24 JANUARY 2020

GLOBAL COAL FIRED GENERATOR EMISSIONS - 1904 TO 2050

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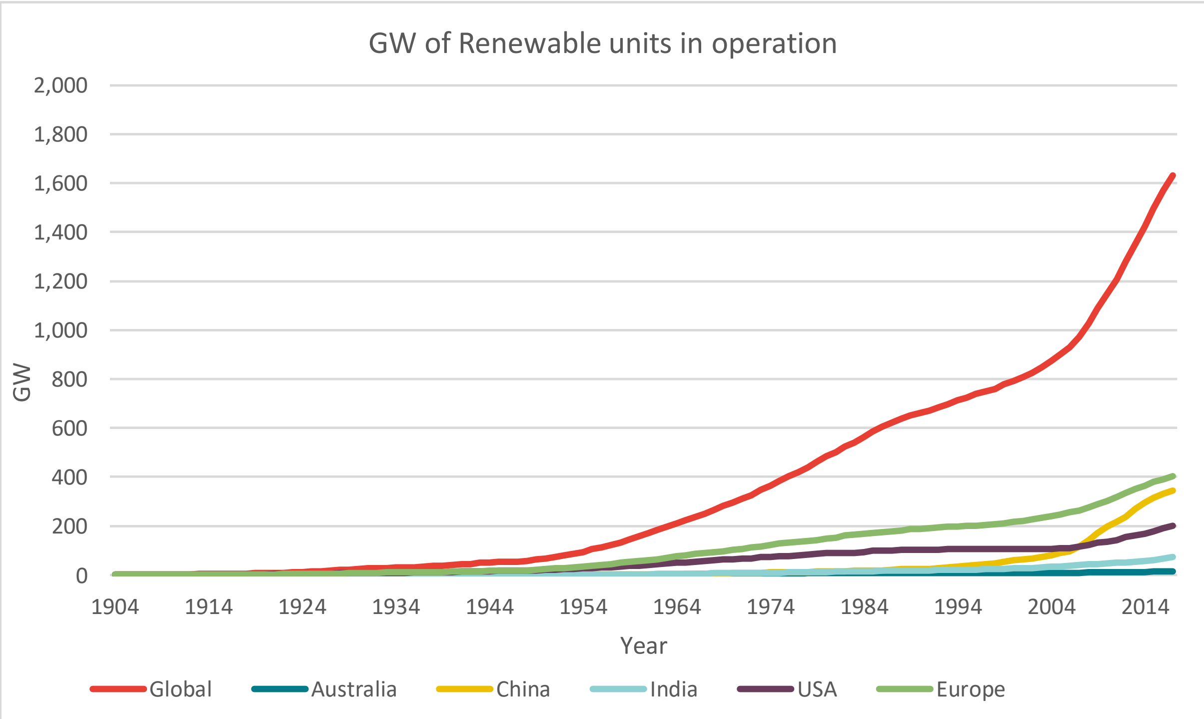
1 INTRODUCTION

Coal is a word that immediately polarises the community nowadays. Coal has been the mainstay of electricity production since the late 19th century. More than 100 years later, coal-fired generation is a particularly controversial topic in Australia.

Some suggest that we should build new coal-fired power plants with more efficient coal burning technology (therefore producing less emissions) for continuing reliable power generation, while others argue that Australia should proactively abandon coal sooner and replace it with a combination of renewable generators and energy storage. A third argument is that the rapid growth in renewable capacity globally, as shown in **Figure 1**, will soon take over coal and other fossil fuel generation as a natural progression and therefore no policy action is required.

Figure 1: Growth in renewable capacity (1904 to 2017)



Source: Frontier Economics analysis of Platts data

No matter which side of the argument you are on, the fact is coal generators produce much more greenhouse gas emissions per megawatt hour (MWh) than most other forms of electricity generation. To the extent that the global community believes that human-produced greenhouse gas emissions are a problem, then it should be worried about the build-up of greenhouse gases over time as it is the atmospheric concentration of these gases that creates adverse climate changes. [1]

To help understand the contribution that electricity generation from sources such as coal have made to current and, more importantly, future atmospheric concentration levels of carbon dioxide (CO_2) we attempt to estimate CO_2 emissions for the global stock of generation from 1904 to 2017. We also attempt to estimate the future growth in CO_2 emissions using highly conservative assumptions that underestimate the future contribution from electricity generation using coal.

The purpose of undertaking this projection is to determine whether concentrations of CO_2 are likely to flatten out, grow slowly or rapidly or decline and, at what rate. This projection of CO_2 production will help understand whether the growth in generation from renewables is likely to result in a material reduction in the growth in the concentration levels of CO_2 or whether more governments should take active steps to avoid further CO_2 emissions from thermal power stations.

To help assess whether governments need to actively take action to curtail emissions from coal plants, or other forms of high emission generation, we examine the extent to which the development of renewable capacity, which is often presented as nothing short of miraculous, is likely to be sufficient to abate the emissions from fossil fuel generators. If these new renewables are not sufficient to cap global emissions from other sources of generation and governments have decided that even current emissions are too high, then governments will need to implement policies that actively reduce emissions from the electricity generation sector.

[1] Frontier Economics has not found a definite answer on the estimation of time that CO2 is resident in the atmosphere. The estimates range from tens to thousands of years: longer than the timeframe considered in this study. Our assumptions therefore assume no decay, as noted in section 2.2.

2 APPROACH

2.1 Overview of approach

The aim of the study is to determine an estimate of the cumulative greenhouse gas emissions from coal generators from as long a series as possible and, taking the current stock of generation capacity (i.e. assuming no more coal generators are built), estimate the future greenhouse gas emissions from these generating plants. We have used a conservative approach to estimate the cumulative total emissions (i.e. underestimation of cumulative emissions) to avoid any accusation of being an alarmist (noting that this approach will mean that we may be accused of being soft on coal).

It is a conservative approach because we assume no new greenhouse gas emitting coal plants are built past the last year of globally available data (2017) – of course, more high emitting plants have been built in the past two years. Further, the emissions estimates are conservative because we assume the operating lives of the more recently developed plants are significantly less than they have been in the past and because we assume a lower capacity factor for operating plants.[2]

More specifically, our approach involves:

- calculating an average capacity factor for coal generating plants based on actual data for countries where data is available and where country data is not available, the capacity factor is based on the regional capacity factor data available.[3]
- calculating an average emissions rate by plant by country where this data was present, and by average regional data where determining a specific country's average emissions rating wasn't available [4]
- comparing the number and size of different generation technology types in the market. [5]

2.2 Generalised assumptions

We use the Platts Database of electric power plants to derive a global stock of generators from 1904 to 2017.

Based on the Platts Database, of the 12,697 coal generating units that have been recorded as commissioned from 1904 to 2017 globally, an astonishing 8,249 coal generating units (65%) are still in operation. Of these operational units, 2,010 (totalling 289,272 megawatts (MW), or, 14% of the global operational coal generators) were built over 40 years ago. Older coal generators are relatively inefficient compared to newer plants in terms of the fuel burned to produce a megawatt hour of electricity.[6] This

[2] Capacity factor measures the level of utilization of a plant. It is measured as the generation of a plant divided by the maximum potential generation from a plant. It is represented as a percentage.

[3] This work is partially based on the World Energy Outlook 2017 developed by the International Energy Agency, © OECD/IEA [2017] but the resulting work has been prepared by Frontier Economics Pty Ltd and does not necessarily reflect the views of the International Energy Agency. Hence forth referred to as 'WEO/IEA Data'

[4] *ibid*, WEO/IEA Data

[5] S&P Global Market Intelligence World Electric Power Plants Database – see: https://www.platts.com.es/products/world-electric-power-plants-database. Hence forth referred to as 'Platts Database'

[6] See for example D. A. Tillman (2018), The Emergence of Modern Coal Fired generators, in Coal Fired Electricity and Emissions Control, Elsevier. Website: https://www.sciencedirect.com/topics/engineering/power-generation-efficiency

means that, generally, older coal generators produce more greenhouse gas emissions than newer, more energy efficient coal generators.

The Platts Database contains information for nearly 220,000 power station units covering all technology types. Within the scope of this study, it is not possible to determine operating parameters for each generating unit to estimate production and, hence, emissions. Therefore, we have made some general assumptions for each plant type according to location.

The following assumptions have been made in developing the emissions and operating levels across the globe:

- we assumed that any non-renewable units (excluding nuclear) that were already classified as decommissioned or permanently stored occurred after 25 years of operation from the date of commissioning) it is likely that the operational lives would have been considerably more)
- all non-renewable units (excluding nuclear) commissioned from 1904-1999 that are identified as still in operation have been classed as retired after 50 years of operation from the date of commissioning
- all non-renewable technology units (excluding nuclear) commissioned from 2000 was given an operational life of 25 years from the date of commissioning
- it is assumed that no further generation units are built past 2017
- all nuclear plant units have an operational life of 50 years
- all renewable plant units (excluding hydro) have an operational life of 25 years
- all hydro plant units have an operational life of 75 years
- all coal plants have the same capacity factor as has been determined from 2015 data for all years of operation of that country or region [7]
- the emissions rate is the same for all coal plant units within a country or region as at the average from 2015 [8]
- observations that had missing critical data were excluded from the analysis:
  - 7.26% of the number of operational generation units had a missing commissioning year data and were excluded (0.94% of MW)
  - 1.18% of the number of observations were generation units that have been retired that had missing commissioning year data (0.44% of MW)
  - 0.08% of the number of observations were generation units that have been deactivated that had missing commissioning year data (0.01% of MW)
  - 0.17% of the number of observations were generation units that have been shutdown that had missing commissioning year data (0.01% of MW)
- Cumulative emissions – the cumulative emissions did not account for any decay in CO_2 based on the lifetime of CO_2 exceeding the period of study by many times. Even if this is not true, what will be important is the proportionate change in cumulative emissions from now until all existing emitting coal plants are decommissioned.

[7] *Op cit*, WEO/IEA Data

[8] *ibid*, WEO/IEA Data

3 SUMMARY OF RESULTS

3.1 Recent development of generating units

Considering the last 10 years of the data used (2008-2017), we observe the following trends, as an average, in electricity generation growth from coal, renewables and non-renewables (excluding coal):

- 226 coal generating units were commissioned per year. In 2017 only 128 coal plant units were commissioned, but this was a low outlier compared to other years
- 3,043 renewable generating units were commissioned per year,
- 1,452 non-renewable (excluding coal) units were commissioned per year

Clearly the number of new renewable generating units is outstripping the number of coal units by almost 25 times. It is not surprising that many people believe that if this trend continues, the rise in emissions will be arrested.[9] However, it is important to consider the size of these renewable units and their output before drawing such a conclusion. These aspects are considered below.

3.2 Recent development of generating (megawatt) capacity

Between 2008 and 2017, on average 220,735 MW of generating capacity was commissioned per year globally, of which:

- Coal generating plants accounted for 78,106 MW (35%), averaging 345.6 MW per unit
- Renewable generating plants accounted for 68,677 MW (31%), averaging 22.57 MW per unit
- Non-renewable generating plants (excluding coal) accounted for 73,952 MW (34%), averaging 50.9 MW per unit

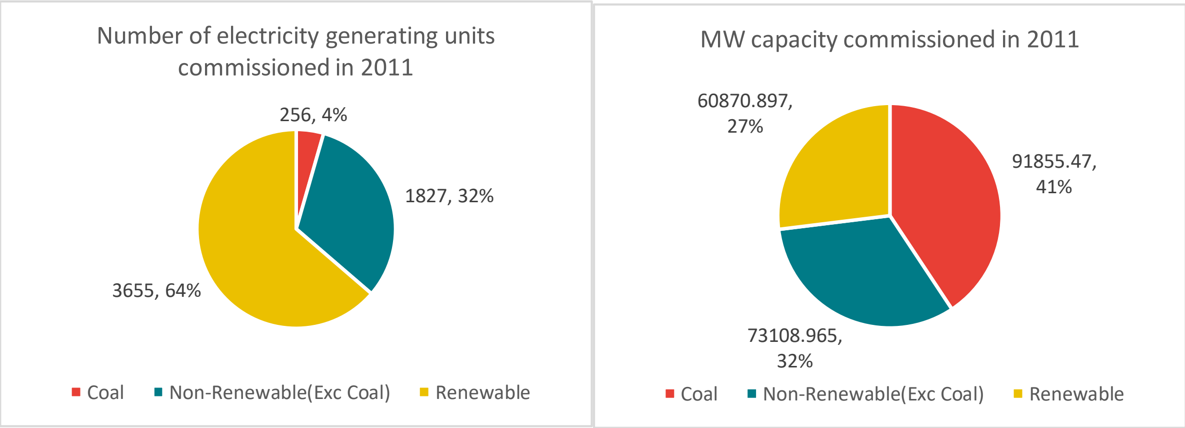
To illustrate the relationship between the number of power station units being commissioned and the amount of capacity (MW) these power stations represent, consider the global generator plant built in 2011. This year was chosen because it was the peak build of renewables for a year. The results are summarised in **Figure 2**.

In the left-hand panel, the number of plant units built are presented for the three main plant categories – coal, renewables and non-renewables (excluding coal). It is clear that in 2011 more renewable units were built than either coal units or non-renewable (excluding coal) units together.

In the right-hand panel, the corresponding MW capacity built for each plant category is presented. The shares of capacity are vastly different to the number of plant units built. This is clearest for coal, which accounted for less than 5% of the number of plant units built but represented over 40% of the capacity built. In contrast, renewable units accounted for 64% of the number of plant units built but accounted for around 27% of capacity.

[9] The Guardian (2019), "Coal is on the way out"", Website: https://www.theguardian.com/environment/2019/mar/25/coal-more-expensive-wind-solar-us-energy-study

Figure 2: 2011 Global commissioning of different generation categories

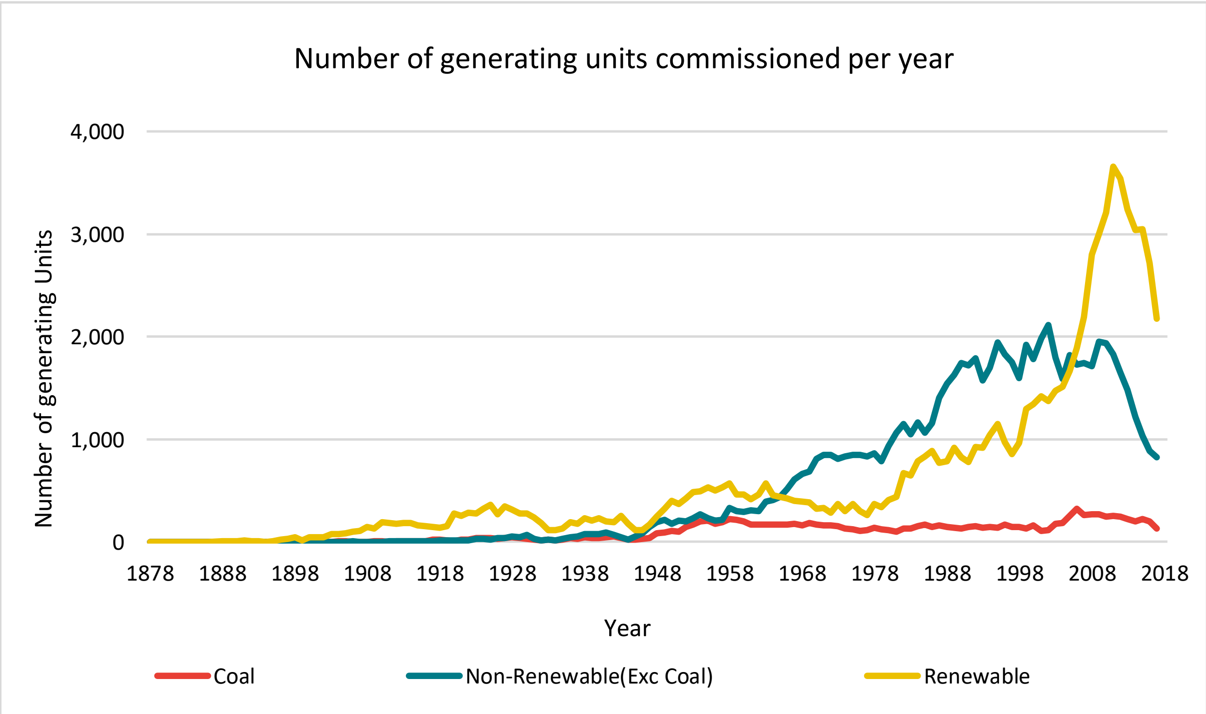


Source: Frontier Economics using the Platts Database

Since 2006, the number of new renewables units has outpaced the growth in the number of either coal or non-renewables (excluding coal). The **capacity** of renewables has only exceeded the capacity of either coal or non-renewables (excluding coal) in a few of the more recent years.

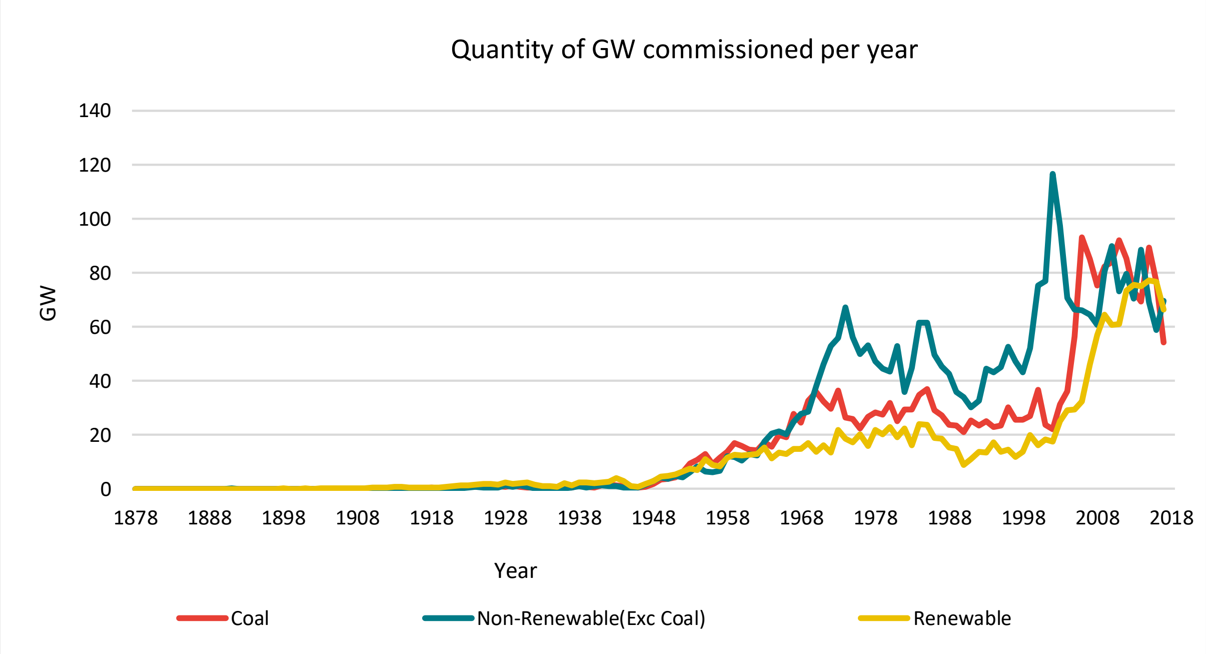
Figure 3 shows the number of generating units commissioned each year from 1878 to 2017 while **Figure 4** show the corresponding quantity of capacity (GW) commissioned each year.

Figure 3: Number of generation units commissioned per year by category (1878 to 2017)



Source: Frontier Economics using the Platts Database

Figure 4: Quantity of capacity (GW) commissioned per year by category (1878 to 2017)

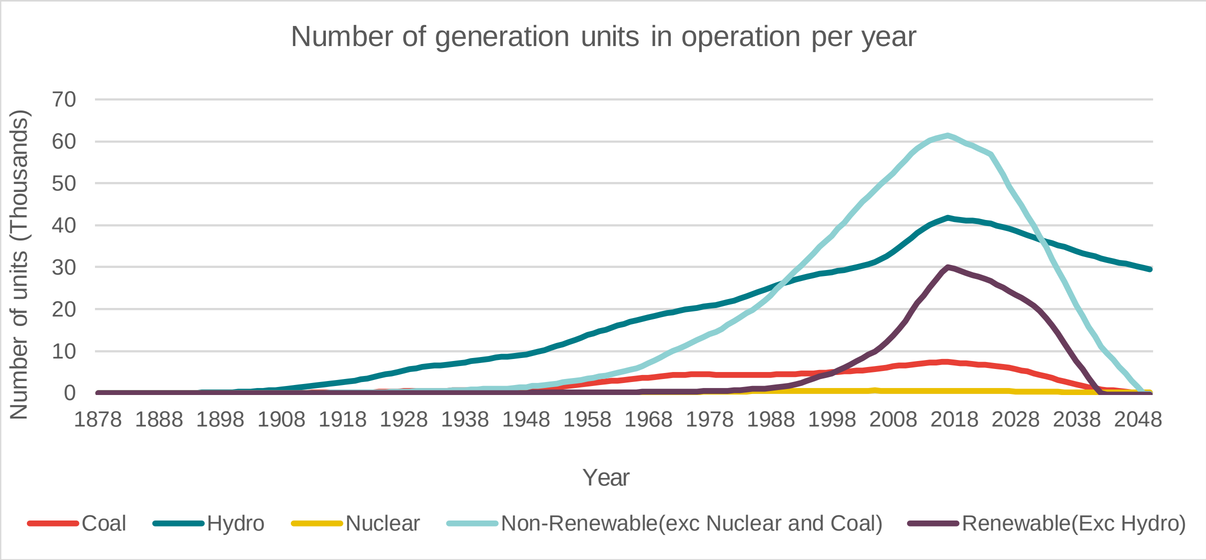


Source: Frontier Economics using the Platts Database

Not all generating units in the Platts database that are classified as operational are operating for various reasons, including being out on major planned maintenance, wet-stored, dry-stored, or awaiting decommissioning. Of the GW capacity of renewables in the global market, hydro usually accounts for more than a 70% share of all renewable capacity in operation each year using our operational life assumptions. Globally, solar, wind, biomass, ocean and geothermal power accounts for no more than 8% of the total operational MW capacity of generation of all types in any year, although this share is slowly increasing.

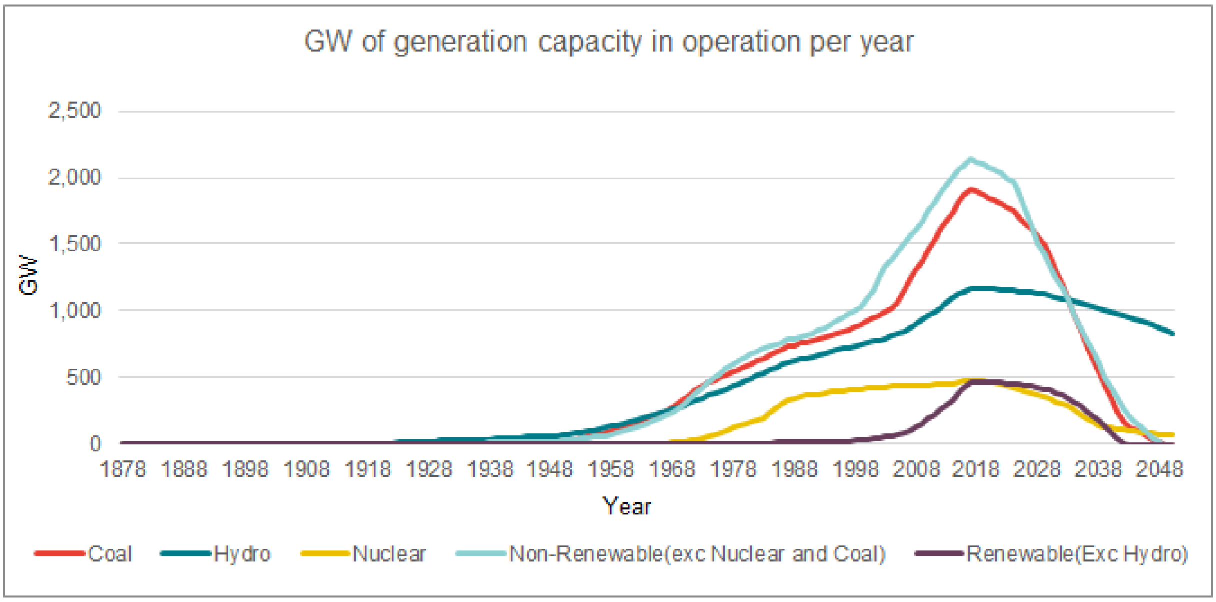
The number of generating units that are operational, using our operational life assumption, by type, is presented in **Figure 5** while the corresponding capacity (GW) of operational capacity is presented in **Figure 6**.

Figure 5: Number of generation units in operation per year (1878 to 2050)



Source: Frontier Economics using the Platts Database

Figure 6: Operational GW capacity of generation in the global market (1878 to 2050)



Source: Frontier Economics using the Platts Database

Since existing power plants will continue to operate according to the economic lives assumed in Section 2.2, it is possible to estimate future emissions. With this information it is possible to show the estimated CO_2 emissions by year from 1904 to 2017 and then an estimate for each year from all existing coal plant units to 2050. It is also possible to form a measure of cumulative emissions over time (noting that it has been assumed that there is no decay of CO_2 emissions).[10]

[10] This assumption of no CO2 decay will tend to overestimate the cumulative emissions, but against this the generation levels and economic lives of power plants used are on the low side. This will tend to cause an underestimation of emissions.

Using the operational assumptions summarised in Section 2.2 for coal plants, an estimate of the generation per coal plant per year was determined. From this estimate an assumed emissions rate was applied per MWh to determine the CO_2 of each coal plant and these estimates were totalled by year.

Figure 7 presents the annual emissions produced globally by coal plants per year from 1904 until 2050. Based on the modelling assumptions, peak coal emissions occurs in 2017 (because we assume no new coal plants are built after this time). In 2017 it is estimated that over 9.3 billion tonnes of CO_2 emissions were emitted from the world's coal plants.

With China's relatively young but large coal fleet[11], the projection shows that in 2021, China would be producing more than half of the world's coal plant CO_2 emissions per year for that year and the subsequent 10 years.

The US experienced a very large increase in the commissioning of coal generating units from the late 1960's to the mid 1980's. With gas fuelled electricity generation and renewables becoming relatively cheap in the US[12], CO_2 emissions from coal generated electricity has already peaked and is now falling.[13]

In Australia, there was a relatively large increase in coal generating units from the 1960's to the 1980's. Of the 13,153 MW of coal generating units that were commissioned in Australia in the 1980's, 10,579 MW (80%) are still operational according to Platts. While Australia's contribution to global emissions is small as a share of total emissions, Australia is still producing over 120 million tonnes of CO_2 emissions p.a. from coal plants.[14]

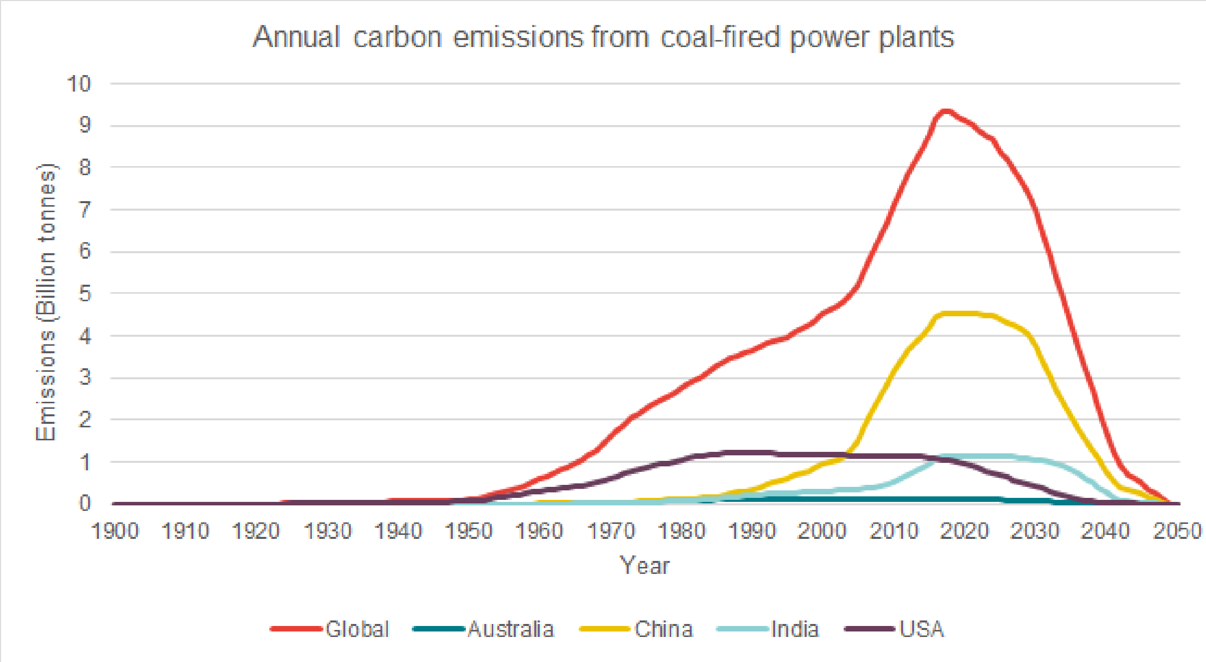
[11] 85% of China's operational Coal-Fired Power Plant's (in MW) has been commissioned since 2000, with 47% of their Coal-Fired Power plants being commissioned in the last 10 years (since 2009).

[12] US Energy Information Administration -Annual Energy Outlook 2019 https://www.eia.gov/outlooks/aeo/pdf/aeo2019.pdf

[13] The change in capacity factor over time, to reduce for the exchange of gas-fired power plants has not been taken into account in the graph.

[14] This is a conservative assumption as the Australian Clean Energy Regulator (CER) shows that Australia's coal fleet produces over 150 million tonnes of CO2e per year. Website: http://www.cleanenergyregulator.gov.au/DocumentAssets/Documents/Australia%E2%80%99s%20largest%20electricity%20generators%20factsheet.pdf

Figure 7: Annual carbon emissions from coal-fired power plants (1904 to 2050)



Source: Frontier Economics using the Platts Database and WEO/IEA Data

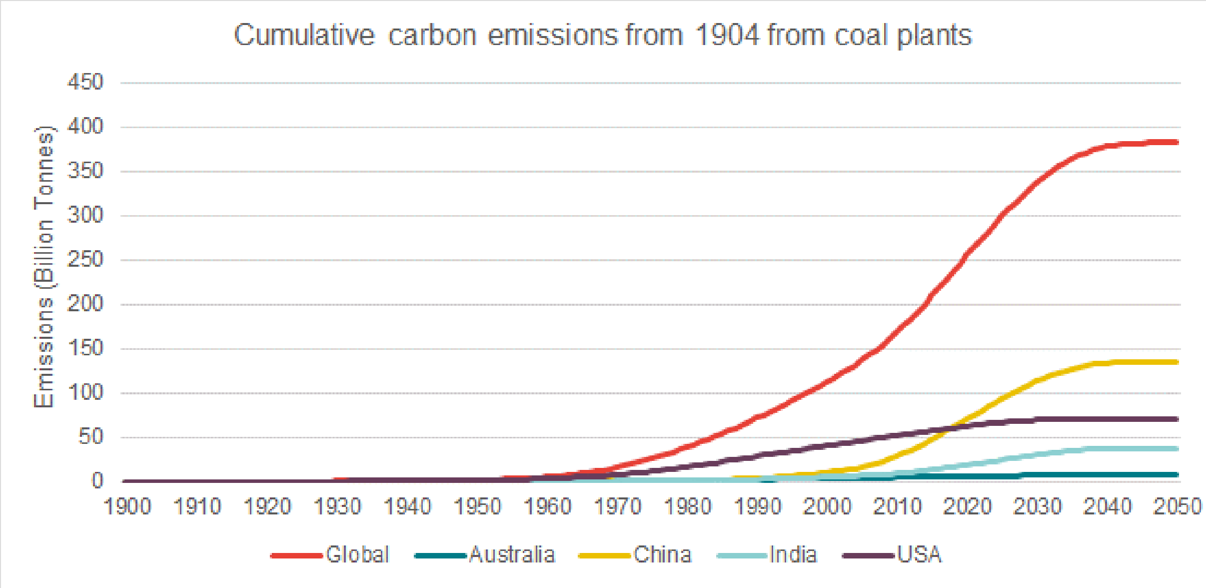
Figure 8: Cumulative emissions from coal plants (1904 to 2050) presents the estimated cumulative emissions from all coal plants from 1904 to 2050. Very conservatively, by 2050 it is estimated that cumulative global CO_2 emissions from coal plants will be over 380 billion tonnes, growing from about 250 billion tonnes cumulative to 2017. This represents about a 50% increase on current levels.

By 2050 the US, China and India, combined, will make up 64% of total cumulative CO2 emissions from coal generators.

From 2019 China will be the largest single emitter per year *and* cumulatively of CO_2 from coal generated electricity and, worryingly, China's emissions will continue to rise dramatically.

China's cumulative carbon emissions were about the same as Australia's in 1975 and about 6% of the cumulative emissions of the USA in the same year. China's rapid growth in emissions occurred from about 2000. From then, it took China a mere 18 years to produce as much cumulative emissions as the second biggest emitter, the USA, took to produce in the previous 114 years.

Figure 8: Cumulative emissions from coal plants (1904 to 2050)



Source: Frontier Economics using the Platts Database and WEO/IEA Data

3.3 Conservative estimate of emissions

As indicated above, Frontier Economics has deliberately aimed to derive a conservative estimate of emissions. The reason for this is because if the growth in the emissions estimated by Frontier Economics is alarming, then the reality will be worse.

3.3.1 Comparison to IEA's World Energy Outlook

In comparison to sources such as the International Energy Agency, Frontier Economics' model of global yearly emissions is deliberately well below the WEO/IEA reported emissions for the same year.

Due to the operational life assumptions used for coal plants in this report, in 2016 Frontier Economics' estimates show 1,876 GW of operational coal plants compared to the WEO/IEA which shows 2,025GW[15] of coal plants. While this difference is not large in this year, subsequently the differences between Frontier Economics plant capacity and, hence, emissions grows. This is primarily because we assume that no new coal plants are built after 2017 when this is blatantly not true. By constrast, the IEA have attempted to forecast the growth in coal plants and, from this, forecast emissions.

To demonstrate the extent of our underestimation, we present in **Table 1** to **Table 4** a comparison of annual emissions as estimated by the WEO/IEA to Frontier Economics' estimates. These comparisons are shown for, respectively, global emissions, the USA, China and India.

[15] WEO/IEA Data

Table 1: Global emissions comparison

YEAR	WEO/IEA (MT)	FRONTIER ECONOMICS (MT)	DIFFERENCE (MT)
2000	6,458	4,518	1,940
2016	9,515	9,152	363
2017	9,822	9,335	487
2025	10,300	8,379	1,921
2030	11,097	7,004	4,093
2040	12,758	1,761	10,997

Source: Frontier Economics using the Platts Database and WEO/IEA Data, and WEO/IEA Data.

Table 2: USA emissions comparison

YEAR	WEO/IEA (MT)	FRONTIER ECONOMICS (MT)	DIFFERENCE (MT)
2000	2,014	1,172	842
2016	1,270	1,100	170
2017	1,239	1,069	170
2025	1,037	694	343
2030	1,005	415	590
2040	1,011	43	968

Source: Frontier Economics using the Platts Database and WEO/IEA Data, and WEO/IEA Data.

Table 3: China emissions comparison

YEAR	WEO/IEA (MT)	FRONTIER ECONOMICS (MT)	DIFFERENCE (MT)
2000	1,382	950	432
2016	4,246	4,425	-179
2017	4,441	4,530	-89
2025	4,731	4,403	328
2030	5,083	3,793	1,290
2040	5,607	796	4,811

Source: Frontier Economics using the Platts Database and WEO/IEA Data, and WEO/IEA Data

Table 4: India emissions comparison

YEAR	WEO/IEA (MT)	FRONTIER ECONOMICS (MT)	DIFFERENCE (MT)
2000	409	317	92
2016	1,013	1,085	-72
2017	1,095	1,142	-47
2025	1,496	1,378	118
2030	1,772	1,062	710
2040	2,400	285	2,115

Source: Frontier Economics using the Platts Database and WEO/IEA Data, and WEO/IEA Data

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