solar.[32]

32 See Footnote 15.

Table 6. Model results and a power price break even analysis based on an 800 MW coal project

Province	NPV	IRR	DSCR	Prevailing power price	Break even power price
Henan	–255	1.3%	0.47	58	75
Inner Mongolia	–591	-8.5%	0	42	68
Jiangsu	–66	6.2%	0.87	59	64
Shandong	–84	5.7%	0.83	61	67

Source: *TransitionZero analysis*
Notes: *Based on the following assumptions: 600 MW unit, provincial average fuel price, no carbon price, FOM of ¥9.5/kW, VOM of ¥6/MWh (Zhang and Paltsev, 2016), cost of debt of 7% (2.25% higher than the prime loan rate), loan term of 15 years and discount rate of 8.6%. The debt to equity ratio is assumed to be 80/20. The capacity factors are based on market conditions and are derived from our technology. The prevailing power price is adjusted from the benchmark tariff to account for market trading. The Debt Service Coverage Ratio (DSCR) is a measurement of a project's available cash flow to pay current debt obligations. Inner Mongolia has two markets for domestic and East Coast demand. This analysis is based on Inner Mongolia's domestic market.*

06 Our technology

We train ML models on satellite images of coal power plants with published plant level generation data to estimate plant level production and emissions for regions where this information is unavailable.[33] We use both visible and thermal signals, as detected by satellite imagery, given off by thermal power plants as generation indicators. The models are trained to learn how a plant behaves using images where we know the generation. The models are therefore able to predict a plant's generation when presented with an image at the point of time the image was taken.

Observable signals of the production of a power plant vary by facility technology. Most power plants emit flue gas from chimneys, clearly visible on satellite imagery. Some of the cooling processes used by power plants also emit detectable signals. The cooling technology and their observability varies by power plant, with most power plants using either natural draft cooling, mechanical draft cooling or once through cooling. Draft cooling uses cooling towers, which emit visible vapour plumes. Once through cooling ingests water from nearby water sources for cooling and discharges the warm water back into the water source, which can be detected on thermal imagery. Due to the disparate nature of these signals, we train separate models for different cooling technologies, using thermal and visible imagery from Sentinel 2 and Landsat 8. For this report, we model plants cooled by NDT and with a nameplate capacity of 1 GW, where we see the clearest signal.

For our training data set we label each satellite image with hourly and sub hourly generation data from sources including the Environmental Protection Agency (EPA)'s Air Markets Program Data (AMPD), the European Network of Transmission System Operators Electricity (ENTSOE), and from the Australian Energy Market Operator (AEMO). Our training data, therefore, covers most of the US, EU and Australia's capacity in 2013–2020. The satellite images taken by Landsat-8 and Sentinel-2 each have multiple bands with different spatial resolution. From this we develop a multi-band imagery data set by aligning and resolution matching images, filtering the images to only use those with low cloud cover. The images are cropped around a 1.5x1.5 km2 region of interest (ROI) around the centre of each power plant. We additionally train models using small image patches centred on each plant's cooling towers and flue stacks (annotated patches). We developed and tested a variety of ML approaches, including gradient boosted trees and convolutional neural networks. We train models using both the whole 1.5 km region of interest and the annotated patches, with separate models for different satellite collections.

We produce models that predict, in each image, whether the plant is off or on (classification), as well as models which directly predict the production of the plant at the time of the image (regression). The individual predictions produced by these models are then combined into a time-series of predicted generation using an ensemble time series model. The final output of this model is a prediction of the capacity factor of a plant over a 30 day period.

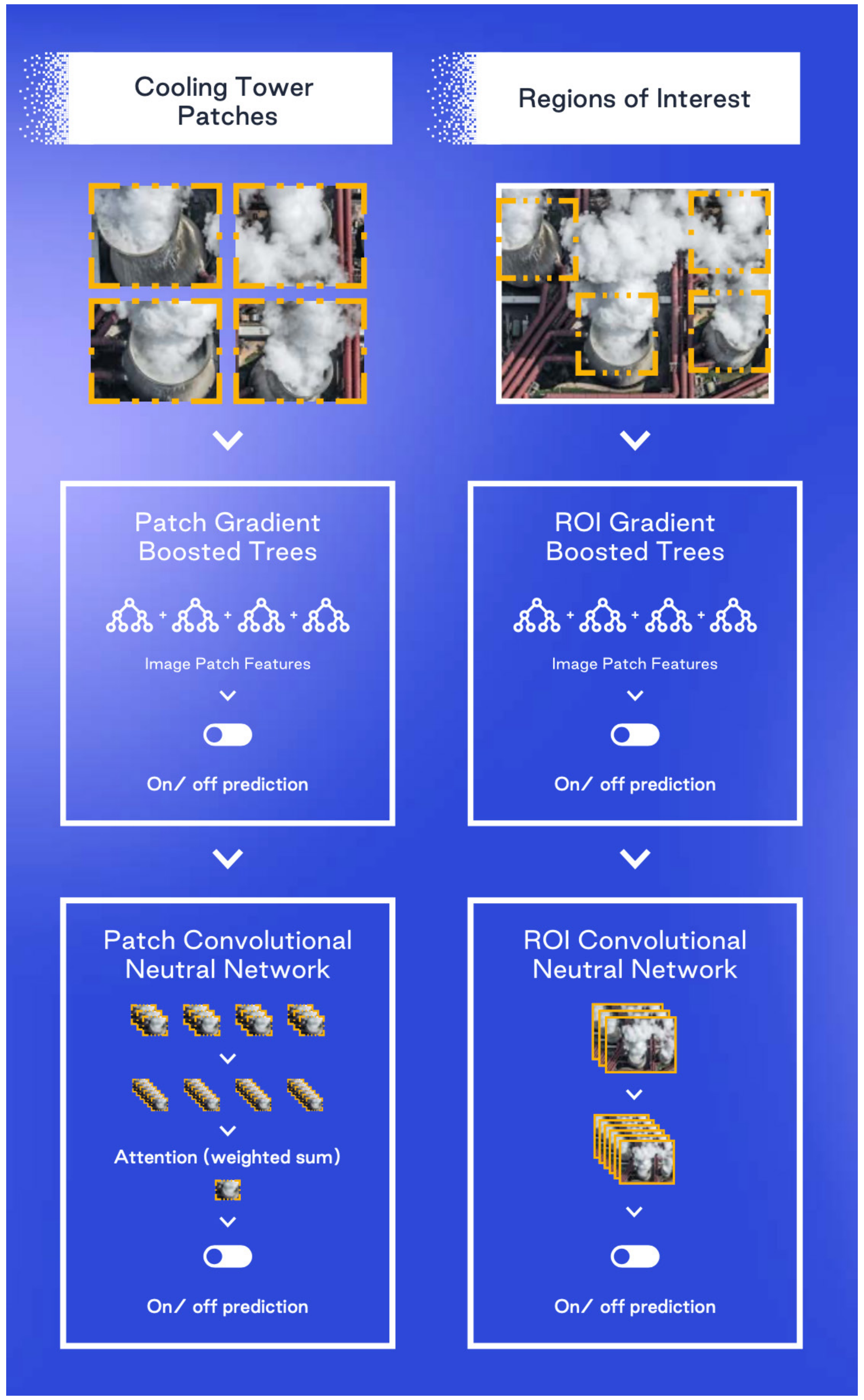
We validate the performance of our models in two main ways. Firstly, using four fold cross validation on the training set, where all images from a particular plant are placed in the same fold. We estimate an MAE on the 30 day capacity factor of an unseen plant to be 14%. When aggregating predictions to the country level, this MAE falls to around 5%.

Secondly, we aggregate our final predictions on Chinese plants to the province level and compare them with reported monthly generation, based on disaggregated data from the Chinese government. In regions for which we model at least five plants, we predict the region level monthly capacity factor with accuracy varying from 3% to 18% MAE.

We continue to improve the models used in this analysis, as well as our coverage of plants. Training data suggests that including PlanetScope imagery at inference time will improve accuracy by several percentage points, with its higher spatial resolution and daily revisit rate. By September 2021 we plan to extend our modelling to cover 90% of the generation from coal, gas, and oil power plants globally. These will initially be published as annual country level estimates via the Climate TRACE coalition.

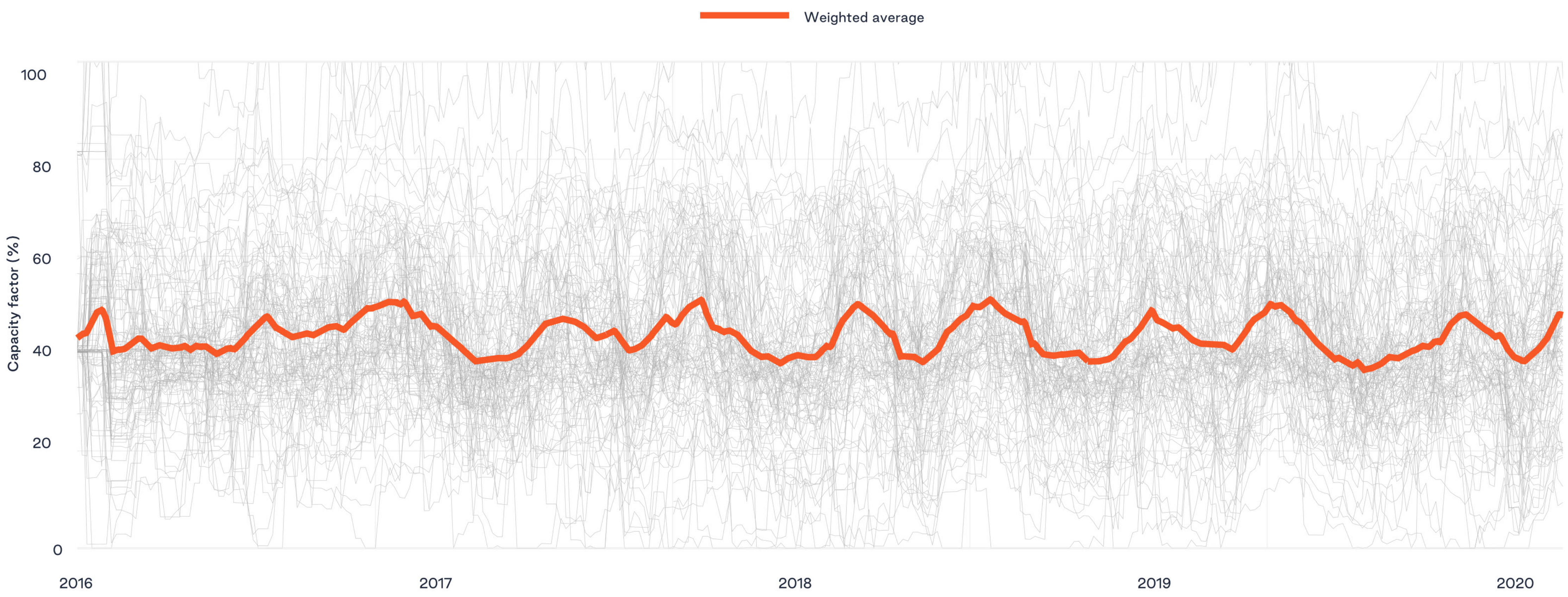
33 For a thorough explanation of our modelling methodology, please refer to Couture, et al (2020).

Figure 5. Illustration of methodology to estimate generation and emissions from coal power plants



Source: TransitionZero analysis
Notes: Please see Couture, et al (2020) for a more detailed explanation of our methodology.

Figure 6. Monthly estimates of coal plant capacity factors in China



Source: TransitionZero analysis

> We estimate an MAE on the 30 day capacity factor of an unseen plant to be 14%. When aggregating predictions to the country level, this MAE falls to around 5%.

07 Actionable analytics

ETS emissions monitoring and fundamental analysis

Background

In 2011, the National Development and Reform Committee (NDRC) launched emission trading pilots in several cities and provinces, including: Beijing, Shanghai, Tianjin, Shenzhen, Chongqing, Guangdong, and Hubei.[34] These pilots paved the way for a national ETS. After several delays, in January this year, the MEE launched what it is calling the "trial phase" of China's ETS. According to the MEE, the first compliance cycle is from January 1 to December 31, 2021 and will cover the emissions of 2,225 entities from 2019 and 2020. The ETS will initially cover power generation, which last year accounted for about 30% of China's total carbon emissions. China's ETS does not have an absolute cap on emissions, but rather a series of intensity benchmarks which power generators must meet. Power generators are allocated allowances based on their fuel and plant type benchmarks. If their plant exceeds carbon intensity benchmarks, generators need to purchase allowances from more efficient generators or shut down. Regulated entities are also allowed to use voluntary Chinese Certified Emissions Reductions (CCERs) to meet up to 5% of their compliance obligations under the scheme each year.[35]

Satellite imagery and machine learning could reduce ETS enforcement costs

China currently uses MRV to regulate companies covered under the ETS. The MRV process requires regulated companies to submit an emissions report, which is verified by local governments every year. In December 2020, China's MEE released a consultation document on GHG emissions accounting and report guidelines.[36] This document forms the basis of MRV for power generation facilities regulated by the ETS. Several provinces, including Hebei, are also piloting CEMS of carbon emissions from power plants.[37] CEMS is where sensors are installed on facilities and provide near real time estimates of emissions.

China faces several hurdles with regards to scaling these approaches to effectively enforce the ETS. SOEs have historically been cautious with regards to making data publicly available.[38] MEE requires ETS emissions data to be made publicly available, which should increase the level of compliance, and possibly allow regulators and the public to challenge non compliance and misreporting. However, data falsification has long been an issue in China. A recent study found potential misreporting from China's air pollution CEMS.[39] This issue is compounded by misaligned incentives between the central and local governments. According to interviews with market experts, a number of local governments have argued they do not have adequate resources to undertake the MRV process thoroughly. As illustrated in Figure 7 below, by combining onsite CEMS with "offsite" CEMS, an anomaly detection system could be developed to reduce the cost of the MRV process.

34 Liu and Zhang (2019).
35 S&P Global (2021).
36 MEE (2020).
37 Hebei Daily (2021).

Figure 7. Illustration of an anomaly detection system to determine MRV audits for companies regulated by China's ETS

Source: TransitionZero analysis

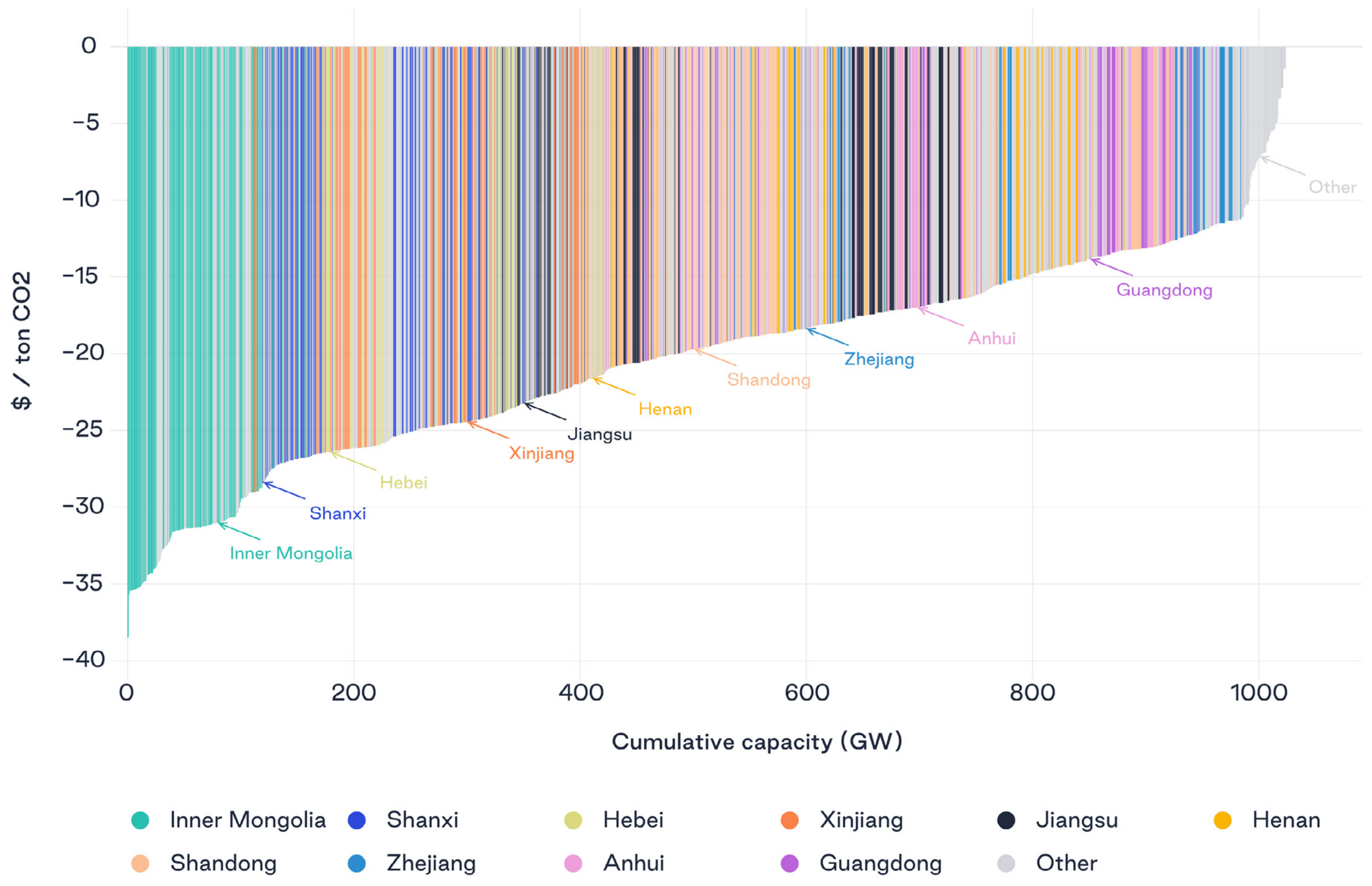
Carbon price depends on ETS reform

In trading systems with an absolute cap, the fair value of carbon is a function of the highest cost of abatement in the future, discounted back in real terms. Assuming market efficiency, the marginal cost of abatement in most regions should come from the retirement of old and inefficient coal with wind or solar.[40] Our analysis shows that the abatement cost of switching from existing coal to VALCOE of wind and solar is negative in 2021. This process is dynamic as, all else equal, the cost of integrating variable renewable energy (VRE) increases as penetration levels increase. Nonetheless, this analysis underscores the potential impact of deregulation on coal generation independent of any carbon pricing.

> By combining onsite CEMS with "offsite" CEMS, an anomaly detection system could be developed to reduce the cost of the MRV process.

38 For example, in July last year, five of China's largest power companies halted daily coal demand data, without providing a reason. South China Daily (2020).
39 Karplus, et al (2018).
40 The coal to clean switch price depends on the market value of wind and solar, which is influenced by several factors, including: penetration levels of wind and solar, grid flexibility, market regulations and investment plans in transmission and distribution.

Figure 8. Unit level marginal abatement cost to replace existing coal by province



Source: TransitionZero analysis
Notes: See the below for more information on the risks and limitations of this analysis.

However, China's ETS is a carbon intensity system, with benchmarks rather than an absolute emissions cap. For plants that meet or exceed the carbon intensity benchmark, the more power they generate, the more oversupply will increase. Our analysis shows China's ETS will be vastly oversupplied from 2019 to 2020, due to relaxed intensity benchmarks.[41] According to our analysis, the ETS is oversupplied by 1.56 billion tons from 2019 to 2020. This assessment does not take into consideration the use of CCERs, which would exacerbate oversupply further. Since supply is greater than demand, the fair value of allowances is theoretically zero. Without a price signal from the government, we expect the price to crash, or remain close to zero, like Phase 1 of the EU's ETS. It is unclear to what extent the government plans to rely on market mechanisms to drive abatement in the future. Based on previous policy decisions, most abatement will continue to come from direct interventions, which tend to reflect China's wider development priorities.

Table 7. Fundamental analysis of China's ETS from 2019 to 2020 (billion tCO2)

	2019	2020
Supply	5.19	5.32
Demand	4.45	4.49
Net balance	0.74	0.83
Cumulative balance	0.74	1.56

Source: TransitionZero analysis

41 See the appendix for more information on our modelling methodology.

Risk index system for assessing coal plant vulnerability

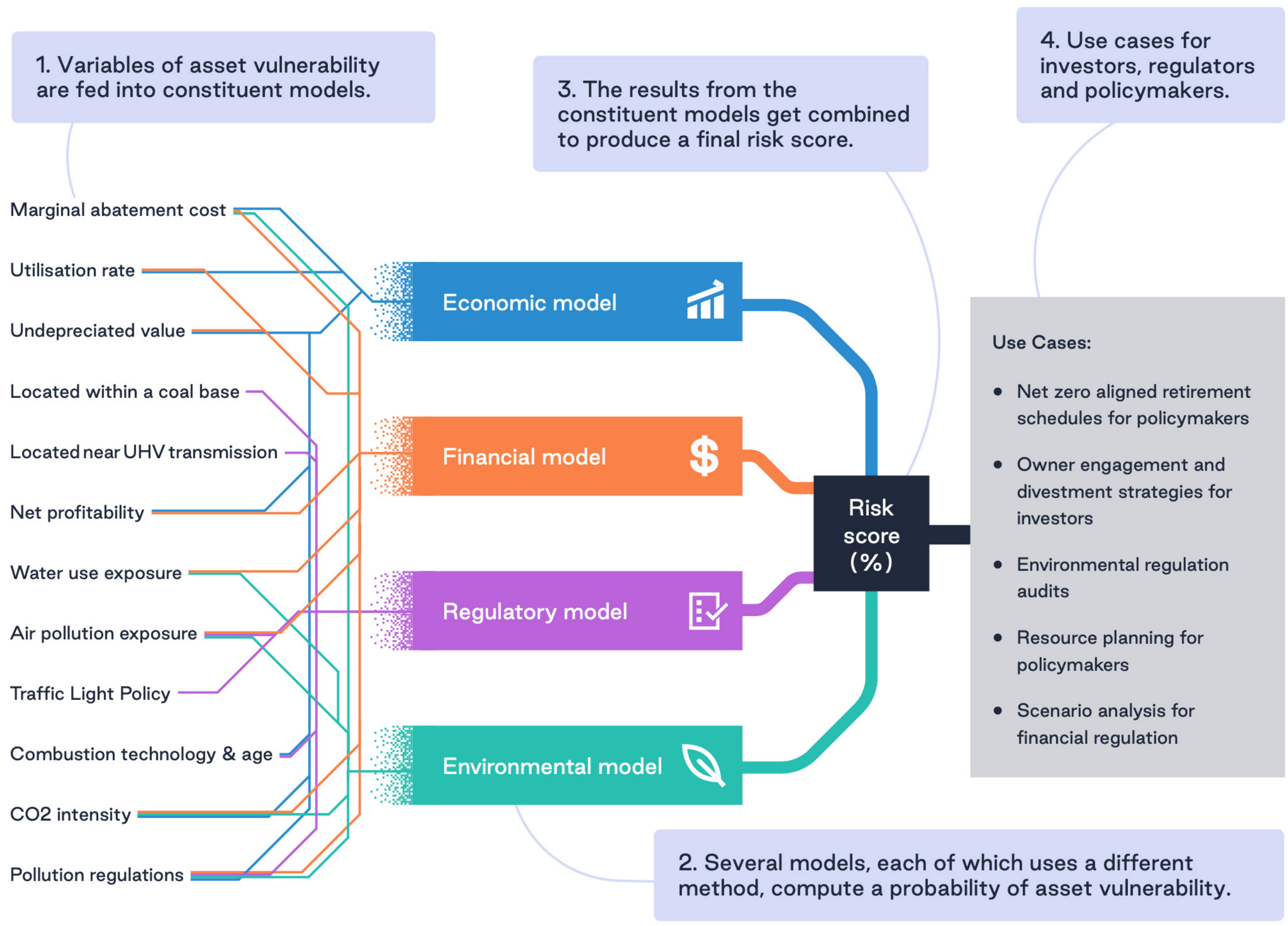
RIS is a tool for investors, policymakers and regulators to prepare for a transition to a zero carbon economy. RIS can be used for resource planning for policymakers, investor engagement and scenario analysis for financial regulation. A feature of RIS is its ability to predict the vulnerability of fossil generation assets based on metrics that capture SDG 3 (air pollution), SDG 6 (water use), SDG 8 (energy affordability) and SDG 13 (climate action). RIS is enhanced from our use of satellite imagery and ML to improve transparency in locations where data is unavailable, unreliable or untimely. RIS is an ensemble model based on the following asset level metrics: abatement cost, net profitability, undepreciated value, carbon intensity, water use, air pollution and regulatory considerations. These metrics are fed into constituent models to give an overall risk score from 0 to 1, with 0 being low risk and 1 being high risk. These metrics are detailed further in Table 8 below.

Table 8. Information on the variables used in our RIS

Variable	Definition	Expression	Reference
Age	We define age as the age of the asset since being operational.	Years	GEM
Size	We define size based on nameplate capacity.	MW	GEM
Marginal abatement cost	We define relative competitiveness as the marginal abatement cost of the VALCOE of zero carbon alternatives.	$/MWh	TransitionZero estimates
Undepreciated value	We define undepreciated value as linear depreciation. For coal capacity, we assume a depreciation period of 30 years for China.	$/MW	TransitionZero estimates
Replacement cost	We define replacement costs as the investment costs and O&M costs of clean power required to replace the value of electricity from coal plants.	$	TransitionZero estimates
Net profitability	For deregulated markets, we define gross profitability as in-market and out-of-market revenues minus fuel, carbon, variable O&M and fixed O&M.	$/MWh	TransitionZero estimates
Carbon intensity	We define carbon intensity as tons of CO2 per unit of production. Based on Scope 1 emissions only.	tCO2/MWh	TransitionZero estimates
Water use exposure	We define water use as gallons of water used per unit of production based on the installed cooling technology. We define drought risk based on water risk indicators from the World Resources Institute (WRI).	Gallons/MWh and exposure based on location	TransitionZero estimates based on the US Government Accountability Office (2009) and WRI (2019)
Air pollution exposure	If the plant is located in an air pollution priority region.	Location relative to city boundary	Centre for Research on Energy and Clean Air (CREA)
Regulatory considerations	Proximity of plant relative to Traffic Light Policy	Location relative to Traffic Light Policy	GEM Wiki (2020)
	Proximity of plant relative to coal base proximity	Location relative to coal base	TransitionZero estimates
	Proximity of plant relative to ultra high voltage (UHV) electricity transmission	Location relative to UHV transmission	TransitionZero estimates

An illustrative overview of the methodology of RIS is detailed below.

Figure 9. Inside the RIS tool from variables used to use cases for decision makers



Source: TransitionZero analysis

The results of RIS for coal power in China are broken down by province in Table 9 below. The most striking conclusion of RIS is it now makes sense to close existing coal and replace it with clean energy alternatives. We come to this conclusion by comparing the cost to replace the generation with the lowest cost clean energy alternative. The lowest cost clean energy alternative in China is currently wind or solar, which is a VRE source. To compensate for the variability of wind and solar we adjust the levelised cost based on the value it adds to the grid. Termed VALCOE, this approach has been pioneered by the IEA, and builds on LCOE analysis by incorporating grid flexibility and capacity.[42] Combining these elements provides a stronger basis for comparisons between VRE and dispatchable technologies. Based on this analysis we found replacing the coal fleet with wind and solar could save $1.6 trillion or cost net negative $20/tCO2. See the appendix for more information on our abatement cost methodology.

42 IEA (2019).

Table 9. Selected RIS variables, overall RIS score and high risk capacity by province

Province	Operating capacity (GW)	Abatement cost ($/tCO2)	Replacement saving (bn$)	Undepreciated value (bn$)	Net profit ($/MWh)	RIS score (0-1)	High risk capacity (GW)
Anhui	50.37	-15.85	62.17	17.44	-1.21	0.69	4.49
Chongqing	13.49	-21.30	17.63	5.11	-2.09	0.60	-
Fujian	26.87	-14.00	34.23	8.80	13.20	0.32	-
Gansu	18.10	-23.08	31.70	6.46	-12.83	0.63	1.20
Guangdong	61.88	-16.17	91.73	21.13	10.29	0.49	-
Guangxi	19.24	-15.48	24.36	7.10	12.66	0.37	-
Guizhou	32.57	-17.44	38.45	12.58	-6.74	0.65	0.60
Hainan	3.34	-14.81	4.74	1.18	11.55	0.39	-
Hebei	48.34	-24.63	105.98	17.07	-2.15	0.57	0.90
Heilongjiang	18.75	-24.97	41.07	5.80	-6.06	0.70	1.72
Henan	65.04	-17.33	64.93	23.23	-0.51	0.66	0.64
Hubei	27.59	-17.48	32.85	9.50	5.36	0.53	-
Hunan	18.89	-6.16	8.69	5.89	27.75	0.47	-
Inner Mongolia	86.28	-31.05	237.66	32.24	-23.23	0.63	2.16
Jiangsu	76.60	-19.45	125.62	24.68	0.91	0.70	4.08
Jiangxi	20.12	-18.16	33.51	7.10	7.52	0.51	-
Jilin	16.85	-26.77	35.89	5.73	-6.95	0.65	0.15
Liaoning	31.35	-13.61	32.02	10.18	7.47	0.41	-
Ningxia	28.77	-13.67	30.26	11.21	-6.22	0.43	-
Qinghai	3.16	-9.00	1.16	1.24	-1.35	0.35	-
Shaanxi	41.78	-23.51	76.51	16.21	-8.50	0.53	-
Shandong	101.02	-17.28	144.38	35.58	1.03	0.61	3.99
Shanghai	14.91	-15.59	19.00	3.23	2.88	0.69	0.80
Shanxi	61.27	-25.15	121.27	22.13	-10.72	0.53	0.81
Sichuan	11.16	-18.49	15.18	3.56	-5.36	0.68	1.96
Tianjin	11.83	-6.3	6.56	4.09	6.96	0.53	-
Xinjiang	59.79	-24.46	112.35	27.07	-16.38	0.51	0.22
Yunnan	11.39	-26.28	19.03	3.79	-15.69	0.78	2.34
Zhejiang	42.17	-14.72	61.20	12.92	8.00	0.56	-
Total	1,023	-19.80	1,630.13	362.25	-0.36	0.56	26.06

Source: TransitionZero analysis
Notes: Where applicable, variables are capacity-weighted averages. The overall RIS score is from 0 to 1, with 0 being low risk and 1 being high risk of closure. High risk capacity has an RIS score of 0.85 or higher. This analysis assumes no net carbon price impact in 2021 due to structural oversupply.

Net zero aligned coal plant retirement schedule

To meet the temperature goal in the Paris Agreement, unabated coal capacity needs to be closed, converted or put into reserve capacity by 2040 or shortly thereafter. This equates to between 2 and 3 coal units every week until 2040. How and when this occurs requires high quality data to inform strategic policy and investor decision making. Our coal plant phase out mechanism seeks to quantify the changes needed to reach the key energy related goals of the UN Sustainable Development Agenda. The mechanism provides an asset level blueprint for how policymakers and investors can reduce the impacts of air pollution (SDG3) and water use (SDG6), while tackling climate change in line with the Paris Agreement (SDG13). Importantly, our approach is based on a commercial understanding of asset economics and thus aims to fully incorporate energy affordability (SD 8) by assessing the competitiveness and profitability of power generation technologies at the asset level. An overview of the methodology is outlined in Table 10.

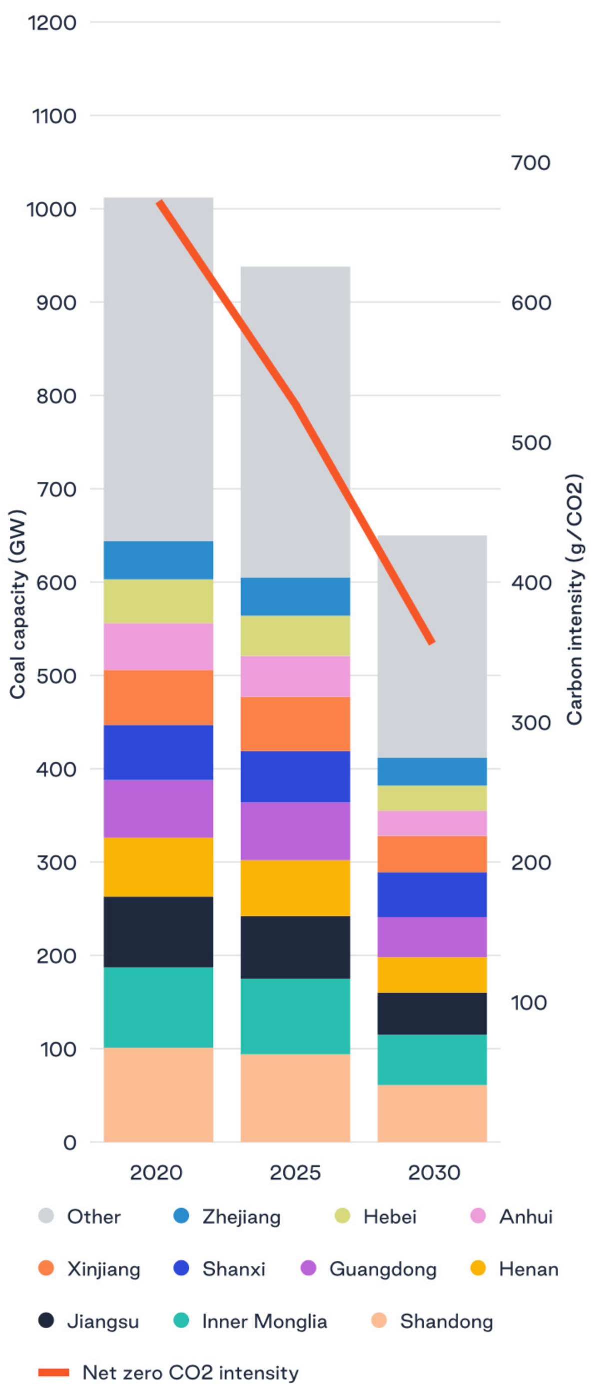
Table 10. Analytical steps to calculate our SDG aligned coal plant retirement schedule

Step	Detail	Reference
1. Identify pathway	Our demand-constraint is based on the IEA's SDS from the World Energy Outlook 2020.	IEA (2020)
2. Rank as-sets	Rank assets by power grid based on RIS. Power grids include: Northwest, North, Northwest, East, Central and South. Within each power grid, units are ranked by the lowest to highest RIS score.	n/a
3. Close capacity	Every year the units with the highest RIS score are phased out until the aggregated generation reaches the limits set out in the Paris aligned generation pathway.	n/a

Source: TransitionZero analysis

The results of the coal plant phase out mechanism are broken down by province in Figure 10 below. As detailed above, the debate amongst key stakeholders is currently centred around adding more coal capacity, not less. According to the results of our phase out mechanism, China would need to shut, convert or put into reserve capacity 364 GW of coal capacity by 2030 to be consistent with their net zero pledge. This results in the carbon intensity of power generation halving by 2030, from 672 gCO2/kWh in 2019 to 356 gCO2/kWh.[43] We believe the closure of unabated coal capacity in China will not be linear across provinces due to water stress, air pollution and regional development priorities.

Figure 10. Unabated coal capacity under our coal phase out mechanism from 2020 to 2030



Source: TransitionZero analysis
Notes: See the report for more information on the methodology.

43 Based on the IEA's Sustainable Development Scenario. IEA (2020).

08 Policy recommendations

We offer the following high level recommendations to help stakeholders navigate risks and opportunities associated with China's power sector transition.

Cancel all new coal immediately and indefinitely. Issue guidance on a net zero aligned phase out.

After decades of high economic growth from capital intensive infrastructure investments, China's economy is undergoing structural change. This change has exposed inefficient investments in coal power. China is continuing to build more coal plants than they need and in doing so is misallocating capital at an alarming rate. Independent of climate considerations, it makes sense for China to act on its coal overcapacity crisis. The maths associated with continued growth in China's coal capacity do not add up and the 14th FYP marks the point where this cannot be ignored any longer. The changing power generation mix, the likely slowdown in load growth and existing overcapacity has an obvious policy implication: cancel all new coal immediately and indefinitely. A wider conversation with stakeholders is urgently required about how to close, convert or put into reserve capacity coal in a manner consistent with China's net zero goal. Based on the IEA and Tsinghua University estimates, unabated coal power will be phased out somewhere between 2040 and 2050. We recommend China phase out coal in a manner consistent with wider development objectives, such as those outlined in the UN's SDG framework.

Use offsite CEMS to help reduce ETS enforcement costs

MEE's decision to make ETS emissions data publicly available should increase the level of compliance and possibly allow prosecutors and the public to challenge misreporting. The MEE is already using drones equipped with air pollution sensors to identify non compliance events. The use of satellite imagery and ML could be another powerful tool for enforcement of the ETS. In the absence of additional resourcing for local governments, the MEE should also explore introducing an anomaly detection system that uses a combination of CEMS and selective MRV audits based on the likelihood of data misreporting.

Reform the ETS to create scarcity

The ETS in its current form will likely have no impact reducing power generation emissions in China and could generate windfall profits for efficient coal generators. While it is widely known that emissions reductions are not the objective of the trial phase of the ETS, China's climate policy is at a crossroad. Historically, China's climate policy has relied almost exclusively on direct interventions. It is unclear as to what extent the government plans to rely on market mechanisms to drive abatement in the future. We believe most abatement will continue to come from direct interventions, which tend to reflect China's wider development priorities.

If the government intends to rely on the ETS to drive abatement, it needs to commit to the economic and financial implications of deregulation. In non discriminatory deregulated markets, such as Western Europe, coal power struggles to compete and is often closed prematurely. Cap and trade works most efficiently in deregulated markets, where power generators manage risk dynamically over space and time. For example, in Western Europe, several utilities have financially hedged their carbon exposure for the next decade.[44] They do this by selling power and buying the associated costs, such as fuel and carbon, in the future or forward market when their assets deliver a positive return.

A number of these lessons can be learned from the EU ETS, which has been reformed to respond to exogenous and endogenous factors. Without a price signal from the government, we expect the price to crash, or remain close to zero, like Phase 1 of the EU's ETS. We recommend the government implements an absolute emissions cap (with a linear reduction factor) and a supply adjustment mechanism.

44 RWE (2020).

09 Conclusion

In this report we use our technology and data driven approach to shine a spotlight on the investment and operational implications of China's net zero goal for coal power. China's net zero pledge has huge consequences for the global economy and humanity's ability to avoid dangerous climate change. At the heart of this challenge is the phase out of unabated coal power. To be net zero aligned China will need to close, convert or put into reserve capacity most of its coal fleet by 2040 or shortly thereafter. Progressively shuttering coal capacity will require a long term policy framework. The implementation gap between the government's net zero target and what is happening on the ground is a cause for concern from both a climate and economic perspective. For this reason, we recommend China cancel all new coal immediately and indefinitely, issue guidance on a net zero aligned phase out, reform their ETS and use satellite imagery and ML to keep ETS data falsification in check.

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11 Appendix

Appendix 1. Economic modelling

- Per GEM's Global Coal Plant Tracker, only units over 30 MW are included in the analysis.
- Profitability calculations exclude any profit or loss due to forward hedges or long-term contracts.
- Capital costs are excluded from all calculations of existing units.
- Generation is based on plant level estimates from our technology.
- Unit efficiency rates are based on our estimate and range from 28.9% to 45.7% depending on age and technology.
- Fuel price is based on daily provincial averages from WIND, with 8% added for mine IRR.
- Benchmark tariff prices are adjusted for market trading. Market adjustments were obtained from Northeast Electric Power University.
- Conversion of coal price in tonnes to MWh = Coal price ($/t) / Efficiency
- Fuel cost = Fuel price (€/MWh / unit efficiency rate)
- FOM costs are averaged $10/kW for all units.
- Annual FOM per unit = FOM x installed capacity.
- VOM costs are averaged $6/MWh for all units.
- We assume a carbon price of $0/t for 2021 increasing to $50 by 2040.
- Conversion of CO2 price in tonnes to MWh = CO2 price ($/t) x Efficiency
- CO2 cost = CO2 price (€/MWh) / unit efficiency rate.
- Capacity factor = Generation / installed capacity.
- Revenue ($/MWh) = Generation x adjusted tariff prices.
- Gross profitability ($/MWh) = Revenue – ((Fuel + VOM + CO2 cost) x generation).
- Net profitability ($/MWh) = Gross profitability – FOM.
- See Appendix 2 for more information on the marginal abatement cost and replacement saving calculations.

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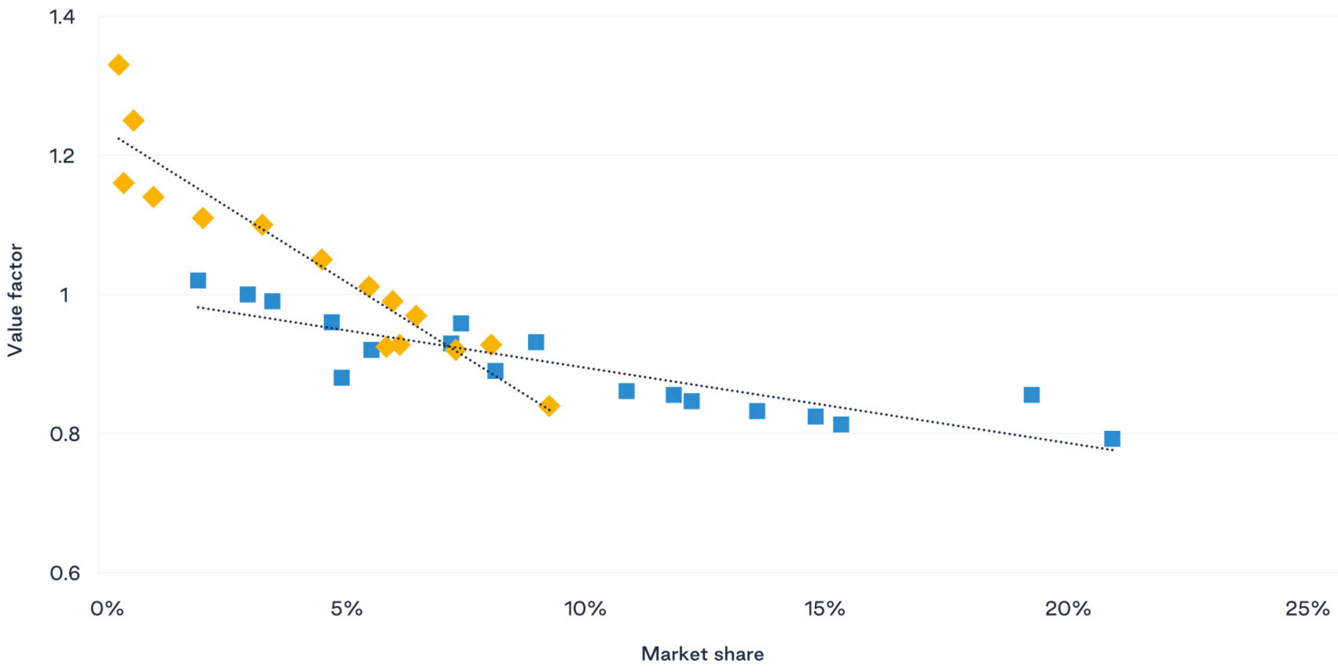
Appendix 2. Abatement cost analysis

The guiding principle of the analysis is the value of electricity from different generation technologies is different from a market and system operator perspective. The market value is the average hourly price captured by different generators. The ratio of the market value and the realised average electricity price is the value factor. The value factor can be above or below 1. Dispatchable resources such as coal, gas and nuclear can be more easily matched with demand and thus they have a higher market value. An average MWh generated by coal is more valuable than an average MWh generated by VRE since a larger share of it is generated when demand is high due to the different shape of the production profiles. This relationship exists in all power systems independently if they are deregulated or not, but the analysis can be best performed where hourly price and generation data is available. Furthermore, the relationship is dynamic, at lower penetration rates the value of VRE is high and thus integration costs are negative or minimal.

As the penetration of these technologies increases, the market value of VRE decreases (Figure 11). This relationship has implications for replacing dispatchable generation technologies with VRE. In this respect, the cost (per unit of CO2) of replacing the generation of electricity from a coal plant must consider the value of that electricity to the grid. At lower penetration levels an average MWh produced by VRE is more valuable than that produced by coal plants, but this relationship reverses with increasing shares of VRE. The exact value of the value factor depends on how flexible an electricity system is, namely if it has more flexible capacity, such as gas and hydro. Empirically, we can observe that systems with higher shares of hydro and gas generation have lower costs of integration expressed by value factors closer to 1.

Figure 11. Value factor of wind and solar in Germany from 2001 to 2020



Source: *Adapted from Hirth (2013).*

This type of analysis is easily performed in deregulated markets where price and generation data are readily available. In a regulated market, such as China, a set of assumptions was used based on research performed on various deregulated markets. We have analysed the value factor of solar, wind and coal in 2019 in five European markets. These markets are Germany, Poland, Netherlands, Czech Republic, Poland and Romania. Figure 12 shows the differences in the value factor of coal, solar and wind in different markets that have varying degrees of coal, wind, solar and hydro generation. The highest value of coal power is observed in Germany, 1.19, which has the highest share of VRE generation. While the value factor of coal is 1.03 in Poland where coal represents 73% of generation. Based on this research and the share of various generation capacity, we have used the value factors of coal observed in various EU countries as proxies for what would be the value factor of coal in Chinese provinces.

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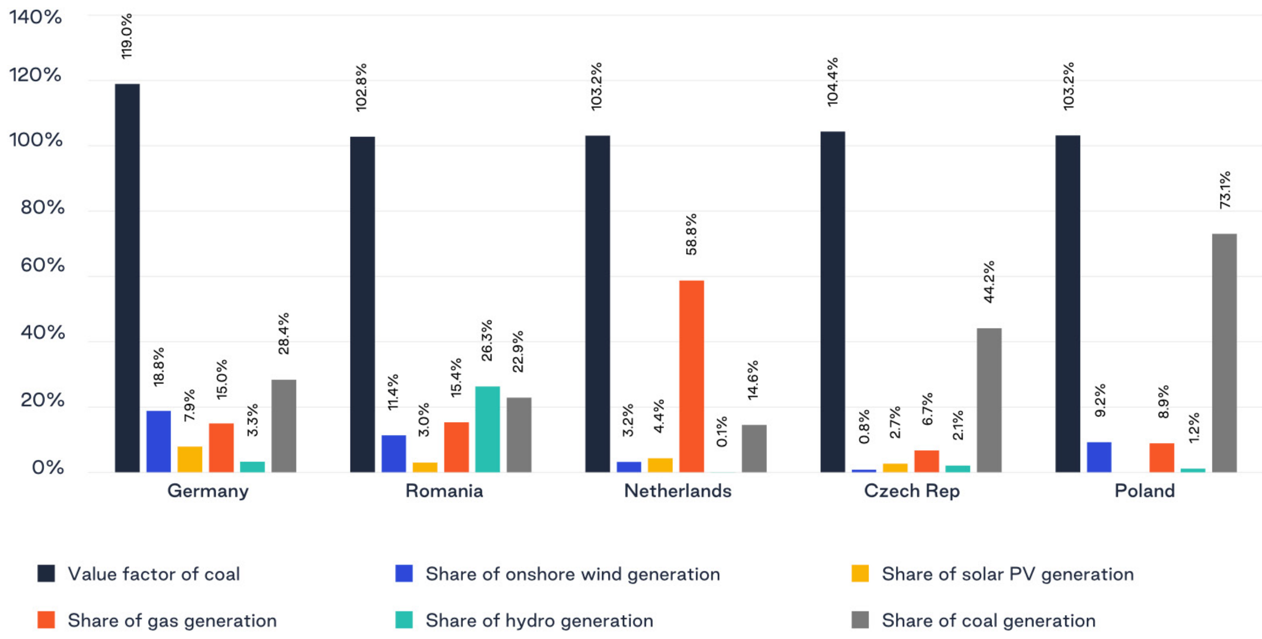
Figure 12: Value factor of coal, wind and solar in various EU countries



Source: TransitionZero based on ENTSO-E

Calculation steps

1. Using inventory data from S&P's World Electric Power Plants (WEPP) database, we calculated the total annual generation of coal plants for 20 years by multiplying capacity with capacity factors and the number of hours in a year.
2. Annual FOM were calculated by multiplying generation with fixed costs per MWh for 20 years.
3. Annual VOM was calculated by multiplying generation with variable costs per MWh for 20 years.
4. Fuel costs were calculated by multiplying generation with fuel costs per MWh for 20 years.
5. The value factor of coal was proxied from the EU based on VRE and fossil fuel capacity in Chinese provinces. These vary between 1.03 to 1.19.
6. The replacement technology was chosen based on the existing wind and solar in the region, namely a region that had more wind was assigned wind capacity to replace coal, while a region with more solar was assigned solar as replacing capacity.
7. The capacity of solar and wind to replace coal generation was calculated based on the total coal generation needed, the market value of coal and the highest capacity factor of solar or wind respectively in the region.
8. Fixed O&M costs of solar and wind are assumed to be 1% of CAPEX per year and were calculated for 20 years.
9. Investment costs of renewable energy capacity were taken from IRENA (2020).
10. CO2 emissions of coal generation were assumed to be 0.979 tons per MWh in line with China Energy Portal (2020). Total CO2 emissions to be abated is calculated based on 20 years of generation.
11. Marginal abatement costs are calculated as the investment costs of solar/wind assets plus 20 years FOM costs minus the FOM, VOM and fuel costs of 20 years coal generation divided by CO2 emissions over 20 years.

Caveats

The marginal abatement cost methodology presents an undiscounted and static calculation that does not take into consideration the changing dynamic of the market value of electricity when coal capacity is removed from the generation stack. This method finds that if all coal capacity were replaced with wind and solar, the abatement cost would be negative $20/tCO2. All else equal, the marginal abatement costs increase with every single unit that is taken out of the system, as shown in the difference in the market value of coal in Poland versus Germany. But everything is not equal for a number of reasons. For example, the replacement technologies, wind and solar, are still declining in cost. For this reason we believe these cost declines will more than offset the increased market value of coal. We are aware that the model's implicit assumption – namely that coal can be fully replaced by wind and solar – has hard limits. Future iterations will be based on systems planning modelling, which captures the spatial and temporal nature of electricity grids.

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Appendix 3. Calculating ETS fundamentals

Coal plants

The calculation of allowances for coal power plants come from two primary data sources. Firstly, the GEM's Global Coal Plant Tracker and S&P's WEPP database. Secondly, a detailed translation of the official Chinese document with guidelines to calculate the permits allocated to each coal plant is sourced from China Energy Portal (2019). Capacity factor data for Chinese coal plants are taken from work conducted by TransitionZero, while data on cooling technologies is taken from WEPP. The total number of permits allocated involves four steps:

1. The total generation in MWh, calculated using capacity factor data.
2. Reference value of CO2 ton per MWh of 0.979 ton CO2/MWh for plants lower than 400 MW, 0.877 ton CO2/MWh for plants higher than 400 MW and 1.146 for circulating fluidised bed units.
3. Correction factor for cooling technology: 1 = water cooling; and 1.05 = air cooling.
4. Correction factor for capacity factor derived using the formula 1.015^(16-20*CapacityFactor).

The number of allowances for each plant for 2018 are calculated using a correction factor of 0.7 as indicated in the guidelines while in 2019 no correction factor is applied.

Combined heat and power plants

To estimate the heat generated at the plant level, we use the heat and steam in GJ generated in 2019 and divided it by the installed capacity of CHP plants to derive the GJ/MW of heat produced. Heat generation data was sourced from the China Statistical Yearbook (2019). We assumed that every CHP plant produces the same amount of heat per MW. Furthermore, we assumed a 2% increase of heat generation in 2019 and 4% in 2020 in line with data from WIND. The total number of permits allocated involves two steps:

1. Reference value of CO2 ton per GJ of heat produced – 0.126.
2. Heat supply calculated as GJ/MW assumed multiplied by the installed capacity of the plant.

Coal and CHP permit allocations

In order to get a total number of permits, we added the power permits and the heat permits to derive a single estimate for the number of permits allocated in 2019 and 2020.

Gas plants

The same data sources for coal power plants are used for gas. The total number of permits allocated involves four steps:

1. The total generation in MWh, calculated using capacity factor data.
2. Reference value of CO2 ton per MWh of 0.392.
3. Correction factor for cooling technology - 1.05 for the entire fleet.
4. Correction factor for heat supply in case of CHP plants calculated as a function of electricity generation and heat supply based on a formula provided by the emissions guideline calculations document.

The number of allowances for each plant for 2018 are calculated using a correction factor of 0.7 as indicated in the guidelines while in 2019 no correction factor is applied.

Combined heat and power plants

To estimate the heat generated at the plant level, we use the total heat and steam in GJ generated and divide it by the installed capacity of CHP plants to derive the GJ/MW of heat produced. Heat generation data was sourced from the China Statistical Yearbook (2019). We assumed that every CHP plant produces the same amount of heat per MW. We also assumed a 2% increase in heat generation in 2019 and 4% in 2020 in line with data from WIND. The number of permits for the heat component of combined heat and power plants involves two steps:

1. Reference value of CO2 ton per GJ of heat produced – 0.059.
2. Heat supply calculated as GJ/MW assumed multiplied by the installed capacity of the plant.

The permits for 2018 are calculated using a correction factor of 0.7 as indicated by the guidelines, while those for 2019 are not corrected.

Gas and CHP permit allocations

We added the power permits and the heat permits to derive a single estimate for the number of permits allocated in 2019 and 2020.

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