Carbon Tracker Initiative

GLOBAL COAL POWER ECONOMICS MODEL METHODOLOGY

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About Carbon Tracker

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

www.carbontracker.org | hello@carbontracker.org

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Power & Utilities Team

Matt Gray
Managing Director – Co-Head of Team
mgray@carbontracker.org

Sriya Sundaresan
Senior Analyst – Co-Head of Team
ssundaresan@carbontracker.org

Bell Udomchaiporn
Senior Analyst
budomchaiporn@carbontracker.org

Durand D'souza
Data Scientist
ddsouza@carbontracker.org

Stefan Lavelle
Junior Data Scientist
slavelle@carbontracker.org

Valeria Ehrenheim
Junior Analyst
vehrenheim@carbontracker.org

Lily Chau
Junior Analyst
lchau@carbontracker.org

Isabella Soldner-Rembold
Junior Data Scientist
isoldner-rembold@carbontracker.org

Aurore Le Galiot
Associate
alegaliot@carbontracker.org

Joseph O'Connor
Data Scientist
jo'connor@carbontracker.org

Nicolás Gonzalez
Contract Data Scientist
ngonzalez@carbontracker.org

Andrei Ilas
Consultant

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1. Overview

This document explains the methodology of our Global Coal Power Economics Model (GCPEM). GCPEM is a propriety techno-economic simulation model which covers ~95% of operating, under-construction and planned coal-fired capacity. The modelling regions include: China, the United States (US), India, the European Union (EU28), Russia, Japan, South Africa, South Korea, Indonesia, Australia, Ukraine, Turkey, Vietnam, the Philippines, Malaysia, Bangladesh and Pakistan. GCPEM provides boiler or asset-level estimates of the:

- Capital cost, short-run marginal cost (SRMC) and long-run marginal cost (LRMC).
- Operating cashflow independent of cost and revenue hedging.
- Internal Rate of Return (IRR) and Net Present Value (NPV).
- Stranded cost risk based on the levelised cost (LCOE) of utility-scale solar photovoltaics (PV), onshore wind or offshore wind.[1]
- Stranded asset risk in a below 2°C scenario.

GCPEM data and model outputs are summarised via a publicly-available website.

2. Model inputs and definitions

2.1 Model inputs

To model the cost and cashflow profile of individual coal-fired power units it requires a comprehensive, detailed and diverse number of datasets. The GCPEM draws upon the most up-to-date 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.

The primary asset-level inventory data builds on the Global Energy Monitor (GEM) Global Coal Plant Tracker (GCPT) and Platts World Electric Power Plants (WEPP) databases[2]. 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 mid-2019. In addition, the units that are in construction and are estimated to be completed over 2019 to 2030 have also been included. Those plants in construction with no estimated start year in the GCPT have been excluded from this analysis, as have plants that have an installed capacity of less than 30MW.

[1] This includes an analysis of the competitiveness of operating coal and renewable energy projects within a similar location to show which coal plants could be replaced locally (within "x" miles of the existing coal plant) at a saving. LRMC or cashflow-optimised retirement year in a below 2°C scenario.
[2] For further information about the GPCT and WEPP see https://endcoal.org/global-coal-plant-tracker/ and https://www.spglobal.com/platts/en/products-services/electric-power/world-electric-power-plants-database, respectively.

Table 1 – Universal Parameters in the Global Coal Economics Model

PARAMETER	SOURCE	DETAILS
Plant-level characteristics	GEM GCPT; National reports, statistics and databases.	Name; Location; Installed Capacity; Unit Status; Year of operation; Parent organisation; Sponsor organisation; Combustion technology type; Coal type; and Heat rate.
Cooling type and pollution control technologies by plant	Platts WEPP; National reports, statistics and databases; 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: subcritical, supercritical, ultra-supercritical, integrated gasification combined cycle (IGCC) and circulating fluidized bed (CFB). See 2.3.1.1
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: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more See 2.2.1.3
Fuel Type	GEM; IEA; WoodMackenzie Coal Supply Data; National reports, statistics and databases; Consultancy reports.	See 2.2.1.1
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 2.2.1.1
Fuel cost	National statistics, reports; Country experts; Consultancy reports.	See 2.2.1.1
Fuel transport cost	National reports, statistics and databases.	See 2.2.1.1
Carbon Price	ICAP, National reports, statistics and databases.	See 2.2.1.2

Combustion efficiency	IEA; Consultancy reports.	Gross, Low Heating Value (LHV).
Efficiency adjustments for 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.
Air pollution regulations	National and provincial regulations.	See 2.3.1.2
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.	Dependent on whether an electricity grid in a country or region is administered by different system operators.
Unabated coal-fired power generation pathways	IEA's Beyond 2°C Scenario.	Specified for most countries, apportioned from region level where appropriate by share of existing coal capacity otherwise.
Levelised Cost of Energy	CTI analysis	The LCOE is the sum of all costs divided by the amount of generation. The costs include capital costs, capital recovery factor, FOM, VOM, fuel and carbon. See 2.4

2.2 Terminology and definitions

2.2.1 SRMC

We define the SRMC as fuel, carbon (where applicable) and VOM costs.

2.2.1.1 Fuel cost

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 Free on-board (FOB)[3] benchmark price indices from Bloomberg LP and National statistics reports.

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. Inputs to the cost-optimised algorithm are as follows:

- **International coal balances.** The model incorporates the balances for countries of thermal coal by coal grade according to national statistics or reputable international energy data sources. Assessments of coal trade routes between countries and/or regions are made in addition to corroborate findings. This can be broken down into three types:
  - *Import only*: we use a weighted average of Bloomberg terminal stats for coal product export price indices from main export regions.
  - *Consumption of domestic coal*: coal product domestic price indices from Bloomberg 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.

2.2.1.2 Carbon cost

We only include carbon price where it is implemented or has been approved and will be implemented in the future. This includes the following markets:

- The European Union Emissions Trading System (EU ETS) which covers EU28 member states.
- The South Korean Emissions Trading system.

[3] 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

- The Regional Greenhouse Gas Initiative which covers the states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.
- The Chinese pilot programs which covers Beijing, Chongqing, Guangdong, Hubei, Shanghai, Shenzhen and Tianjin provinces.
- The Chinese Emissions Trading System which has been ratified and is due to be implemented in 2021.

2.2.1.3 VOM costs

VOM 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.

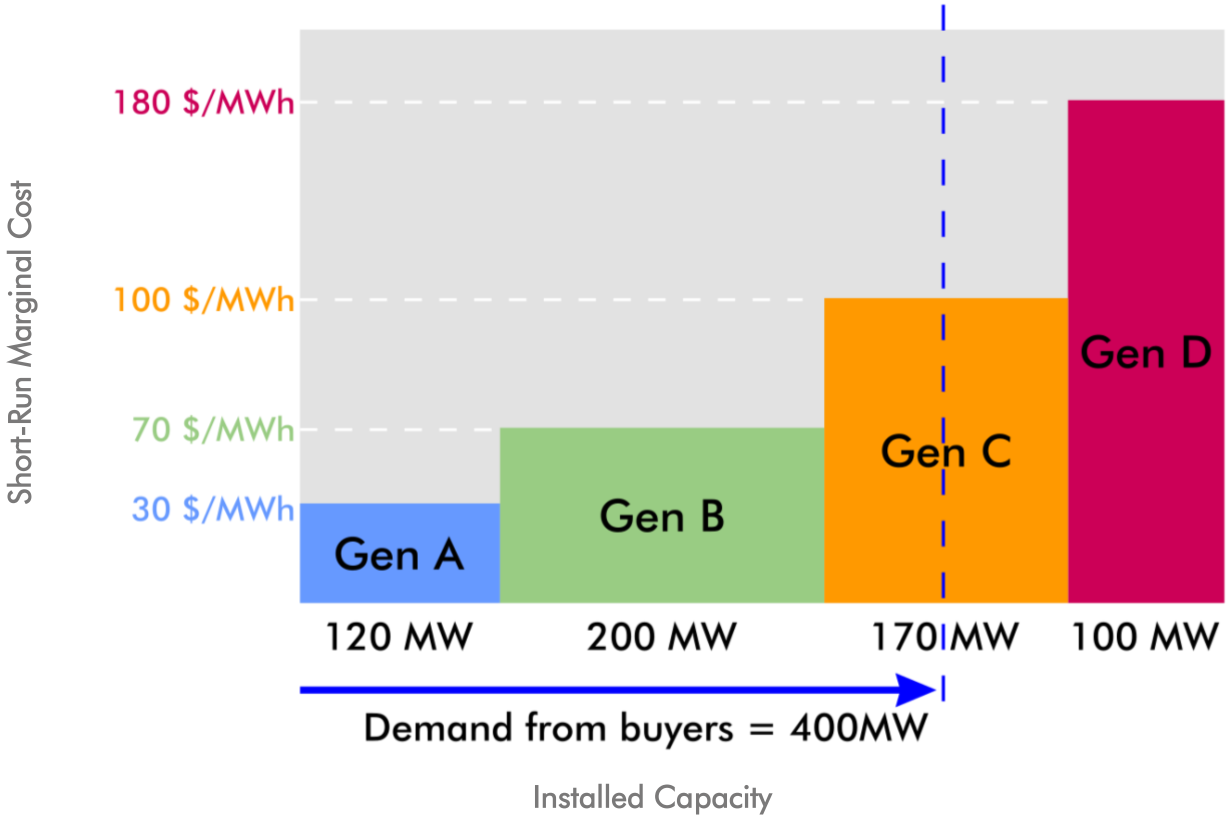
2.2.1.4 SRMC and dispatch decisions

The SRMC 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:

- The grid operator forecasts power demand ahead of time.
- The grid operator asks for bids to supply quantity of power required to meet the forecast. Power generators typically bid at SRMC of producing the next unit of power.
- The grid operator starts purchasing the power offered by the lowest bid operators until they reach the required power in the forecast. This is called the uniform clearing price.
- 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 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 – Merit order and dispatch decision



Source: Carbon Tracker

2.3 LRMC

LRMC includes SRMC plus FOM and any capital additions from meeting environmental regulations. LRMC does not include infrastructure cost.

2.3.1.1 FOM

FOM include the expenses incurred at a power plant that do not vary significantly with generation and include staffing, equipment, administrative expenses, maintenance and operating fees. While the SRMC governs dispatch decisions, the LRMC impacts the bottom-line.

2.3.1.2 Air pollution regulations

There are a variety of policies and air quality standards designed to reduce air pollution across different regions and countries. For our analysis we principally focus on the NOx, SOx and PM emission limits for existing coal-fired power plants, allowing us to understand which additional units will need to retrofit under existing environmental regulation. We only include environmental regulation where it is implemented or has been approved and will be implemented in the future. These regulations frequently change.

2.4 LCOE

LCOE is a standard analytical tool used to compare power generation technologies and is widely used in power market analysis and modelling[4]. The LCOE is the sum of all costs divided by the amount of generation. The costs include capital costs, capital recovery factor, FOM, VOM, fuel and carbon. 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.

Our modelling methodology for the regional LCOE involved three steps. Firstly, for solar PV, our algorithm extracts irradiance data based on coal plant locations. The capacity factors calculated from this are applied to our country and regional estimates to get local a LCOE for each coal plant.[5] For solar PV, there was no need to sample around plants or filter out locations based on land use because irradiance does not vary much over short distances, meaning point capacity factors closely approximate local maxima. Wind capacity factors on the other hand vary significantly over very short distances because topography significantly affects wind speeds. To obtain good coverage of potential project locations in grid connectible range, we sampled 1,000 points in a 15km radius around each plant with capacity factors by location[6]. The maximum capacity factors among these points for both solar PV and wind were selected after filtering out protected, urban and water covered areas using global databases on protected areas[7] and land use[8].

Secondly, both solar and wind capacity factors were normalised by country level estimates before being combined with the country level inputs to calculate a unit LCOE estimate. In most regions, renewables to be uneconomic near coal plants as site decisions were not based on wind speeds or solar irradiance in mind. We apply the 40th percentile of the unit LCOEs for wind and 20th for solar in each grid to all units in that grid. This modelling approach is based on the notion that a coal unit's capacity could be replaced by renewables at the best location in its grid. Connection will not be prohibitively costly at such locations because each location is a maximum of 15km from a coal unit.

Thirdly, wind and solar capacity factors were normalised by country-level capacity factors. This is an important step (especially for wind) for a number of reasons:

1. Our area-filtering algorithm for wind spots ignores many of the practical constraints on selecting wind locations. There was a systematic tendency for a grid's wind capacity factors to be much higher than the corresponding country estimates. Since the latter are based on real projects, it is likely that the original filtering method – removing urban, water filled and protected areas – was not strict enough. By normalising, relative differences between geographies while guarding against any optimism bias in the unit methods.

2. The capacity factors from global wind atlas are based on three turbine types, whereas in reality the turbine type will depend on wind speeds and any regulatory constraints. A single type was chosen for consistency[9]. Combined with the fact that the relative magnitudes of

[4] For more information refer to https://www.nrel.gov/analysis/tech-lcoe-documentation.html
[5] http://globalsolaratlas.info/map
[6] https://globalwindatlas.info/downloads/gis-files
[7] https://www.protectedplanet.net/
[8] https://www.esa-landcover-cci.org/?q=node/197
[9] Type II.

capacity factors do not differ significantly between turbine classes, this means normalisation will give reasonably accurate costs[10].

Local solar estimates showed the opposite trend to wind estimates in that grid capacity factors were slightly lower than the corresponding country level estimates. For wind, this is offset by the fact that wind varies so much locally, making it easy to find pockets of high wind speeds in a high-resolution map even if these may not be practical locations[11] even if these may not be practical locations. Normalisation corrects for these biases irrespective of the bias direction because the country estimates are based on real projects. Relative differences by geography are retained.

2.5 Operating cashflow

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

2.6 Below 2°C scenario retirement year

The year when the unit should be retired to be consistent with the temperature goal in the Paris Agreement. The retirement schedule is determined based on the long run marginal cost or operating cashflow.

2.7 Below 2°C scenario stranded asset risk

The potential revenues lost from shutting the unit prematurely in accordance with the retirement year mentioned above.

Stranded asset. A fossil fuel energy and generation resources which, at some time prior to the end of their economic life (as assumed at the investment decision point), are no longer able to earn an economic return (i.e. meet the company's internal rate of return), as a result of changes in the market and regulatory environment associated with the transition to a low-carbon economy.

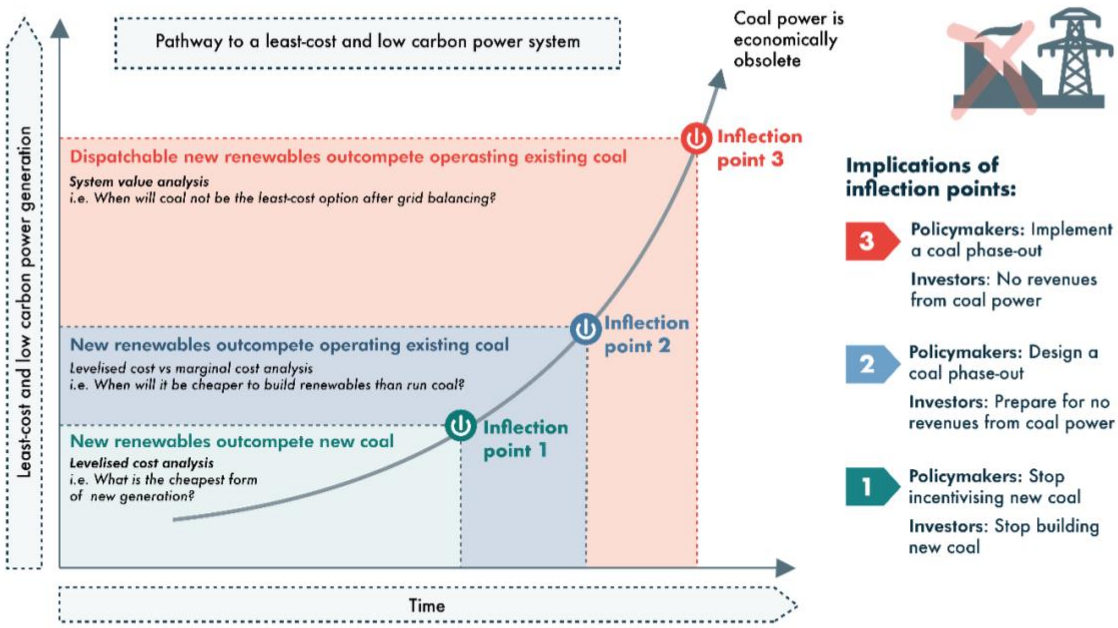
[10] The exception to this would be if a grid has an extreme capacity factor that would warrant the selection of an atypical turbine type for the country. This is unlikely given our conservative use of the 20th percentile(for sun) and 40th percentile (for wind) in a grid connectible region that already ignores many locations.

[11] The global wind atlas has 250m grid spacing.

3. Stranded cost risk model

Our stranded cost risk model compares three tipping or inflection points that will make coal-fired power economically obsolete. There are three economic inflection points that policymakers and investors need to track to provide the least-cost power: 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. These inflection points have implications for investors and policymakers, as detailed 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 analysis (2018)

Notes: We acknowledge that LCOE analysis is a limited metric as it does not consider revenues from generation and the system value of wind and solar. According to the IEA, the best way to integrate variable renewable energy (VRE) is to transform the overall power system through system-friendly deployment, improved operating strategies and investment in additional flexible resources. Flexible resources include better located generation, grid infrastructure, storage and demand side integration.[12] See: IEA (2016), Next-generation wind and solar power: From cost to value.

[12] See: IEA (2016), Next-generation wind and solar power: From cost to value. See: https://www.iea.org/publications/freepublications/publication/NextGenerationWindandSolarPower.pdf

4. Below 2°C scenario model

Our below 2°C scenario model identifies the year when a coal unit needs to be retired and the amount of stranded asset risk associated with keeping the unit open. We define a stranded asset as the difference between the NPV of revenues in a business as usual (BAU) scenario and a scenario consistent with the temperature goal in the Paris Agreement. The modelling approach involves three steps.

Firstly, we identify the amount of capacity that is required to fill the generation requirement in the IEA's beyond 2°C scenario (B2DS). Under the B2DS, coal generation without carbon capture and storage (CCS) is phased-out globally by 2040. This analysis assumes CCS will not be available to extend the lifetimes of coal capacity, as the costs will likely be prohibitively expensive.[13] Regions have different phase-out dates. For Japan, we assume a phase-out date of 2030 which is broadly consistent with other OECD countries.[14]

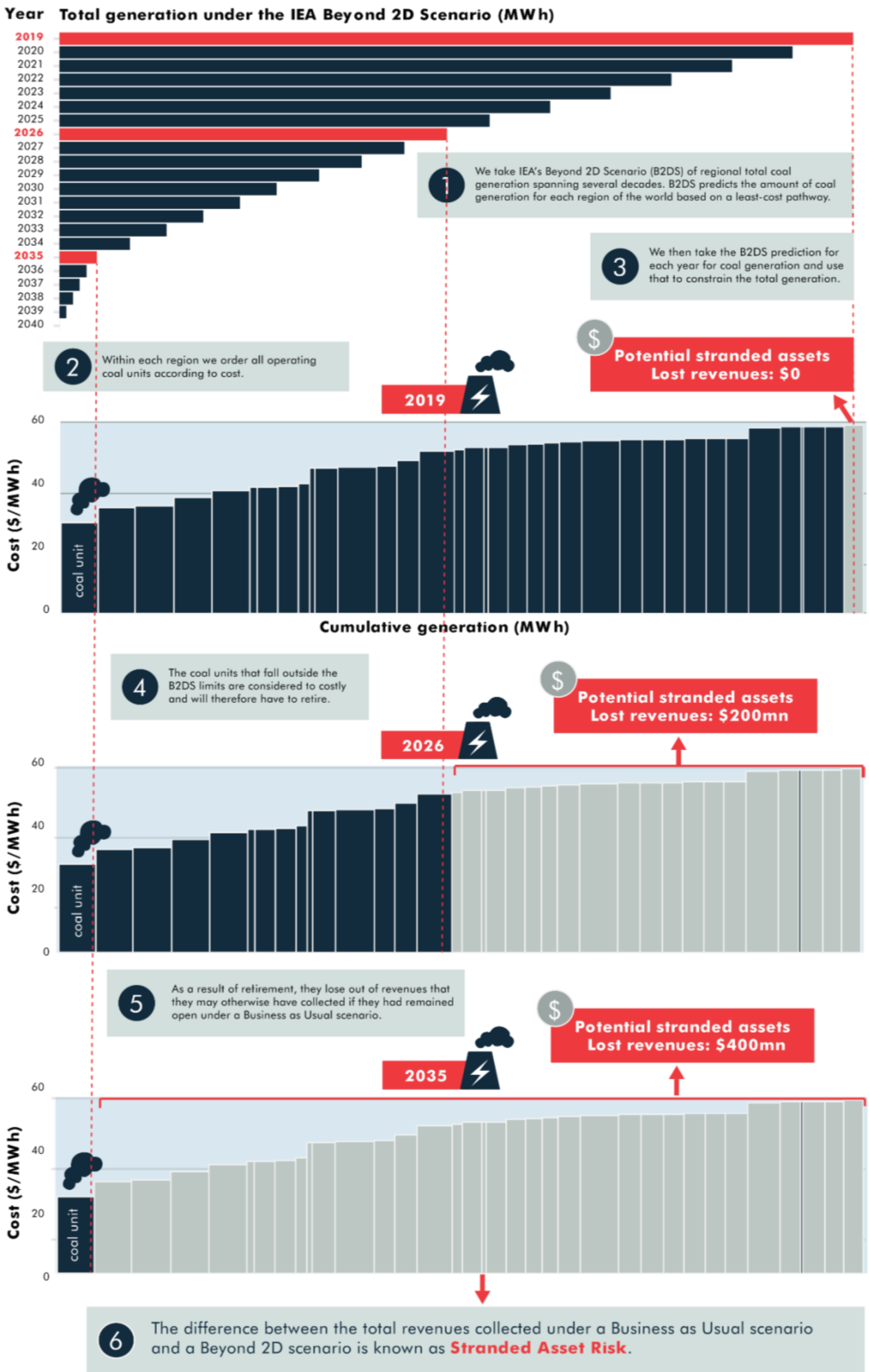
Secondly, we rank the coal-fired generation units to develop a retirement schedule, based on the authority, region or grid responsible for maintaining security of supply. The units are ranked based on the LRMC or operating cashflows. The coal units with the highest LRMC or lowest operating cashflows are phased-out until the aggregated asset level generation reaches the limits set out in the B2DS.

Thirdly, we calculate the cash flow of every operating and under-construction unit in both the B2DS and BAU outcomes to understand stranded asset risk. Stranded asset risk under the B2DS is defined as the difference between the NPV of cash flows in the B2DS (which phases-out all coal power by 2030) and the NPV of cash flows in the BAU scenario (which includes announced retirements in company reports or otherwise assumes a minimum lifetime of 40 years). Figure 3 provides a schematic illustration of the below 2°C stranded asset modelling methodology.

13 There is currently two CCS-equipped coal-fired power plant operating in the world today (Boundary Dam in Canada and Petra Nova in the US). Due to limited progress to date and the new build and retrofit costs compared to other decarbonisation options, this report assumes that CCS will only be viable in niche applications over the lifetimes of the fossil fuel plants analysed, and thus is not included in this study which focuses on global averages without subsidies. For more information see: Carbon Tracker (2016). End of the load for coal and gas? Available: https:// www.carbontracker.org/reports/the-end-of-the-load-for-coal-and-gas/

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

Figure 3. Schematic illustration of the modelling methodology



5. Risks and 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 assumptions 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 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.
- No revenue and cost hedging are assumed. Utilities often hedge their revenue and cost exposure through the future and forward markets. The level and extent of hedging varies depending on whether the utility operates in a liberalised or regulated market, as well as the evolution of power market price formation. Estimating.

- FOM is challenging, especially for lignite units. The amount an operator spends on FOM depends on a variety of factors, such as the useful life of the unit, air pollution regulations and long-term fuel contracts.

6. Regional assumptions

6.1 Australia

6.1.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	Global Energy Monitor
Cooling type and pollution control technologies by plant	Cooling technologies as well as environmental control technologies for nitrogen dioxide, sulphur dioxide and particulate matter were taken from Platts.	Platts
FOM	Where possible, FOM data is taken from AEMO's integrated resource plan assumptions. The underlying data changes over time in accordance with Treasury wage growth projections. For units on the SWIS system, installed capacity weighted averages of total fixed costs are calculated using data from Jacobs (2016). Whyalla power station is a captive plant and has no statistics: standardised costs of \$58/kW/year are used for this plant.	AEMO, Jacobs
VOM	VOM data are based on AEMO's integrated resource plan assumptions. For plants on the SWIS system, we use inflation adjusted values from Jacobs (2016). A country average is taken for the captive Whyalla works plant.	AEMO
Capacity factor	Where possible, unit level generation data from AEMOs was combined with nameplate capacities to calculate capacity factors. Missing values were filled with 2016/17 values from BNEF. Any remaining missing values were filled with the country level average. Values were clipped at 95% to adjust for data inconsistencies. Plants with repair works in the generation year were adjusted to the average for the plant.	BNEF, AEMO Generation Data
Fuel type, cost and transport	Plant level fuel costs from AEMO's integrated system plan assumptions were used where possible. For units on the SWIS system, Jacobs (2016) data was used. In both cases fuel costs are inclusive of transport. Country level averages were used for any remaining missing units. For AEMO, future cost projections were included in the assumptions. For other units the real fuel cost is assumed constant over time.	AEMO, Jacobs
Carbon price	We assume no carbon pricing throughout the modelling horizon.	-
Combustion efficiency	Combustion efficiency values are calculated using data on high heating values (HHVs) from AEMOs integrated system plan assumptions. For consistency with CTI analysis for other units, these HHVs are converted to LHVs using a 4% difference assumption. For units not in AEMO, IEA country level data on efficiency by boiler type is used. Gross, low heating values (LHV) are adjusted for unit age.	Heating value assumptions, IEA, Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance (\$/kW per year) and variable operations and maintenance (\$/MWh). Adjusted for technology and nameplate capacity of plant.	EPA
Unabated coal-fired power generation	We used OECD decline rates from the IEA's Beyond 2°C scenario (B2DS) for Australia generation.	IEA, Carbon Tracker estimate

pathway for below 2°C scenario		
Pollution limit regulations and associated capital and operational costs	No changes to existing air pollution regulations assumed over the modelling period.	-
Plant revenues	Annual volume weighted average spot prices (2019/20) were used for 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

6.1.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX data for Australia was sourced from real world projects. CAPEX break down was sourced from the IRENA 2017 costs publication. A lower and upper band was calculated using a 20% assumption.	Projects 1, Projects 2, IRENA
O&M Costs	O&M costs were assumed to be 1.9% of CAPEX. A lower and upper band was calculated using a 20% assumption.	IRENA, Carbon Tracker estimate
Capacity factor	Country level capacity factor data was sourced from real world projects developed in Australia. Lower and upper bands were calculated using a 20% assumption. Local capacity factors were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm.	Protected Planet, ESA(Land Cover), Global Wind Atlas, Carbon Tracker estimate
Return on Equity	Return on equity for Australia was assumed to be 12%, in line with OECD observed values such as US.	Carbon Tracker estimate
Cost of debt	Data on long term lending rates were sourced from the World Bank. 1% was added to account for long term risks. Data for inflation was sourced from the IMF. A lower and upper band was calculated using a 20% assumption.	World Bank, IMF
Capacity deployment and learning rate	Data on deployment projections was sourced from REMAP file for G20 countries. A learning rate of 19% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP
Assumptions for solar PV		
Capital Expenditure	CAPEX data for solar PV was sourced from an IRENA 2019 cost publication together with cost breakdown. A lower and upper band was calculated using a 20% assumption.	IRENA
O&M Costs	O&M costs were assumed to be 0.09 % of CAPEX. A lower and upper band was calculated using a 20% assumption.	IRENA
Capacity factor	Capacity factor data was sourced from a real world project. A lower and upper band was calculated using a 20% assumption. Local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	Real world project, Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity for Australia was assumed to be 12%, in line with OECD observed values, such as US.	Carbon Tracker estimate
Cost of debt	Data on long term lending rates were sourced from the World Bank and 1% was added to account for long term risks while data for inflation was sourced from the IMF. A lower and upper band was calculated using a 20% assumption.	World Bank, IMF

Capacity deployment and learning rate	Data on deployment projections was sourced from REMAP file for G20 countries. A learning rate of 27% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP

6.2 Bangladesh

6.2.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	Global Energy Monitor
Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide, sulphur dioxide and particulate matter, as well as the type of cooling technology.	Platts
FOM	In the absence of Bangladesh-specific value for FOM cost, we assume 60% of Asia O&M costs from IEA WEO 2015. FOM assumptions depend on the combustion technology of the boiler. We assume US$12/kW for subcritical technologies; US$16/kW for supercritical technologies; US$19/kW for ultra-supercritical technologies; and US$29/kW for integrated gasification combined cycle technologies (IGCC).	Carbon Tracker estimates based on IEA WEO
VOM	VOM assumptions depend on the combustion technology of the boiler. We assumed US$5.41/MWh for subcritical technologies; US$4.33/MWh for supercritical technologies; US$4.06/MWh for ultra-supercritical technologies; and US$6.99/MWh for integrated gasification combined cycle technologies. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more.	Carbon Tracker estimates based on North America Electric Reliability Corporation
Capacity factor	Where possible, unit-level generation data from Bangladesh annual report 2018-19 were used. For the remaining missing values, regional averages from the Bangladesh Economic Review 2018 were used.	Bangladesh Economic Review Bangladesh Annual report
Fuel type, cost and transport	Fuel costs include the expenses incurred in buying, transporting, and preparing the coal. For the cost of coal for producers we use benchmarks from Bloomberg LP. Estimates of fuel cost are based on daily price averages between 2017-2019. For every year up to 2019 a yearly average was used. For 2020 onwards, the average of the last 3 years (2017-2019) was used. Fuel costs also include a model which calculates the coal transport. This is a cost-optimised supply route algorithm, which computes the distance between a unit's location and the nearest suitable coal mine, considering coal type, mode of transport and related costs and other charges, and available port, mine and import capacities. We assume coal is imported from Indonesia (30%) and South Africa (20%), sourced via seaborne from East Kalimantan and Richard's Bay to Chittagong respectively, and then land routes to Bangladesh's plants. While there are cases where this may be invalid, it is a good proxy assumption. No lignite used in Bangladesh.	Bloomberg , Ports.com , IEA/OECD Coal Statitics and Secreteriat , Carbon Tracker estimate
Carbon price	We assume no carbon pricing throughout the modelling horizon.	-
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age. Baseline values are country and boiler type specific.	IEA, Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	We assume Non-OECD decline rates in the IEA's Beyond 2°C scenario (B2DS) for Bangladesh generation.	IEA, Carbon Tracker estimate
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.	-

Plant revenues	We use tariff prices data from Bangladesh Electricity Prices (BEP) 2019 as a proxy for plant revenues. We estimate the average plant revenue between 2018 and 2019 using a starting point methodology following the analysis made by South Asian Association for Regional Cooperation (SAARC) 2017 and a growth rate from the International Institute for Sustainable Development (IISD). This value is constant over the modelling period.	BEP, IISD, SAARC

6.2.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	Bangladesh had about 3 MW of onshore wind in 2018 according to IRENA statistics. Thus, project level data is non existent for the country. CAPEX was assumed to be USD 2150/kW. CAPEX break down was assumed to be the same as in Pakistan. A lower and upper band was calculated using a 20% assumption.	IRENA
O&M Costs	O&M costs were assumed to be 2%, the higher end of O&M costs, a typical assumption for very small or emerging markets. A lower and upper band was calculated using a 20% assumption.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were assumed to be 0.31 in line with capacity factors for the newest turbines in good wind locations. Lower and upper bounds were calculated using a 20% assumption. Local capacity factors were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm.	Protected Areas, Land Cover, Global Wind Atlas
Return on Equity	Return on equity was assumed to be 20% for Bangladesh, 5% more than the value estimated by Damodaran for emerging markets (mostly due to the high inflation rate).	Damodaran
Cost of Debt	The cost of debt was sourced from the World Bank at 9.6%. 5% points were added to this to account for longer term and riskier debt for renewable energy projects. Inflation data was sourced from the IMF. Lower and upper bounds were calculated using a 20% assumption.	World Bank, IMF
Capacity deployment and learning rate	There is not a lot of potential for onshore wind in Bangladesh. 10 GW of cumulative capacity by 2040 was assumed. A learning rate of 19% was assumed and the most aggressive deployment scenario to project LCOE to 2040.	Bangladesh Wind Potential
Assumptions for solar PV		
Capital Expenditure	CAPEX for solar PV in Bangladesh was sourced from project level data and news releases about development finance in the country, leading to a value of 1460 USD/kW. Lower and upper bounds were calculated using a 20% assumption.	Project1, Project 2, Project 3, Project 4, Project 5, Project 6
O&M Costs	O&M costs were assumed to be 1.35% of CAPEX, the same as in Pakistan. Lower and upper bounds were calculated using a 20% assumption.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were sourced from project level data and were assumed to be 0.1953. A lower and upper bound was calculated using a 20% assumption. Local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was assumed to be 20% for Bangladesh, 5% more than the value estimated by Damodaran for emerging markets (mostly due to the high inflation rate).	Damodaran
Cost of Debt	The cost of debt was sourced from the World Bank, at 9.6%. 5 % points were added to this to account for longer term and riskier debt for renewable energy projects. Inflation data was sourced from the IMF. Lower and upper bounds were calculated using a 20% assumption.	World Bank, IMF

6.3 China

6.3.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	Global Energy Monitor
Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide (NO2), sulphur dioxide (SO2) and particulate matter (PM), as well as the type of cooling technology.	Platts
FOM	In the absence of China specific cost for FOM, we assume 40% of Chinese O&M costs from IEA WEO 2018. FOM costs depend on the combustion technology of the boiler. We assumed: Subcritical US$11,76/kW; Supercritical US$17,63/kW; Ultra-supercritical US$17,63/kW; IGCC US$29,39/kW. For Lignite, we use FOM cost assumptions from Agora (2017). Lignite FOM cost depend on age of the unit.	Carbon Tracker estimates based on IEA WEO; Agora
VOM	VOM assumptions depend on the combustion technology of the boiler. We assume: Subcritical US$3,35/MWh; Supercritical US$2,68/MWh; Ultra-supercritical US$2,51/MWh; IGCC US$4,32/MWh. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more. For lignite, we use VOM cost assumptions from Agora (2017). Lignite VOM cost depend on age of the unit.	Carbon Tracker estimates based on North America Electric Reliability Corporation ; Agora
Capacity factor	Regional averages provided by Bloomberg and Platts were used for 2017-2019. For 2020 onwards, a 3-year average from the previous years was used. For missing values, countrly-level average is used.	Platts , Bloomberg, Carbon Tracker estimate
Fuel type, cost and transport	Fuel costs include the expenses incurred in buying, transporting, and preparing the coal. For the cost of coal for producers we use benchmarks from Bloomberg LP. Estimates of fuel cost are based on daily price averages between 2017-2019. For every year up to 2019 we use a yearly average, and for 2020 onwards, we use the average of the last 3 years (2017-2019). Fuel costs also include a model which calculates the transport of coal. This is a cost-optimised supply route algorithm, which computes the distance between a unit's location and the nearest suitable coal mine, considering coal type, mode of transport and related costs and other charges, and available port, mine and import capacities. We assume all thermal coal product types are sourced domestically. For sub-bituminous coal we use Indonesian sub-bituminous coal price. For lignite plants coal cannot be transported long distances. We therefore calculate the fixed cost of running a Lignite mine and use this as the fuel cost. Fixed O&M cost assumptions for Lignite come from Agora (2017) and depend on a unit's age.	Bloomberg, Ports.com , Agora, Carbon Tracker estimate
Carbon price	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 $40/tCO2 by 2040.	ICAP, Carbon Tracker estimate
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age.	IEA, Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	We use China decline rates from the IEA's Beyond 2°C scenario (B2DS) for China generation.	IEA, Carbon Tracker estimate
Pollution limit regulations and associated capital and operational costs	We assume no changes to existing air pollution regulations assumed over the modelling period until 2020. By law, from that year onwards we assume that all units without PM, NOx or SOx control technologies will install it. Spreading the cost in 5 years.	PRC Ministry of Ecology and Environment ,

Plant revenues	We estimate provincial adjusted benchmark for coal-fired power tariffs based on available data from China Electrity Council.	China Electricity Council , Carbon Tracker estimate

6.3.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX data for onshore wind for China was sourced from the IRENA 2018 cost publication together with the cost breakdown. A lower and upper band was calculated using a 20% assumption.	IRENA
O&M Costs	O&M costs were assumed to be 1.8% of CAPEX. A lower and upper band was calculated using a 20% assumption	Carbon Tracker estimate
Capacity factor	Capacity factor data was sourced from REN21 publication which is based on IRENA data and from the IRENA 2018 cost publication. A lower and upper band was calculated using a 20% assumption.	REN 21
Return on Equity	Return on equity was sourced from Damodaran.	Damodaran
Cost of Debt	Data on long term lending rates was sourced from World Bank to which 2% was added to account for long term risk while inflation data was sourced from IMF.	World Bank ; IMF
LCOE decline rate	Data on deployment projections was sourced from REMAP file for G20 countries. A learning rate of 15% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP
Assumptions for solar PV		
Capital Expenditure	CAPEX data for solar PV for China was sourced from the IRENA 2018 cost publication ogether with the cost breakdown. A lower and upper band was calculated using a 20% assumption.	IRENA
O&M Costs	O&M costs were assumed to be 1.5% of CAPEX. A lower and upper band was calculated using a 20% assumption.	Carbon Tracker estimate
Capacity factor	Capacity factor data was sourced from REN21 publication which is based on IRENA data from the IRENA 2018 cost publication. A lower and upper band was calculated using a 20% assumption.	REN 21
Return on Equity	Return on equity was sourced from Damodaran.	Damodaran
Cost of Debt	Data on long term lending rates was sourced from World Bank to which 2% was added to account for long term risk while inflation data was sourced from IMF	World Bank ; IMF
Capacity deployment and learning rate	Data on deployment projections was sourced from REMAP file for G20 countries. A learning rate of 25% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP

6.4 European Union

6.4.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	Global Energy Monitor , Carbon Tracker estimate
Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide, sulphur dioxide and particulate matter, as well as the type of cooling technology.	Platts

FOM	FOM assumptions depend on the combustion technology of the boiler. We assume US$12.61/kW for subcritical technologies; US$16.81/kW for supercritical technologies; US$19.21/kW for ultra-supercritical technologies; and US$29.72/kW for integrated gasification combined cycle technologies (IGCC). Plants with unknown boiler types were assumed to have subcritical FOM costs We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more. For Lignite, we use FOM cost assumptions from Agora (2017). Lignite FOM cost depend on age of the unit.	Carbon Tracker estimates based on IEA WEO, Agora
VOM	VOM assumptions depend on the combustion technology of the boiler. We assume: US$6.07/MWh for subcritical technologies; US$4.86/MWh for supercritical technologies; US$4.55/MWh for ultra-supercritical technologies; and US$7.83/MWh for integrated gasification combined cycle technologies. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more. For Lignite, we use VOM cost assumptions from Agora (2017). Lignite VOM cost depend on age of the unit.	Carbon Tracker estimates based on North America Electric Reliability Corporation; Agora
Capacity factor	Obtained at asset-level for 2017-2019. For 2020 onwards we use the average from the previous years. Any remaining missing values were filled using country averages. Values were clipped at a minimum of 0.05% and a maximum of 90% to avoid data inconsistencies.	ENTSO-E
Fuel type, cost and transport	Fuel costs include the expenses incurred in buying, transporting, and preparing the coal. For the cost of coal for producers we use benchmarks from Bloomberg LP. Fuel cost estimates are based on daily price averages between 2017-2019. For every year up to 2019 we use a yearly average, and for 2020 onwards, we use the average of the last 3 years (2017-2019). Transport costs are based on routes from Rotterdam port to each plant. For lignite plants coal cannot be transported long distances. We therefore assume zero transport costs and that Lignite units mine their own coal. We calculate the fixed cost of running a Lignite mine, convert this to $/kW of energy and use this as the fuel cost. Fixed O&M cost assumptions for operating a Lignite mine come from Agora (2017) and depend on a unit's age.	Bloomberg, Agora, Carbon Tracker estimate
Carbon price	Current EU ETS prices taken with conservative forecast to 2030.	Carbon Tracker analysis , Sandbag
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age. Baseline values are country and boiler type specific.	IEA , Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	We take the IEA B2DS projections for coal generation within the European Union.	IEA, Carbon Tracker estimate
Pollution limit regulations and associated capital and operational costs	The Industrial Emissions Directive and BREF regulations give emissions rates per pollutant. We assume that in 2021, all units that fail BREF regulations will need new control technology for particulate matter (PM), Sulphur Oxide (SOx) and Nitrous Oxide (Nox).	European Comission, EEB
Plant revenues	Calculated from country-level power tariffs for baseload and peakload from Bloomberg., Out-of-market payments are included where appropriate. Balancing and ancillary services payments were assumed constant across the fleet. Capacity payment revenues are included for the UK and Poland. For the UK data is from Sandbag and for Poland from PSE.	Bloomberg, Sandbag , PSE

6.4.2 Renewable LCOE assumptions

- Germany

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX data together with cost breakdown was sourced from IRENA 2019 cost report. A lower and upper band was calculated using a 20% assumption.	IRENA
O&M Costs	O&M cost data was assumed to be 2% of CAPEX and was sourced from IEA research (here, here). A lower and upper band was calculated using a 20% assumption.	IEA Wind
Capacity factor	Country level capacity factor data was sourced from the same IRENA report. A lower and upper band was calculated using a 20% assumption. Local capacity factors were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm.	IRENA , Protected Areas, Land Cover, Global Wind Atlas
Return on Equity	Return on equity was estimated using the median between data for Europe from Damodaran.	Damodaran.
Cost of Debt	Data on lending rates from World Bank was not available for Germany and was sourced from a combination of OECD data and a commercial data provider. 1% was added to account for long term risks. Inflation data was sourced from IMF.	OECD, German lending rates, IMF
Capacity deployment and learning rate	Data on deployment projections was sourced from the REMAP dataset for G20 countries. A learning rate of 30% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP
Assumptions for solar PV		
Capital Expenditure	CAPEX data together with cost breakdown was sourced from IRENA 2019 cost report. A lower and upper band was calculated using a 20% assumption.	IRENA
O&M Costs	O&M cost data was assumed to be 1.2% of CAPEX and was sourced from a US study from NREL and slightly increased for Germany.	NREL, New Energy Update
Capacity factor	Country level capacity factors were assumed to be slightly higher than the ones observed in Poland. A lower and upper band was calculated using a 20% assumption. Local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis	Global Solar Atlas, Carbon Tracker analysis
Return on Equity	Return on equity was estimated using the median between data for Europe from Damodaran	Damodaran
Cost of Debt	Data on lending rates from World Bank was not available for Germany and was sourced from a combination of OECD data and a commercial data provider. 1% was added to account for long term risks. Inflation data was sourced from IMF.	OECD, German lending rates, IMF
Capacity deployment and learning rate	Data on deployment projections was sourced from the REMAP dataset for G20 countries. A learning rate of 37% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP

- United-Kingdom

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX data together with cost breakdown was sourced from IRENA 2019 cost report. A lower and upper band was calculated using a 20% assumption.	IRENA
O&M Costs	O&M cost data was assumed to be 2% of CAPEX and was sourced from IEA research (here, here) on Germany and maintained for United Kingdom. A lower and upper band was calculated using a 20% assumption.	IEA Wind

Capacity factor	Country level capacity factor data was sourced from the same IRENA report. A lower and upper band was calculated using a 20% assumption. Local capacity factors were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm.	IRENA, Protected Areas, Land Cover, Global Wind Atlas
Return on Equity	Return on equity was estimated using the median between data for Europe from Damodaran The rate was the same as In the case of Germany.	Damodaran.
Cost of debt	Data on lending rates from World Bank was not available for United Kingdom and was sourced from a combination of OECD data and a commercial data provider. 2% were added to account for long term risks. Inflation data was sourced from IMF.	OECD, IMF UK Lending Rates
Capacity deployment and learning rate	Data on deployment projections was sourced from the REMAP dataset for G20 countries. A learning rate of 35% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP
Assumptions for solar PV		
Capital Expenditure	CAPEX data together with cost breakdown was sourced from IRENA 2019 cost report. A lower and upper band was calculated using a 20% assumption.	IRENA
O&M Costs	O&M cost data was assumed to be 1.0% of CAPEX and was sourced from a US study from NREL.	NREL (2017), NREL (2018)
Capacity factor	Capacity factor was sourced from a real world project, from the developer's website. A lower and upper band was calculated using a 20% assumption. Local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	Hive Project , Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was estimated using the median between data for Europe from Damodaran. The rate was the same as In the case of Germany.	Damodaran
Cost of Debt	Data on lending rates from World Bank was not available for United Kingdom and was sourced from a combination of OECD data and a commercial data provider. 2% were added to account for long term risks. Inflation data was sourced from IMF.	OECD, IMF, UK Lending Rates
Capacity deployment and learning rate	Data on deployment projections was sourced from the REMAP dataset for G20 countries. A learning rate of 28% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP

- Poland

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX data for Poland was sourced from real world project data from a set of projects that won fixed tariffs in a 2018 auction. CAPEX break down was sourced from an IRENA publication on costs. A lower and upper band was calculated using a 20% assumption.	IRENA, Poland project source1, Poland Project Source 2
O&M Costs	O&M costs were assumed to be 1.75% of CAPEX per year. Lower and upper bands were calculated using a 20% assumption.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were assumed to be 0.33 and were sourced from real world project data (the same batch as the ones used for CAPEX data). Lower and upper bands were calculated using a 20% assumption. Local capacity factors were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm.	Poland project source1, Poland Project Source 2 IRENA 2019, Protected Areas, Land Cover, Global Wind Atlas
Return on Equity	Return on equity was assumed to be 12.45% and was sourced from CSI market, to which 3% was added to be more in line with regional expected returns on equity.	CSI
Cost of Debt	Data on long term lending rates was sourced from CEIC and 2% was added. World Bank and Damodaran do not have specific data for Poland. Inflation data was sourced from IMF. A lower and upper band was calculated using a 20% assumption.	CEIC, IMF

Capacity deployment and learning rate	Data on deployment projections was sourced from a REMAP study for Poland. A learning rate of 17% and the most aggressive deployment scenario were used to project LCOE to 2040.	Poland REMAP
Assumptions for solar PV		
Capital Expenditure	CAPEX data was sourced from real world projects and from discussions with personal contacts who work engineering and construction projects in Poland. CAPEX breakdown was sourced from IRENA. A lower and upper band was calculated using a 20% assumption.	Poland Solar CAPEX 1, Poland Solar CAPEX 2
O&M Costs	O&M costs were assumed to be 1.65% of CAPEX. A lower and upper band was calculated using a 20% assumption.	-
Capacity factor	Capacity factor data was sourced from real world projects developed in Poland and quoted for CAPEX data. A lower and upper band was calculated using a 20% assumption. Local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	Poland Solar CAPEX 1, Poland Solar CAPEX 2, Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was assumed to be 12.45% and was sourced from CSI market, to which 3% was to be more in line with regional expected returns on equity.	CSI
Cost of Debt	Data on long term lending rates was sourced from CEIC to which 2% was added. World Bank and Damodaran do not have specific data for Poland. Inflation data was sourced from IMF. A lower and upper band was calculated using a 20% assumption.	CEIC, IMF
Capacity deployment and learning rate	Data on deployment projections was sourced from a REMAP study for Poland. A learning rate of 19% and the most aggressive deployment scenario were used to project LCOE to 2040.	Poland REMAP

- Italy

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX data together with cost breakdown was sourced from IRENA 2019 cost report. A lower and upper band was calculated using a 20% assumption.	IRENA
O&M Costs	O&M cost data was assumed to be 2% of CAPEX and was sourced from IEA research (here, here) on Germany and maintained for Italy. A lower and upper band was calculated using a 20% assumption.	IEA Wind
Capacity factor	Country level capacity factor data was sourced from the same IRENA report. A lower and upper band was calculated using a 20% assumption. Local capacity factors were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm.	IRENA , Protected Areas, Land Cover, Global Wind Atlas
Return on Equity	Return on equity was estimated using the median between data for Europe from Damodaran. The rate was the same as in the case of Germany.	Damodaran
Cost of Debt	Data on lending rates was sourced from World Bank to which 2% was added to account for long term risks. Inflation data was sourced from IMF.	IMF, World Bank
Capacity deployment and learning rate	Data on deployment projections was sourced from the REMAP dataset for G20 countries. A learning rate of 30% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP
Assumptions for solar PV		
Capital Expenditure	CAPEX data together with cost breakdown was sourced from IRENA 2019 cost report. A lower and upper band was calculated using a 20% assumption.	IRENA
O&M Costs	O&M cost data was assumed to be 1.2% of CAPEX and was sourced from a US study from NREL, slightly increased for Italy.	NREL (2017), NREL (2018)
Capacity factor	Capacity factor was assumed to be 18% to account for more solar resources in Southern Europe. A lower and upper band was calculated using a 20% assumption.	Global Solar Atlas, Carbon Tracker estimate

	Local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	
Return on Equity	Return on equity was estimated using the median between data for Europe from Damodaran. The rate was the same as in the case of Germany.	Damodaran
Cost of Debt	Data on lending rates was sourced from the World Bank to which 2% was added to account for long term risks. Inflation data was sourced from the IMF.	World Bank, IMF
Capacity deployment and learning rate	Data on deployment projections was sourced from the REMAP dataset for G20 countries. A learning rate of 30% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP

- Spain

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for both technologies was sourced from the IRENA report on costs launched in 2019.	IRENA
O&M Costs	O&M costs were assumed to be 2% of CAPEX for onshore wind and 1.2% for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors for both wind and solar were sourced from the same report at IRENA as the Capex. Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	IRENA 2019, Protected Areas, Land Cover, Global Wind Atlas, Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was estimated using proxy data from neighboring countries. Inflation data was sourced from IMF.	IMF
Cost of Debt	Data on lending rates was sourced from a financial statistics website,Trading Economics, as the World Bank did not have data available for Spain.	Trading Economics
Capacity deployment and learning rate	Data on deployment projections was sourced using ration observed among countries modeled by the REMAP team at IRENA and additional data from research pieces and solar Power Europe. A high learning rate of 32% was used for onshore wind and a mid-value of 19% was used for solar PV.	Solar Power Europe, RED, IRENA REMAP

- Romania

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for both technologies was sourced through local experts and discussion with engineering companies active in the market.	Local experts
O&M Costs	O&M costs were assumed to be 2.2% of CAPEX for wind and 1.2% of CAPEX for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were obtained from the same source as the CAPEX data Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm.	*IRENA*, *Protected Areas, Land Cover*, *Global Wind Atlas*, *Global Solar Atlas*, Carbon Tracker estimate

	For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	
Return on Equity	Return on equity was sourced from local sources active in the market.	Local experts
Cost of Debt	Data on lending rates was sourced from World Bank to which 1.5% was added to account for long term risks associated to project financing. Inflation data was sourced from IMF.	World Bank, IMF
Capacity deployment and learning rate	Deployment projections were made using rates of growth observed in countries modeled by the REMAP team at IRENA. A mid-level learning rate of 24% was used for onshore wind and 15% for solar PV.	IRENA REMAP

- Bulgaria

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for Bulgaria was sourced from a triangulation of IRENA costs data and data on Romania, as a neighboring country with similar conditions.	IRENA
O&M Costs	O&M costs were assumed to be 2% of CAPEX for onshore wind and 1.5% for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were obtained from the Same as for the CAPEX data. Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	IRENA, Protected Areas, Land Cover, Global Wind Atlas, Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was assumed to be slightly higher than Romania's	Carbon Tracker estimate
Cost of Debt	Data on lending rates was sourced from World Bank. Inflation data was sourced from IMF.	World Bank, IMF
Capacity deployment and learning rate	Capacity projections were estimated using growth rates observed in REMAP research. A learning rate of 21% (mid) was used for onshore wind while a learning rate of 25% (mid) was used for solar PV.	IRENA REMAP

- France

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for France for both technologies was sourced from IRENA report on costs in 2018	IRENA
O&M Costs	O&M costs were assumed to be 2% of CAPEX for onshore wind and 1.3% for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were obtained from the same source as the CAPEX data. Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	IRENA 2019, Protected Areas, Land Cover, Global Wind Atlas, Global Solar Atlas, Carbon Tracker estimate

Return on Equity	Return on equity was assumed to be 8.5% in line with assumptions used for neighboring countries.	Carbon Tracker estimate
Cost of Debt	Data on lending rates was sourced from Trading Economics and upped by 1% to account for long term risks. Inflation data was sourced from IMF.	Trading Economics, IMF
Capacity deployment and learning rate	Long term projections were sourced from REMAP datafile as France is a G20 member. A learning rate of 22% was used for onshore wind (mid) and 20% for solar PV (mid).	IRENA REMAP

- Portugal

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for Portugal for both technologies was estimating using IRENA cost data and neighboring countries estimates, mainly Spain.	IRENA
O&M Costs	O&M was assumed to be 2.1% of CAPEX for onshore wind and 1.4% of CAPEX for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were obtained from the same source as the CAPEX data. Local capacity factors were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	IRENA, Protected Areas, Land Cover, Global Wind Atlas, Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was assumed to be 10% based on neighboring countries proxies.	Carbon Tracker estimate
Cost of Debt	Data on lending rates was sourced from Trading Economics and increased by 1% to account for long term risks. Inflation data was sourced from IMF.	Trading Economics, IMF
Capacity deployment and learning rate	Long term projections of deployment were made using observed rates of growth in REMAP research. A learning rate of 39% was assumed for onshore wind (high) and 20% for solar PV (mid).	IRENA REMAP

- Greece

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for Greece for both technologies was estimated using IRENA costs data and proxies from Southern European economies.	IRENA
O&M Costs	O&M costs were assumed to be 2.2% of CAPEX and 1.5% of CAPEX for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were obtained from the same source as the CAPEX data. Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	IRENA, Protected Areas, Land Cover, Global Wind Atlas, Global Solar Atlas Carbon Tracker estimate
Return on Equity	Return on equity was assumed to be 13% in line with higher expected returns for Southern European economies.	Carbon Tracker estimate

Cost of Debt	Data on lending rates was sourced from Trading Economics and increased by 1.5% to account for long term risks. Inflation data was sourced from IMF.	Trading Economics, IMF
Capacity deployment and learning rate	Long term projections of deployment were estimated using growth rates observed in REMAP research. A learning rate of 35% (high) was used for onshore wind and 28% (mid) for solar PV.	IRENA REMAP

- Sweden

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for onshore wind and solar PV in Sweden was sourced and estimated using IRENA (2019) cost data and IEA research.	IEA, IRENA
O&M Costs	O&M costs were assumed to be 2% of CAPEX for onshore wind and 1.2% of CAPEX for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were obtained from the same source as the CAPEX data. Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	IRENA, Protected Areas, Land Cover, Global Wind Atlas Global Solar Atlas Carbon Tracker estimate
Return on Equity	Return on equity was estimated using proxies from neighboring countries.	Carbon Tracker estimate
Cost of Debt	Lending rates were sourced from Trading Economics and increased by 2.5% to account for long term risks. Inflation data was sourced from IMF.	Trading Economics, IMF
Capacity deployment and learning rate	Long term projections of capacity deployment were estimated using growth rates from REMAP research. A learning rate of 18% (mid) was used for onshore wind and 19% (mid) for solar PV.	IRENA REMAP

- Ireland

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for Ireland for onshore wind and solar PV was estimated using IRENA data for 2018 and neighboring country data.	IRENA
O&M Costs	O&M costs were assumed to be 2% of CAPEX for onshore wind and 1.2% of CAPEX for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were obtained from the same source as the CAPEX data. Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	IRENA, Protected Areas, Land Cover, Global Wind AtlasGlobal Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was estimated using proxies from neighboring countries.	Carbon Tracker estimate
Cost of Debt	Lending rates were sourced from Trading Economics and increased by 2.5% to account for long term risks. Inflation data was sourced from IMF.	Trading Economics, IMF
Capacity deployment and learning rate	Long term projections of capacity deployment were estimated using growth rates from REMAP research.	IRENA REMAP

	A learning rate of 16% (mid) was used for onshore wind and 11% (mid) for solar PV.	

- Netherlands

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for onshore wind and solar PV for Netherlands was estimated using IRENA (2019) data and neighboring countries proxies.	IRENA
O&M Costs	O&M costs were assumed to be 2% of CAPEX for onshore wind and 1.2% of CAPEX for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were obtained from the same source as the CAPEX data. Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	IRENA, Protected Areas, Land Cover, Global Wind Atlas Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was estimated using proxies from neighboring countries.	Carbon Tracker estimate
Cost of Debt	Lending rates were sourced from Trading Econimics and increased by 1% to account for long term risks. Inflation data was sourced from IMF.	Trading Economics, IMF
Capacity deployment and learning rate	Long term projections of capacity deployment were estimated using growth rates from REMAP research. A learning rate of 14% (mid) was used for onshore wind and 21% (mid) for solar PV.	IRENA REMAP

- Finland

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for Finland for onshore wind and solar PV was estimated using IRENA (2019) data.	IRENA
O&M Costs	O&M costs were assumed to be 2% of CAPEX for onshore wind and 1.2% of CAPEX for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were obtained from the same source as the CAPEX data. Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	*IRENA* , *Protected Areas, Land Cover*, *Global Wind Atlas*, *Global Solar Atlas*, Carbon Tracker estimate
Return on Equity	Return on equity was estimated using proxies from neighboring countries.	Carbon Tracker estimate
Cost of Debt	Lending rates were sourced from Trading Economics and increased by 0.25% to account for long term risks.	*Trading Economics*
Capacity deployment and learning rate	Long term projections of capacity deployment were estimated using growth rates from REMAP research.	*IRENA REMAP*

	A learning rate of 16% (mid) was used for onshore wind and 19% (mid) for solar PV.	

- Denmark

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for Denmark for onshore wind and solar PV was estimated using IRENA (2019) data	IRENA
O&M Costs	O&M costs were assumed to be 2% of CAPEX for onshore wind and 1.2% of CAPEX for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors for wind were obtained from the same source as the CAPEX data. Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	IRENA , Protected Areas, Land Cover, Global Wind Atlas, Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was estimated using proxies from neighboring countries.	Carbon Tracker estimate
Cost of Debt	Lending rates were sourced from Trading Economics. Inflation data was sourced from IMF	Trading Economics, IMF
Capacity deployment and learning rate	Long term projections of capacity deployment were estimated using growth rates from REMAP research. A learning rate of 17% (mid) was used for onshore wind and 25% (high) for solar PV.	IRENA REMAP

- Hungary

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for Hungary for onshore wind and solar PV was estimated using IRENA (2019) data and neighboring country proxies.	IRENA
O&M Costs	O&M costs were assumed to be 2% of CAPEX for onshore wind and 1.2% of CAPEX for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were obtained from the same source as for the CAPEX data. Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	IRENA, Protected Areas, Land Cover, Global Wind Atlas , Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was estimated using proxies from neighboring countries.	Carbon Tracker estimate
Cost of Debt	Lending rates were sourced from Trading Economics increased by 3% to account for long term risks. Inflation data was sourced from IMF.	Trading Economics, IMF

Capacity deployment and learning rate	Long term projections of capacity deployment were estimated using growth rates from REMAP research. A learning rate of 14% (mid) was used for onshore wind and 27% (high) for solar PV.	IRENA REMAP

- Austria

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for Austria for onshore wind and solar PV was estimated using IRENA (2019) data and neighboring country proxies.	IRENA
O&M Costs	O&M costs were assumed to be 2% of CAPEX for onshore wind and 1.2% of CAPEX for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were obtained from the same source as for the CAPEX data. Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	IRENA, Protected Areas, Land Cover, Global Wind Atlas, Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was estimated using proxies from neighboring countries.	Carbon Tracker estimate
Cost of Debt	Lending rates were sourced from Trading Economics and increased by 1.5% to account for long term risks. Inflation data was sourced from IMF.	Trading Economics, IMF
Capacity deployment and learning rate	Long term projections of capacity deployment were estimated using growth rates from REMAP research. A learning rate of 17% (mid) was used for onshore wind and 23% (high) for solar PV.	IRENA REMAP

- Czech Republic

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for Czech Republic for onshore wind and solar PV was estimated using IRENA (2019) data and neighboring country proxies.	IRENA
O&M Costs	O&M costs were assumed to be 2% of CAPEX for onshore wind and 1.2% of CAPEX for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were obtained from the same source as for the CAPEX data. Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	IRENA, Protected Areas, Land Cover, Global Wind Atlas, Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was estimated using proxies from neighboring countries.	Carbon Tracker estimate

Cost of Debt	Lending rates were sourced from Trading Economics and increased by 1.2% to account for long term risks. Inflation data was sourced from IMF.	Trading Economics, IMF
Capacity deployment and learning rate	Long term projections of capacity deployment were estimated using growth rates from REMAP research. A learning rate of 22% (high) was used for onshore wind and 23% (high) for solar PV.	IRENA REMAP

- Croatia

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for Croatia for onshore wind and solar PV was estimated using IRENA (2019) data and neighboring country proxies.	IRENA
O&M Costs	O&M costs were assumed to be 2% of CAPEX for onshore wind and 1.2% of CAPEX for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were obtained from the same source as for the CAPEX data. Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	IRENA , Protected Areas, Land Cover, Global Wind Atlas, Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was estimated using proxies from neighboring countries.	Carbon Tracker estimate
Cost of Debt	Lending rates were sourced from Tradin Economics and increased by 1.5% to account for long term risks. Inflation data was sourced from IMF.	Trading Economics, IMF
Capacity deployment and learning rate	Long term projections of capacity deployment were estimated using growth rates from REMAP research. A learning rate of 25% (high) was used for onshore wind and 12% (high) for solar PV.	IRENA REMAP

- Slovakia

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for Slovakia for onshore wind and solar PV was estimated using IRENA (2019) data and neighboring country proxies.	IRENA
O&M Costs	O&M costs were assumed to be 2% of CAPEX for onshore wind and 1.2% of CAPEX for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were obtained from the same source as for the CAPEX data. Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	IRENA, Protected Areas, Land Cover, Global Wind Atlas, Global Solar Atlas, Carbon Tracker estimate

Return on Equity	Return on equity was estimated using proxies from neighboring countries.	Carbon Tracker estimate
Cost of Debt	Lending rates were sourced from Trading Economics and increased by 1.5% to account for long term risks. Inflation data was sourced from IMF.	Trading Economics, IMF
Capacity deployment and learning rate	Long term projections of capacity deployment were estimated using growth rates from REMAP research. A learning rate of 8% (low) was used for onshore wind and 21% (mid) for solar PV.	IRENA REMAP

- Slovenia

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind & solar PV		
Capital Expenditure	CAPEX data for Slovenia for onshore wind and solar PV was estimated using IRENA (2019) data and neighboring country proxies.	IRENA
O&M Costs	O&M costs were assumed to be 2% of CAPEX for onshore wind and 1.2% of CAPEX for solar PV.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were obtained from the same source as for the CAPEX data. Local capacity factors for wind were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm. For solar, local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	IRENA , Protected Areas, Land Cover, Global Wind Atlas, Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was estimated using proxies from neighboring countries.	Carbon Tracker estimate
Cost of Debt	Lending rates were sourced from Trading Economics and increased by 1.5% to account for long term risks. Inflation data was sourced from IMF.	Trading Economics, IMF
Capacity deployment and learning rate	Long term projections of capacity deployment were estimated using growth rates from REMAP research. A learning rate of 9% (low) was used for onshore wind and 19% (mid) for solar PV.	IRENA REMAP

6.5 India

6.5.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	*Global Energy Monitor*
Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide, sulphur dioxide and particulate matter, as well as the type of cooling technology.	*Platts*
FOM	In the absence of India-specific value for Fixed O&M cost, we assume 40% of Indian O&M costs from IEA WEO 2018. FOM assumptions depend on the combustion technology of the boiler. We assume US$22/kW for subcritical technologies; US$31/kW for supercritical technologies; US$34/kW for ultra-supercritical technologies; and US$44/kW for integrated gasification combined cycle technologies (IGCC). Plants with unknown boiler types were assumed to have subcritical FOM costs.	Carbon Tracker estimates based on *IEA WEO* , *Agora*

	For Lignite, we use FOM cost assumptions from Agora (2017). Lignite FOM cost depend on age of the unit.	
VOM	VOM assumptions depend on the combustion technology of the boiler. We assume US$5.8/MWh for subcritical technologies; US$4.6/MWh for supercritical technologies; US$4.3/MWh for ultra-supercritical technologies; and US$7.5/MWh for integrated gasification combined cycle technologies. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more. For Lignite, we use VOM cost assumptions from Agora (2017). Lignite VOM cost depend on age of the unit.	Carbon Tracker estimates based on North America Electric Reliability Corporation , Agora
Capacity factor	Asset level capacity factor data was calculated using monthly generation reports from the India Central Electric Authority. Missing values were filled using state-level capacity factors.	India Central Electricity Authority
Fuel type, cost and transport	Fuel costs include the expenses incurred in buying, transporting, and preparing the coal. For the cost of coal for producers we use benchmarks from Coal India Limited. For imported coal we use Bloomberg LP. Fuel costs vary depending on a plant's location. Fuel costs also include a model which calculates the transport of coal. This is a cost-optimised supply route algorithm, which computes the distance between a unit's location and the nearest suitable coal mine, considering coal type, mode of transport and related costs/other charges, available ports and mine and import capacities. We assume coal supplying regions supply 100% of demand locally, some can meet a portion of demand and others rely solely on coal from coal supplying regions. We assume India import hard coal from Indonesia (59%), South Africa (24%) and Australia (7%) via seaborne and land routes to plant. For lignite plants coal cannot be transported long distances. We therefore calculate the fixed cost of running a Lignite mine and use this as the fuel cost. Fixed O&M cost assumptions for Lignite come from Agora (2017) and depend on a unit's age.	Coal India Limited, Coal controller of India , Agora , Carbon Tracker analysis
Carbon price	We assume no carbon pricing throughout the modelling horizon.	-
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age. Baseline values are country and boiler type specific.	IEA, Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant control tech type and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	We take the IEA B2DS projections for coal generation within India.	IEA, Carbon Tracker estimate
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), Nitrous Oxide (NOx) and Sulphur Oxide (Sox) controls for all existing plants that do not have control technologies installed by 2023. The start year for capital additions in 2022. The technology installed to control PM is the same for all plants but depends on Unit nameplate capacity for Sox controls and build date for Nox controls.	Country Experts, IISD (2019)
Plant revenues	We use India Power Plant Tariffs for 2016-17 and inflate it to present day values	India Central Electricity Authority

6.5.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX data was sourced from from IRENA 2019 costS together with a cost breakdown. Lower and upper bands were calculated using a 20% assumption.	IRENA

O&M Costs	O&M costs were assumed to be 1 % of CAPEX, some of the lowest observed among the countries due to low labor costs in India and a relatively large deployment base. Lower and upper bands were calculated using a 20% assumption.	Carbon Tracker estimate
Capacity factor	Country level capacity factor data was sourced from the same IRENA publication as CAPEX data. A lower and upper band was calculated using a 20% assumption. Local capacity factors were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm.	Protected Areas, Land Cover, Global Wind Atlas Carbon Tracker estimate
Return on Equity	Return on equity was sourced from Damodoran.	Damodaran
Cost of Debt	Data on long term lending rates was sourced from the World Bank while inflation data was sourced from the IMF.	World Bank, IMF
Capacity deployment and learning rate	Data on deployment projections was sourced from REMAP file for G20 countries. A learning rate of 21% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP
Assumptions for solar PV		
Capital Expenditure	CAPEX data for solar PV in India together with cost break down was sourced from the IRENA 2019 cost publication. Lower and upper bounds were calculated using a 20% assumption.	IRENA
O&M Costs	O&M costs were assumed to be 0.09% of CAPEX. Lower and upper bands were calculated using a 20% assumption.	Carbon Tracker estimate
Capacity factor	Country level capacity factor data was sourced from REN21 which is based on IRENA data. Lower and upper bands were calculated using a 20% assumption. Local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	REN21, Global Solar Atlas Carbon Tracker estimate
Return on Equity	Return on equity was sourced from Damodoran.	Damodaran
Cost of Debt	Data on long term lending rates was sourced from the World Bank while inflation data was sourced from the IMF.	World Bank, IMF
Capacity deployment and learning rate	Data on deployment projections was sourced from REMAP file for G20 countries. A learning rate of 17% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP

6.6 Indonesia

6.6.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	Global Energy Monitor
Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide, sulphur dioxide and particulate matter, as well as the type of cooling technology.	Platts
FOM	In the absence of Indonesia-specific value for FOM cost, we assume 40% of ASEAN O&M costs from IEA WEO 2015. FOM assumptions depend on the combustion technology of the boiler. We assume, US$11/kW for subcritical technologies; US$15/kW for supercritical technologies; US$17/kW for ultra-supercritical technologies; and US$26/kW for integrated gasification combined cycle technologies (IGCC).	Carbon Tracker estimates based on IEA
VOM	VOM assumptions depend on the combustion technology of the boiler. We assume, US$5.83/MWh for subcritical technologies; US$4.67/MWh for supercritical technologies; US$4.38/MWh for ultra-supercritical technologies; and US$7.53/MWh for integrated gasification combined cycle technologies. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more.	Carbon Tracker estimates based on North America Electric Reliability Corporation

Capacity factor	Realised 2018 average capacity factors at provincial level for existing capacity.	PLN
Fuel type, cost and transport	Fuel costs include the expenses incurred in buying, transporting, and preparing the coal. For the cost of coal for producers we use benchmarks from APBI-ICMA (2019) while scaling Bituminous and Sub-bituminous coal prices by calorific values. Indonesia currently tracks coal prices using a coal price benchmark, known as HARGA BATUBARA ACUAN. It has a cap on coal prices at $70/t for PLN and so PLN unit fuel costs are clipped at this value. In calculating transport costs, we assume domestic coal used is used for coal-fired power gen nationally. Producing areas of Kalimantan and Sumatra are assumed to use local coal transported by road. Plants located on the islands of Papua, Java-Bali, Sulawesi and Nusa Tengara are assumed to source their coal from Kalimantan via seaborne and land routes. While there are cases where this may be invalid, it is a good proxy assumption. In any case, the only a small proportion of costs are transport related. For lignite plants coal cannot be transported long distances. We therefore calculate the fixed cost of running a Lignite mine and use this as the fuel cost. Fixed O&M cost assumptions for Lignite come from Agora (2017) and depend on a unit's age.	APBI-ICMA , Ports.com , Agora , Carbon Tracker estimate
Carbon price	We assume no carbon pricing throughout the modelling horizon.	-
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age. Baseline values are country and boiler type specific.	IEA, Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	We use ASEAN decline rates from the IEA's Beyond 2°C scenario (B2DS) for Indonesia generation.	IEA , Carbon Tracker estimate
Pollution limit regulations and associated capital and operational costs	Though air pollution regulations have been updated for Indonesia, we assume no additional capital costs for the installation of environmental control technologies across the fleet because given the age of Indonesian units, the regulated limits are generally too high to warrant retrofits.	Indonesia Regulations
Plant revenues	Provincial tariffs are used as per the MoEMR Regulation No. 19/2017 provisions on tariffs, with limited visibility on PPAs. The new maximum benchmark price follows the national BPP (USD cent 7.66/kWh) in the case of coal-fired plants with a capacity higher than 100 MW if they are installed in any region where the Regional BPP > National BPP.	PwC

6.6.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX for onshore wind in Indonesia in 2019 was sourced from a research paper published in 2015 and was estimated to be the median point between the low and high end of the estimates. A lower bound and upper band was assumed using a 20% decline/increase. Cost break down of CAPEX was sourced from the same research paper.	*Kamal et al.*
O&M Costs	O&M costs were collected from the same source and assumed to be 2.2% of CAPEX. A lower bound and upper band was assumed using a 20% decline/increase.	Carbon Tracker estimate
Capacity factor	Country level capacity factor data was from the same source as CAPEX and O&M data. A lower bound and upper band was assumed using a 20% decline/increase. Local capacity factors were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local	*Protected Areas*, *Land Cover*, *Global Wind Atlas*

	capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm.	
Capacity (MW)	Data for capacity (MW) projections was sourced from BNEF (NEO 2018) and was generally kept low as the potential for onshore wind is considered quite low in Indonesia, almost 7 GW in 2040 which is equivalent to 6.5 times higher than BNEF.	BNEF
Return on Equity	Data on return on equity was taken from a dataset maintained by Aswath Damodaran, a finance professor at NYU Stern. There was no specific data for Indonesia and instead the value for emerging markets was used 12.83% to which 3% was added to reflect higher risks taken on an emergent market such as Indonesia.	Darmodaran
Cost of Debt	Data on cost of debt was sourced from the World Bank. The rate, 11%, found was for loans on short and medium term to which another 2% points was added to account for the more riskier long term loan. Finally, inflation data was sourced from IMF. The debt equity split was assumed to be 70% debt and 30% equity, a common assumption for non-OECD member countries and emergent markets.	World Bank , International Monetary Fund
Capacity deployment and learning rate	A learning curve of 15%, assumed from global cost declines, was used to project LCOE declines going forward based on global results published in 2018. The low, mid and high LCOE and the highest capacity projections were used to compute the LCOE of onshore wind going to 2040.	IRENA
Assumptions for solar PV		
Capital Expenditure	CAPEX for solar PV in Indonesia in 2019 was sourced an IRENA report in 2019 and declined by 8% to account for cost decreases to 2019. CAPEX breakdown was assumed to be the same as the one reported by IRENA for Indonesia in 2018. A higher bound and lower bound was calculated using a 20% assumption.	IRENA
O&M Costs	O&M costs data was assumed to be 8% lower than the one observed in Japan. A lower bound O&M was calculated using 20% assumption and a higher bound using a 20% assumption.	Carbon Tracker estimate
Capacity factor	Country level capacity factors were assumed to be 0.22 as Indonesia has very good irradiation levels. The capacity factor was 16% higher than the one observed in Japan. The lower bound capacity factor was assumed to be 20% lower while the higher bound capacity factor was assumed to be 20% higher. Local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	Global Solar Atlas, Carbon Tracker estimate
Capacity (MW)	Data for capacity (MW) projections was sourced from BNEF (NEO 2018) and IRENA to which some more aggressive deployment targets were.	BNEF, IRENA
Return on Equity	Data on return on equity was taken from a dataset maintained by Aswath Damodaran, a finance professor at NYU Stern. There was no specific data for Indonesia and instead the value for emerging markets was used 12.83% to which 3% was added to reflect higher risks taken on an emergent market such as Indonesia.	Darmodaran
Cost of Debt	Data on cost of debt was sourced from World Bank. The rate, 11%, found was for loans on short and medium term to which 2 percentage points were added to account for the more riskier long term loan. Finally, inflation data was sourced from IMF. The debt equity split was assumed to be 70% debt and 30% equity, a common assumption for non-OECD member countries.	World Bank, International Monetary Fund
Capacity deployment and learning rate	A learning rate of 20% was used for solar PV LCOE in Indonesia, close to the lower bound observed for solar PV globally. Learning rates were calculated using the most aggressive deployment scenario and the mid, low, and high 2019 LCOE for solar PV.	IRENA REMAP

6.7 Japan

6.7.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	Kiko Network, Global Energy Monitor

Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide (NO2), sulphur dioxide (SO2) and particulate matter (PM), as well as the type of cooling technology.	Platts
FOM	In the absence of Japan-specific value for FOM cost, we assume 40% of Japan O&M costs from IEA WEO 2015. FOM assumptions depend on the combustion technology of the boiler. We assume US$9/kW for subcritical technologies; US$12/kW for supercritical technologies; US$13/kW for ultra-supercritical technologies; and US$21/kW for integrated gasification combined cycle technologies (IGCC).	Carbon Tracker estimates based on IEA
VOM	VOM assumptions depend on the combustion technology of the boiler. We assume: Subcritical US$5.98/MWh; Supercritical US$4.79/MWh; Ultra-super US$4.49/MWh; IGCC US$7.73/MWh. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more.	Carbon Tracker estimates based on North America Electric Reliability Corporation
Capacity factor	Using generation unit-level data from Kiko Network based on METI (2019), we calculate capacity factor for most of the plants, and for those without data we assign the national average capacity factor.	Kiko Network based on METI
Fuel type, cost and transport	Fuel costs include the expenses incurred in buying, transporting, and preparing the coal. For the cost of coal for producers we use benchmarks from Bloomberg LP. Estimates of fuel cost are based on daily price averages between 2017-2019. For every year up to 2019 we use a yearly average, and for 2020 onwards, we use the average of the last 3 years (2017-2019). Fuel costs also include a model which calculates the transport of coal. This is a cost-optimised supply route algorithm, which computes the distance between a unit's location and the nearest suitable coal mine, considering coal type, mode of transport and related costs and other charges, and available port, mine and import capacities. We assume coal is imported from Australia (60%), Indonesia (14%) and Russia (12%), sourced via seaborne from Newcastle, Mahakam River and Vladivostok to Fukuyama respectively, and then land routes to Japan's plants. While there are cases where this may be invalid, it is a good proxy assumption. No lignite in Japan.	Bloomberg , Ports.com, Carbon Tracker estimate
Carbon price	US$2.64 t/CO2 based on 289 yen/tCO2 from implemented government policy.	Environment and Economy Division Ministry of the Environment
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age.	IEA), Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	We use OECD decline rates from the IEA's Beyond 2°C scenario (B2DS) for Japan generation.	IEA, Carbon Tracker estimate
Pollution limit regulations and associated capital and operational costs	We assume no changes to existing air pollution regulations over the modelling period until 2019. From 2019 onwards, we assume that all units without PM or NOx control technologies will install it. Spreading the cost over 5 years.	Local Experts, Carbon Tracker estimate
Plant revenues	Japan is in the process of liberalizing its power market. The real sales price per kWh is decided by over-the-counter trading and not disclosed to the third parties. As a proxy for revenues we use average day-ahead spot prices from Japan Electric Power Exchange.	Carbon Tracker estimate

6.7.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		

Capital Expenditure	CAPEX was estimated using data from 2016 from a research paper produced by the Renewable Energy Institute. The cost breakdown structure came from the same sources. CAPEX values were reduced by 8% annually going to 2019 to account for cost declines during the period. A lower bound CAPEX was calculated using 15% assumption and a higher bound using a 20% assumption.	Renewable Energy Institute
O&M Costs	O&M costs were collected from the Renewable Energy Institute research paper. Decline by 5% per year going to 2019. A lower bound O&M was calculated using 15% assumption and a higher bound using a 20% assumption.	Renewable Energy Institute
Capacity factor	Capacity factor data was also collected from REI research paper, mid value. The lower bound capacity factor was declined by 3 percentage points while the higher bound capacity factor was added 3 percentage points.	Renewable Energy Institute
Capacity (MW)	Data for capacity (MW) projections was sourced from the REMAP team at IRENA while data for 2019 was projected using historical deployment data from IRENA. The underlying file is not be shared or quoted, as per the request of the REMAP team who created the projections using very aggressive carbon prices.	REMAP, IRENA
Return on Equity	Data on return on equity was taken from Aswath Damodaran dataset maintained by, a finance professor at NYU Stern. The mid value 14.67% return on equity was reduced by 15% to obtain the lower bound and increased by 15% to obtain the higher bound. Upper variation of RoE is assumed to be less significant as the upper variation of other variables.	Damodaran
Cost of Debt	Data on cost of debt was sourced from World Bank. The rate, 0.99%, found was for loans on short and medium term to which another 1 percentage point was added to account for the more riskier long term loan. Finally, inflation data was sourced from IMF. The debt equity split was assumed to be 80% debt and 20% equity, a common assumption for OECD member countries.	World Bank , International Monetary Fund
Capacity deployment and learning rate	A learning curve of 25%, upped from 21%, was used to project LCOE declines going forward based on global results published in 2018. Finally, the low, mid and high LCOE and the REMAP highest capacity projections were used to compute the LCOE of onshore wind going to 2040.	IRENA
Assumptions for solar PV		
Capital Expenditure	CAPEX for solar PV in Japan in 2019 was estimated using data from an IRENA publication, specifically for Japan, for 2018 that was declined by 8% for 2019. The cost breakdown structure came from the same sources. A lower bound CAPEX was calculated using 15% assumption and a higher bound using a 20% assumption. The cost breakdown of solar PV is from the same paper.	IRENA
O&M Costs	O&M costs data was sourced from data on *USA* solar PV plants which was scaled upwards by the difference between CAPEX in Japan versus CAPEX in USA to account for generally a more expensive market in Japan. A lower bound O&M was calculated using 15% assumption and a higher bound using a 20% assumption.	New Energy
Capacity factor	Capacity factor was calculated using fleet generation data for 2018 and adding an 8% premium to account for the utility average production being dragged down by less productive rooftop installations. The lower bound capacity factor was assumed to 15% lower while the higher bound capacity factor was assumed to be 20% higher.	Renewable Energy Institute
Capacity (MW)	Capacity projections were collated usingREMAP data and assumptions from BNEF NEO 2018 as the REMAP data was less aggressive for 2040.	IRENA REMAP
Capacity deployment and learning rate	A learning rate of 60% was used for solar PV LCOE for two reasons: Japan has the highest CAPEX and LCOE of utility solar PV which allows for significant declines going to 2040. Secondly, the LCOE decline for Japan from 2010 to 2018 was 75% according to IRENA data. Learning rates were calculated using the most aggressive deployment scenario and the mid, low, and high 2019 LCOE for solar PV.	IRENA
Assumptions for offshore wind N.B. high quality data for offshore wind is harder to come by for Japan given the thin deployment of the technology in the country, 65 MW cumulative capacity at end of 2018 according to *IRENA* stats. However, going further it seems that the government provides increasing support (*see here*) to the nascent industry.		
Capital Expenditure	CAPEX data for offshore wind was sourced from IRENA, from global weighted average CAPEX for offshore wind and from the insight that projects outside of Europe tend to be less expensive than the ones in Europe, mostly due to cheaper wind turbine use. Thus, assumed a 95% of the global weighted average offshore wind CAPEX in 2019 in Japan. IEA is providing 2% lower value for 2017 modeled project. A lower bound CAPEX was calculated using 15% assumption and a higher bound using a 20% assumption. Cost break down of CAPEX was sourced from NREL and IEA.	IRENA, IEA, NREL

O&M Costs	O&M costs were sourced from IRENA and IEA, and were assumed to 2.5% of CAPEX for Japan in 2019, the mid-point between approximately 2% of CAPEX for IRENA and 3% from IEA. A lower bound O&M was calculated using 15% assumption and a higher bound using a 20% assumption.	IRENA, IEA
Capacity factor	Capacity factor values were sourced as well from IRENA and IEA as the mid-point between the global weighted average in IRENA publication and the value provided in the IEA offshore wind report. A lower bound capacity factor was calculated using a 15% decline rate and a higher bound using a 20% increase rate.	IRENA, IEA
Capacity deployment and learning rate	The low, mid and high LCOE calculated was used to compute the cost decline going further to 2040. REMAP most aggressive deployment scenario was used and a learning rate of 12%, 2% lower than in IRENA 2018 publication at global level, lower due to Japan having more uncertainties over how much offshore will develop.	IRENA

6.8 Malaysia

6.8.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	*Global Energy Monitor* , *Malaysia Energy Commission*
Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide (NO2), sulphur dioxide (SO2) and particulate matter (PM), as well as the type of cooling technology.	*Platts*
FOM	In the absence of Malaysia specific cost for FOM, we assume 40% of Indian O&M costs (from IEA WEO 2018). FOM costs depend on the combustion technology of the boiler. We assume the following: Subcritical US$23/kW; Supercritical US$33/kW; Ultra-supercritical US$36/kW; IGCC US$46/kW. For Lignite, we use FOM cost assumptions from Agora (2017). Lignite FOM cost depend on age of the unit.	Carbon Tracker estimates based on *IEA WEO* , *Agora*
VOM	VOM assumptions depend on the combustion technology of the boiler: Subcritical US$5,65/MWh; Supercritical US$4,52/MWh; Ultra-supercritical US$4,24/MWh; IGCC US$7,29/MWh. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more. For Lignite, we use VOM cost assumptions from Agora (2017). Lignite VOM cost depend on age of the unit.	Carbon Tracker estimates based on North America *Electric Reliability Corporation* , *Agora*
Capacity factor	In the absence of asset-level generation, we use 2017 thermal coal capacity factors for each of the principal regional power systems.	*Malaysia Energy Commission*
Fuel type, cost and transport	Fuel costs include the expenses incurred in buying, transporting, and preparing the coal. For the cost of coal for producers we use benchmarks from Bloomberg LP. Estimates of fuel cost are based on daily price averages between 2017-2019. For every year up to 2019 we use a yearly average, and for 2020 onwards, we use the average of the last 3 years (2017-2019). Fuel costs also include a model which calculates the transport of coal. This is a cost-optimised supply route algorithm, which computes the distance between a unit's location and the nearest suitable coal mine, considering coal type, mode of transport and related costs and other charges, and available port, mine and import capacities. We assume coal is imported from Indonesia (63%), Australia (24%), Russia (11%) and South Africa (2%) sourced via seaborne from East Kalimantan, Newcastle, Vladivostok and Richard's Bay to Lumut respectively, and then land routes to peninsular Malaysia's plants. While there are cases where this may be invalid, it is a good proxy assumption. For lignite plants coal cannot be transported long distances. We therefore calculate the fixed cost of running a Lignite mine and use this as the fuel cost. Fixed O&M cost assumptions for Lignite come from Agora (2017) and depend on a unit's age.	*Bloomberg*, *GeoDatos* , *Ports.com* , *The Star*, *Agora*
Carbon price	We assume no carbon pricing throughout the modelling horizon.	-

Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age.	IEA (2015), Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	We assume ASEAN decline rates from the IEA's Beyond 2°C scenario (B2DS) for Malaysia generation.	IEA, Carbon Tracker estimate
Pollution limit regulations and associated capital and operational costs	We assume no additional capital costs for the installation of environmental control technologies across the fleet. In most cases, emissions limits of TNB & IPP plants are well within the regulatory limits as local plants have generally been designed to meet international limits, which are usually higher than the locally imposed limits.	Country Experts
Plant revenues	Wholesale price and base tariff from Tenaga Nasional - scraped from a Tenaga Nasional Investor Presentation (Dec 2018)	Tenaga Nasional Investor Presentation

6.8.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	There is no onshore wind deployment in Malaysia as of 2018, according to IRENA statistics and no plans for short term deployment. Thus, assumed the same costs for onshore wind development as in South Korea, some of the highest costs observed world wide, close to Japan CAPEX. For the CAPEX breakdown, I chose to assign more weight to the wind turbine as in more expensive markets such as Russia. A lower and higher band using 20% assumption was calculated.	IRENA statistics
O&M Costs	O&M costs were assumed to be among the highest at 2% of CAPEX annually as deployment is non existent and thus an O&M market would be a very thin market with high prices. A lower and higher band using 20% assumption was calculated.	Carbon Tracker estimate
Capacity factor	Capacity factor data had to be assumed from global weighted averages and capacity factors reported for newer turbines, from IRENA reports, and was estimated at 0.3425. A lower and higher band using 20% assumption was calculated.	IRENA
Return on Equity	Return on equity was assumed to be 16%, 1% point higher than emergent markets data from Damodaran.	Damodaran
Cost of Debt	Data on cost of debt was sourced from World Bank to which 2% more was added to account for long term debt. Inflation data was sourced from IMF. The equity debt split was assumed to be 80/20. A lower and higher band using 20% assumption was calculated for real WACC.	World Bank, IMF
Capacity deployment and learning rate	Data on deployment of onshore wind was sourced from an older REMAP report and testifies to the low potential for onshore wind in Malaysia. Given all this, a learning rate of 17% was used and the most aggressive deployment scenarios to project LCOE to 2040.	IRENA REMAP
Assumptions for solar PV		
Capital Expenditure	CAPEX data for Malaysia was sourced from project level data and we settled finally for 1487 USD/kW closer to regional data (e.g. Indonesia). CAPEX breakdown was assumed to be in line with data for South Africa sourced from IRENA report.	(Project 1, Poject 2, Project 3), IRENA
O&M Costs	O&M was assumed to be 1.1% of CAPEX, closer to regionally assumed values.	Carbon Tracker estimate
Capacity factor	Capacity factor was sourced from project level data and assumed to be 0.21. A lowe and higher bound was calculated for all variables using a 20% assumptions.	-
Return on Equity	Return on equity was assumed to be 16%, 1% point higher than emergent markets data from Damodaran.	Damodaran

Cost of Debt	Data on cost of debt was sourced from World Bank to which 2% more was added to account for long term debt. Inflation data was sourced from IMF. The equity debt split was assumed to be 80/20. A lower and higher band using 20% assumption was calculated for real WACC.	World Bank, IMF
Capacity deployment and learning rate	A learning rate of 18% was used and the most aggressive deployment scenarios to project LCOE to 2040.	IRENA

6.9 Pakistan

6.9.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	Global Energy Monitor
Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide (NO2), sulphur dioxide (SO2) and particulate matter (PM), as well as the type of cooling technology.	Platts
FOM	In the absence of Pakistan-specific value for Fixed O&M cost, we assume 40% of Asia O&M costs from IEA WEO 2015. FOM assumptions depend on the combustion technology of the boiler. We assume the following, Subcritical US$12/kW; Supercritical US$16/kW; Ultra-supercritical US$19/kW; IGCC US$29/kW.	Carbon Tracker estimates based on IEA WEO
VOM	VOM assumptions depend on the combustion technology of the boiler. We assume the following, Subcritical US$5.41/MWh; Supercritical US$4,33/MWh; Ultra-supercritical US$4,06/MWh; IGCC US$6,99/MWh. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more.	Carbon Tracker estimates based on North America Electric Reliability Corporation
Capacity factor	In the absence of asset-level generation, we use 2019 regional thermal coal generation data and therefore regional average capacity factors for each unit.	NEPRA, BPDB Annual report
Fuel type, cost and transport	Fuel costs include the expenses incurred in buying, transporting, and preparing the coal. For the cost of coal for producers we use benchmarks from Bloomberg LP. Estimates of fuel cost are based on daily price averages between 2013-2019. As proxy for 2020 onwards, we use the 2019 average price. Fuel costs also include a model which calculates the transport of coal. This is a cost-optimised supply route algorithm, which computes the distance between a unit's location and the nearest suitable coal mine, considering coal type, mode of transport and related costs and other charges, and available port, mine and import capacities. We assume coal is imported from South Africa (83%), Indonesia (12%), Russia (4%) and Australia (1%) sourced via seaborne from Richard's Bay, East Kalimantan, Vladivostok and Newcastle and to Qasim respectively, and then land routes to Pakistan's plants. While there are cases where this may be invalid, it is a good proxy assumption. We also consider if a plant is fed by domestic coal mine and use their coal price instead. For sub-bituminous coal we use Indonesian sub-bituminous coal price.	Bloomberg, Ports.com, OEC, Carbon Tracker estimate
Carbon price	We assume no carbon pricing throughout the modelling horizon.	-
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age.	IEA , Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	We use non-OECD decline rates from the IEA's Beyond 2°C scenario (B2DS) for Pakistan generation.	IEA , Carbon Tracker estimate

Pollution limit regulations and associated capital and operational costs	We assume no changes to existing air pollution regulations over the modelling period.	Country Experts
Plant revenues	We use tariff prices data from NEPRA (2016) as a proxy for plant revenues. We estimate the average plant revenue between 2018 and 2019. This value is constant over our complete modelling period.	NEPRA

6.9.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX data for onshore wind in Pakistan was sourced from project level data and assumed to be USD 1843/kW in 2019. CAPEX breakdown was assumed to be closer to the one in South Africa, where there is slightly closer to 3 GW of onshore in 2019 versus 2.7 GW in Pakistan. A lower and upper bound was calculated using 20% assumption.	Project
O&M Costs	O&M costs were assumed to be 1.65% of CAPEX, higher than the one assumed for South Africa at 1.31% of CAPEX. A lower and upper bound was calculated using 20% assumption.	Carbon Tracker estimate
Capacity factor	Capacity factor was assumed to be 0.36 and was sourced from project level data. A lower and upper bound was calculated using a 20% assumption.	(Project 1, Project 2)
Return on Equity	Return on equity was assumed to be 25%, 10% more than expected return for emergent markets, as Pakistan has a relatively high inflation rate at 8%.	Carbon Tracker estimate
Cost of Debt	Cost of debt was sourced from World Bank at 8.5% to which 5% was added to account for long term debt and more risks associated with investing in Pakistan. Inflation rate was sourced from IMF. Debt equity split was assumed to be 70/30 as Pakistan is a riskier investment destination. A lower and upper bound rWACC was calculated using a 20% assumption.	World Bank, IMF
Capacity deployment and learning rate	The REMAP team at IRENA does not have a projection for Pakistan. Thus, we extrapolated based on REMAP growth assumptions the 2019 estimated cumulative capacity to 45 GW in 2040. We used a learning curve of 21%, the global learning curve observed for onshore wind, and the most aggressive deployment scenario to project LCOE to 2040.	IRENA REMAP
Assumptions for solar PV		
Capital Expenditure	CAPEX for solar PV in Pakistan in 2019 was assumed to be USD 1075/kW and was sourced from project level data. CAPEX breakdown was assumed to be the same as in Malaysia. A lower and upper band was calculated using a 20% assumption.	(Project 1, Project 2, Project 3)
O&M Costs	O&M was assumed to be 1.35%, higher than the one in Malaysia due to local economic conditions and higher inflation rate in Pakistan. A lower and upper band was calculated using a 20% assumption.	Carbon Tracker estimate
Capacity factor	Capacity factor for solar PV was assumed to be 0.21 and was sourced from project level data. A lower and upper band was calculated using a 20% assumption.	-
Return on Equity	Return on equity was assumed to be 25%, 10% more than expected return for emergent markets, as Pakistan has a relatively high inflation rate at 8%.	Carbon Tracker estimate
Cost of Debt	Cost of debt was sourced from World Bank at 8.5% to which 5% was added to account for long term debt and more risks associated with investing in Pakistan. Inflation rate was sourced from IMF. Debt equity split was assumed to be 70/30 as Pakistan is a riskier investment destination. A lower and upper bound WACC was calculated using a 20% assumption.	World Bank, IMF
Capacity deployment and learning rate	The REMAP team at IRENA does not have a projection for Pakistan. Thus, extrapolation based on REMAP growth assumptions the 2019 estimated cumulative capacity to 65 GW in 2040. Learning rate of 22%, mid assumption, and the highest deployment rates to project LCOE of solar PV in 2040.	IRENA REMAP

6.10 Philippines

6.10.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	Global Energy Monitor
Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide (NO2), sulphur dioxide (SO2) and particulate matter (PM), as well as the type of cooling technology.	Platts
FOM	In the absence of Philippines specific cost for FOM, we assume 40% of Indian O&M costs (from IEA WEO 2018). The FOM costs depend on the combustion technology of the boiler. We assume the following: Subcritical US$21/kW; Supercritical US$30/kW; Ultra-supercritical US$33/kW; IGCC US$42/kW. For Lignite, we use FOM cost assumptions from Agora (2017). Lignite FOM cost depend on age of the unit.	Carbon Tracker estimates based on IEA WEO, Agora
VOM	VOM assumptions depend on the combustion technology of the boiler. We assume the following: Subcritical US$5,06/MWh; Supercritical US$4,05/MWh; Ultra-supercritical US$3,80/MWh; IGCC US$6,53/MWh. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more. For Lignite, we use VOM cost assumptions from Agora (2017). Lignite VOM cost depend on age of the unit.	North America Electric Reliability Corporation , Agora
Capacity factor	In the absence of asset-level generation, we use 2018 regional thermal coal generation data to calculate the regional average capacity factors for each unit.	Department of Energy Philippines
Fuel type, cost and transport	Fuel costs include the expenses incurred in buying, transporting, and preparing the coal. For the cost of coal for producers we use benchmarks from Bloomberg LP. Estimates of fuel cost are based on daily price averages between 2017-2019. For every year up to 2019 we use a yearly average, and for 2020 onwards, we use the average of the last 3 years (2017-2019). Fuel costs also include a model which calculates the transport of coal. This is a cost-optimised supply route algorithm, which computes the distance between a unit's location and the nearest suitable coal mine, considering coal type, mode of transport and related costs and other charges, and available port, mine and import capacities. We assume 95% of thermal coal is imported from Indonesia. For the transports costs we assume that distances to the region will be roughly the same and since most units are in the coast, rail cost are considered zero. For lignite plants coal cannot be transported long distances. We therefore calculate the fixed cost of running a Lignite mine and use this as the fuel cost. Fixed O&M cost assumptions for Lignite come from Agora (2017) and depend on a unit's age.	Bloomberg, Ports.com , IEEFA , Agora , Carbon Tracker estimate
Carbon price	We assume no carbon pricing throughout the modelling horizon.	-
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age.	IEA , Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	We use ASEAN decline rates from the IEA's Beyond 2°C scenario (B2DS) for the Philippines generation, and apply it to its current proportional share of coal-fired power generation. Coal is phased out across Luzon, Visayas and Mindanao based on current production shares.	IEA, Philippines Department of Energy, Carbon Tracker estimate
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	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.	WESM

6.10.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX for onshore wind in Philippines was assumed to be 6% lower than the one observed in South Korea in 2019. A lower and upper bound using 20% assumption was calculated. Cost break down of CAPEX was assumed to be the same as in the case of Indonesia.	Carbon Tracker estimate
O&M Costs	O&M costs were assumed to be 24% less than the ones observed in Vietnam. A 20% lower and upper bound was calculated.	Carbon Tracker estimate
Capacity factor	Capacity factor was assumed to be the same as the one observed in Vietnam in 2019. A lower an upper bound was calculated for capacity factors, using a 20% assumption.	Carbon Tracker estimate
Capacity (MW)	Data for capacity (MW) projections was sourced from BNEF (NEO 2018) and IRENA to which some more aggressive deployment targets were added.	BNEF NEO, IRENA
Return on Equity	Data on return on equity was taken from a dataset maintained by Aswath Damodaran, a finance professor at NYU Stern. There was no specific data for Philippines and instead the value for emerging markets was used 12.83% to which 3% was added as 12.83% is too low for an emergent market such as Philippines.	Damodaran
Cost of Debt	Data on cost of debt was sourced from World Bank. The rate, 6.1%, found was for loans on short and medium term to which another 2 percentage points were added to account for the more riskier long term loan. Finally, inflation data was sourced from IMF. The debt equity split was assumed to be 70% debt and 30% equity, a common assumption for emergent markets.	World Bank, International Monetary Fund
Capacity deployment and learning rate	A learning curve of 15%, assumed from global cost declines, was used to project LCOE declines going forward based on global results published in 2018. The low, mid and high LCOE and the highest capacity projections were used to compute the LCOE of onshore wind going to 2040.	IRENA
Assumptions for solar PV		
Capital Expenditure	CAPEX for solar PV in Philippines was assumed to be 10% lower than the one observed in South Korea in 2019 and published in the IRENA report. A 20% lower and upper bound was calculated.	IRENA
O&M Costs	O&M costs data was assumed to be on the higher end of observed costs in South East Asia given the relatively low deployment in the country as compared to South Korea. A lower and upper bound O&M costs were calculated using a 20% assumption.	Carbon Tracker estimate
Capacity factor	Capacity factor was assumed to be at the same level as the ones observed in Vietnam. A lower and upper bound O&M costs were calculated using a 20% assumption.	Carbon Tracker estimate
Capacity (MW)	Data for capacity (MW) projections was sourced from BNEF (NEO 2018) and IRENA to which I added some more aggressive deployment targets.	BNEF NEO, IRENA
Return on Equity	Data on return on equity was taken from a dataset maintained by Aswath Damodaran, a finance professor at NYU Stern. There was no specific data for Philippines and instead the value for emerging markets was used 12.83% to which I added 3% as 12.83% is too low for an emergent market such as Philippines.	Damodoran
Cost of Debt	Data on cost of debt was sourced from World Bank The rate, 6.1%, found was for loans on short and medium term to which another 2 percentage points were added to account for the more riskier long term loan. Finally, inflation data was sourced from IMF. The debt equity split was assumed to be 70% debt and 30% equity, a common assumption for emergent markets	World Bank , International Monetary Fund

Capacity deployment and learning rate	A learning rate of 18% was used for solar PV LCOE as this is more in line with the lower range of learning curves for solar PV. Learning rates were calculated using the most aggressive deployment scenario and the mid, low, and high 2019 LCOE for solar PV.	IRENA REMAP

6.11 Russia

6.11.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	Global Energy Monitor
Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide, sulphur dioxide and particulate matter, as well as the type of cooling technology.	Platts
FOM	In the absence of Russia specific cost for FOM, we assume 40% of Russian O&M costs (from IEA WEO 2018). FOM assumptions depend on the combustion technology of the boiler US$9/kW for subcritical technologies. We assume US$12/kW for supercritical technologies; US$14/kW for ultra-supercritical technologies; and US$22/kW for integrated gasification combined cycle technologies (IGCC).	Carbon Tracker estimates based on IEA WEO
VOM	VOM assumptions depend on the combustion technology of the boiler. We assume US$3.84/MWh for subcritical technologies; US$3.08/MWh for supercritical technologies; US$2.89/MWh for ultra-supercritical technologies; and US$4.96/MWh for integrated gasification combined cycle technologies. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more.	Carbon Tracker estimates based on North America Electric Reliability Corporation
Capacity factor	In the absence of asset-level generation, or even coal-fired generation, we use 2018 thermal capacity factors for each of the principal regional power systems.	Joint-Stock Company System Operator of the Unified Energy System (JSC SO UES)
Fuel type, cost and transport	Fuel costs include the expenses incurred in buying, transporting, and preparing the coal. For the cost of coal for producers we use benchmarks from Bloomberg LP. Estimates of fuel cost are based on daily price averages between 2017-2019. For every year up to 2019 we use a yearly average, and for 2020 onwards, we use the average of the last 3 years (2017-2019). Fuel costs also include a model which calculates the transport of coal. This is a cost-optimised supply route algorithm, which computes the distance between a unit's location and the nearest suitable coal mine, considering coal type, mode of transport and related costs and other charges, and available port, mine and import capacities. We assume all coal is source locally. For lignite plants coal cannot be transported long distances. We therefore calculate the fixed cost of running a Lignite mine and use this as the fuel cost. Fixed O&M cost assumptions for Lignite come from Agora (2017) and depend on a unit's age. For sub-bituminous coal we use Indonesian coal prices.	Bloomberg, Ports.com , Agora , Carbon Tracker estimate
Carbon price	We assume no carbon pricing throughout the modelling horizon.	-
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age.	IEA , Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	We take the IEA B2DS projections for coal generation within Russia. Coal-fired power generation is assumed to be 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	IEA, Country experts, Carbon Tracker estimate

	South, Magadan, Chukotka Autonomous Okrug, Irkutsk, Sakha Republic, Amur, Sakhalin and Kaliningrad Oblast.	
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. For Siberia the average of East and West were used. For North West and East price zone from Grid regions were used.	Trade System Administrator of the Russian Wholesale Electricity Market

6.11.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX data was sourced from a news release from ENEL who was awarded a 71 MW onshore wind development in Russia. The plant will be operational in 2024, thus the CAPEX estimated to be 30% higher in 2019. Breakdown of CAPEX was sourced from cost breakdown data at global level from IRENA. A lower band CAPEX and higher band CAPEX was calculated using a 20% assumption.	ENEL, IRENA
O&M Costs	O&M data was sourced from IRENA Renewable Cost Database assumptions using a 30% increase rate, form 1% to 1.3% of CAPEX due to Russia not having a significant wind base to allow for a large pool of O&M providers. A lower band and higher band was calculated using a 20% assumption.	IRENA, Carbon Tracker estimate
Capacity factor	Capacity factor data was sourced form the same news release as CAPEX data, ENEL. A lower band and higher band was calculated using a 20% assumption.	ENEL
Capacity (MW)	Capacity projections were sourced from IRENA REMAP data file as Russia is a G20 members and they modeled capacity additions for it.	IRENA REMAP
Return on Equity	Return on equity in the Damodaran database was not found for Russia. A proxy was used instead, consisting of the median return on equity of Gazprom to which another 5% was added as renewable energy is a new sector in Russia, thus riskier.	Gazprom
Cost of Debt	Data for cost of debt was sourced from World Bank to which another 2% was added to account for long term loans. Inflation data was sourced from IMF data. A lower band and higher band real weighted average cost of capital was calculated using a 20% assumption.	World Bank, IMF
Capacity deployment and learning rate	A learning rate of 16% was assumed for Russia, 3% lower than the learning rate observed at global level due to Russia having less ambitions wind plans. Learning rates were calculated using the most aggressive deployment scenario and the mid, low, and high 2019 LCOE for onshore wind.	IRENA
Assumptions for solar PV		
Capital Expenditure	CAPEX data was sourced from IRENA cost report for 2018 and was reduced by 10% for 2019. CAPEX breakdown was sourced from the same report. A lower band CAPEX and higher band CAPEX was calculated using a 20% assumption.	IRENA
O&M Costs	O&M data was sourced from IRENA Renewable Cost Database assumptions which were slightly higher than those assumed for Japan, at 1.4% of CAPEX. A lower band and higher band was calculated using a 20% assumption.	IRENA, Carbon Tracker estimate
Capacity factor	Capacity factor data was sourced from a news release of a 60 MW solar PV Plant commissioned in 2019. A lower band and higher band was calculated using a 10% assumption.	PVTech
Capacity (MW)	Capacity projections were sourced from IRENA REMAP data file as Russia is a G20 members and they modeled capacity additions for it.	IRENA REMAP
Return on Equity	Return on equity in the Damodaran database was not found for Russia. A proxy was used instead, consisting of the median return on equity of Gazprom to which I added another 5% as renewable energy is a new sector in Russia, thus riskier.	Gazprom
Cost of Debt	Data for cost of debt was sourced from World Bank to which another 2% was added to account for long term loans. Inflation data was sourced from IMF data.	World Bank, IMF

	A lower band and higher band real weighted average cost of capital was calculated using a 20% assumption. Debt equity split was assumed to be 70/30, a realistic assumption for non-OECD countries given that they are perceived as riskier thus require more capital for capital intensive projects.	
Capacity deployment and learning rate	A learning rate of 25% was assumed for Russia. Learning rates were calculated using the most aggressive deployment scenario and the mid, low, and high 2019 LCOE for solar PV.	IRENA REMAP

6.12 South-Africa

6.12.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	Global Energy Monitor
Cooling type and pollution control technologies by plant	Cooling technologies as well as environmental control technologies for nitrogen dioxide, sulphur dioxide and particulate matter were taken from Platts. We also have unit level information on future plans to implement technologies for compliance with regulations.	Platts, Eksom Unit Control Technologies
FOM	We use plant FOM cost data published in Meridian economics 2017 report "Eskom's Financial crisis and the viability of coal-fired power in South-Africa". For plants not included in this report, IEA WEO 2015 benchmarks (broken down by boiler type) are used.	Meridian Economics , IEA WEO
VOM	Where possible, we use plant level VOM cost data published in the Meridian economics 2017 report "Eskom's Financial crisis and the viability of coal-fired power in South-Africa" VOM assumptions for other plants depend on the boiler's combustion technology: US$5.42/MWh for subcritical technologies; US$4.34/MWh for supercritical technologies; US$4.07/MWh for ultra-supercritical technologies; US$7/MWh for integrated gasification combined cycle technologies; and US$4.34/kW for Fluidized Bed. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more.	Meridian Economics
Capacity factor	Annual capacity factors were calculated by taking 3 year averages of plant level generation from 2016-2018. Country averages were used in the absence of asset-level data.	Eskom
Fuel type, cost and transport	Fuel costs include the expenses incurred in buying, transporting, and preparing the coal. Transport cost are detailed by plant, using Denton (2015) and McCall et al (2018). These reports aggregate information on coal contracts at each plant. Though these reports contain the most up to date publicly available information, some of these contracts may have expired. In the absence of data on this, we inflate contracts using Bloomberg prices. The costs in these reports are for final delivered price and are therefore inclusive of transport costs. Bloomberg used for coal price inflation.	Bloomberg, Energy Research Centre, University of Cape Town, Dentons
Carbon price	We assume no carbon pricing throughout the modelling horizon.	-
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age. Baseline values are country and boiler type specific.	IEA, Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA

Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	We take the IEA B2DS projections for coal generation within South-Africa.	IEA , Carbon Tracker estimate
Pollution limit regulations and associated capital and operational costs	We incorporate the capital and operating costs of control technologies to comply with existing regulations using the timing of the planned installation of environmental control technologies.	Meridian Economics, Eskom Emission Reduction Plan
Plant revenues	Tariff assumes electricity tariff from Eskom revenue application 18/19	National Energy Regulator of South Africa

6.12.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX data together with cost breakdown were sourced from IRENA Renewable Cost Data for South Africa together with cost breakdown assumptions. A lower band CAPEX and higher band CAPEX was calculated using a 20% assumption.	IRENA
O&M Costs	Capacity factors and O&M data were sourced from the same database – IRENA Renewable Cost Database. A lower band CAPEX and higher band CAPEX was calculated using a 20% assumption for both variables.	IRENA
Capacity factor	Country level capacity factor data was obtained from the IRENA Renewable Cost Database. Local capacity factors were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm.	Protected Areas, Land Cover, Global Wind Atlas, Carbon Tracker estimate
Capacity (MW)	Capacity projections were sourced from IRENA REMAP data for South Africa.	IRENA REMAP
Return on Equity	Data on return on equity for South Africa was estimated using the emergent market rates found on Damodaran. 3% was added to this as South Africa is generally perceived as a more riskier investment destination than South Korea, for example.	Damodaran
Cost of Debt	Data for cost of debt was sourced from the World Bank and 3% was added to account for long term loans. Inflation data was sourced from the IMF. A lower band and higher band real weighted average cost of capital was calculated using a 20% assumption.	World Bank, IMF
Capacity deployment and learning rate	A 19% learning curve was assumed for South Africa, in line with global observed LCOE learning curves. Learning rates were calculated using the most aggressive deployment scenario and the mid, low, and high 2019 LCOE for onshore wind.	IRENA REMAP, Carbon Tracker estimate
Assumptions for solar PV		
Capital Expenditure	Disaggregated CAPEX data was sourced from the IRENA 2019 cost report. The 2018 data was reduced by 10 to account for the trajectory of cost declines to 2019. A lower band CAPEX and higher band CAPEX was calculated using a 20% assumption.	IRENA
O&M Costs	O&M data was sourced from IRENA 2019 costs report and assumed to be 1.5% of CAPEX.	IRENA
Capacity factor	Country level capacity factor data was sourced from news releases on PV plants commissioned in South Africa.	PV plants, Global Solar Atlas, Carbon Tracker estimate

	Local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	
Capacity (MW)	Capacity projections were sourced from IRENA REMAP.	IRENA REMAP
Return on Equity	Data on return on equity for South Africa was estimated using the emergent market rates found on Damodaran. 3% was added to this as South Africa is generally perceived as a more riskier investment destination than South Korea, for example.	Damodaran
Cost of Debt	Data for cost of debt was sourced from the World Bankto and 3% was added to account for long term loans. Inflation data was sourced from the IMF. A lower band and higher band real weighted average cost of capital was calculated using a 20% assumption.	World Bank, IMF
Capacity deployment and learning rate	A 25% learning curve was assumed for South Africa. Learning rates were calculated using the most aggressive deployment scenario and the mid, low, and high 2019 LCOE for solar PV.	IRENA REMAP, Carbon Tracker estimate

6.13 South-Korea

6.13.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	Global Energy Monitor , Country Experts
Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide (NO2), sulphur dioxide (SO2) and particulate matter (PM), as well as the type of cooling technology.	Platts
FOM	In the absence of South-Korea-specific values for FOM costs, we assume 40% of Japanese O&M costs (in IEA WEO 2018). The FOM costs depend on the combustion technology of the boiler. We assume Subcritical US$34/kW; Supercritical US$44/kW; Ultra-supercritical US$50/kW; IGCC US$62/kW.	Carbon Tracker estimates based on IEA WEO
VOM	VOM assumptions depend on the combustion technology of the boiler. We assume: Subcritical US$5,87/MWh; Supercritical US$4,70/MWh; Ultra-supercritical US$4,41/MWh; IGCC US$7,58/MWh. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more	Carbon Tracker estimates based on North America Electric Reliability Corporation
Capacity factor	We use annual capacity factors at the asset level for existing coal-fired power capacity from 2018. For units without data we applied an average per fuel.	KEPCO
Fuel type, cost and transport	Fuel costs include the expenses incurred in buying, transporting, and preparing the coal. For the cost of coal for producers we use benchmarks from Bloomberg LP. Estimates of fuel cost are based on daily price averages between 2017-2019. For every year up to 2019 we use a yearly average, and for 2020 onwards, we use the average of the last 3 years (2017-2019). Fuel costs also include a model which calculates the transport of coal. This is a cost-optimised supply route algorithm, which computes the distance between a unit's location and the nearest suitable coal mine, considering coal type, mode of transport and related costs and other charges, and available port, mine and import capacities. We assume all thermal coal is imported from Australia (33%), Indonesia (28%), Russia (18%) and South Africa (5%) via seaborne and then land routes to South-Korea's plants. We assume coal is imported from Australia (33%), Indonesia (28%), Russia (18%) and South Africa (5%) sourced via seaborne from Newcastle, Mahakam River, Vladivostok and Richard's Bay to Gwangyang respectively, and then land routes to peninsular South-Korea's plants. While there are cases where this may be invalid, it is a good proxy assumption. Imported bituminous and anthracite figures used from Korean Energy Statistical Information System. Anthracite assumes 33% premium on bituminous. No lignite used in South-Korea.	Bloomberg (2019), Ports.com (2018), EIA (2018), Carbon Tracker estimate

Carbon price	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
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age.	IEA, Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	We use OECD decline rates from the IEA's Beyond 2°C scenario (B2DS) for South-Korea generation.	IEA, Carbon Tracker estimate
Pollution limit regulations and associated capital and operational costs	Air pollution regulation incorporates both regulatory and consulted standards and applies the most stringent. We assume no changes to existing air pollution regulations assumed over the modelling period until 2019, from that year onwards we assume that all units without PM or NOx control technologies will install it. Spreading the cost in 5 years.	Country Experts, Carbon Tracker estimate
Plant revenues	We assume that the wholesale electricity price reflects the costs of the marginal unit generating. The revenue used is pulled from KEPCO statistics 2019 and applied at a yearly level.	KEPCO

6.13.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX for onshore wind in South Korea in 2019 was estimated from data on a 43.2 MW wind farm completed in 2018 from which 8% was subtracted to account for cost declines going to 2019. The cost breakdown structure was assumed to be the same as in the case of Japan as South Korea appears to be having at least one domestic turbine manufacturer that is given some market share. A lower bound CAPEX was calculated using 15% assumption and a higher bound using a 20% assumption, the standard assumption for OECD countries.	Project
O&M Costs	O&M costs were assumed to be the same as in Japan. A 15% less expensive lower band was calculated and a 20% more expensive upper bound.	Carbon Tracker estimate
Capacity factor	Capacity factor was assumed to be the same as in the case of Japan, again due to the share of the market given to local turbine manufacturers.	Carbon Tracker estimate
Capacity (MW)	Data for capacity (MW) projections was sourced from the REMAP team at IRENA while data for 2019 was projected using historical deployment data from IRENA	IRENA REMAP, IRENA Statistics
Return on Equity	Data on return on equity was taken from a dataset maintained by Aswath Damodaran, a finance professor at NYU Stern. There was no specific data for South Korea and instead the value for emerging markets was used 12.83% to which 2% was added as 12.83 is too low for South Korea given that Japan has an ROE for renewables of 15%.	Damodaran
Cost of Debt	Data on cost of debt was sourced from World Bank. The rate, 3.6%, found was for loans on short and medium term to which another 1 percentage point was added to account for the more riskier long term loan. Finally, inflation data was sourced from IMF. The debt equity split was assumed to be 80% debt and 20% equity, a common assumption for OECD countries.	World Bank, International Monetary Fund
Capacity deployment and learning rate	A learning curve of 19%, assumed from global cost declines, was used to project LCOE declines going forward based on global results published in 2018. The low, mid and high LCOE and the highest capacity projections were used to compute the LCOE of onshore wind going to 2040.	IRENA
Assumptions for solar PV		
Capital Expenditure	CAPEX for solar PV in South Korea in 2019 was estimated using data from IRENA 2018 cost report declined by 8% to account for cost reductions to 2019, together with the cost breakdown. A lower bound CAPEX was calculated using 15% assumption and a higher bound using a 20% assumption.	IRENA

O&M Costs	O&M costs data was assumed to be 12% higher than in the case of solar PV in Vietnam. A lower bound O&M was calculated using 15% assumption and a higher bound using a 20% assumption.	Carbon Tracker estimate
Capacity factor	Capacity factor was assumed to be the same as in the case of Japan. The lower bound capacity factor was assumed to be 50% lower while the higher bound capacity factor was assumed to be 20% higher	Carbon Tracker estimate
Capacity (MW)	Data for capacity (MW) projections was sourced from the REMAP team at IRENA while data for 2019 was projected using historical deployment data from IRENA.	IRENA REMAP, IRENA Statistics
Cost of Debt	Data on cost of debt was sourced from World Bank. The rate, 3.6%, found was for loans on short and medium term to which another 1 percentage point was added to account for the more riskier long term loan. Finally, inflation data was sourced from IMF. The debt equity split was assumed to be 80% debt and 20% equity, a common assumption for OECD countries.	World Bank, International Monetary Fund
Capacity deployment and learning rate	A learning rate of 30% was used for solar PV LCOE as this is more in line with global learning curves for solar PV and South Korea has a much lower cost base than Japan. Learning rates were calculated using the most aggressive deployment scenario and the mid, low, and high 2019 LCOE for solar PV	IRENA, Carbon Tracker estimate
Assumptions for offshore wind		
Capital Expenditure	CAPEX for offshore wind in South Korea in 2019 was estimated using global weighed average CAPEX data from IRENA report in 2019 from which 10% was substracted to account for cost declines over the year, 2018 to 2019 and generally lower CAPEX structures observed in Asia. A lower bound using 15% decline was calculated and a higher band using 20% increase was calculated. The cost breakdown structure was assumed to be the same as in the case of Japan as South Korea appears to be having at least one domestic turbine manufacturer that is likely to be given market share in the offshore wind market as well.	IRENA
O&M Costs	O&M costs were assumed to be the same as in Japan and sourced from IRENA and IEA data. A lower band, 15%, and a higher band 20% was calculated.	Carbon Tracker estimate
Capacity factor	Capacity factor was assumed to be 13% higher than the one observed at global level in IRENA 2019 study to account for annual increases and better technology. A lower band, -15%, and a higher band +20% was calculated.	IRENA
Capacity (MW)	Data for capacity (MW) projections was sourced from the REMAP team at IRENA while data for 2019 was projected using historical deployment data from IRENA.	IRENA REMAP, IRENA Statistics
Return on Equity	Data on return on equity was taken from a dataset maintained by Aswath Damodaran, a finance professor at NYU Stern. There was no specific data for South Korea and instead the value for emerging markets was used 12.83% to which 2% was added as 12.83 is too low for South Korea given that Japan has an ROE for renewables of 15%.	Damodaran
Cost of Debt	Data on cost of debt was sourced from World Bank. The rate, 3.6%, found was for loans on short and medium term to which another 2 percentage points was added to account for the more riskier long term loan and for the more riskier offshore wind technology. Finally, inflation data was sourced from IMF. The debt equity split was assumed to be 75% debt and 25% equity to account for more equity being asked for in offshore wind projects as they are generally riskier investments.	World Bank, International Monetary Fund
Capacity deployment and learning rate	A learning curve of 19%, assumed from global cost declines, was used to project LCOE declines going forward based on global results published in 2018. The low, mid and high LCOE and the highest capacity projections were used to compute the LCOE of onshore wind going to 2040.	IRENA

6.14 Turkey

6.14.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	Global Energy Monitor

Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide (NO2), sulphur dioxide (SO2) and particulate matter (PM), as well as the type of cooling technology.	Platts
FOM	In the absence of Turkey-specific value for FOM cost, we assume 40% of European O&M costs from IEA WEO 2018. The FOM costs depend on the combustion technology of the boiler. We assume: Subcritical US$24/kW; Supercritical US$32/kW; Ultra-supercritical US$34/kW; IGCC US$47/kW. For lignite, we use FOM cost assumptions from Agora (2017). Lignite FOM cost depend on age of the unit.	Carbon Tracker estimates based on IEA WEO, Agora
VOM	VOM assumptions depend on the combustion technology of the boiler. We assume : Subcritical US$4,26/MWh; Supercritical US$3,41/MWh; Ultra-supercritical US$3,20/MWh; IGCC US$5,50/MWh. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more. For lignite, we use VOM cost assumptions from Agora (2017). Lignite VOM cost depend on age of the unit.	Carbon Tracker estimates based on North America Electric Reliability Corporation , Agora
Capacity factor	We use annual capacity factors at the asset level for existing capacity for 2018-2019. Where no generation data is available then national average is taken.	EPIAS, Source watch
Fuel type, cost and transport	Fuel costs include the expenses incurred in buying, transporting, and preparing the coal. For the cost of coal for producers we use benchmarks from Bloomberg LP. Estimates of fuel cost are based on daily price averages between 2017-2019. For every year up to 2019 we use a yearly average, and for 2020 onwards, we use the average of the last 3 years (2017-2019). Fuel costs also include a model which calculates the transport of coal. This is a cost-optimised supply route algorithm, which computes the distance between a unit's location and the nearest suitable coal mine, considering coal type, mode of transport and related costs and other charges, and available port, mine and import capacities. We assume Turkey import hard coal from Colombia (59%), Russia (36%) and South Africa (5%). Sourced via seaborne from Mariupol, Colombia and Richard's Bay in South Africa to Alanya and from Vladivostok, Russia to Zonguldak, and then land routes to Turkey's plants. While there are cases where this may be invalid, it is a good proxy assumption. For lignite plants coal cannot be transported long distances. We therefore calculate the fixed cost of running a Lignite mine and use this as the fuel cost. Fixed O&M cost assumptions for Lignite come from Agora (2017) and depend on a unit's age. For sub-bituminous coal we use Indonesian sub-bituminous coal price	Eurasia review, Ports.com , Hellenic Shipping news , Agora, Carbon Tracker estimate
Carbon price	We assume no carbon pricing throughout the modelling horizon.	-
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age.	IEA , Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	We assume OECD decline rates in the IEA's Beyond 2°C scenario (B2DS) for Turkey generation.	IEA, Carbon Tracker estimate
Pollution limit regulations and associated capital and operational costs	We assume no changes to existing air pollution regulations assumed over the modelling period until 2019. By law, from that year onwards we assume that all units without PM, NOx or SOx control technologies will install it. Spreading the cost over 10 years.	TEPAV, Carbon Tracker estimate
Plant revenues	For those plants eligible, plant-level revenues derive from TETAS's power purchase tariffs and an average of day-ahead market prices. For İSKEN and Çayırhan plants, we use TETAS'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.	Tetas

6.14.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind and sole PV		
Capital Expenditure	CAPEX data for Turkey for onshore wind and solar PV was estimated using IRENA 2018 data. Onshore wind was declined by 10% year on year and solar PV 15%.	IRENA
O&M Costs	O&M costs were assumed to be 2.2 % of CAPEX for onshore wind and 1.3% of CAPEX for solar PV.	Carbon Tracker estimate
Capacity factor	IRENA data served as input for capacity factor for wind and Global Solar Atlas for solar PV.	IRENA
Return on Equity	Return on equity was estimated using proxies from lending rate and inflation rate.	Carbon Tracker estimate
Cost of Debt	Lending rates were sourced from Trading Economics and increased by 8% to account for long term risks associated with a highly volatile economy. Inflation data was sourced from IMF	Trading Economics, IMF
Capacity deployment and learning rate	Long term projections of capacity deployment were sourced from IRENA REMAP research. A learning rate of 26% (high) was used for onshore wind and 28% (mid) for solar PV.	IRENA REMAP

6.15 Ukraine

6.15.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	*Global Energy Monitor*
Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide, sulphur dioxide and particulate matter, as well as the type of cooling technology.	*Platts*
FOM	FOM assumptions depend on the combustion technology of the boiler. We assume US$10/kW for subcritical technologies; US$13/kW for supercritical technologies; US$15/kW for ultra-supercritical technologies; and US$23/kW for integrated gasification combined cycle technologies (IGCC).	Carbon Tracker estimates based on *IEA*
VOM	VOM assumptions depend on the combustion technology of the boiler. We assume US$6.91/MWh for subcritical technologies; US$5.53/MWh for supercritical technologies; US$5.19/MWh for ultra-supercritical technologies; and US$8.92/MWh for integrated gasification combined cycle technologies. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more.	Carbon Tracker estimates based on *North America Electric Reliability Corporation*
Capacity factor	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 (2017) DTEK (2018)*
Fuel type, cost and transport	We assume ARA + transport tariffs for all plants as adopted for steam coal by the National Commission for State Regulation of Energy and Public Utilities of Ukraine. Coal prices are broken down by type (Bituminous, Sub-Bituminous and Anthracite). This may be out of date but is used as a benchmark because coal prices are currently very difficult to ascertain in Ukraine due to politicisation and market arrangements.	Local experts
Carbon price	Carbon price assumed at UAH 10 throughout the modelling period (current value).	*Ukraine Carbon Price*
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age. Baseline values are country and boiler type specific.	*IEA*, Carbon Tracker analysis

Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	We use non-OECD decline rates from the IEA's Beyond 2°C scenario (B2DS) for Ukraine generation. We use 2017 data for coal-fired generation statistics and incorporate existing retirement schedules. Coal-fired power generation is phased out nationally.	IEA, Ukrainian Ministry of Energy and Coal Industry, Carbon Tracker estimate
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	Used an average of the weighted average daily prices from the beginning of the operation of the Ukrainian liberalized electricity market (July 2019). Separate prices were used for the ENTSO-e synchronized Burshtyn energy island bidding zone and the Russia integrated Energy System of Ukraine zone.	Ukrainian Energy Exchange, Local experts

6.15.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX data for Ukraine was sourced from real world projects while cost break down was sourced from IRENA 2017 cost publication. A lower and upper band was calculated using a 20% assumption.	Project
O&M Costs	O&M costs were assumed to be 1.5% of CAPEX. A lower and upper band was calculated using a 20% assumption.	Carbon Tracker estimate
Capacity factor	Country level capacity factor data was sourced from the same real world project used for CAPEX estimation. A lower and upper band was calculated using a 20% assumption. Local capacity factors were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm.	Protected Areas, Land Cover, Global Wind Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was estimated using the datasets from Damodaran and assumed to be 16% for Ukraine given the higher risks that the country poses for investors	Damodaran
Cost of Debt	Data on long term lending rates was sourced from World Bank while inflation data was sourced from IMF.	World Bank, IMF
Capacity deployment and learning rate	Data on deployment projections was sourced from a REMAP study on Ukraine. A learning rate of 15% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP
Assumptions for solar PV		
Capital Expenditure	CAPEX data for Ukraine was sourced from real world projects while cost break down was sourced from IRENA 2017 cost publication. A lower and upper band was calculated using a 20% assumption.	(Project 1, Project 2)
O&M Costs	O&M costs were assumed to be 1.3 % of CAPEX. A lower and upper band was calculated using a 20% assumption.	Carbon Tracker estimate
Capacity factor	Capacity factor data was sourced from the same real world project used for CAPEX estimation. A lower and upper band was calculated using a 20% assumption. Local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was estimated using the datasets from Damodaran and assumed to be 16% for Ukraine given the higher risks that the country poses for investors.	Damodaran

Cost of Debt	Data on long term lending rates was sourced from World Bank while inflation data was sourced from IMF.	World Bank, IMF
Capacity deployment and learning rate	Data on deployment projections was sourced from a REMAP study on Ukraine. A learning rate of 35% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP

6.16 United-States

6.16.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	Global Energy Monitor , EPA
Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide, sulphur dioxide and particulate matter, as well as the type of cooling technology.	Platts
FOM	FOM assumptions depend on the combustion technology of the boiler. We assume US$21/kW for subcritical technologies; US$28/kW for supercritical technologies; US$32/kW for ultra-supercritical technologies; US$49.5/kW for integrated gasification combined cycle technologies (IGCC); and US$28/kW for Fluidized Bed.	Carbon Tracker estimates based on IEA WEO
VOM	VOM assumptions depend on the combustion technology of the boiler. We assume US$5.42/MWh for subcritical technologies; US$4.34/MWh for supercritical technologies; US$4.07/MWh for ultra-supercritical technologies; and US$7/MWh for integrated gasification combined cycle technologies; and US$4.34/kW for Fluidized Bed. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more.	Carbon Tracker estimates based on North America Electric Reliability Corporation
Capacity factor	Capacity factor data is obtained at plant level from EIA-923 for 2017, 2018 and 2019. For every year after this we project forwards using the average from 2017-2019. If there are any missing capacity factors after we fill gaps first by grid average if possible, then if not by state average and finally by country average.	EPA, EIA-923
Fuel type, cost and transport	Fuel costs include the expenses incurred in buying, transporting, and preparing coal. Plant level fuel costs are available in EIA-923 for 2017, 2018 and 2019. For every year after this we project forwards using the average from 2017-2019.	EIA 923, Carbon Tracker estimate
Carbon price	RGGI costs included for applicable states. We forecast a carbon price of $7.17/tCO2 by 2040. Otherwise none.	NYISO
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age. Baseline values are country and boiler type specific.	IEA, Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	We take the IEA B2DS projections for coal generation within the United-States.	IEA, Carbon Tracker 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.	EPA
Plant revenues	Wholesale market data for 2019 provided by the EIA.	EIA

6.16.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX data for onshore wind for USA was sourced from the IRENA 2019 cost publication with the cost breakdown. A lower and upper band was calculated using a 20% assumption.	IRENA
O&M Costs	O&M costs were assumed to be 1.2% of CAPEX. A lower and upper band was calculated using a 20% assumption.	Carbon Tracker estimate
Capacity factor	Country level capacity factor data was sourced from a REN21 publication which is based on data from the IRENA 2019 cost publication. A lower and upper band was calculated using a 20% assumption. Local capacity factors were calculated with an algorithm that combines global wind resource data from the World bank with land cover data and data on nationally protected areas to filter out inappropriate locations. The resulting local capacity factors were normalised by the country specific capacity factors to account for any project constraints not captured by the algorithm.	REN21, IRENA, Protected Areas, Land Cover, Global Wind Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was sourced from Damodaran.	Damodaran
Cost of Debt	Data on long term lending rates was sourced from the World Bank to which 1% was added to account for long term risk while inflation data was sourced from the IMF.	World Bank, IMF
Capacity deployment and learning rate	Data on deployment projections was sourced from REMAP file for G20 countries. A learning rate of 17% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP
Assumptions for solar PV		
Capital Expenditure	CAPEX data for solar for USA was sourced from the IRENA 2019 cost PUBLICATION together with the cost breakdown. Supplementary data from NREL was used to lower the estimate. A lower and upper band was calculated using a 20% assumption.	IRENA , NREL
O&M Costs	O&M costs were assumed to be 0.7% of CAPEX. A lower and upper band was calculated using a 20% assumption.	Carbon Tracker estimate
Capacity factor	Country capacity factor data was sourced from a REN21 publication which is based on the IRENA 2019 cost publication. Lower and upper bands were calculated using a 20% assumption. Local capacity factors were calculated using solar irradiance data from the World Bank's global solar atlas and normalised by the country capacity factors to account for any constraint's not captured by the local analysis.	REN21, Global Solar Atlas, Carbon Tracker estimate
Return on Equity	Return on equity was sourced from Damodaran.	Damodaran
Cost of Debt	Data on long term lending rates was sourced from the World Bank to which 1% was added to account for long term risk while inflation data was sourced from the IMF.	World Bank, IMF
Capacity deployment and learning rate	Data on deployment projections was sourced from REMAP file for G20 countries. A learning rate of 22% and the most aggressive deployment scenario were used to project LCOE to 2040.	IRENA REMAP

6.17 Vietnam

6.17.1 Coal model assumptions

PARAMETER	DETAIL	SOURCE
Inventory data on unit-level characteristics	Unit name, plant name, plant location, unit installed capacity; unit status, year of unit operation, parent organization, combustion technology type, coal type, heat rate, and emissions factor.	Global Energy Monitor

Cooling type and pollution control technologies by plant	Installed environmental control technologies for nitrogen dioxide (NO2), sulphur dioxide (SO2) and particulate matter (PM), as well as the type of cooling technology.	Platts
FOM	In the absence of Vietnam-specific value for FOM cost, we assume 40% of Indian O&M costs from IEA WEO 2018. The FOM costs depend on the combustion technology of the boiler. We assume: Subcritical US$22/kW; Supercritical US$31/kW; Ultra-supercritical US$34/kW; IGCC US$44/kW. For Lignite, we use FOM cost assumptions from Agora (2017). Lignite FOM cost depend on age of the unit.	Carbon Tracker estimates based on IEA WEO Agora
VOM	VOM assumptions depend on the combustion technology of the boiler. We assume: Subcritical US$5,65/MWh; Supercritical US$4,52/MWh; Ultra-supercritical US$4,24/MWh; IGCC US$7,29/MWh. We also index the cost depending on the unit's size: 133% for units 0 to 100 MW; 107% for units 100 to 300 MW and 100% for units 300 MW or more. For Lignite, we use VOM cost assumptions from Agora (2017). Lignite VOM cost depend on age of the unit.	North America Electric Reliability Corporation , Agora
Capacity factor	Estimates provided by Green ID, based upon 2014 generation at the asset level.	Green ID
Fuel type, cost and transport	Fuel costs include the expenses incurred in buying, transporting, and preparing the coal. For the cost of coal for producers we use benchmarks from Bloomberg LP. Estimates of fuel cost are based on daily price averages between 2017-2019. For every year up to 2019 we use a yearly average, and for 2020 onwards, we use the average of the last 3 years (2017-2019). Fuel costs also include a model which calculates the transport of coal. This is a cost-optimised supply route algorithm, which computes the distance between a unit's location and the nearest suitable coal mine, considering coal type, mode of transport and related costs and other charges, and available port, mine and import capacities. We assume coal is imported from Australia (36%), Indonesia (34%), Russia (17%) and China (3%). Sourced via seaborne from Newcastle, Balikpapan and Vladivostok to Vong Tau respectively, and then land routes to Vietnam's plants. While there are cases where this may be invalid, it is a good proxy assumption. For lignite plants coal cannot be transported long distances. We therefore calculate the fixed cost of running a Lignite mine and use this as the fuel cost. Fixed O&M cost assumptions for Lignite come from Agora (2017) and depend on a unit's age. We also assume that all anthracite is sourced locally and use prices accordingly.	Bloomberg; Ports.com ; Vietnam news ; Agora ; Carbon Tracker estimate
Carbon price	We assume no carbon pricing throughout the modelling horizon.	-
Combustion efficiency	Gross, low heating value (LHV) adjusted for unit age.	IEA , Carbon Tracker estimate
Efficiency adjustments from cooling and pollution controls	Adjustments made to the overall combustion efficiency of the plant depending on the technology installed.	EPA
Environmental control technology capital and operational costs	These costs include fixed operations and maintenance ($/kW per year) and variable operations and maintenance ($/MWh). Adjusted for pollutant and nameplate capacity of plant.	EPA
Unabated coal-fired power generation pathway for below 2°C scenario	Electricity transmission and distribution integrated nationally and wholly operated are owned by the National Power Transmission Corporation. Thus, phase-out is national rather than regional. We assume ASEAN decline rates in the IEA's Beyond 2°C scenario (B2DS) for Vietnam generation.	IEA , Carbon Tracker estimate
Pollution limit regulations and associated capital and operational costs	We assume no changes to existing air pollution regulations assumed over the modelling period until 2019, from that year onwards we assume that all units without PM or NOx control technologies will install it. Spreading the cost in 5 years.	Country Experts
Plant revenues	Vietnam is in the process of liberalizing its power market. Half of all capacity operates inside a day-ahead power market, while the rest is paid via regulated tariffs set by EVN. We assume that inmarket payments and regulated tariffs are the same and constant over our modelling period.	EVN

6.17.2 Renewable LCOE assumptions

PARAMETER	DETAIL	SOURCE
Assumptions for onshore wind		
Capital Expenditure	CAPEX for onshore wind in Vietnam in 2019 was estimated using a GIZ provided financial model that had estimated CAPEX in 2019. We subtracted 20% to account for cost declines by year 2019. The cost breakdown structure came from the same source and using IRENA cost breakdown model to compensate for missing info. A lower bound CAPEX was calculated using 20% assumption and a higher bound using a 20% assumption. The lower bound is higher than in the case of Japan as non-OECD countries usually have higher variation in CAPEX.	GIZ , IRENA
O&M Costs	O&M costs were collected from the GIZ financial model, and assumed to be 1.84%. A lower bound O&M was calculated using 20% assumption and a higher bound using a 20% assumption.	GIZ
Capacity factor	Capacity factor data was collected from the same financial model and increased by 2% to account for technology improvement since 2016. The lower bound capacity factor was declined by 20% while the higher bound capacity factor was increased by 20%.	GIZ
Capacity (MW)	Data for capacity (MW) projections was sourced from the other sources than REMAP team at IRENA while data for 2019 was projected using historical deployment data from IRENA. IRENA REMAP team maintains a dataset with capacity projections for G20 countries only.	IRENA, Wind Minds , CleanTechnica
Return on Equity	Data on return on equity was taken from a dataset maintained by Aswath Damodaran, a finance professor at NYU Stern. There was no specific data for Vietnam and instead the value for emerging markets was used 12.83% to which 2% was added as 12.83 is too low for Vietnam given that Japan has an ROE for renewables of 15%.	Damodaran
Cost of Debt	Data on cost of debt was sourced from World Bank. The rate, 7%, found was for loans on short and medium term to which another 2 percentage points was added to account for the more riskier long term loan. Finally, inflation data was sourced from IMF. The debt equity split was assumed to be 70% debt and 30% equity, a realistic assumption for non-OECD member countries and the same split found in the GIZ model.	World Bank, International Monetary Fund
Capacity deployment and learning rate	A learning curve of 19%, assumed from global cost declines, was used to project LCOE declines going forward based on global results published in 2018. The low, mid and high LCOE and the highest capacity projections were used to compute the LCOE of onshore wind going to 2040.	IRENA
Assumptions for solar PV		
Capital Expenditure	CAPEX for solar PV in Vietnam in 2019 was estimated using data from a news report from ACWA power who commissioned a 50 MW solar PV asset in Vietnam in 2019. The cost breakdown structure came from IRENA 2018 cost report as was assumed to be the same as in the case of South Korea. A lower bound CAPEX was calculated using 20% assumption and a higher bound using a 20% assumption.	ACWA power , IRENA
O&M Costs	O&M costs data was assumed to be 8% lower than the one observed in Japan. A lower bound O&M was calculated using 20% assumption and a higher bound using a 20% assumption.	Carbon Tracker estimate
Capacity factor	Capacity factor was taken from the ACWA Power press release for the 50 MW power plant. The lower bound capacity factor was assumed to be 20% lower while the higher bound capacity factor was assumed to be 20% higher.	ACWA power
Capacity (MW)	Capacity projections were collated using the 2019 aggressive deployment numbers reported by PV magazine for 2019, although these appear to be numbers for half year.	PV magazine
Capacity deployment and learning rate	A learning rate of 30% was used for solar PV LCOE as this is more in line with global learning curves for solar PV and Vietnam has a much lower cost base than Japan. Learning rates were calculated using the most aggressive deployment scenario and the mid, low, and high 2019 LCOE for solar PV.	IRENA
Assumptions for offshore wind		

Capital Expenditure	CAPEX for offshore wind in Vietnam in 2019 was estimated using data from a real world project that is being currently built in Vietnam, a 48 MW offshore wind project in the intertidal area (the area that is above water level at low tide and underwater at high tide). Although the project has a very low CAPEX in comparison to projects further from shore, its LCOE is highly likely to be representative of the future cost structures. A lower bound CAPEX was calculated using 20% assumption and a higher bound using a 20% assumption. Cost break down of CAPEX was sourced from NREL and IEA.	Project 1, Wikipedia, NREL, IEA
O&M Costs	O&M costs were assumed to be equal to those observed in Japan and modeled by IEA (https://community.ieawind.org › System › DownloadDocumentFile) and IRENA. O&M was assumed to 2.5% of CAPEX for Vietnam in 2019, the mid-point between approximately 2% of CAPEX for IRENA and 3% from IEA. A lower bound O&M was calculated using 20% assumption and a higher bound using a 20% assumption.	IRENA, IEA Wind
Capacity factor	Capacity factor was assumed to be 37%, some 13% lower than the global weighted average supplied by IRENA given that the project is closer to the shore, in the intertidal area and it has less wind resources than projects further from shores. A 20% lower and higher bands were calculated for capacity factors.	IRENA
Capacity (MW)	Data for capacity (MW) projections was sourced from news pieces for short term plans and extrapolated from there to more ambitious deployment targets.	Recharge news
Return on Equity	Data on return on equity was taken from a dataset maintained by Aswath Damodaran, a finance professor at NYU Stern. There was no specific data for Vietnam and instead the value for emerging markets was used 12.83% to which 2% was added as 12.83 is too low for Vietnam given that Japan has an ROE for renewables of 15%.	Damodaran
Cost of Debt	Data on cost of debt was sourced from Wolrd Bank. The rate, 7%, found was for loans on short and medium term to which another 3 percentage points were added to account for the more riskier long term loan and the fact offshore is a more riskier investment. Finally, inflation data was sourced from IMF. The debt equity split was assumed to be 60% debt and 40% equity, a realistic assumption for non-OECD member countries and for offshore wind in non-OECD countries which generally is a more riskier technology. 20% lower and higher bands were calculated for real weighted average cost of capital.	World Bank, International Monetary Fund
Capacity deployment and learning rate	A learning curve of 15%, assumed from global cost declines published by IRENA 2018, *was used mainly due to the low CAPEX observed for 2019.* The low, mid and high LCOE and the highest capacity projections were used to compute the LCOE of offshore wind going to 2040.	IRENA

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