Global Coal Economics Report and Portal

Methodology document

November, 2018

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.

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Table of Contents

1 Introduction to the Global Coal Economics Model 1
2 Asset economic modelling 3
2.1 Inputs 3
2.2 Dispatch Supply Cost Curve and the Uniform Clearing Price 4
2.3 The cost of coal and fuel transport model 6
2.4 Profitability 7
3 Market Scenario Analysis 8
4 Below 2°C scenario analysis 10
4.1 The phaseout of the coal-fired power fleet 10
4.2 Stranded asset risk 11
5 Limitations 12
6 Country level inputs 14
7 Appendix – Methodology Overview 28
8 References 29

1 Introduction to the Global Coal Economics Model

This document explains Carbon Tracker's methodology of its proprietary global coal asset economic model, which underpins both the *Global Coal Asset Economics* report and the *Global Coal Asset Economics Portal*[1].

The global asset-level coal economics model represents a set of fourteen regional techno-economic models, which inform Carbon Tracker's asset-level modelling, market scenario analysis (see Section 3) and below 2°C scenario analysis (see Section 4).

The model covers approximately 95% of global installed thermal coal-fired capacity in operation (approximately 1,900GW) and those in construction due to come online by 2022. The regions studied in this report are: China[2], the United States (US), India, the European Union (EU28)[3], Russia, Japan, South Africa, South Korea, Indonesia, Australia, Ukraine, Turkey, Vietnam and the Philippines. Table 1 below illustrates the installed coal-fired power capacity included in the model by country/region, both in operation in 2018 and estimated to be in operation by 2022.

TABLE 1 - INSTALLED CAPACITY OF COAL-FIRED POWER GENERATION ACROSS MODELLED COUNTRIES IN 2018 AND 2022

	IN OPERATION IN 2018		IN OPERATION IN 2022		
Country/region	Installed Capacity (GW)	% of Global Installed Capacity	Installed Capacity (GW)	% of Global Installed Capacity	Change (GW)
China	958.01	50.36	1,036.99	51.22	78.97
United States	260.92	13.72	252.16	12.45	-8.76
India	233.76	12.29	256.76	12.68	23.00
EU28	155.18	8.16	148.44	7.33	-6.74
Russia	48.69	2.56	48.69	2.40	0.00
Japan	45.17	2.37	51.04	2.52	5.87
South Africa	42.10	2.21	48.45	2.39	6.35

[1] *See www.carbontracker.com/reports/coal-portal*

[2] *Including Hong Kong*

[3] *Austria, Bulgaria, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, UK*

South Korea	37.94	1.99	41.50	2.05	3.56
Indonesia	29.98	1.58	41.13	2.03	11.14
Australia	24.84	1.31	24.84	1.23	-
Ukraine	20.75	1.09	20.75	1.02	-
Turkey	18.47	0.97	18.47	0.91	-
Vietnam	16.85	0.89	24.30	1.20	7.46
Philippines	9.60	0.50	11.16	0.55	1.56
TOTAL	**1,902.25**	**100.00**	**2,024.67**	**100.00**	**122.42**

Source: CoalSwarm, Global Coal Plant Tracker, July 2018 Update.

2 Asset economic modelling

To model the cost profile of individual coal-fired power units it requires a comprehsive, detailed and diverse number of datasets. The global asset-level coal economics model draws upon the most up-to-date and industry-leading data sources with regards to asset inventory data, asset performance data and technical, market and regulatory assumptions. This spans: pollution control technologies; recent unit capacity factors; fuel prices; fuel transport prices; and tariffs. National, regional or local policies governing environmental pollution, carbon prices, retirement schedules and market structures are also included. See Table 2 for a high-level snapshot of data and sources used (for country-specific data sources please refer to Section 6).

2.1 Inputs

The primary asset-level inventory data builds on the CoalSwarm Global Plant Coal Tracker database (July 2018 update)[4]. The scope of the coal-power plants included in this study represent those plants that are in operation and those expected to be completed by the end of 2018. In addition, the plants that are in construction and are estimated to be completed over 2019 to 2022 have also been included. Those plants in construction with no estimated start year in the CoalSwarm database have been excluded from this analysis, as have plants that have an installed capacity of less than 30MW. See the Appendix for high-level illustration of the methodology.

TABLE 2 - UNIVERSAL PARAMETERS IN THE GLOBAL COAL ECONOMICS MODEL

PARAMETER	SOURCE	DETAILS
Plant-level characteristics	CoalSwarm; National reports, statistics and databases	Name; Location; Installed Capacity; Unit Status; Year of operation; Parent organisation; Sponsor organisation; Combustion technology type; Coal type; Heat rate; Emissions factor
Cooling type and pollution control technologies by plant	Platt World Electric Power Plant Database; Consultancy reports	Installed environmental control technologies for NOx, SO2 and PM; Cooling technology
Fixed Operations & Maintenance (FOM) costs	IEA; National reports, statistics and databases; Consultancy reports	Cost per kW. The fixed cost assumptions included in this report depend on the combustion technology of the unit: $7.79/kW for subcritical; $10.39/kW for supercritical; $11.87/kW for ultra-supercritical; $18.37/kW for integrated gasification combined cycle (IGCC); and $10.39/kW for circulating fluidized bed (CFB).
Non-fuel Variable Operations and Maintenance (VOM) costs	IEA; National reports, statistics and databases; Consultancy reports	Cost per MWh or cost per kW. The variable costs we used depend on the size of the unit: 0-100 MW ($4.49/MWh), 100-300 MW ($3.59/MWh) and 300 MW or more ($3.37/MWh).

[4] *For further information about the Global Coal Plant Tracker, see https://endcoal.org/global-coal-plant-tracker/*

Fuel Type	CoalSwarm; IEA; WoodMackenzie Coal Supply Data; National reports, statistics and databases; Consultancy reports	Se Fuel Transport Model
Capacity Factor	National reports, statistics and databases; Consultancy reports	Granularity by asset or region in country, depending on country. Capacity yet to come online assumes a regional average.
International Coal Balances	UN Comtrade; IEA; National reports, statistics and databases	See Fuel Transport Model
Fuel cost	Wood Mackenzie; National statistics, reports; Country experts; Consultancy reports	See Fuel Transport Model
Fuel transport cost	National reports, statistics and databases	See Fuel Transport Model
Carbon Price	ICAP, National reports, statistics and databases	-
Combustion efficiency	IEA; WoodMackenzie Coal Supply Data; Consultancy reports	Gross, Low Heating Value (LHV)
Efficiency adjustments from cooling, age and pollution controls	EIA; IEA, Ecofys	Adjustments made to the overall combustion efficiency of the plant
Environmental control technology capital and operational costs	US EPA; National reports, statistics and databases; Consultancy reports	Capex ($/kW), Fixed Operations and Maintenance ($/kw-yr) and Variable Operations and Maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.
Pollution limit regulations	IEA; National reports, statistics and databases	-
Plant revenues	National reports, statistics and databases; Consultancy reports	Includes wholesale prices, regulated tariffs and various out-of-market revenues, where applicable.
Macroeconomic data	OECD; IMF; Bloomberg	All values are represented in 2018 USD
Country/Regional Grids	National reports, statistics and databases; Local experts	Dependent on whether an electricity grid in a country or region is administered by different system operators
Unabated coal-fired power generation pathways	IEA Beyond 2°C Scenario (B2DS)	Specified for most countries, apportioned from region level where appropriate by share of existing coal capacity otherwise.

2.2 Dispatch Supply Cost Curve and the Uniform Clearing Price

There are a number of factors to consider when calculating the costs of a coal-fired power plant. The operating cost can be categorised in two ways: short-run and long-run operating costs.

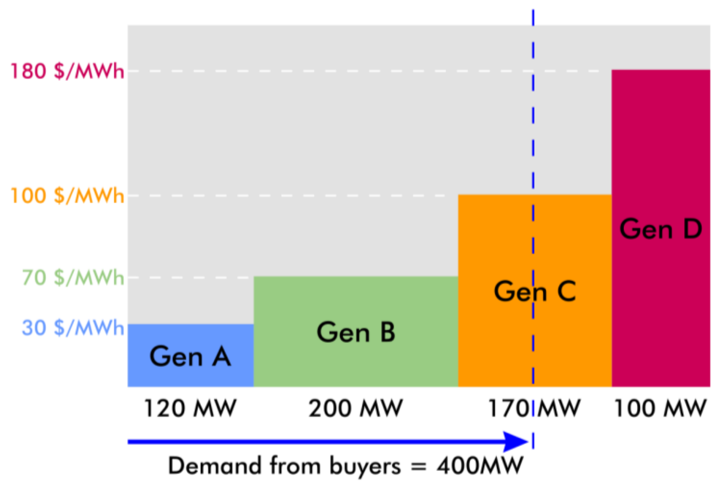
The short-run operating cost of a coal unit and include: fuel, carbon (where applicable) and variable operations and maintenance (O&M) cost. Fuel costs include the cost of buying, transporting and preparing the coal. There are different types of coal which vary in cost depending on the energy content. 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 short-run operating cost 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. In China, for example, coal units have historically been given guaranteed hours and therefore are not dependent on operating costs. Figure 1 below presents a stylised cost curve based on short-run operating cost.

FIGURE 1 – STYLISED SHORT-RUN MARGINAL COST (SRMC) CURVE FOR EXISTING OPERATING COAL-FIRED POWER GENERATION



Source: Carbon Tracker

Long-run operating costs include short-run operating costs plus fixed O&M and any capital additions from meeting environmental regulations. Fixed costs include the costs 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 short-run operating costs govern dispatch decisions, the long-run operating costs impact the bottomline[5].

2.3 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 to 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[6] 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 transport of coal, a distance-optimised route algorithm has been developed, which calculates the distance between a unit's demand 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.

2.3.1 Inputs

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

[5] *For more information, refer to* https://www.carbontracker.org/understanding-operating-cost-coal-fired-power-us-example/

[6] *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

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.

- **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 transport 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.

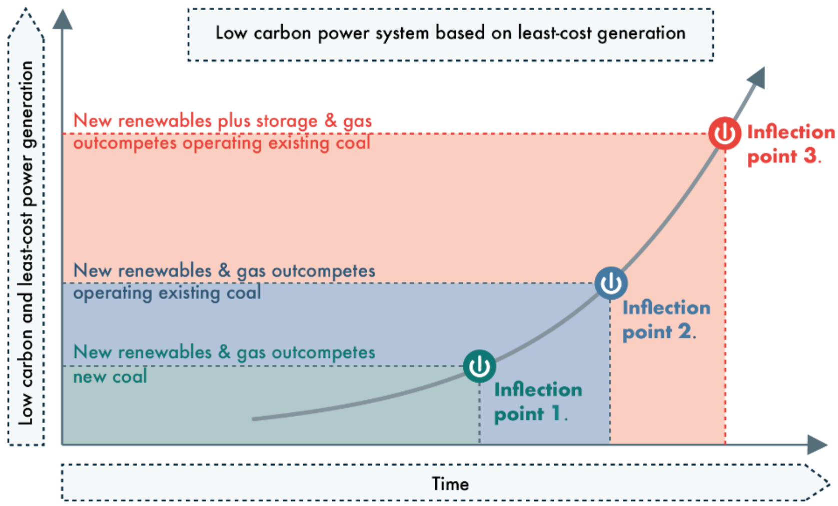
2.4 Profitability

Lastly, another principal output from the asset economic modelling is the asset-level gross profitability. Gross profitability is defined as revenues from in-market (i.e. wholesale power markets) and out-of-market (i.e. ancillary and balancing services and capacity markets) sources minus the long-run operating costs (see above).

3 Market Scenario Analysis

As detailed in the report, we list three economic inflection points that policymakers and investors will need to look at to provide the least-cost power and avoid stranded assets. These are as follows: 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. This can be referred to in Figure 2.

FIGURE 2 – THE INTERSECTION BETWEEN THE ECONOMIC INFLECTION POINTS AND THE POLICYMAKING PROCESS FOR A LEAST-COST POWER SYSTEM



Source: Carbon Tracker

The market scenario analysis compares the long-run operating cost of coal with the levelised cost of energy (LCOE) of new onshore wind and utility-scale solar PV[7] (the second inflection point above). LCOE is a standard analytical tool used to compare power generation technologies and is widely used in power market analysis and modelling[8]. While the limitations of using generic LCOE analysis for understanding the economics of power generation have been well documented, this provides 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.

The LCOE is simply the sum of all costs divided by the amount of generation. The costs include capital costs, capital recovery factor, fixed O&M, variable O&M, fuel and carbon. We use 2018 LCOE estimates for onshore wind and solar PV are predominantly

[7] *This analysis highlights the competition from utility-scale PV and onshore wind. We acknowledge that there are a range of other competing renewable electricity technologies as well as other power generation sources that can be noted, particularly on a regional basis. For purposes of comparability we have chosen these.*

[8] *For more information refer to* https://www.nrel.gov/analysis/tech-lcoe-documentation.html

from Bloomberg NEF[9]. We apply country learning rates based on the forecasted deployment of utility-scale solar PV and onshore wind in Bloomberg NEF's New Energy Outlook (NEO) 2018[10].

[9] *LCOE estimates were sourced from Bloomberg NEF. 2018 LCOE data estimates were sourced from either the New Energy Outlook 2018, Country Profiles or 2H 2018 LCOE Data Viewer. For 2019 onwards, LCOE data was sourced from the aforementioned Bloomberg NEF sources, with the exception of Russia, South Africa, Ukraine and Vietnam which are Carbon Tracker estimates. The EU is based on an unweighted average from relevant countries in New Energy Outlook 2018. For more information, see: https://www.carbontracker.org/data-sources-and-disclaimers-interactive-portal/*

[10] *See https://about.bnef.com/new-energy-outlook/*

4 Below 2°C scenario analysis

In order to comply with the target of "well below 2 degrees" set out by the Paris Agreement in 2015, power generation along with other sectors will need to decarbonise dramatically over the coming decades. As a relatively carbon intensive fuel, unabated coal-fired power generation bears the brunt of this decline.

4.1 The phaseout of the coal-fired power fleet

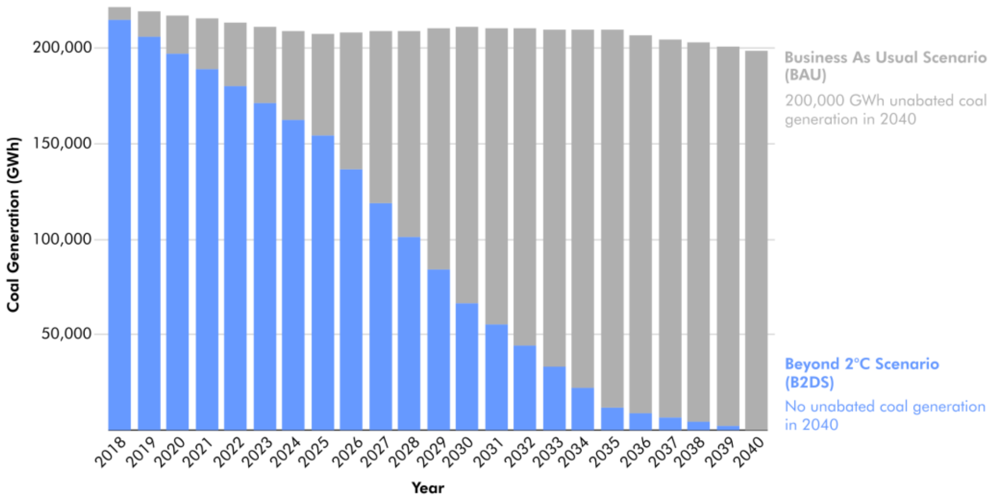
The regional coal asset economics models are informed by country or regional coal-fired power generation pathways set out by the IEA Below 2 Degrees Scenario (B2DS)[11], seen as consistent with a below 2˚C pathway which aims to achieve a 1.75°C temperature limit. This scenario presents a reputable and ambitious scenario with regional granularity. The model uses coal-fired power generation in 2017 as a baseline and requires that the volume of coal-fired electricity generated declines in line with the allocated generation prescribed for each individual country or region. For example, Figure 3 illustrates the required decline in coal-fired power generation in South Africa (in blue) versus the projected generation incorporating only those policy commitments in place today (grey). Where results are not given for individual countries in the B2DS, a proportionate decline in coal-fired electricity generation is derived from a related region[12].

FIGURE 3 - UNABATED COAL-FIRED POWER GENERATION IN SOUTH AFRICA IN THE B2DS VS BAU, 2018-2040[13]

11 The Beyond 2°C Scenario (B2DS) provides a rapid decarbonisation pathway in line with international policy objectives out to 2060. See the IEA's Energy Technology Perspectives (ETP) 2017 report at https://www.iea.org/etp/.

12 for example, Vietnam assumes the proportionate decline of ASEAN coal-fired power generation

13 Data points are interpolated between the five-year periods provided in the IEA B2DS. Similar to the NPS in the World Energy Outlook, the RTS refers to the Reference Technology Scenario, which provides a baseline scenario for current policy commitments.



Source: IEA

As coal-fired power generation declines in the B2DS across all regions, less coal-fired power stations are able to provide electricity to the grid. As a result, we rank the cost competitiveness of plants per year and phase out plant units that are either least profitable or most costly, depending on whether they are situated in a liberalised market or a regulated market. As such, those plants that are most costly in a given year are phased out until the aggregated asset level generation for a given year is below the prescribed limits set out in the B2DS. Ultimately, this informs a phase out year per plant unit.

4.2 Stranded asset risk

The stranded asset risk in our below 2°C scenario is defined as the difference between the net present value (NPV) of revenues in a BAU scenario (which is based on retirements announced in company reports) and a scenario consistent with the temperature goal in the Paris Agreement (which phases-out all coal power in line with the B2DS). The retirement schedules are developed based on gross profitability, if a liberalised market, or long-run operating cost, if a regulated market. Underlying this analysis is the logic that in the context of efforts to reduce carbon emissions and demand for coal power, the least economically-efficient coal power generation will be retired first.

In liberalised markets, stranded asset risk is often low or negative as coal generators operating in liberalised markets are cashflow negative due to suppressed wholesale power prices from renewable energy, whilst also witnessing an increased cost profile due to carbon pricing or complying with environmental regulation in some regions. Stranded asset risk typically materialises with the shareholders of utilities. However in regulated markets, stranded asset risk is often high or positive as coal generators get a fixed rate of return regardless of market conditions. Stranded asset risk materialises with the state through either higher tax rates, greater debt levels or increased power prices.

5 Limitations

The global coal asset economics report is, as far as the authors are aware, the most comprehensive study made on the economics of coal-fired power generation to date.

While the modelling and analysis aims to utilise the most up-to-date and detailed data, there are a number of limitations given the comprehensive nature of the study. The principal limitations/caveats include:

- Many parameters and assumptions are subject to constant change. This includes a variety of policy, economic and technological assumptions. As a result, the portal will be updated on a periodic basis.
- Coal is traded and contracted in multiple ways, with supply contracts often not publicly available. We use spot prices for international trade using price indices from Wood MacKenzie and Bloomberg.
- If a plant is assumed to be required to install an environmental control technology, we do not factor in the reduction to the plant's utilisation.
- Coal-fired power plants can derive revenues through multiple grid services they provide. This is dependent from grid to grid, however can include wholesale pricing, capacity payments, regulated tariffs to name a few. This can also be traded over different periods. We aim to reflect this as accurately as possible using publicly available data and through conversations with local experts, however data provision or granularity can prohibit this in certain regions (such as visibility of PPAs).
- The methodology used assumes that markets are efficient, and that the projects with the lowest supply costs are used to satisfy demand on an aggregate basis over a period. Given the highly regulated nature of power markets, the cyclical nature of commodity markets and other factors that influence electricity prices, this may not be what is realised in reality.
- We only include environmental regulation and carbon pricing where it is implemented or has been approved and will be implemented in the future. These regulations frequently change.
- Besides carbon prices, we do not forecast commodity prices and use 1-3-year averages for our forward-looking estimates. In addition, we assume a continuation of plants based on 2018 statistics. We do not try and model the impact to coal from a system perspective, nor attempt to model the change to a plant's generation over time.
- We assume that coal-fired power will need to be phased out and do not make any explicit assumptions on the retrofitting of CCS to existing capacity. This is however incorporated in the IEA B2DS, upon which our climate scenario modelling is derived.
- Future costs do not take into consideration decommissioning, retirement or clean-up costs when they are phased out. Nor do we make assumptions on the technical lifetimes of coal plants.

- We do not adjust efficiency for atmospheric condition to coal plants. Instead thermal efficiencies of the plants are assumed by technology, age and adjustments from additional environmental control or cooling technologies.
- Several plants captured in the inventory data produce heat as well as electricity (Combined Heat and Power – CHP). We do not factor in the revenues derived from heat production and only capture the value delivered in the form of electricity.
- Captive plants, typically tied to a large industrial site, are treated in a similar fashion to all coal plants on the grid and will be phased out accordingly.

6 Country level inputs

In addition to the universal approaches outlined in Table 2, any additional approaches taken across each of the fourteen regions are detailed below

6.1.1 Australia

TABLE 3 – AUSTRALIA MODEL

PARAMETER	COMMENT	SOURCE
Asset-level generation	Realised annual capacity factors at the asset level for existing coal-fired power capacity from 2016.	Jacobs
International balances, fuel and fuel transport	We assume all coal is sourced domestically. Plant-level fuel, fixed operations and maintenance, variable operations and maintenance and transport of fuel costs are used.	UN Comtrade, WoodMackenzie Coal Supply Data, IEA, CoalSwarm, Jacobs, AEMO
Carbon prices	We assume no carbon pricing throughout the modelling horizon	-
Pollution limit regulations and associated capital and operational costs	We adopt a conservative view on future air pollution regulation and assume no additional capital costs for the installation of environmental control technologies across the fleet.	Country experts
Plant revenues	Annual volume weighted average spot prices (2017/18) among Queensland, New South Wales, Victoria, South Australia, Tasmania. An average has been derived for Western Australia in the absence of spot price data.	Australian Energy Regulator
National statistics for coal-fired power generation	We use 2017 data for coal-fired generation statistics. Coal-fired power generation is phased out on the basis of the National Electricity Market (VA, NSW, SA & Queensland) and South West Interconnected System (SWIS) (WA).	BP, IEA, AEMO

6.1.2 China

TABLE 4 – CHINA MODEL

PARAMETER	COMMENT	SOURCE
Asset-level generation	Average utilisation hours of thermal generation in 2015 by province. Plants in Yunnan, Shaanxi and Hong Kong assumes a national average	China Electricity Council (CEC)
International balances, fuel and fuel transport	Fuel costs are detailed by plant which uses a weighted average price considering coal supply contract type and volume of supply. We assume all thermal coal product types are sourced domestically and use provincial published coal tariffs.	Country experts, WoodMackenzie Coal Supply Data, IEA, Mining Atlas, CoalSwarm, Bloomberg
Carbon prices	Carbon prices are applied between 2018 – 2020 for Tianjin ($2.88/tCO2), Shanghai ($1.08/tCO2), Hubei ($2.49/tCO2), Guangdong ($2.00/tCO2) and Chongqing ($1.52/tCO2). Thereafter a carbon price of $5/tCO2 is assumed and increasing on a linear basis to $40/tCO2 by 2040.	ICAP, CTI estimates
Pollution limit regulations and associated capital and operational costs	We assume that plants without control technologies for SOx, NOx and/or PM will need to fit relevant controls by 2020. Domestics capital and operational costs are applied. Main Goals of Fully Implementing Ultra-Low Emission and High-Efficiency Retrofits for Coal-Fired Power Plants[14].	National Development and Reform Commission (NRDC), IEA, Country experts
Plant revenues	We incorporate provincial adjusted benchmark coal-fired power tariffs. We assume 0.4 €/MWh increase in the power price for every €1/t increase.	National Development and Reform Commission (NRDC), Country experts
National statistics for coal-fired power generation	We use 2017 data for coal-fired generation statistics. Coal-fired power generation is phased out by grid (Northwest, Central, North, Northeast, Southern and East)	BP, IEA

[14] *The authors received a translated version from Lauri Myllyvirta on October 4, 2018. Unavailable without request.*

6.1.3 EU

TABLE 5 – EU MODEL

PARAMETER	COMMENT	SOURCE
Asset-level generation	Obtained at asset-level for 2017. While more recent data exists, it was desirable to examine data over whole year periods to find average capacity factors. CO2 emissions and pollutant data was additionally obtained from the ETS transaction log.	European Network of Transmission System Operators for Electricity (ENTSO-E), EU Transaction Log
International balances, fuel and fuel transport	Fuel prices obtained from European supply hubs, transport costs estimated by CTI.	Bloomberg LP, CTI Estimates
Carbon prices	Current EU ETS prices taken with conservative forecast to 2030.	CTI estimate
Pollution limit regulations and associated capital and operational costs	The Industrial Emissions Directive and BREF regulations give emissions rates per pollutant. Capital and operational costs from EIA.	European Commission, EIA
Plant revenues	Calculated from country-level power tariffs, and out-of-market payments where appropriate. Balancing and ancillary services payments were assumed across the fleets	Bloomberg LP
National statistics for coal-fired power generation	We use 2017 data for coal-fired generation statistics for the EU.	BP, IEA

6.1.4 India

TABLE 6 – INDIA MODEL

PARAMETER	COMMENT	SOURCE
Asset-level generation	Realised annual capacity factors at the asset level for existing coal-fired power capacity from 2017.	CEC
International balances, fuel and fuel transport	Fuel costs vary depending on plant's location. Coal supplying regions supply 100% of demand locally, some regions can meet a portion of demand while others rely on coal from coal supplying regions	Country experts, WoodMackenzie Coal Supply Data, IEA, Mining Atlas, CoalSwarm
Carbon prices	We assume no carbon pricing throughout the modelling horizon	-
Pollution limit regulations and associated capital and operational costs	We assume capital and operational costs associated with the installation of control technologies for particulate matter (PM) and Nitrous Oxides (NOx) controls for all existing plants that do not have installed over 2019-2023.	Country experts
Plant revenues	India Plant Tariffs 2014-15 from Government of India Power Sector Report - Scraped from CEA Government PDF	India Central Electricity Authority
National statistics for coal-fired power generation	We use 2017 data for coal-fired generation statistics. Coal-fired power generation is phased out by grid (Northern, Western, Eastern, Southern and North Eastern)	BP, IEA

6.1.5 Indonesia

TABLE 7 – INDONESIA MODEL

PARAMETER	COMMENT	SOURCE
Asset-level generation	Realised 2017 average capacity factors at provincial level for existing capacity across energy sources.	PLN
International balances, fuel and fuel transport	Producing areas of Kalimantan and Sumatra use local coal transported by road. Plants located on the islands of Papua, Java-Bali, Sulawesi and Nusa Tengara source their coal from Kalimantan via seaborne and land routes.	UN Comtrade, WoodMackenzie Coal Supply Data, IEA, Mining Atlas, CoalSwarm, Ports.com, CoalTrans
Carbon prices	We assume no carbon pricing throughout the modelling horizon	-
Pollution limit regulations and associated capital and operational costs	We adopt a conservative view on future air pollution regulation and assume no additional capital costs for the installation of environmental control technologies across the fleet.	IEA
Plant revenues	Provincial tariffs are used as per the MoEMR Regulation No. 19/2017 provisions on tariffs, with limited visibility on PPAs.	PLN, PwC
National statistics for coal-fired power generation	2017 data for coal-fired generation statistics. The phaseout of coal in Indonesia and follows the ASEAN phaseout pathway in the B2DS, based on its current proportional share of coal-fired power generation. Coal is phased out across Java-Bali, Kalimantan, Papua, Sulawesi and Nusa Tenggara based on current production shares.	BP, IEA

6.1.6 Japan

TABLE 8 – JAPAN MODEL

PARAMETER	COMMENT	SOURCE
Asset-level generation	In the absence of asset-level generation we derive implied capacity factors from CO2 emissions per plant, using standardised emissions factors.	Renewable Energy Institute Japan, IPCC
International balances, fuel and fuel transport	We assume anthracite, bituminous and sub-bituminous coal is imported from Australia (Port of Newcastle), Indonesia (Mahakam River) and Russia (Port of Vladivostok) via seaborne routes to Fukuyama terminal and then land routes to plant. Export price indices are used from the three regions, where a weighted average is calculated.	UN Comtrade, WoodMackenzie Coal Supply Data, IEA, Mining Atlas, CoalSwarm, Ports.com
Carbon prices	We assume no carbon pricing throughout the modelling horizon	-
Pollution limit regulations and associated capital and operational costs	We assume capital and operational costs associated with the installation of control technologies for particulate matter (PM) and Nitrous Oxides (NOx) controls for all existing plants that do not have installed over 2019-2023.	IEA
Plant revenues	We assume a regulated tariff is set so that the electricity sales are equal to the cost of producing electricity, including fuel cost, fixed and variable operations and maintenance plus regulated return.	Country expert
National statistics for coal-fired power generation	We use 2017 data for coal-fired generation statistics. The phaseout of coal-fired power happens across the major regional grids of Chūbu, Chūgoku, Kansai, Hokkaido, Kansai, Shikoko, Kyūshū, Tokyo and Tohoku.	BP, IEA, Thomson Reuters Practical Law

6.1.7 The Philippines

TABLE 9 – THE PHILIPPINES MODEL

PARAMETER	COMMENT	SOURCE
Asset-level generation	Realised 2017 regional capacity factors of coal-fired power plants in the Philippines	Philippine Department of Energy
International balances, fuel and fuel transport	We use export coal price benchmarks from Wood Mackenzie assuming hard coal and lignite is imported from Indonesia to plants in Luzon, Visayas and Mindanao	UN Comtrade, WoodMackenzie Coal Supply Data, IEA, Mining Atlas, CoalSwarm, Ports.com, IEEFA
Carbon prices	We assume no carbon pricing throughout the modelling horizon	-
Pollution limit regulations and associated capital and operational costs	We adopt a conservative view on future air pollution regulation and assume no additional capital costs for the installation of environmental control technologies across the fleet.	IEA
Plant revenues	Average monthly prices per region (Luzon, Visayas) from the Philippine Wholesale Electricity Spot Market (WESM) with limited visibility on PPAs. Midanao uses a national average.	Philippine WESM
National statistics for coal-fired power generation	2017 data for coal-fired generation statistics. The phaseout of coal in the Philippines follows the ASEAN phaseout pathway in the B2DS, based on its current proportional share of coal-fired power generation. Coal is phased out across Luzon, Visayas and Mindanao based on current production shares.	Philippine Department of Energy, BP, IEA

6.1.8 Russia

TABLE 10 – RUSSIA MODEL

PARAMETER	COMMENT	SOURCE
Asset-level generation	In the absence of asset-level generation, or coal-fired generation, we use 2017 realised thermal capacity factors for each of the principal regional power systems	Joint-Stock Company System Operator of the Unified Energy System (JSC SO UES)
International balances, fuel and fuel transport	We assume all thermal coal product types are sourced domestically and transported by train using a distance-optimised algorithm	UN Comtrade, EIA, WoodMackenzie Coal Supply Data, IEA, Mining Atlas, CoalSwarm
Carbon prices	We assume no carbon pricing throughout the modelling horizon	-
Pollution limit regulations and associated capital and operational costs	We adopt a conservative view on future air pollution regulation and assume no additional capital costs for the installation of environmental control technologies across the fleet.	Country experts
Plant revenues	For those plants that belong to Price Zones 1 and 2, we assume that 60% of revenues are derived from the electricity sales, 90% of which derive from sales into the wholesale market and 10% from direct contracts. An annual average of daily wholesale prices in 2017 was used for both price zones. The other 40% of revenues are assumed to derive from capacity payments. Plants outside Price Zone 1 and 2 receive regulated tariffs that are based on cost-recovery plus a regulated return.	Trade System Administrator of the Russian Wholesale Electricity Market, Country Experts
National statistics for coal-fired power generation	2017 data for coal-fired generation statistics. Coal-fired power generation is phased out for each of the seven regional power systems. For those locations which don't have an apparent connection to these systems they assume a contained system. This includes MES Siberia, MES Center, Khabarovsk, MES North-West, MES East, MES Urals, MES South, Magadan, Chukotka Autonomous Okrug, Irkutsk, Sakha Republic, Amur, Sakhalin and Kaliningrad Oblast.	BP, IEA, Country experts

6.1.9 South Africa

TABLE 11 – SOUTH AFRICA MODEL

PARAMETER	COMMENT	SOURCE
Asset-level generation	Realised average annual capacity factors at the asset level over 2014-16, or regional averages in the absence of asset-level data.	Country experts
International balances, fuel and fuel transport	Fuel costs are detailed by plant which uses a weighted average price considering coal supply contract type and volume of supply. We assume all thermal coal product types are sourced domestically.	Country experts, WoodMackenzie Coal Supply Data, IEA, Mining Atlas, CoalSwarm, Dentons
Carbon prices	We assume no carbon pricing throughout the modelling horizon	-
Pollution limit regulations and associated capital and operational costs	We incorporate the capital and operating costs of control technologies and timing of the planned installation of environmental control technologies for those applicable. For other plants we adopt a conservative view on future air pollution regulation and assume no additional capital costs for the installation of environmental control technologies across the fleet. We do however source local operation and maintenance costs for South Africa.	Meridian Economics, Eskom Emission Reduction Plan
Plant revenues	Tariff assumes electricity tariff from Eskom revenue application 18/19	National Energy Regulator of South Africa
National statistics for coal-fired power generation	We use 2017 data for coal-fired generation statistics. Coal-fired power generation is phased out nationally.	BP, IEA

6.1.10 South Korea

TABLE 12 – SOUTH KOREA MODEL

PARAMETER	COMMENT	SOURCE
Asset-level generation	Realised annual capacity factors at the asset level for existing coal-fired power capacity from 2016.	KEPCO
International balances, fuel and fuel transport	We assume anthracite, bituminous and sub-bituminous coal is imported from Australia, Indonesia and Russia via seaborne and then land routes to plant	UN Comtrade, WoodMackenzie Coal Supply Data, IEA, Mining Atlas, CoalSwarm, Ports.com
Carbon prices	Carbon pricing 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; Phase 3 (2021-2025) 10% auctioned	ICAP
Pollution limit regulations and associated capital and operational costs	Air pollution regulation incorporates both regulatory and consulted standards and applies the most stringent. We adopt a conservative view on future air pollution regulation and assume no additional capital costs for the installation of environmental control technologies across the fleet.	IEA, Country expert
Plant revenues	In-market and out-of-market payments are incorporated in the form of: Scheduled Energy Payment (SEP); Constrained-On Energy Payment (CON), Trading Period Capacity Payment (TPCP); Constrained-Off Energy Payment (COFF); Renewable Portfolio Standard Payment (RPS); Emission Trading Payment (ETP); Local Resources Tax Payment (LTP); and Operation cost of preventive facilities.	Solutions for Our Climate, Country expert
National statistics for coal-fired power generation	We use 2017 data for coal-fired generation statistics. Coal-fired power generation is phased out nationally.	BP, IEA

6.1.11 Turkey

TABLE 13 – TURKEY MODEL

PARAMETER	COMMENT	SOURCE
Asset-level generation	Realised annual capacity factors at the asset level for existing coal-fired power capacity from 2012-16.	Country experts, Enerji Atlas
International balances, fuel and fuel transport	We assume Turkey import hard coal from Colombia and Russia via seaborne and land routes to plant. Lignite is sourced domestically.	UN Comtrade, WoodMackenzie Coal Supply Data, IEA, Mining Atlas, CoalSwarm, Ports.com
Carbon prices	We assume no carbon pricing throughout the modelling horizon	-
Pollution limit regulations and associated capital and operational costs	We adopt a conservative view on future air pollution regulation and assume no additional capital costs for the installation of environmental control technologies across the fleet.	Country experts
Plant revenues	For those plants eligible, plant-level revenues derive from TETAŞ's power purchase tariffs and an average of day-ahead market prices. For İSKEN and Çayırhan plants, we use TETAŞ's power purchase figures. For those plants applicable, capacity payments are provided by the system operator TEİAŞ and adjusted for plants with imported or domestic fuel.	TETAŞ, TEİAŞ, country experts
National statistics for coal-fired power generation	2017 data for coal-fired generation statistics. Coal-fired power generation is phased out nationally.	BP, IEA

6.1.12 Ukraine

TABLE 14 – UKRAINE MODEL

PARAMETER	COMMENT	SOURCE
Asset-level generation	Realised annual capacity factors at the asset level for existing DTEK coal-fired power capacity from 2017. Other plants take company level or an regional average of generation.	DTEK, Country experts
International balances, fuel and fuel transport	We assume ARA + transport tariff for all plants as adopted for steam coal by the National Commission for State Regulation of Energy and Public Utilities of Ukraine	Country experts, IEA
Carbon prices	We assume no carbon pricing throughout the modelling horizon	-
Pollution limit regulations and associated capital and operational costs	We incorporate the installation schedule of pollution control technologies from the national plan for reducing emissions from large combustion plants set out by the Ukrainian Ministry of Energy and Coal Industry	Ukrainian Ministry of Energy and Coal Industry
Plant revenues	An average of a 12-month trailing price (Aug 2017 to Jul 2018) from the Ukrainian Wholesale Electricity Market was used.	Energorynok
National statistics for coal-fired power generation	We use 2017 data for coal-fired generation statistics and incorporate existing retirement schedules. Coal-fired power generation is phased out nationally.	BP, IEA, Ukrainian Ministry of Energy and Coal Industry

6.1.13 US

TABLE 15 – US MODEL

PARAMETER	COMMENT	SOURCE
Asset-level generation	Generation and air pollutant quantities obtained at asset-level from the Environmental Protection Agency (EPA) Continuous Emissions Monitoring Service	EPA CEMS
International balances, fuel and fuel transport	Fuel costs at asset level found from EIA form data, including transport and cleaning.	EIA
Carbon prices	RGGI costs included for applicable states, forecasts from CTI estimates. Otherwise none.	CTI Estimate
Pollution limit regulations and associated capital and operational costs	EPA and regulations associated with the Clean Air Act specifies limits for pollutant emissions rates. Capital and operational costs from EIA.	EPA, EIA
Plant revenues	Estimated from regional power tariffs. In our report 'No Country for Coal Gen' on stranded value of USA coal owners, we assessed regulated unit revenues calculated against the rate base - the undepreciated value of the asset. For this assessment we have taken the merchant unit approach for all units for comparability reasons.	EIA Form data
National statistics for coal-fired power generation	We use 2017 data for coal-fired generation statistics for the US.	BP, IEA

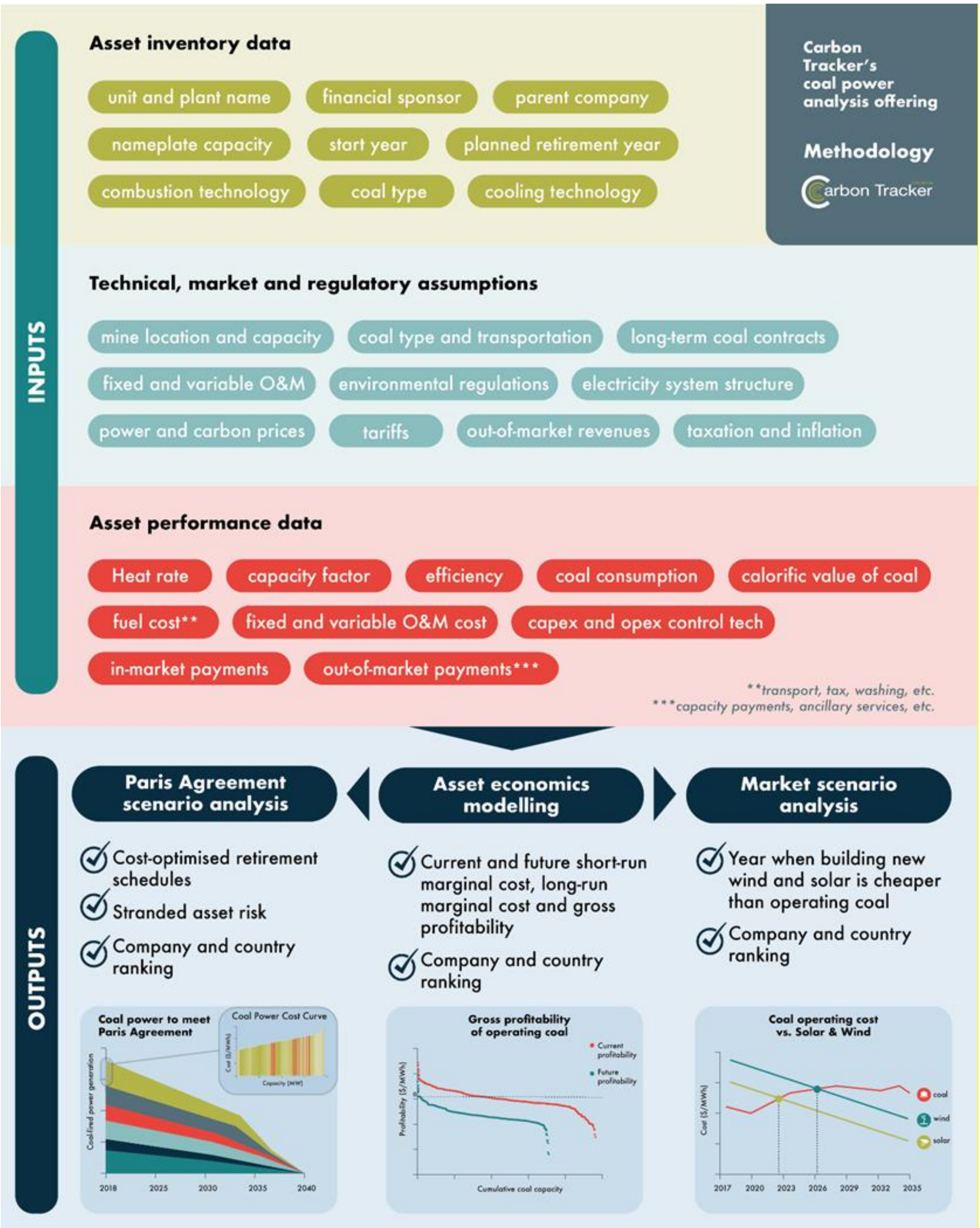
6.1.14 Vietnam

TABLE 16 – VIETNAM MODEL

PARAMETER	COMMENT	SOURCE
Asset-level generation	Realised 2014 capacity factors of coal-fired power plants in Vietnam for existing coal-fired power capacity. New capacity use GreenID estimates.	GreenID, country experts
International balances, fuel and fuel transport	We assumes bituminous coal is imported from Australia, Russia and Indonesia via seaborne and then land routes to plant and take a weighted average of the respective export price indices. Anthracite is sourced domestically where we take a domestic price index.	UN Comtrade, WoodMackenzie Coal Supply Data, IEA, Mining Atlas, CoalSwarm, Ports.com
Carbon prices	We assume no carbon pricing throughout the modelling horizon	-
Pollution limit regulations and associated capital and operational costs	We adopt a conservative view on future air pollution regulation and assume no additional capital costs for the installation of environmental control technologies across the fleet.	IEA
Plant revenues	Prices from the newly introduced competitive wholesale market are used with limited visibility on PPAs	EVN
National statistics for coal-fired power generation	2017 data for coal-fired generation statistics. The phaseout of coal in Vietnam follows the ASEAN phaseout pathway in the B2DS, based on its current proportional share of coal-fired power generation.	BP, IEA

7 Appendix – Methodology Overview

Figure 4 - DIAGRAM OF THE RESEARCH METHODOLOGY FOR COAL POWER ANALYSIS



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