

## RESEARCH ARTICLE

# Climate, thermal coal and carbon

Eric Lilford

**Abstract:** Pressure is mounting globally for the discontinuation of the use of thermal coal and other carbon-based fuels for power generation. The pressure to shift power-generating fuel sources to cleaner propositions comes from many fronts, including from financial institutions that have removed funding options for new and existing coal projects, large investment houses that have discontinued coal equity investments from their portfolios, social movements that have heightened awareness and have created industrial and societal disruptions and, notably, scientists and other researchers who have pronounced the need to reduce carbon-rich energy sources for environmental reasons. However, despite this, thermal coal continues to play an important role in power generation in many regions around the world and will continue to do so for decades to come. This is because coal is an abundant mineral, the power-conversion technology is tried and tested and, comparatively, coal power generation tends to be a more affordable option when considered against numerous alternatives. This latter point excludes the cost impacts associated with carbon taxes. This paper specifically covers the relationship between the amount of CO<sub>2</sub> produced from the combustion of thermal coal for power generation purposes and the additional heating effect, measured in degrees Celsius, that this CO<sub>2</sub> creates. It also provides explicit and comparative figures relating to the world's largest thermal coal consumers and hence the largest contributors to climate change relating to the combustion of thermal coal.

**Keywords:** carbon, climate change, coal, carbon dioxide

## 1 Introduction

As the world pushes towards developing and securing cleaner sources of energy and ultimately a collective net-zero carbon emissions target, the attainment of this objective and the commensurate benefits expected to culminate from this collective drive cannot be accomplished overnight, let alone over the next few decades. Irrespective of the ultimate timing, it is still necessary to aim at significantly reducing anthropogenic sources of carbon gases and other pollutants in as short a time frame as possible for reasons of overall health and climatic impacts. One of the notable sources of pollutants including carbon dioxide is from the combustion of coal for both power generation and as a reductant in steel manufacturing. This report focuses on thermal coal for power generation.

Coal fired power plants provided approximately 38% of the world's electricity in 2018<sup>[1]</sup> as a base load energy source. Base load is best described as the amount

of power that is generated and made available for consumption by the collective power generators in a country necessary to meet the minimum power demanded by the various consumers in that country over a specific period of time. Importantly, base load power is not intermittent and therefore cannot be subject to the vagaries of input factors including wind velocities, sunshine (cloud-cover, day/night), battery capacities and discharge/depletion rates, *etc.*

It is apparent that there is a general drive by energy providers to demonstrate their intentions and strategies to provide cleaner energy, including energy from renewable sources. Cleaner energy in this instance does not necessarily mean a net-zero carbon basis, but rather the lowering of emissions based on a unit of energy generated. This includes energy providers motivating the move away from less efficient to more efficient sources and uses of a particular source of energy, often suggesting the preferred use of cleaner coal, or carbon sequestration, or improving operational efficiencies to lower carbon emissions per unit of energy, or moving away from one fossil fuel but replacing it with another such as from coal to gas, or moving away from fossil fuels altogether.

For completeness and for information purposes, gas, when ignited, produces less carbon dioxide (CO<sub>2</sub>) for each unit of energy generated compared with any coal

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type. However, if that gas is not ignited and it escapes into the atmosphere, the escaped methane (CH<sub>4</sub>) tends to be approximately 28 to 36 times worse as a greenhouse gas (GHG) than CO<sub>2</sub> itself, based on the Global Warming Potential (GWP) index<sup>[2]</sup>. Simplistically, GWP is a measure of how much heat is trapped in the atmosphere by a specific gas compared with the amount of heat trapped in the atmosphere by the same amount of CO<sub>2</sub>.

Research shows that approximately 33.1 Gt of CO<sub>2</sub> (Giga is 10<sup>9</sup>) was produced anthropogenically over 2018<sup>[3]</sup> with most of that arising from power generation. In isolation, the burning of coal for power generated around 10Gt of CO<sub>2</sub> over the same year<sup>[3]</sup>. According to BP in 2019<sup>[1]</sup>, the world generated approximately 26,614.8 TWh of power in 2018 (25 kWh equates to 90 MJ or 85,303.54 Btu) of which coal was responsible for 10,100.5 TWh, being around 37.95% of global power over that year. From the same IEA report<sup>[3]</sup>, gas generated around 23.2% of global power in 2018, renewables around 9.3% and hydro, nuclear and other sources the rest. Therefore coal was singularly the largest anthropogenic contributor to global power and CO<sub>2</sub> levels in the earth's atmosphere and has been suggested to be directly responsible for increasing global surface temperatures by over 0.3°C out of the 1.0°C temperature increase experienced so far since the industrial revolution<sup>[3]</sup>.

## 2 Thermal Coal

It is important to note that no two coals are the same, albeit they may host similar qualities.

Coal is graded according to its rank, where the rank of a coal improves with the increasing carbon and energy content of that coal commensurate with a reducing moisture content, as shown in [Figure 1](#) (modified after Flores<sup>[4]</sup>). In addition, metallurgical coals including anthracite (high rank) and peat (low rank) do not lend themselves to efficient power generation for a number of reasons including their respective contents of energy, moisture, ash, volatile matter, carbon, sulphur and phosphor, as well as the coal's porosity (density), and preferred alternative uses such as metallurgical coals being used to produce coke for steel making (see [Figure 1](#)). Since no two coals are the same, it is necessary to consider which coal types are used for what purposes, and then to focus on the coals that are used for the generation of power. These latter bituminous coals are referred to as thermal coals.

From [Figure 1](#), most of the world's power from coal comes from bituminous coal, with some still derived from the "dirtier" sub-bituminous coals and from lignite (brown coal). The sub-bituminous coals and lignite are deemed dirtier because these coals have lower unit energy content

commensurate with higher levels of impurities, creating additional solid and gaseous waste compared with cleaner coals. As stated previously, no two coals are the same and even coals within one sub-group (type) will exhibit different qualities. [Table 1](#) provides typical coal types highlighting their respective key attributes.

In conjunction with the current global reliance on coal as a base load power source, the world's continued growth in population (see [Figure 2](#)) will incur an ever-increasing demand for reliable energy. This does not necessarily mean that future power sources will be dominated by carbon-based fuels and therefore will increase the amounts of CO<sub>2</sub> being generated year-on-year, but equally it is probable that more CO<sub>2</sub> will be produced from one year to the next over the near-term as renewable sources replace carbon-based fuels as base load power providers.

In addition to population growth, many countries are moving to increase industrial activities, improve local living standards and conditions, provide economic opportunities for foreign and direct investment and generally increase their countries' prospects and improve their citizens' livelihoods, all of which require power.

The question as to whether this planet can adequately support the current and future population projections is a discussion beyond the scope of this paper despite it warranting a closer look.

The possible short-term continued increase in CO<sub>2</sub> production will depend on:

- (1) the accelerated rate of transitioning to renewable energy;
- (2) the energy efficiency of existing technology (increasing amount of energy production from the same fuels, see [Figure 3](#));
- (3) carbon capture use and sequestration (CCUS) to reduce CO<sub>2</sub> emissions;
- (4) improved energy utilisation (more efficient devices/machines using energy);
- (5) emerging economies introducing new carbon-based fuel generators to ensure their growing populace is provided with reliable power.

## 3 Carbon Dioxide and Coal Combustion

In 2016, Umwelt Bundesamt published a document showing CO<sub>2</sub> emission rates for various fossil fuels<sup>[8]</sup> that are consumed in Germany, largely for power generation. The document provides an emission factor for an average coal type consumed in Germany over time, with that emission factor being lower than the default values provided in the 2006 IPCC Guidelines<sup>[9]</sup>. For example and taken from the former document, Germany's emission factor for hard coal is 93.1 tonnes of CO<sub>2</sub> per tonne of

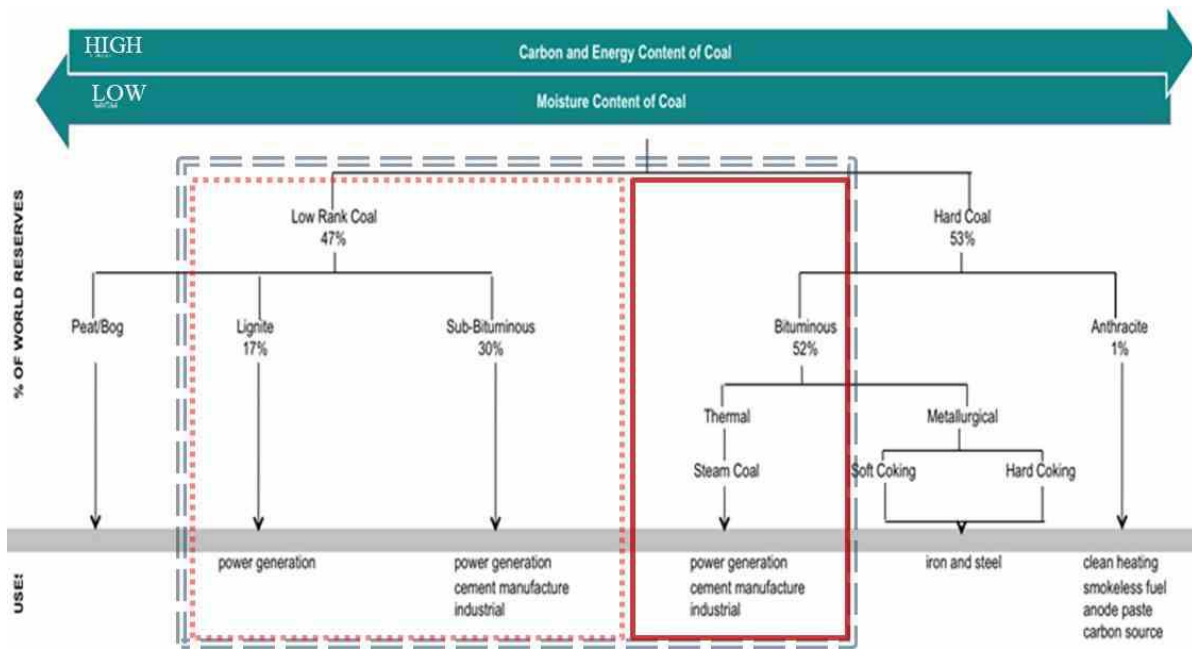


Figure 1. Relative coal ranks (Source: modified after Flores<sup>[4]</sup>)

Table 1. Selected typical coal quality ranges (Source: Modified after Bowen and Irwin<sup>[5]</sup>)

Typical	Calorific Value (MJ/kg)	Fixed Carbon (% weight)	Volatile Matter (% weight)	Sulfur (% weight)	Total Moisture (% weight)	Ash Content (% weight)
Anthracite	32 - 38	86 - 98%	0 - 8%	0.6 - 0.8%	2 - 15%	4 - 12%
Bituminous	20 - 32	35 - 85%	12 - 35%	0.7 - 4.0%	2 - 45%	3 - 15%
Lignite	10 - 20	25 - 35%	35 - 60%	0.4 - 1.0%	30 - 60%	10 - 50%

hard coal combusted in 2011 compared with the IPCC’s 2006 Guideline emission factor of 94.6 tonnes of CO<sub>2</sub> per tonne of hard coal combusted. The discrepancy between the two factors demonstrates that different coals from different areas exhibit different qualities and therefore will release different amounts of CO<sub>2</sub> on combustion.

It is therefore preferred to determine specific CO<sub>2</sub> emission rates for comparative purposes for the different countries under consideration that consume and/or produce different types and qualities of coal.

Irrespective of improving the energy efficiency of coal-fired power generation (Figure 3), the fact remains that this power source relies on the combustion of a carbon-based fuel. To completely eradicate CO<sub>2</sub> released from coal combustion is impossible and so in the final analysis, moving away from coal as a source of energy may be the only solution. On this point, it is noted that there is an increasing drive to use liquefied natural gas (LNG) to replace coal as an energy source as it is a cleaner power source per unit of energy in power generation. However, despite LNG (being CH<sub>4</sub> or methane) providing notably more energy per unit volume or weight than coal, it is

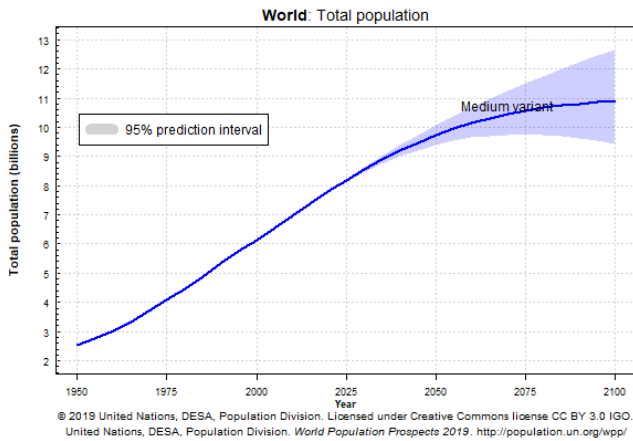
also a carbon-based fuel and therefore also produces CO<sub>2</sub> when combusted, albeit at a lower amount per kWh than coal. It also generates lower levels of particulates.

### 3.1 Calculating CO<sub>2</sub> for the Combustion of Coal

Coal, as with other fossil fuels, is rich in carbon. When coal burns, it produces heat and a variety of waste products, the latter including CO<sub>2</sub>, CO, N<sub>x</sub>O<sub>y</sub> (nitrous oxides), ash, potentially SO<sub>2</sub>, particulate matter (PM10 and PM2.5), mercury and other pollutants.

To calculate the amount of CO<sub>2</sub> expected to be released from burning coal, that coal’s carbon content is required and, since CO<sub>2</sub> is a molecule comprising carbon and oxygen, we must use the atoms’ respective atomic masses relative to CO<sub>2</sub>’s molecular mass to determine the amount/mass of CO<sub>2</sub> produced when the coal is burnt. As can be expected, some of the carbon will end up in the ash as a solid waste, but most of it will be converted to gas as CO<sub>2</sub>.

The atomic mass of carbon is 12 Da (relative atomic



**Figure 2.** Increasing world population, requiring power (Source: United Nations<sup>[6]</sup>)

mass is 12) while the atomic mass of oxygen is 16 Da (relative atomic mass is 16). Therefore the relative molecular mass of CO<sub>2</sub> is 44 (one carbon atom combined with two oxygen atoms). The proportion of CO<sub>2</sub> produced that is actually carbon is therefore:

$$MCO_2/MC = (12 + 2 \times 16)/12 = 3.6667 \quad (1)$$

where:

M = atomic mass;

C = carbon; and

O = oxygen

As stated previously, each coal type contains a different amount of carbon and holds a different amount of energy, amongst other differing factors. Therefore each coal type and each different coal quality will produce a different amount of CO<sub>2</sub> for every unit of mass combusted. The amount of CO<sub>2</sub> that will be produced, ignoring any carbon that reports to ash, is then calculated by determining the product of the contained percentage of carbon in the fuel and the molecular mass of CO<sub>2</sub>.

For example, take 1 kg of wood that is 50% carbon. The CO<sub>2</sub> that may be produced from burning this wood is determined as:

$$C\% \times MCO_2/MC = 0.5 \times 3.6667 = 1.8333 \text{ kg CO}_2 \quad (2)$$

This 1 kg of wood will emit around 1.8 kg of CO<sub>2</sub> once it has been burnt. Acknowledge and accept that the mass of CO<sub>2</sub> produced is greater than the mass of the fuel (wood) burnt.

Coal's energy content is often stated in terms of Mega Joules (MJ) or MJ/kg (refer to Table 1), where 3.6 MJ equates to 1 kWh (kilo-Watt hour), or alternatively where 1 MJ equates to 0.27778 kWh.

Taking the 1 kg of wood above and assuming it holds

16 MJ/kg of energy, then that wood's CO<sub>2</sub> generating capacity per unit of energy is:

$$\begin{aligned} C\% / (E_w/3.6) \times MCO_2/MC &= 0.5 / (16/3.6) \times 3.6667 \\ &= 0.413 \text{ kg CO}_2/\text{kWh} \end{aligned} \quad (3)$$

where:

E<sub>w</sub> = energy contained in this specific wood (MJ/kg)

Simplistically, then, every kWh of power generated through burning this wood will release around 413 grammes of CO<sub>2</sub> into the atmosphere.

The calculation's principles for coal types is the same as for the wood example above. To compare coal's CO<sub>2</sub> emissions with other energy sources, we need to consider the CO<sub>2</sub> emissions on a comparable basis, such as per unit of energy (say, kWh). Table 2 provides the results of these calculations, assuming that all of the available carbon in each fuel is in a gaseous state.

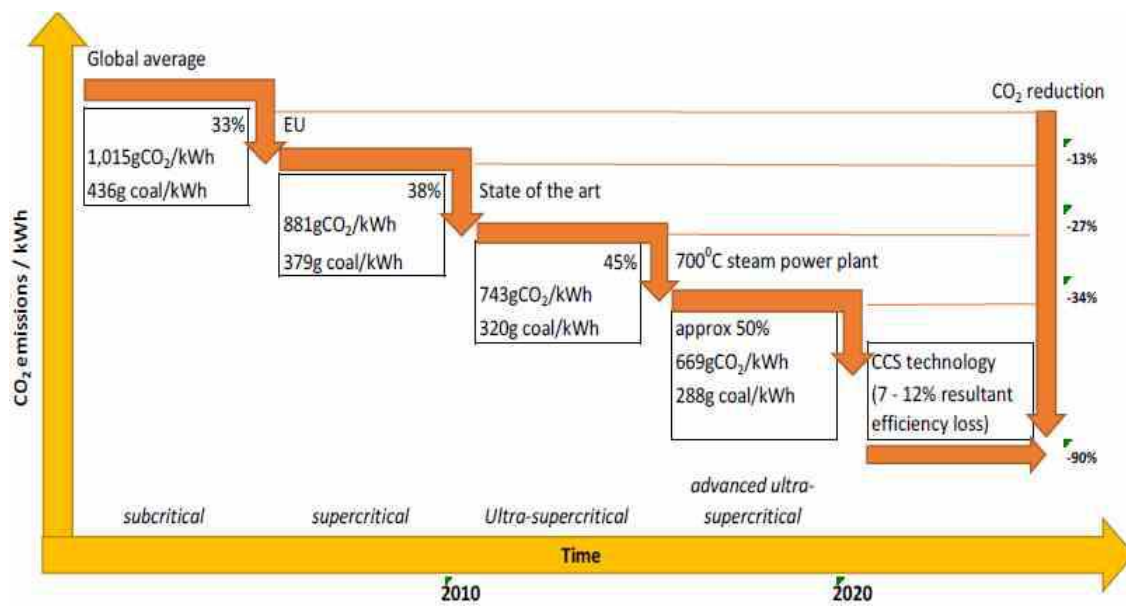
As calculated previously, approximately 37.95% of global power generation is achieved through the combustion of coal through coal-fired power stations to produce approximately 10,100.5 TWh of power in 2018<sup>[3]</sup>.

Globally, coal-fired power plants run at an average efficiency rate of around 33%<sup>[10]</sup>. This means that only around 33% of the contained energy of the coal is converted from effective heat into useful steam that drives the turbines, implying that to achieve the production of 10,100.5 TWh of power from coal, around three times more coal will be required to accommodate this high efficiency loss.

To determine the amount of coal, combined with its associated properties, that needs to be combusted annually around the world to provide base-load power, is an almost impossible task for the reasons provided previously (different energy contents along with varying other inherent constituents). Therefore, simplistically, we will assume that the average coal used will reflect the average qualities of the coal types outlined in Table 2.

Peat and anthracite are excluded from the averages since these two coal types are seldom used in power stations.

Therefore, to produce 10,100.5 TWh of power in 2018 through coal-fired power plants alone, and assuming average global thermal coal qualities are as per Table 3, an approximate amount of 5.1 bn tonnes of coal was combusted to generate this power (assumes 33% efficiency, as discussed above). Therefore this average quality of coal was directly responsible for emitting approximately 13.6 Gt of CO<sub>2</sub> in 2018 (calculated), assuming that 100% of the contained carbon was converted to CO<sub>2</sub>. However, up to approximately 15% of the contained carbon reverts to ash, meaning that around 2.0 Gt less CO<sub>2</sub> will



**Figure 3.** Improving energy efficiency of a coal-fired power station (Source: VGB PowerTech<sup>[7]</sup>)

**Table 2.** CO<sub>2</sub> emissions per unit of energy and mass of fuel

	Carbon (%)	Energy (MJ/kg)	(g CO <sub>2</sub> )/(k Wh)	(kg CO <sub>2</sub> )/(kg fuel)	(kg CO <sub>2</sub> )/(L fuel)
Wood	50.00%	16	412.5	1.833	
Peat	Low C	10	396	1.1	
	High C	15	528	2.2	
Lignite/brown coal	Low C	15	528	2.2	
	High C	18	513.33	2.567	
Sub-bituminous	Low C	18	513.33	2.567	
	High C	23	436.17	2.787	
Bituminous	Low C	23	436.17	2.787	
	High C	33	344	3.153	
Anthracite	Low C	33	344	3.153	
	High C	36	355.67	3.557	
Diesel (86.2% C)	71.98%	44	215.93	3.161	2.639
Petrol (87% C)	65.25%	45	191.4	3.19	2.393
Crude oil (84% C)	75.60%	45	221.76	3.696	2.772
LNG (72.2% C)	72.70%	48	199.93	3.554	2.666
LPG (82.5% C)	45.38%	48	124.78	2.218	1.664

**Table 3.** Coal tonnage required to produce 10,100.5 TWh of power at 33% efficiency

		Carbon (%)	Energy (MJ/kg)	Energy content (k Wh)/(kg coal)	Emissions (g CO <sub>2</sub> )/(k Wh)	Emissions (kg CO <sub>2</sub> )/(kg fuel)	Coal required (kt) (33% eff, 10,100.5 TWh)
Lignite/ brown coal	Low C	60.00%	15	4.167	528.00	2.200	7,345,818
	High C	70.00%	18	5.000	513.33	2.567	6,121,515
Sub-bituminous	Low C	70.00%	18	5.000	513.33	2.567	6,121,515
	High C	76.00%	23	6.389	436.17	2.787	4,790,751
Bituminous	Low C	76.00%	23	6.389	436.17	2.787	4,790,751
	High C	86.00%	33	9.167	344.00	3.153	3,339,008
<b>Average coal for power</b>		73.00%	21.67	6.0185	461.84	2.6767	5,085,566

be generated than calculated above. Therefore a resultant calculation of around 11.6 Gt of CO<sub>2</sub> was generated in 2018 by coal-fired power plants, a figure that is comparable with the IEA<sup>[3]</sup> figure of approximately 10 Gt of CO<sub>2</sub> from thermal coal for power for 2018.

A closer look at the countries that produce most of the world's coal (thermal and metallurgical) as well as those that consume most coal is shown in [Table 4](#).

**Table 4.** Production and consumption of coal in 2018 (Source: Enerdata<sup>[11]</sup>)

Country	Coal Production (Mt)	Coal Consumption (Mt)
China	3,474	3,770
India	764	982
United States	684	624
Australia	502	113
Indonesia	474	109
Russia	412	234
South Africa	257	186
Germany	169	217
Poland	123	129
Kazakhstan	118	
Turkey	85	125
Colombia	84	
Japan		189
South Korea		150

Carbon Brief<sup>[12]</sup> forecasts that 2019 will likely realise a fall in coal-fired power generation of 3% from 2018, being 300 TWh less or a total of 9,798 TWh over 2019. Assuming a half-a-percent global generating efficiency improvement and the same average coal qualities as shown in [Table 3](#), the amount of thermal coal necessary to generate this power will be around 4.9bn tonnes, creating around 11.1 Gt of CO<sub>2</sub> over 2019, which is approximately 0.5Gt of CO<sub>2</sub> less than 2018's CO<sub>2</sub> production from this power source.

Taking this further, Concordia University stated the following<sup>[13]</sup>:

“Globally, the researchers saw an average temperature increase of  $1.7 \pm 0.4^\circ\text{C}$  per trillion tonnes of carbon in CO<sub>2</sub> emissions (TtC), which is consistent with reports from the Intergovernmental Panel on Climate Change.”

Therefore, over 2018, the 11.6 Gt of CO<sub>2</sub> from coal-fired power stations increased average global temperatures by around  $0.0197^\circ\text{C}$  and cumulatively another approximately  $0.0189^\circ\text{C}$  over 2019. Since around 65% to 80% of CO<sub>2</sub> dissolves in the oceans over a 20 to 200 year period<sup>[12]</sup>, the cumulative effect of continued CO<sub>2</sub> emissions is important. Making certain, minimal-impact assumptions and factoring in the growth of coal-fired power generation over the last 20 years, coal-fired power generation alone has accounted for an approximate  $0.3^\circ\text{C}$  global temperature rise alone. Over a longer period of time, this figure will be higher despite the take-up of CO<sub>2</sub> by oceans and vegetation.

[Table 5](#) considers the global consumption of thermal coal, where this thermal coal is predominantly used for electricity generation but also includes consumption for other energy uses. Average thermal coal properties as provided in [Table 3](#) have been assumed.

In summary, thermal coal consumption alone has been responsible for an approximate  $0.42^\circ\text{C}$  global temperature rise over the last two decades.

It is important to note that the above figure only captures thermal coal and excludes metallurgical coal, gas (a notable carbon source) and combusted oil products (another notable carbon source).

### 3.2 Longer Term CO<sub>2</sub> Forecast to 2050 due to Coal-fired Power Plants

According to Bloomberg<sup>[15]</sup>, global electricity energy demand will increase by approximately 50% from 2017 to 2050, to around 38,700 TWh. The EIA<sup>[16]</sup> puts this increase at 79% with energy consumption in general increasing by 50% over the same period. A figure between

**Table 5.** Thermal coal consumption in 2018 (Includes non-electricity coal energy use; Source: Reserve Bank of Australia<sup>[14]</sup>)

Country	Thermal Coal Consumed (Mt)	Mt CO <sub>2</sub> at 2.677 kg CO <sub>2</sub> /kg coal	Added Temp °C in 2018	20 Year Approximate °C Added
China	3,200	7,218	0.0124	0.223
India	850	1,934	0.0033	0.059
US of America	550	1,251	0.0021	0.038
Other Asia	500	1,138	0.0019	0.035
Rest of World	500	1,138	0.0019	0.035
European Union	210	478	0.0008	0.015
Japan	150	341	0.0006	0.01
Australia	50	114	0.0002	0.003
<b>TOTAL</b>	<b>6,010</b>	<b>13,674</b>	<b>0.0232</b>	<b>0.418</b>

the above two at a 62% increase to 2050 has been used in this analysis, of which around 12% will be generated through coal-fired plants. Using the figures provided previously, it can be determined that approximately 5,015 TWh of power in 2050 will still be derived from coal-fired power plants.

If it is assumed that future coal-fired power plants are more efficient and that many producers resort to carbon capture, utilisation and storage practices, as depicted in Figure 3, and that these power stations either shut down or follow a linear improvement profile, then it is likely that in thirty years' time, coal-fired power generation will still be responsible for CO<sub>2</sub> emissions as follows:

$$CO_2\ 2050 = P_{e2050}/E/1000/eff \times (1 - C_A) \quad (4)$$

where:

$P_{e2050}$  = Electric power from coal in 2050 (TWh)

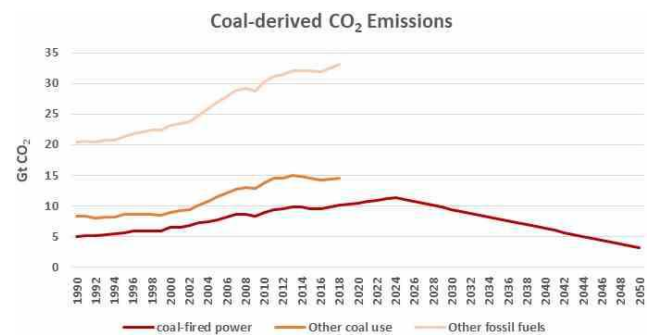
$E$  = Average energy content per unit mass of coal (TWh/kg coal)

$eff$  = Energy efficiency (assumed at 60% in 2050 (was 33% in 2019))

$CA$  = Carbon reporting to ash and not as CO<sub>2</sub>  
 $= 5,015 / TWh/kg / 1000 / 60\% \times 2.6767$   
 $= 3.159\ Gt\ CO_2$

Diagrammatically, and assuming a linear reduction (improving efficiency and reducing reliance on coal), CO<sub>2</sub> emissions generated through coal-fired power stations, globally, over the next 30 years may follow that as proposed in Figure 4.

Although CO<sub>2</sub> emission levels from coal-fired power plants will have reduced significantly by 2050, they will not reach zero according to the research. More importantly, the cumulative CO<sub>2</sub> production over the next 30 years to 2050 may be as high as 200 Gt (calculated from the above assumptions), after allowing for the oceans to



**Figure 4.** CO<sub>2</sub> Emissions with projection to 2050 (Source: Modified after IEA<sup>[3]</sup>)

absorb newly-produced CO<sub>2</sub> after 20 years.

Therefore 200 Gt of additional CO<sub>2</sub> in the atmosphere may increase global temperatures by another 0.35°C, solely from future coal-fired power generation.

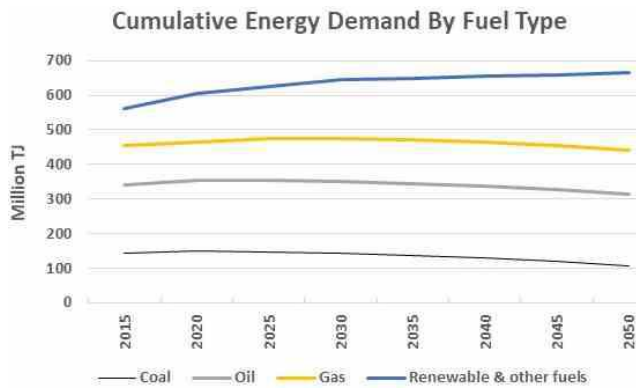
McKinsey shows that coal is only a small part of the carbon-based energy sources enjoyed by the planet<sup>[17]</sup> (see Figure 5). In addition, not all coal is consumed for power generation.

The figure clearly highlights the issue that coal is not the only carbon problem the planet faces.

#### 4 Economic Incentive to Change

This report has focused on carbon sourced from coal and specifically on coal that is used to generate electricity. As is well known and is shown in Figure 5, numerous other carbon-rich sources of energy are combusted to provide energy around the world. It is therefore imperative that all carbon-based sources of energy are dealt with in the world's drive to provide clean(er) energy.

Stating the obvious, the world is driven by economics.



**Figure 5.** 2050 Forecast, fossil fuels and other energy sources (Source: Modified after McKinsey<sup>[17]</sup>)

If something costs too much, it won't be purchased and, if the price of energy increases substantially, there will be an outcry and political parties' support may be impacted.

It is not possible to coordinate every country in the world to place an economic disincentive on carbon-based fuels simultaneously, if at all. That may not be equitable anyway, since many emerging economies do not even have a reliable base-load supply of any form of electrical power, let alone from coal-fired sources. Stated differently, many countries that have stable economic platforms had the historical benefit of using carbon-based fuels to reach their current positions. Therefore, shouldn't emerging markets be afforded the same polluting energy advantage in the future?

Alternatively, should those economies that have already benefited from using these polluting fuels pay amounts into a fund to be used by emerging economies to assist the latter building clean energy sources?

Emissions Trading Schemes (ETS) and other mechanisms have been introduced in many countries as a means to encourage energy producers to produce clean energy (i.e. these schemes typically create economic disincentives to produce green-house gas (GHG) or other forms of untenable waste<sup>[18]</sup>. This latter ICAP report<sup>[18]</sup> states that:

"...the start of China's national ETS, the share of emissions covered by carbon markets will jump to 14% in 2020."

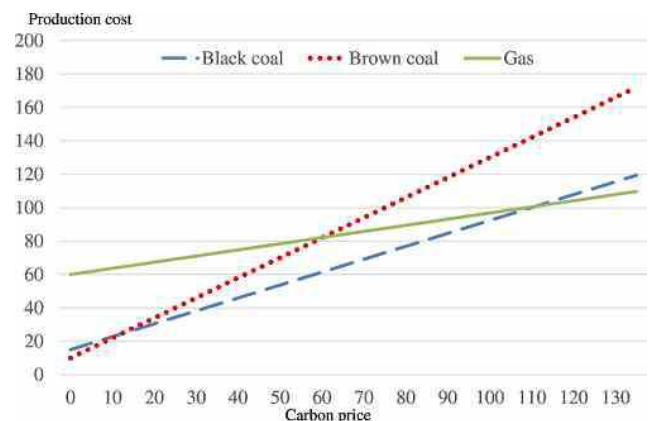
Unless the relevant governments provide subsidies or other forms of economic aid to carbon-based energy producers, the costs associated with these schemes will be passed on to the consumer. Energy prices will therefore increase and, since economies depend heavily on energy, most products and services will become more expensive.

Table 6 provides the typical capital expenditure ranges as well as operating cost comparisons for power from various sources, excluding any costs associated with carbon.

**Table 6.** Capital expenditure and operating cost comparatives in 2019 (Source: self-collected, collated and updated from numerous sources over many years)

Technology	Capital Cost (USD/kW)	Operating Cost (USD/kWh)
Coal-fired combustion turbine	500 - 1,000	0.04 - 0.20
Natural gas combustion turbine	400 - 800	0.04 - 0.10
Coal gasification combined-cycle (IGCC)	1,000 - 1,500	0.04 - 0.08
Natural gas combined-cycle	600 - 1,200	0.04 - 0.10
Wind turbine (includes offshore wind)	1,200 - 5,000	< 0.01
Nuclear	1,200 - 5,000	0.02 - 0.05
Photovoltaic Solar	≥4,500	< 0.01
Hydroelectric	1,200 - 5,000	< 0.01

Meng *et al.*<sup>[19]</sup> consider the Australian case for an ETS and conclude that even with a carbon price of around A\$25/t, leading to a 12% reduction in emissions, the cost of supplying coal-based power remains competitive when compared with "cleaner" gas as a source of power. Therefore, a significantly higher carbon price would be necessary. (see Figure 6)



**Figure 6.** Carbon-based fuels, comparative costs with a carbon price (Source: Meng *et al.*<sup>[19]</sup>)

Potentially, there may be logic in charging a carbon tax on coal exports too such that the importing country will have to pay more for coal imports. As an example, China imports many tens of millions of tonnes of both thermal and metallurgical coal from around the world (notably metallurgical coal from Australia and thermal coal from Indonesia and elsewhere) and should be charged more per tonne as an incentive to move to cleaner power sources sooner. However, the counter argument is that China and India have many coal-fired power plants and also have billions of tonnes of their own coal, but typically poorer quality coal. If the cost to import coal rises too much, China and India, and others, may well use their own poorer (dirtier) coal as a cheaper substitute, or import lower quality coal from markets offering it at a reasonable



price.

Since the technology to store energy is somewhat embryonic at this stage and the fact that wind velocities vary, sunlight occurs during the day only and the quantum of renewable energy that may be produced in the future depends on the availability of land (for solar plants and wind turbines) and near-shore expanses of water (mostly wind turbines), it is difficult to see how the world can economically and totally transition to renewable energy over the near-term. This transition period must also compensate for an increasing global population that will, despite urbanisation, require larger areas of land for habitation (dwellings), growing food, storing water, housing livestock, *etc.* The overall implication is then that over the near-term, both mitigation and adaptation strategies need to be enacted simultaneously<sup>[20]</sup>, not merely one or the other.

In addition to noting that thermal coal is not a clean source of power, consideration must be given to the economic role that thermal coal plays in many economies. As an example, and focussing on only one country, Australia exported 202 Mt of thermal coal and 177 Mt of metallurgical coal over the 2016-2017 year, with a combined value of A\$ 54 bn<sup>[21]</sup>. The Australian coal industry, over this period, employed approximately 47,000 workers directly and another 120,000 indirectly, generated around A\$ 5 bn in royalties and another A\$ 254 m in payroll tax<sup>[22]</sup>. Additional significant corporate income tax was also paid by coal-producing companies.

As a final point worth noting, it is apparent that an ever-increasing number of financial institutions and other lenders are withdrawing from making loans available for new and/or existing coal projects. It is not necessary to identify those financial institutions, but it is increasingly difficult for any company wanting to obtain debt funding for coal opportunities to secure those funds. It is apparent that the equity markets are starting to follow suit such that the pool of equity available for coal projects is also drying up. On top of this, there is public pressure being brought to bear on new coal projects (*eg.* the proposed Adani Coal Mine in Australia). Time will tell whether these actions are more detrimental to this planet or not, notably from a cleaner coal perspective and also from specific countries' economic perspectives.

## 5 Conclusion

The combustion of thermal coal as a primary source of base-load power will continue into the foreseeable future, despite significant protests and efforts to move to cleaner energy sources sooner rather than later. A continued growing global population with an insatiable demand

for power is one of the reasons for this, with others being knowledge, technology and cost, not to ignore the significant areal extents and demands that will be placed on land and water required to provide renewable (solar and wind especially) energy platforms. The last 20 years to end-2018 has seen global temperatures rise notably with coal-fired power generation being responsible for around 0.30°C of that rise, and likely to be responsible for another 0.42°C over the next 30 years to 2050.

The need to move away from carbon-based fuels and specifically coal is justifiable beyond CO<sub>2</sub> generation factors to include numerous other polluting gases as well as particulates released when combusted.

However, many countries are enacting changes to move away from coal-based power to cleaner power sources so that despite coal providing power for the foreseeable future, the reliance on this source will diminish over time. Perhaps not quickly enough.

There has been and continues to be a shift in many countries away from coal-based power to gas power. While this report has focused on coal and thermal coal only, gas is also a carbon-based fuel and, although retaining a higher unit energy value per tonne of carbon, will still produce CO<sub>2</sub> during combustion. In addition, non-combusted methane is a worse GHG than CO<sub>2</sub> itself.

Finally, while coal-fired power generation remains relatively affordable, is reliable and is technologically proven, introducing a cost on carbon may increase the pace at which countries transition to cleaner power sources, away from coal. For this to work effectively and synchronously, all countries need to introduce similar policies simultaneously. If not, higher power-cost countries may witness the relocation of certain industrial activities to cheaper jurisdictions, unless subsidies or transition periods are granted, while emerging markets may unilaterally ignore the need to “go clean” simply because any power is better than none.

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