The Key Coal Producers
ONLINE SUPPORTING MATERIALS to A Global Coal Production Forecast with Multi-Hubbert Cycle Analysis

Tadeusz W. Patzek*[a], Gregory D. Croft[b]

[a] *Department of Petroleum & Geosystems Engineering, The University of Texas, Austin, TX 78712, Tel. 512.232.8368, Fax 512.471.9605*

[b] *Department of Civil and Environmental Engineering, The University of California, Berkeley, Davis Hall, CA 94720*

1. China

The world's most important coal-producing area is North-Central China. The provinces of Inner Mongolia, Ningxia, Shaanxi and Shanxi together accounted for 83 percent of China's proven coal reserves in 2000, and Shanxi alone accounted for 25 percent of production [1]. Coal production from Inner Mongolia exceeded that from Shanxi for the first time during the first half of 2009 [2]. Coals in these provinces are Carboniferous, Permian and Jurassic in age and coals of all three ages often occur in the same area [3]. The older coal deposits are often structurally complex, but the Jurassic Shenmu-Dongfeng coal field, located on the border between Inner Mongolia and Shaanxi, contains undisturbed coal seams up to 10 meters thick [4]. The Jining and Zibo coalfields of Shandong province are an eastern extension of the North-Central China coal province. These are described in [5] and [6] as high-volatile bituminous coal of upper Carboniferous to lower Permian in age.

More than 90 percent of China's coal production comes from underground mines, as compared to about 40 percent in the U.S. According to Pan [7], the average depth of coal mine production in China is 456 meters. In in Shanxi, Hebei and Inner Mongolia, the average producing depth is more than 600 meters and the deepest mine is 1300 meters. By comparison, the average depth of hard coal production in Germany's very mature Ruhr Basin is 920 meters and coal deeper than 1200 meters is not considered reserves [8]. Of China's forecasted coal reserves, a broader category than proven reserves, only 27 percent in East China are less than 1000 meters deep. Shallow coal deposits and some surface mines exist in parts of Inner Mongolia and Xinjiang, in remote areas that will require additional transportation infrastructure.

In 2008, China reported coal production that was almost 3 times higher than that in the United States. The best multi-Hubbert cycle fit of China's total coal production is

URL: patzek@mail.utexas.edu (Tadeusz W. Patzek*)

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shown in **Figures 1** and **2**. The production data for anthracite, bituminous and lignite coals are from the Supplemental Materials to [9]. We predict the peak of production in 2011, and the ultimate coal recovery of 146.5 Gt. The peak of the fundamental Hubbert cycle is in the year 2019. Our estimate is an arithmetic average of "Reserves + Cumulative Production" ($R + C = 156.1$ Gt) and "Best Guess" ($BG = 136.1$ Gt) in Table B.1 in [9].

Note that the area of the small cycle is very small. This cycle may well be an artifact of production overreporting (1958 – 1960), followed by a more recent period of production underreporting (1998 – 2002). The dramatic, 55 percent annual rate of increase of coal production in the small cycle in Figure 2 may also be the result of a short-lived, all out effort by China to fuel its 2000-2008 runaway economic growth. Over-reporting of coal production was standard in the communist Poland and the Soviet Union. Simply a part of mined rock waste mixed with coal was counted as coal.

On July 24, 2009, the Shanghai Securities News reported:

> Chinese net coal imports in H1 surge 8 times to 36.6 million tonnes, www.-steelguru.com Friday, 24 Jul 2009. Statistics indicate that China's coal imports in H1 of the year remained at 48.27 million tonnes exceeding the total volume of the whole last year and surging by 126%YoY. In H1 coal exports stayed at 11.67 million tonnes sliding by 54%YoY. The net import volume stayed 36.6 million tonnes increasing by over 8 times YoY.
>
> As per report, from January to April, China's net coal import volume remained at 13.43 million tonnes and the figure for January to May was 21.67 million tonnes.
>
> Last year China's coal imports were about 40 million tonnes, 1.5% of the volume of China's raw coal production, which remained at over 2.7 billion tonnes. In the first six months of this year, China's raw coal production stayed at 1.35 million tonnes and overseas resource China bought took up over 3.55% of the volume.

The corresponding match of the rate and cumulative emissions of CO_2 in China is shown in **Figures 3** and **4**. The peak emissions of CO_2 of 7 Gt/y are predicted in the year 2011, and the ultimate emissions are 360 Gt of CO_2.

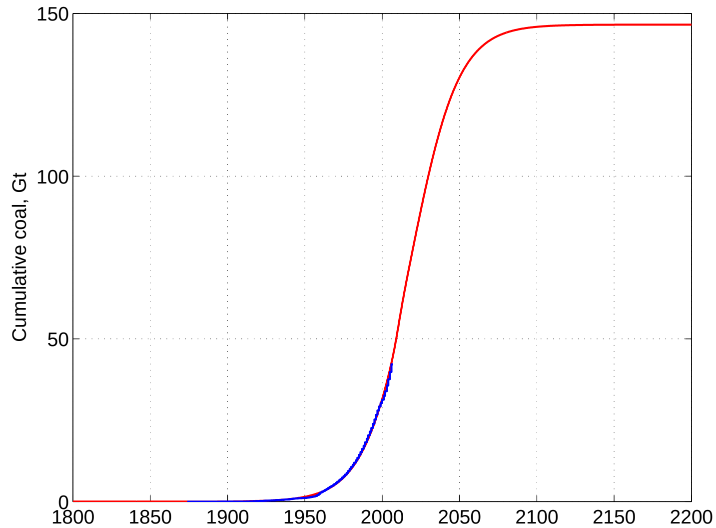

Figure 1: The best multi-Hubbert cycle match of the historical cumulative production of anthracite, bituminous, and lignite coal in China. The year of peak production is 2011, and the ultimate coal production is 146.5 Gt. The broad base peak is in the year 2019. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

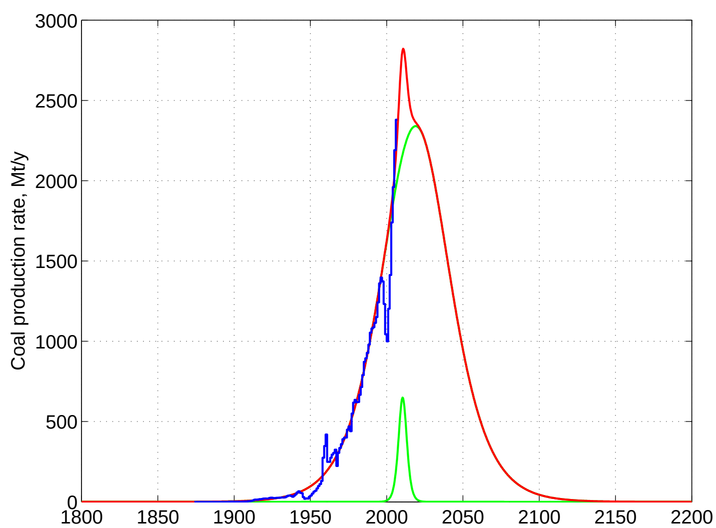

Figure 2: The best multi-Hubbert cycle match of the historical rate of production of anthracite, bituminous, and lignite coal in China. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

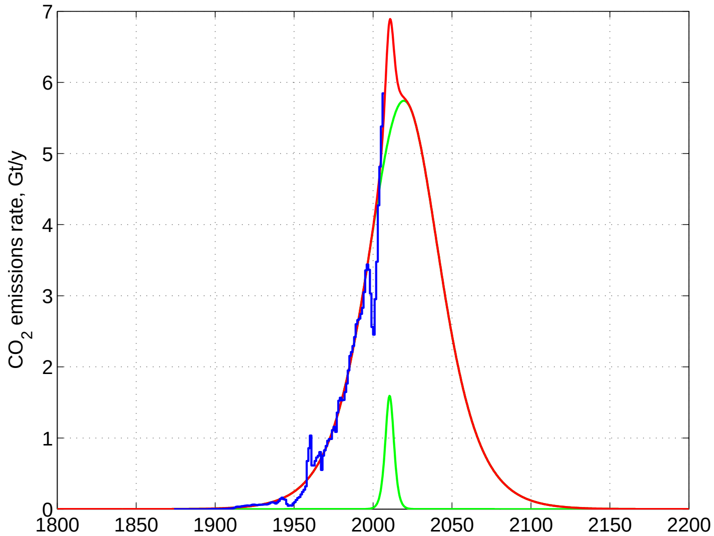

Figure 3: The best multi-Hubbert cycle match of the historical rate of CO_2 emissions in China. The predicted emission peak in the year 2011 is 7 Gt CO_2/y. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

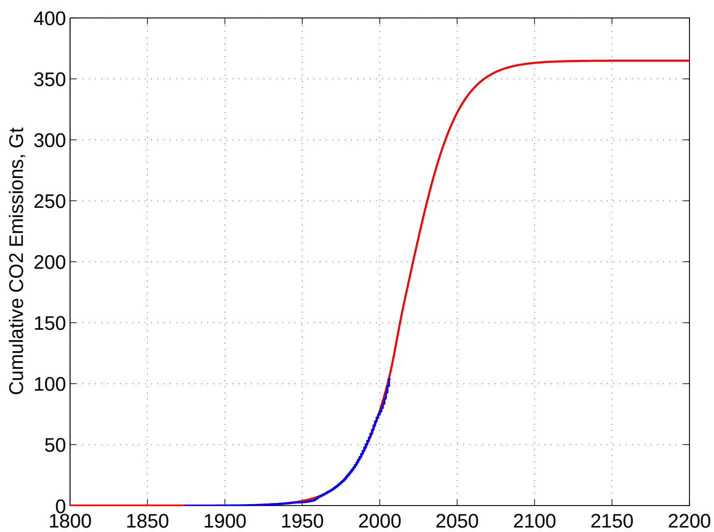

Figure 4: The best multi-Hubbert cycle match of the historical cumulative CO_2 emissions in China. The year of peak emissions is 2011, and the ultimate emissions are 360 Gt of CO_2. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

2. USA

The U.S. coal resources have been summarized in [10]. The best multi-Hubbert cycle fit of total coal production in the United States is shown in **Figures 5** and **6**. The production data for anthracite, bituminous, subbituminous, and lignite coals are from the Supplemental Materials to [9]. We predict the peak of production from the existing mines in 2016, and the ultimate coal recovery of 110 Gt. Our estimate is 50 percent lower that the "Linearized Hubbert" ($LH = 172$) Gt, and roughly 1/3 of the "Reserves + Cumulative Production" ($R + C = 308$ Gt) and the "Best Guess" ($BG = 308$ Gt) in Table B.1 in [9]. There is no doubt that the USA has vast coal resources and the subbituminous (and, perhaps, lignite) coal mines *could* be greatly expanded. However, the current production data do not warrant such high ultimate recovery estimates; for more details see [10, 11]. How the U.S. coal resources will continue be produced, we simply do not know. What we do know is that the new mines will be environmentally and technically ever more challenging, and may not be constructed in the foreseeable future.

The corresponding match of the rate and cumulative emissions of CO_2 in USA is shown in **Figures 7** and **8**. The peak emissions of CO_2 of 2.5 Gt/y are predicted in the year 2015, and the ultimate emissions are 250 Gt of CO_2.

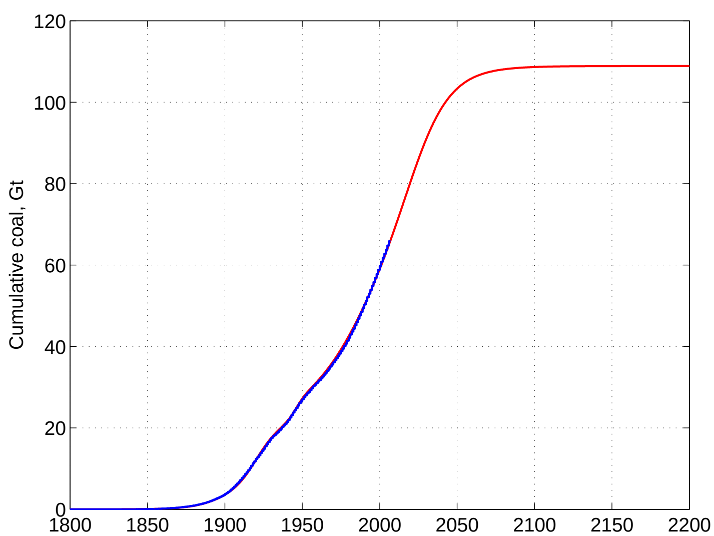

Figure 5: The best multi-Hubbert cycle match of the historical cumulative production of anthracite, bituminous, subbituminous, and lignite coal in the United States. The year of peak production is 2016, and the ultimate coal production is 110 Gt. Data sources: EIA (Croft and Patzek, 2009) [10], and Supplemental Materials to Mohr and Evans (2009) [9].

2.1. Alaska Coal

As a sensitivity case, we assume that 55 Gt of bituminous coal (1/2 of the current ultimate recovery from the lower 48 states) equivalent will be recovered in Alaska in the

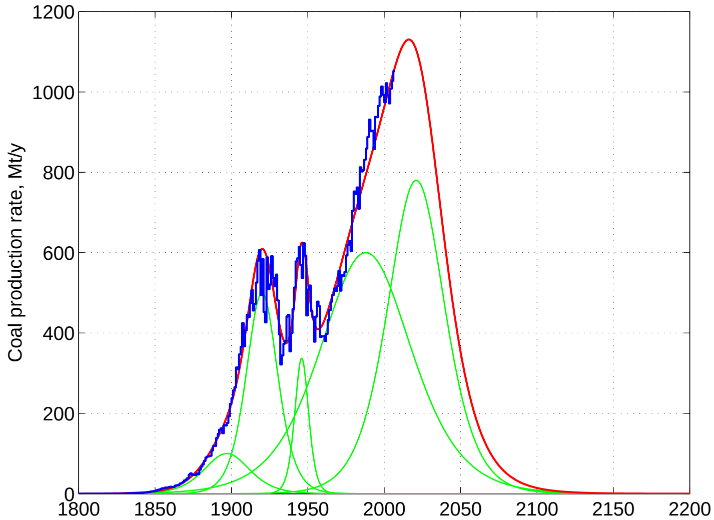

Figure 6: The best multi-Hubbert cycle match of the historical rate of production of anthracite, bituminous, subbituminous, and lignite coal in USA. The individual peaks are in the years 1897 (anthracite), 1920 (world War I), 1946 (World War II), 1988 (bituminous coal), and 2021 (subbituminous coal). The peak production is predicted to occur in the year 2015. Data sources: EIA (Croft and Patzek, 2009) [10], and Supplemental Materials to Mohr and Evans (2009) [9].

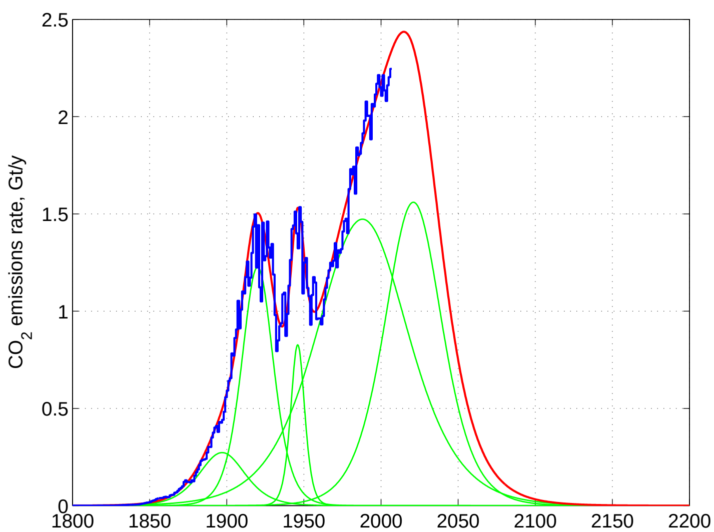

Figure 7: The best multi-Hubbert cycle match of the historical rate of CO_2 emissions in USA. The predicted emission peak in the year 2015 is 2.5 Gt CO_2/y. Data sources: EIA (Croft and Patzek, 2009) [10], and Supplemental Materials to Mohr and Evans (2009) [9].

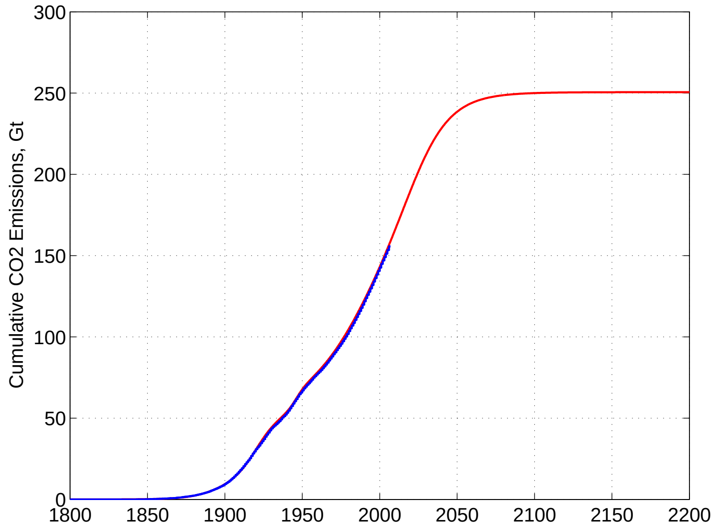

Figure 8: The best multi-Hubbert cycle match of the historical cumulative CO_2 emissions in USA. The year of peak emissions is 2015, and the ultimate emissions are 250 Gt of CO_2. Data sources: EIA (Croft and Patzek, 2009) [10], and Supplemental Materials to Mohr and Evans (2009) [9].

next 200 years. The results are shown in **Figures 9 – 12**. Unlike oil, coal cannot be transported by pipeline over long distances in a harsh climate. Transport of 1Gt per year (2.7 million tons per day) of coal by ship and train is a rather difficult logistic task, requiring, e.g., thirty 100,000 ton coal ships to be loaded each day, 365 days a year. This task might be accomplished by building an equivalent of eleven copies of Australia's Newcastle port, the world's largest coal export terminal, that will work around the clock in the harsh Arctic environment. One train can transport about 9,000 tons of coal, so one would also need to load/unload 300 train loads of coal each day. We doubt that such a high rate of coal production will ever be achieved in Alaska.

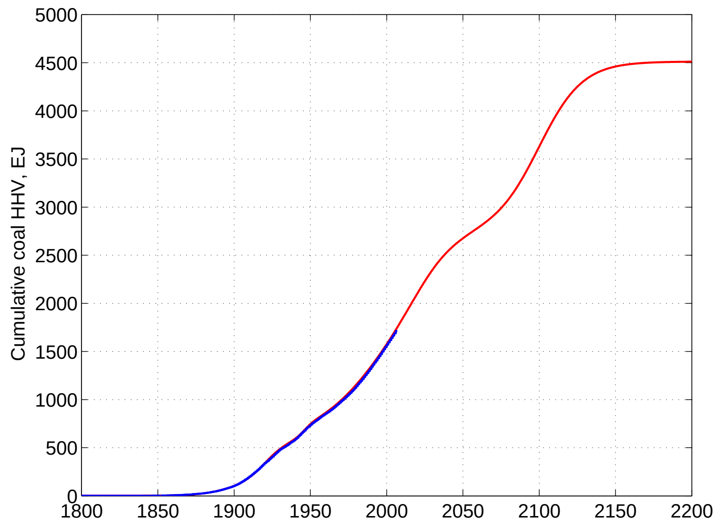

Figure 9: Figure 5 with 55 Gt of Alaska North Slope coal added in. The new ultimate recovery is 160 Gt.

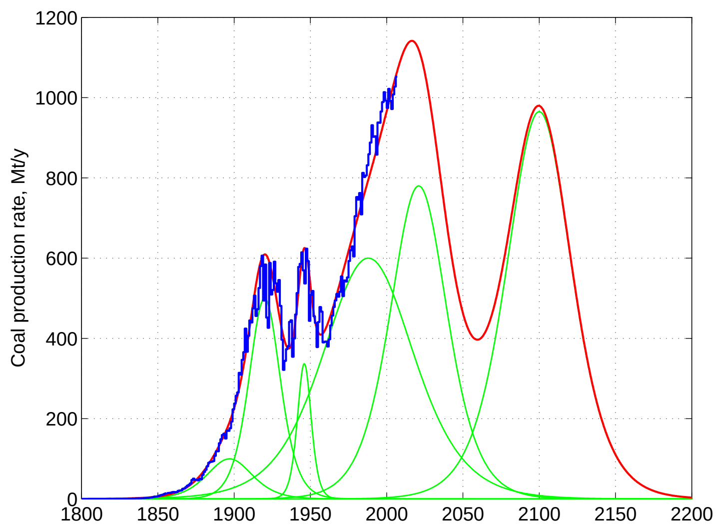

Figure 10: Figure 6 with 55 Gt of Alaska North Slope coal added in. The second production peak in the year 2100 is 1000 million tons of coal per year.

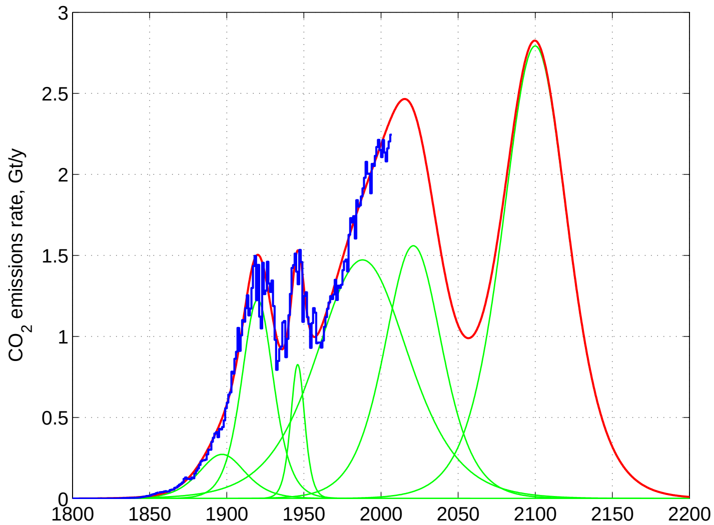

Figure 11: Figure 7 with 55 Gt of Alaska North Slope coal added in. The second production emissions peak in the year 2100 is 2.8 Gt of CO_2 per year. The second peak is slightly higher than the first one because the Alaskan coal is of higher quality.

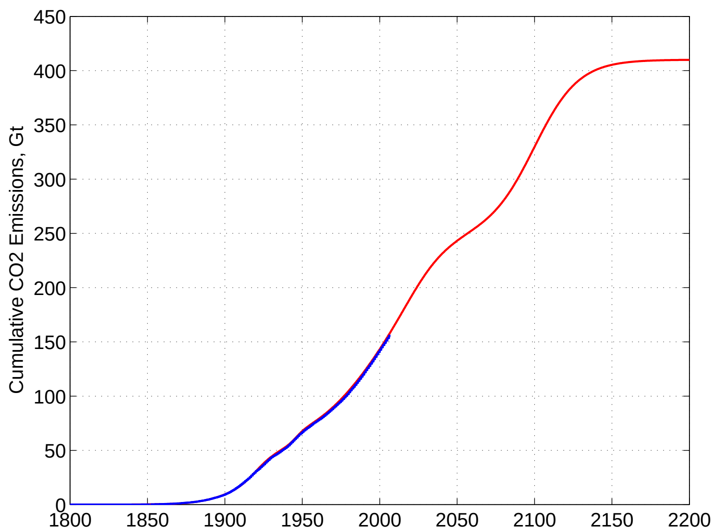

Figure 12: Figure 8 with 55 Gt of Alaska North Slope coal added in. The ultimate CO_2 emissions are 410 Gt.

3. FSU

The most important hard coal-producing areas in the Former Soviet Union are the Donbass region of Ukraine and Russia, the Kuzbass region of Siberia, the Pechora Basin of Russia and the Karaganda Basin of Kazakhstan. Important soft coal resources are present in the Kansk-Achinsk area of Eastern Siberia and the Ekibastuz Basin of Kazakhstan. All of these areas have enough production history to be well-quantified by the Hubbert method. Lena and Tunguska are lower quality deposits spread over vast areas. These deposits are discussed the Sensitivity Analysis and Future Work Section.

The Donetsk Basin (Donbass) coal fields produce bituminous coal and some anthracite from underground mines in Ukraine and Russia. The seams are typically less than 1.2 meters thick, but the coal quality and yield are high. Donbass was historically the most important coal-producing region in the Soviet Union. The production peaked at 223.7 million metric tons per year in 1976 and has been declining since [12]. Many of the mines have been developed to depths of 800 meters or more. The coals are Carboniferous age and numerous folds and faults render mining difficult in places [13]

The Kuznetsk Basin (Kuzbass) region is located around the city of Tomsk in the southeastern part of Western Siberia. This is the most important area in terms of coal reserves, with over 100 feet of coal in 17 seems [13]. Coals here are of Permian age [4]. The Trans-Siberian railroad traverses the area, but long shipping distances to markets have hindered development.

The Kazakh coals are Carboniferous and, in the Karaganda Basin, multiple seams range from 1 to 3.5 meters thick. Coals in the area range from bituminous to anthracite. In the Ekibastuz Basin, a number of seams of sub-bituminous coal have coalesced to form a single seam 130 to 200 meters thick [4].

The best multi-Hubbert cycle fit of the Former Soviet Unions's total coal production is shown in **Figures 13** and **14**. The production data for anthracite, bituminous, subbituminous, and lignite coals are from the Supplemental Materials to [9]. The peak of production occurred in 1990, and the ultimate coal recovery of 43 Gt. Our estimate is 1/3 of the "Reserves + Cumulative Production" ($R + C$ = 120.7 Gt) and the "Best Guess" (BG = 127 Gt) in Table B.1 in [9]. There is no doubt that the FSU has vast coal resources. How these resources will be produced, and what has been the effect of 70 years of communist mismanagement is unknown.

The corresponding match of the rate and cumulative emissions of CO_2 in FSU is shown in **Figures 15** and **16**. The peak emissions of CO_2 of 1.8 Gt/y occurred in the year 1990, and the ultimate emissions are 97 Gt of CO_2.

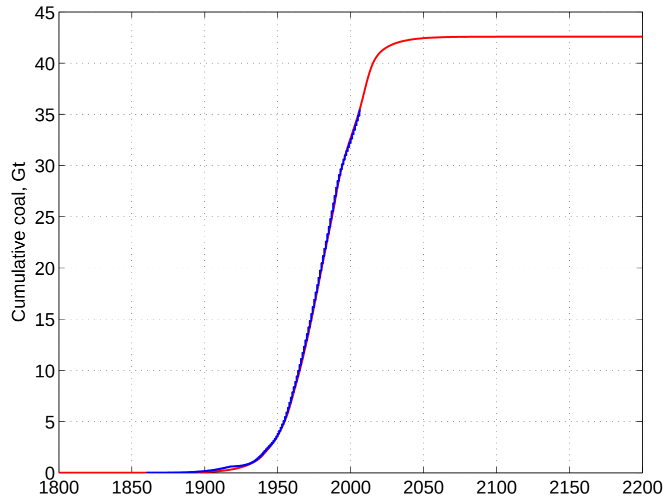

Figure 13: The best multi-Hubbert cycle match of the historical cumulative production of anthracite, bituminous, subbituminous, and lignite coal in the Former Soviet Union (FSU). The year of peak production was 1990, and the ultimate coal production is 43 Gt. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

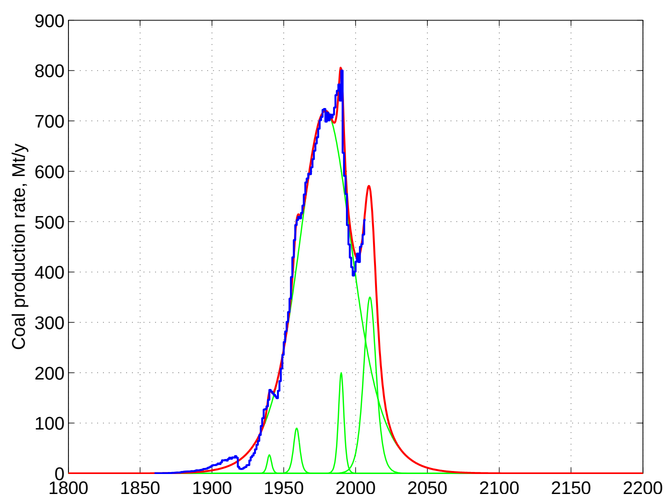

Figure 14: The best multi-Hubbert cycle match of the historical rate of production of anthracite, bituminous, subbituminous, and lignite coal in FSU. The smaller peaks are in the years 1940, 1959, 1970, and 2010. The size of the last peak is questionable. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

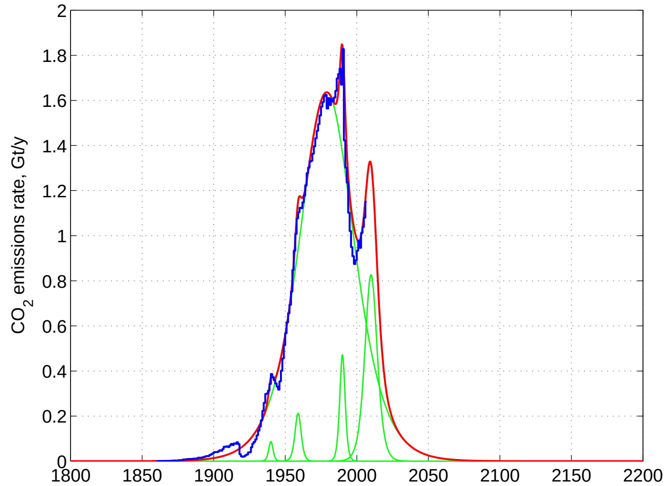

Figure 15: The best multi-Hubbert cycle match of the historical rate of CO_2 emissions in FSU. The emissions peak was the year 1990, at 1.8 Gt CO_2/y. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

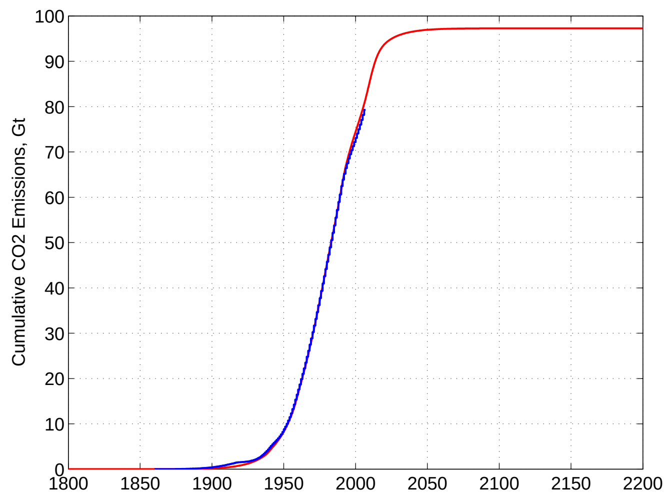

Figure 16: The best multi-Hubbert cycle match of the historical cumulative CO_2 emissions in FSU. The year of peak emissions was 1990, and the ultimate emissions are 97 Gt of CO_2. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

4. Australia

The Bowen Hard Coal Basin in Queensland is the most important coal-producing area in Australia, followed by the Sydney Hard Coal basin in New South Wales, and by the Clarence-Moreton Hard Coal Basin in Queensland and New South Wales. All of these basins contain coal of Permian age [3]. Known hard coal resources further inland in the Cooper and Galilee Basins in Queensland have not been developed because they are too far from the coast. There is also significant production of Tertiary-age lignite in the Latrobe Valley of Victoria [4].

Queensland and New South Wales accounted for more than 98 percent of Australia's hard coal production in the 2007 – 2008 fiscal year. The proximity of major coal resources to Australia's eastern seaboard has facilitated Australia becoming the world's largest coal exporter, accounting for about 20 percent of world steam coal exports and nearly 60 percent of metallurgical coal exports [14].

Nine advanced coal mine developments in Queensland and New South Wales are expected to raise coal production capacity by around 7 million tonnes per year over the next three to four years. In order to handle this increased mine production, there were seven coal terminal expansions and five rail expansions either committed or under construction at the end of April 2009 [15].

The best multi-Hubbert cycle fit of Australia's total coal production is shown in **Figures 17** and **18**. The production data for bituminous, subbituminous and lignite coals are from the Supplemental Materials to [9]. We predict the peak of production in 2047, and the ultimate coal recovery of 77 Gt. Our estimate is below the "Reserves + Cumulative Production" ($R + C = 85.5$ Gt) and is the "Best Guess" ($BG = 94$ Gt) in Table B.1 in [9]. Note that our prediction requires more than doubling of the current rate of coal production, or extending it in time at some lower rate, by constraining the "natural" rate. In other words, the higher the peak rate, the steeper future decline will be.

The corresponding match of the rate and cumulative emissions of CO_2 in Australia is shown in **Figures 19** and **20**. The peak emissions of CO_2 of 2.1 Gt/y are predicted in the year 2042, and the ultimate emissions are 158 Gt of CO_2.

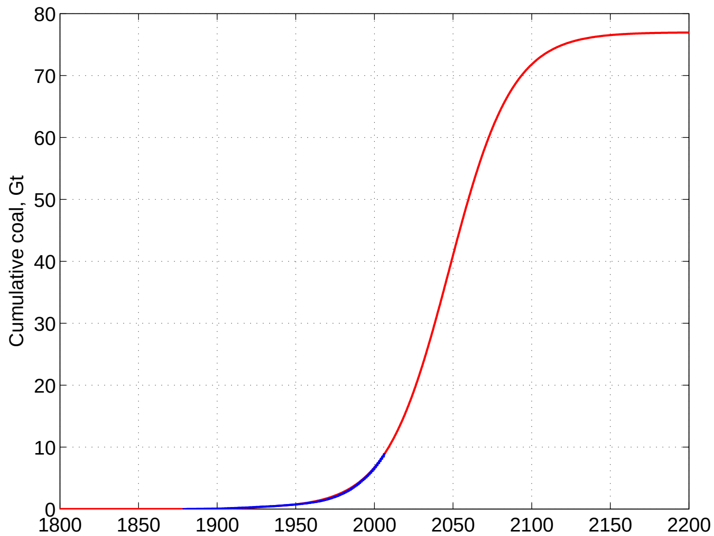

Figure 17: The best multi-Hubbert cycle match of the historical cumulative production of bituminous, subbituminous, and lignite coal in Australia. The year of peak production is 2047, and the ultimate coal production is 77 Gt. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

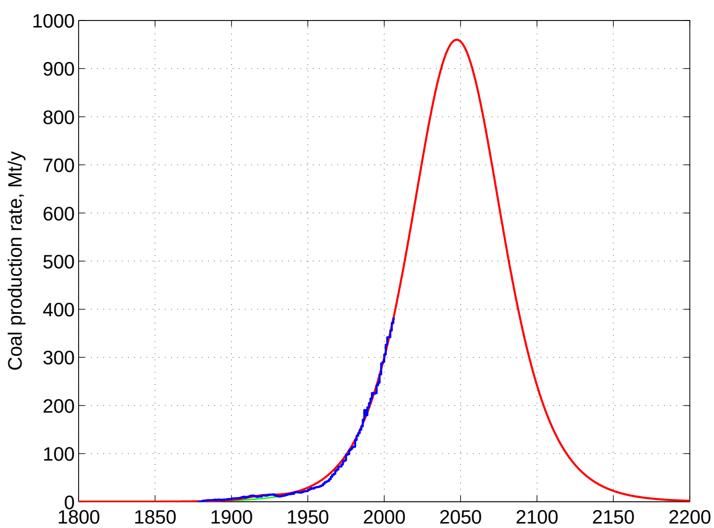

Figure 18: The best multi-Hubbert cycle match of the historical rate of production of bituminous, subbituminous, and lignite coal in Australia. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

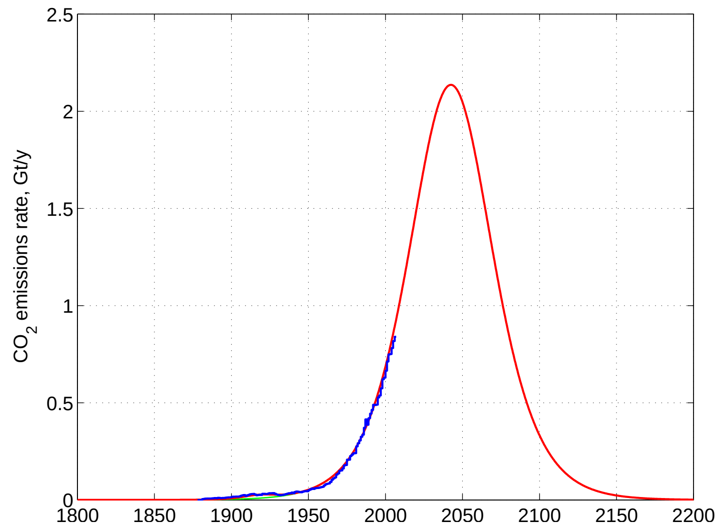

Figure 19: The best multi-Hubbert cycle match of the historical rate of CO_2 emissions in Australia. The predicted emission peak in the year 2042 is 2.1 Gt CO_2/y. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

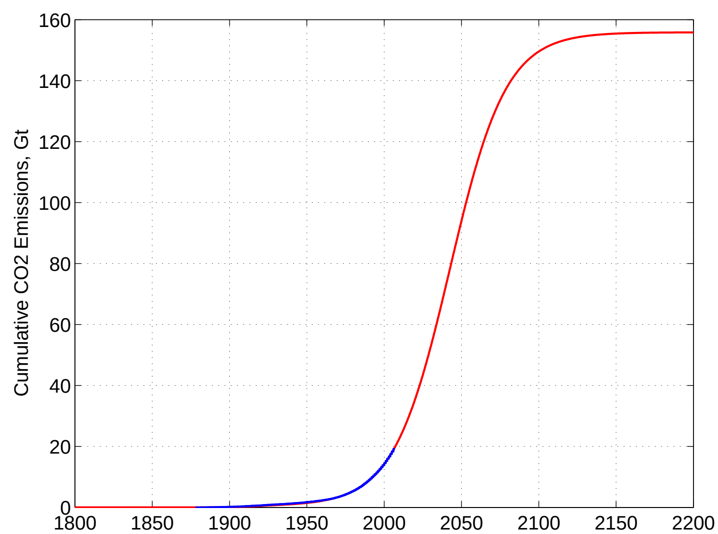

Figure 20: The best multi-Hubbert cycle match of the historical cumulative CO_2 emissions in Australia. The year of peak emissions is 2047, and the ultimate emissions are 158 Gt of CO_2. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

5. Former German Empire

Since Mohr and Evans lumped Germany and some of Poland's coal production data as "German Empire" (sic!), we follow their nomenclature, albeit very reluctantly.[1] Strictly speaking, most of the small Upper Silesian mines and many of the more important Lower Silesian mines, as well as those near the Czech Ostrava, were under German management before WWII.

Germany produces hard coal from the Carboniferous Ruhr, Saar and Aachen basins in the western part of the country. Ruhr is the most important of these, accounting for seven out of eight active hard coal mines. Lignite of Tertiary age is produced from the Rhein Basin in western Germany, as well as in the Leipzig and Lausitz areas. Seams are thick and undisturbed and the lignite is mined by open-cast methods [4].

All of Germany's hard coal production is operated by Deutsche Steinkohle. Average working depth has reached 920 meters, resulting in high operating costs. Coal mining has been subsidized as part of Germany's energy security policy, but those subsidies are to be phased out by 2012 in Saarland and by 2018 in the rest of the country. It is anticipated that hard coal mining in Germany will cease at that time [8]. Not so in Poland; coal production in Poland will continue for the foreseeable future [16].

Poland has three major coalfields; Upper Silesia, Lower Silesia and Lublin. Of these Upper Silesia is the most important, with numerous coal seams as much as 7 meters thick. The basin is structurally complex and coal rank has been increased locally by igneous intrusions [4]. The Upper Silesian Basin accounts for more than 80 percent of Polish hard coal reserves, with 14 percent in the Lublin Coal Basin and less than 1 percent in the Lower Silesian Basin. The Lublin Basin was only discovered after 1960 because of thick overburden; coal seam depths there range from 360 to more than 1,000 meters [17].

Tertiary lignite basins are present in central and southwestern Poland. The lignites range from Paleocene to Miocene in age, with middle Miocene deposits of the greatest economic importance [18]. Ash and sulfur content is low and the lignite is mined by open-cast methods to supply local electric power plants. The reserves of Poland's four major lignite mines will be exhausted between 2017 and 2045, depending on the mine, but large undeveloped resources remain [16].

The best multi-Hubbert cycle fit of Germany and Poland's total coal production is shown in **Figures 21** and **22**. The production data for anthracite, bituminous, and lignite coals are from the Supplemental Materials to [9]. Coal production in Germany and Poland peaked in 1987, and the ultimate coal recovery is 53 Gt. Our estimate is somewhat below the "Reserves + Cumulative Production" ($R + C = 64.2$ Gt) and the "Best Guess" ($BG = 58$ Gt) in Table B.1 in [9]. This makes sense because there is still plenty of producible coal left in Poland.

The corresponding match of the rate and cumulative emissions of CO_2 in the former German Empire is shown in **Figures 23** and **24**. The peak emissions of CO_2 of 1.4 Gt/y occurred in 1987, and the ultimate emissions are 100 Gt of CO_2.

[1] Patzek was born in a Silesian border mining town, Gliwice, where WWII started with a German provocation.

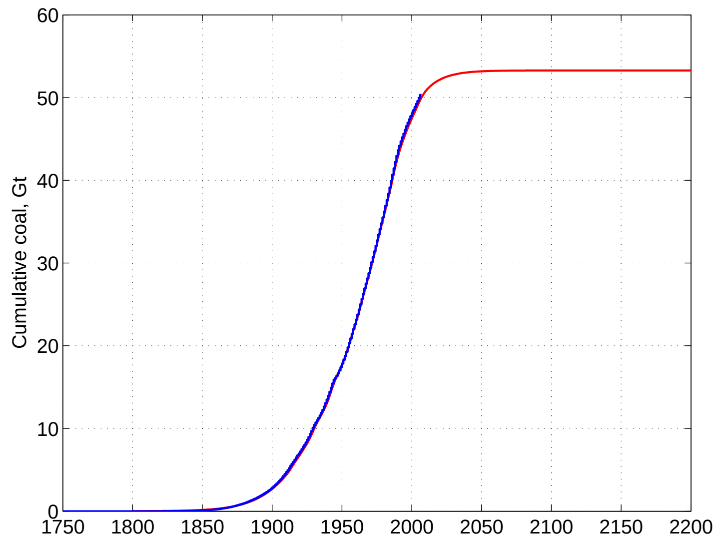

Figure 21: The best multi-Hubbert cycle match of the historical cumulative production of anthracite, bituminous and lignite coal in the former German Empire. The year of peak production was 1987, and the ultimate coal production is 53 Gt. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

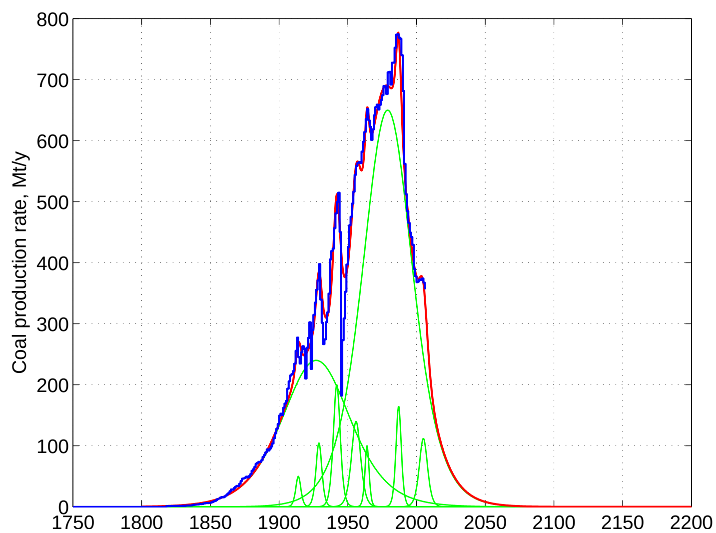

Figure 22: The best multi-Hubbert cycle match of the historical rate of production of anthracite, bituminous and lignite coal in the former German Empire. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

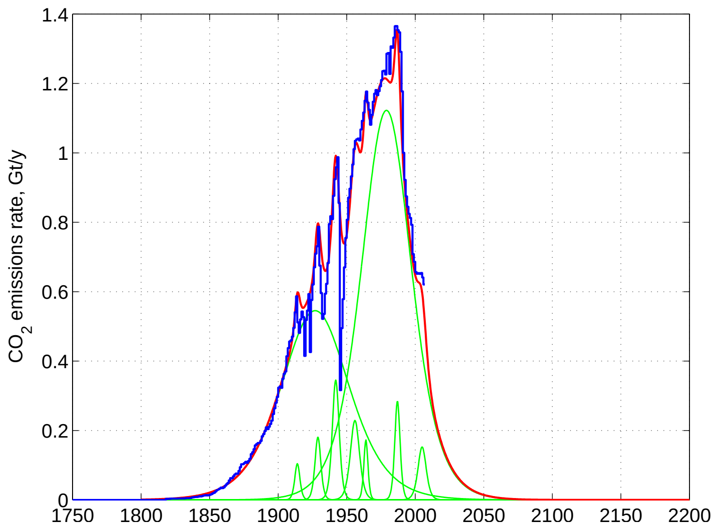

Figure 23: The best multi-Hubbert cycle match of the historical rate of CO_2 emissions in the former German Empire. The emission peak in the year 1987 was 1.4 Gt CO_2/y. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

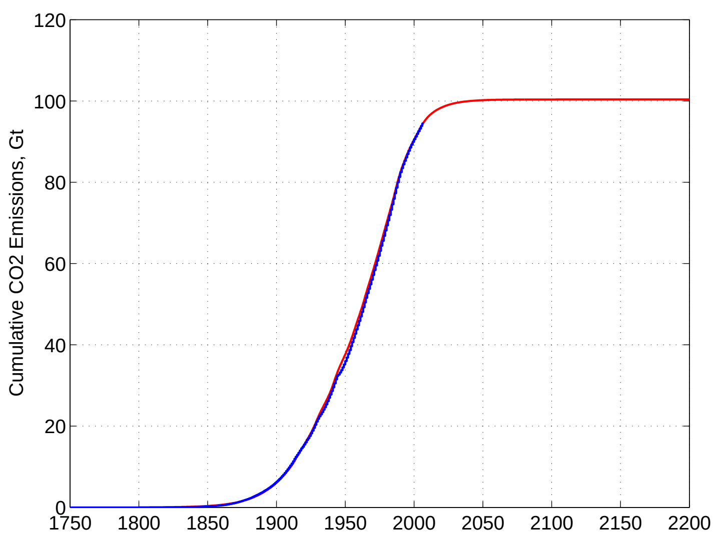

Figure 24: The best multi-Hubbert cycle match of the historical cumulative CO_2 emissions in the former German Empire. The year of peak emissions was 1987, and the ultimate emissions are 100 Gt of CO_2. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

6. The United Kingdom

The United Kingdom has several coal-producing areas. The coals are Carboniferous in age and are principally bituminous, with anthracite locally important in South Wales. Once the most important coal-producing region in the UK, South Wales produced anthracite and low-sulfur bituminous coals from seams 1.0 to 3.5 meters thick [4]. The East Pennine coalfield, stretching from Leeds to Nottingham, contains at least 30 workable seams and is currently the most important coalfield in the U.K. It has a long history and was the source for a major coal export trade in the nineteenth century [3].

The best multi-Hubbert cycle fit of U.K.'s total coal production is shown in **Figures 25** and **26**. The production data for anthracite, bituminous, and lignite coals are from the Supplemental Materials to [9]. The peak of production was in 1913, and the ultimate coal recovery is 28.3 Gt. This estimated ultimate recovery should be discounted by at least 1 Gt of coal because the numerous strikes of the British coal miners, and the ensuing production stoppages, cannot be captured by the Hubbert cycles. With this discount, our estimate is equal to the "Reserves + Cumulative Production" ($R + C = 27.3$ Gt) and the "Best Guess" ($BG = 27.4$ Gt) in Table B.1 in [9]. Note that today the U.K. produces as much coal as it did in the year 1800.

The corresponding match of the rate and cumulative emissions of CO_2 in the U.K. is shown in **Figures 27** and **28**. The peak emissions of CO_2 of 0.7 Gt/y occurred in 1913, and the ultimate emissions are 68 Gt of CO_2.

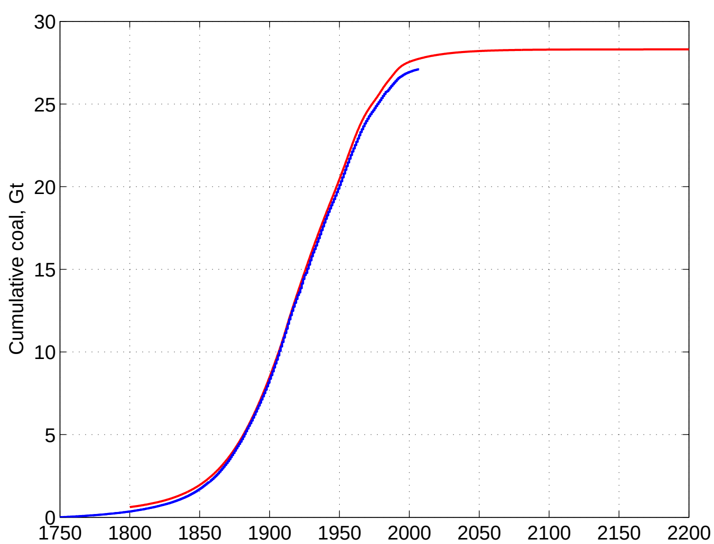

Figure 25: The best multi-Hubbert cycle match of the historical cumulative production of anthracite, bituminous and lignite coal in the U.K. The year of peak production was 1913, and the ultimate coal production is 28.3 Gt. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

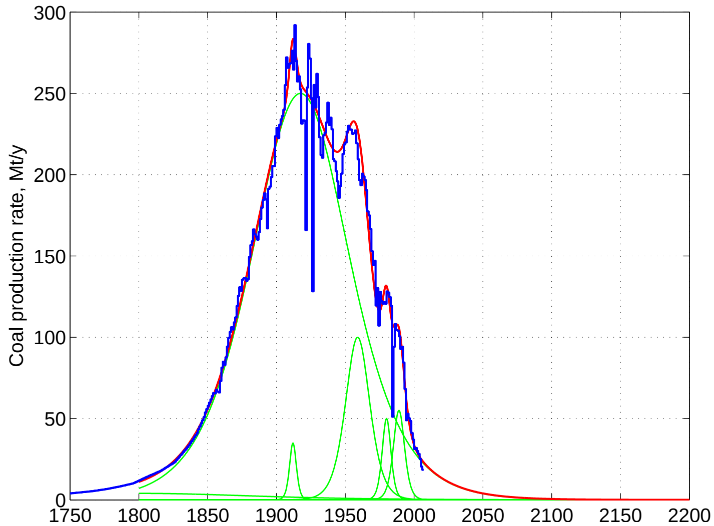

Figure 26: The best multi-Hubbert cycle match of the historical rate of production of anthracite, bituminous and lignite coal in the U.K. Note that the several abrupt production stoppages caused by strikes of the British coal miners cannot be captured by the Hubbert-cycle analysis. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

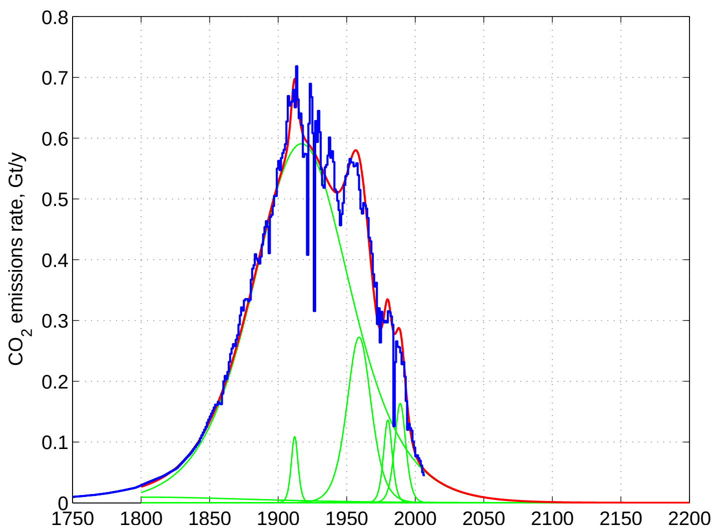

Figure 27: The best multi-Hubbert cycle match of the historical rate of CO_2 emissions in the U.K. The emission peak in the year 1913 was 0.7 Gt CO_2/y. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

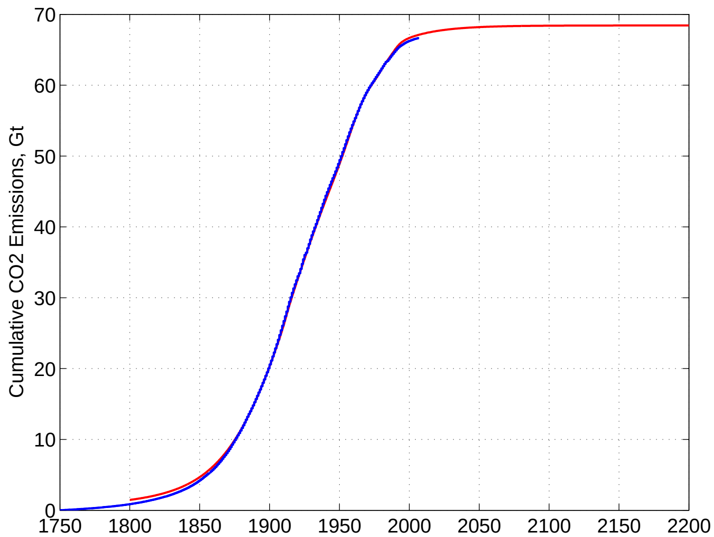

Figure 28: The best multi-Hubbert cycle match of the historical cumulative CO_2 emissions in the U.K. The year of peak emissions was 1913, and the ultimate emissions are 68 Gt of CO_2. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

7. India

More than 85 percent of India's coal production is produced by state-owned Coal India Limited (CIL), making it the world's largest coal company. According to its web site, CIL directly employs 425,000 people. The coal fields are in northeastern and east-central India, with 77 percent of proved reserves in the states of Jharkand, Orissa, Chattisgarh and West Bengal[2]. The most important producing area is the Raniganj Basin, north of Calcutta. Although Tertiary-aged coals exist in northeastern India, 99.5 percent of India's proven coal reserves are associated with Gondwana (Permo-Carboniferous) sediments, and the major coal measures are all of Permian age [3].

Unlike China, 81 percent of India's coal production comes from open-cast mines, but current plans are to increase the proportion of underground mining, see Footnote 2. India's coal production has been growing, but not rapidly enough to satisfy demand growth, so imports are increasing. This has resulted in concerns about the coal supply. According to [19]:

> ... recent experiences have thrown into sharp relief the uncertainties and concerns regarding the adequacy of coal supplies to satisfy the growing hunger for power.

The best multi-Hubbert cycle fit of India's total coal production is shown in **Figures 29** and **30**. The production data for bituminous and lignite coals are from the Supplemental Materials to [9]. We predict the peak of production in 2011, and the ultimate coal recovery of 32.6 Gt. The peak of the broad fundamental Hubbert cycle is in the year 2028. Our production-based estimate is 2 times less than the "Reserves + Cumulative Production" ($R + C = 66.7$ Gt) and 3 times less than the "Best Guess" ($BG = 104.5$ Gt) in Table B.1 in [9]. The latter two predictions are from the International Energy Agency.

The corresponding match of the rate and cumulative emissions of CO_2 in India is shown in **Figures 31** and **32**. The peak emissions of CO_2 of 1.2 Gt/y are predicted in the year 2011, and the ultimate emissions are 79 Gt of CO_2.

[2]Ministry of Coal, *Inventory of Coal Resources of India*, coal.nic.in/reserve2.htm.

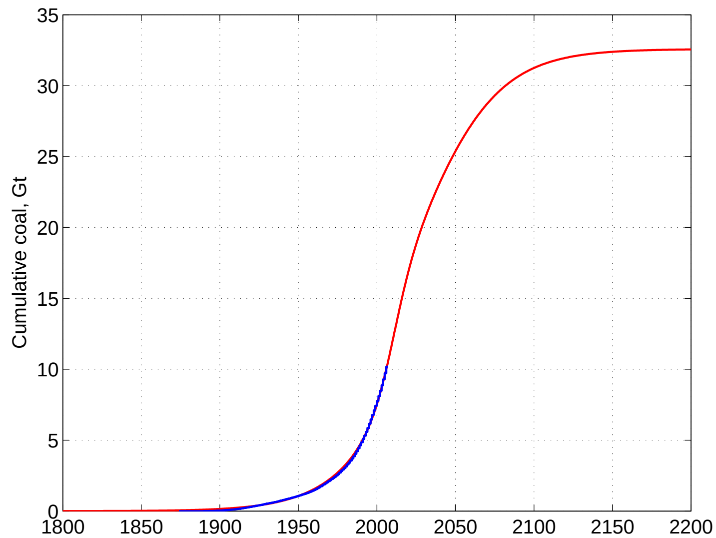

Figure 29: The best multi-Hubbert cycle match of the historical cumulative production of bituminous and lignite coal in India. The year of peak production is 2011, and the ultimate coal production is 32.6 Gt. The broad base peak is in the year 2019. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

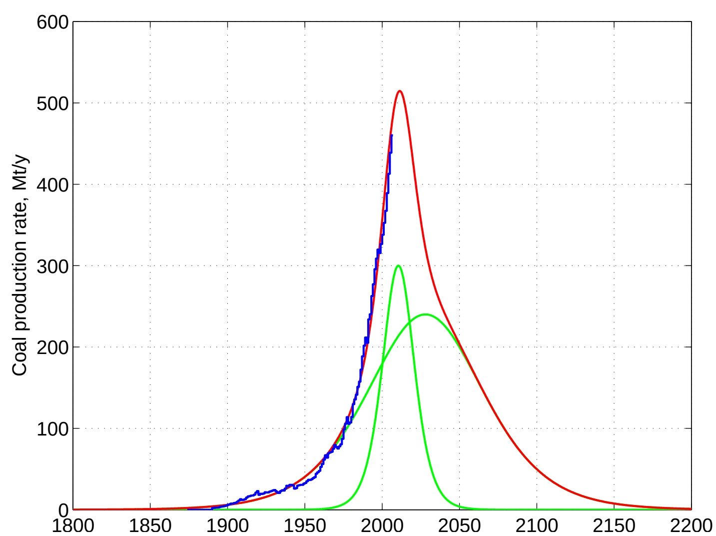

Figure 30: The best multi-Hubbert cycle match of the historical rate of production of bituminous, and lignite coal in India. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

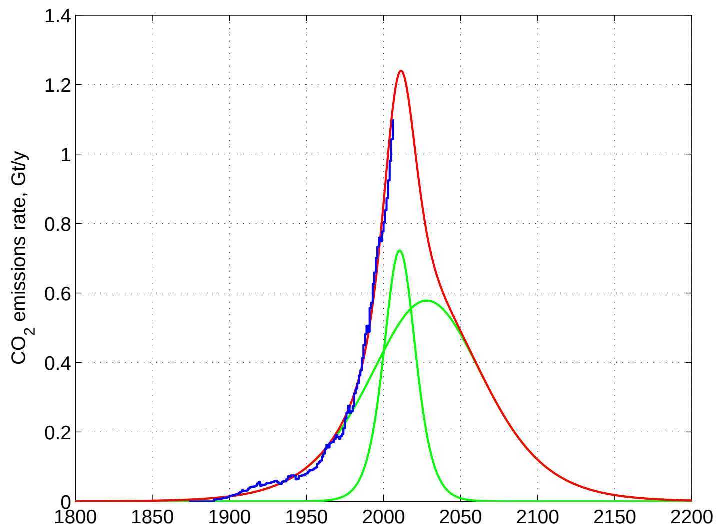

Figure 31: The best multi-Hubbert cycle match of the historical rate of CO_2 emissions in India. The predicted emission peak in the year 2011 is 1.2 Gt CO_2/y. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

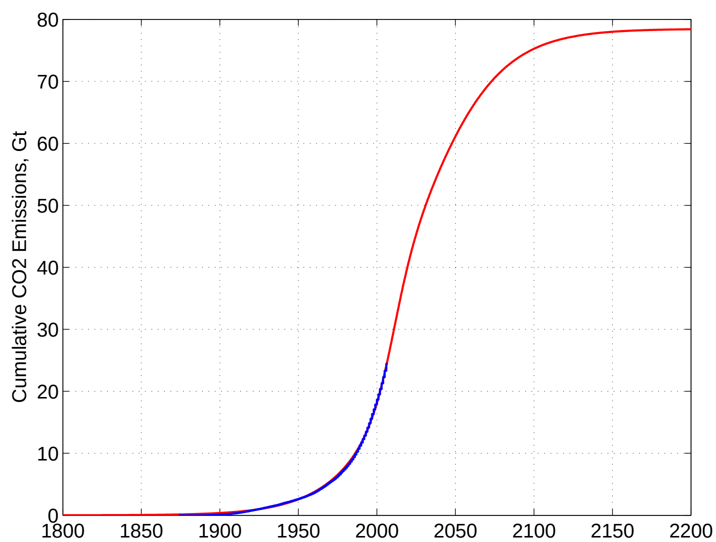

Figure 32: The best multi-Hubbert cycle match of the historical cumulative CO_2 emissions in India. The year of peak emissions is 2011, and the ultimate emissions are 79 Gt of CO_2. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

8. South Africa

South Africa's coal deposits are primarily located in Mpumalanga (formerly Transvaal) and to a lesser extent in KwaZulu-Natal and Free State. These areas are contiguous regions of the Karroo Basin. All reserves are hard coal and are located in the Karroo series of Permian age, which rests upon basement. The coal seams are thick, shallow, and nearly horizontal [4]. An important geological point is that the coal deposits sit on basement and are shallow.

About 51 percent of South African coal mining is done underground and about 49 percent is produced by open-cast methods. The coal-mining industry is highly concentrated with five companies accounting for 85 percent of saleable coal production. These companies are Ingwe Collieries Limited (a BHP Billiton subsidiary), Anglo Coal, Sasol, Eyesizwe and Kumba Resources Limited. The eleven largest mines account for 70 percent of South Africa's coal output [20].

Figures 33 – 34 are based on the data in the Supplemental Materials to [9]. Our best multi-Hubbert cycle estimate shows the South African coal production already peaking and the ultimate coal recovery of 17.8 Gt. This estimate is identical to the "Linearized Hubbert" (LH = 18.0 Gt) estimate in Table B.1 in [9]. A high, single Hubbert peak fit of the data results in the prediction of coal peak in 2035 and ultimate coal recovery of 38.6 Gt that is identical to the "Best Guess" (BG = 38.7 Gt) case in Table B.1. One may note, however, that the high case presented in **Figures 35** and **36** would require the doubling of current peak production in South Africa, or doubling the size and production of current mines there. Circumstantial evidence points to the contrary; most mines only go to about 300 meters depth at most, because the coal deposits sit on basement at that depth. Unlike many other hard coal-producing regions, there is no option of mining deeper seams in the same area. In 2008, the South Africans had to close some mines to save electricity because they had firm export contracts for more coal than they had surplus, resulting in a domestic shortage. As with China, all of the circumstantial evidence points to coal being less abundant than believed.

The corresponding match of the rate and cumulative emissions of CO_2 in South Africa is shown in **Figures 37** and **38**. The peak emissions of CO_2 of 0.6 Gt/y are predicted in the year 2008, and the ultimate emissions are 44 Gt of CO_2.

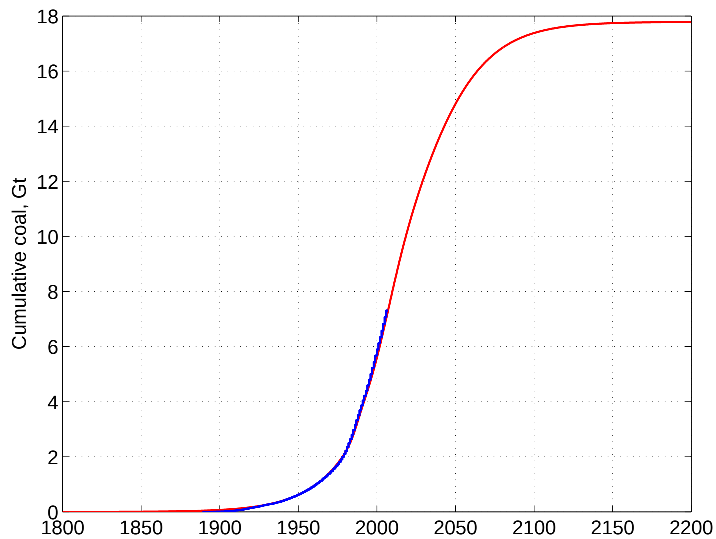

Figure 33: The best multi-Hubbert cycle match of the historical cumulative production of anthracite and bituminous coal in South Africa. The year of peak production is 2008, and the ultimate coal production is 18.2 Gt. The broad base peak is in the year 2022. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

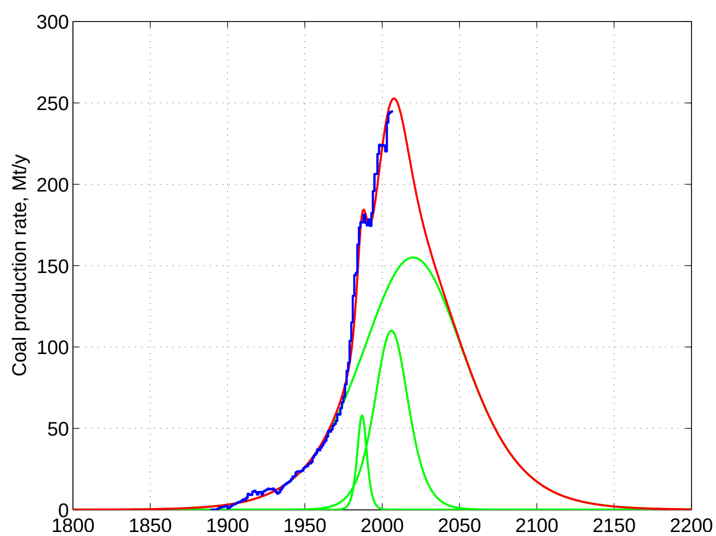

Figure 34: The best multi-Hubbert cycle match of the historical rate of production of anthracite and bituminous coal in South Africa. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

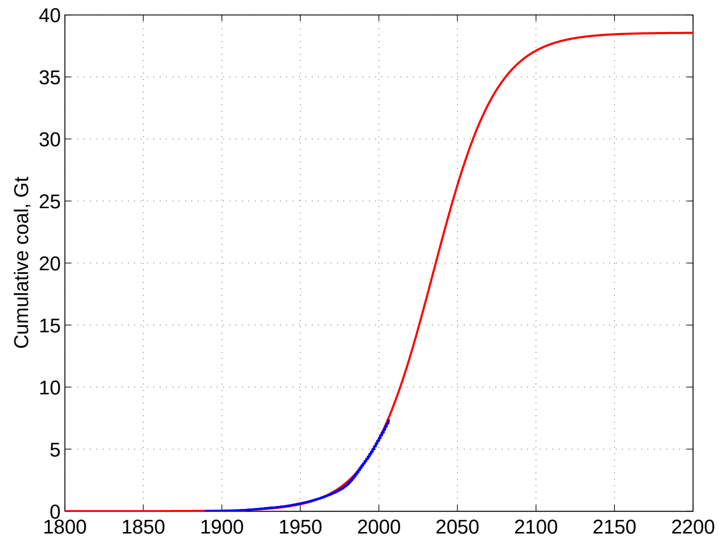

Figure 35: A high single-Hubbert cycle match of the historical cumulative production of anthracite and bituminous coal in South Africa. The year of peak production is 2035, the average logistic growth rate is 5 percent, and the ultimate coal production is 38.6 Gt. Given the geology of coal deposits in South Africa, this scenario seems to be impossible. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

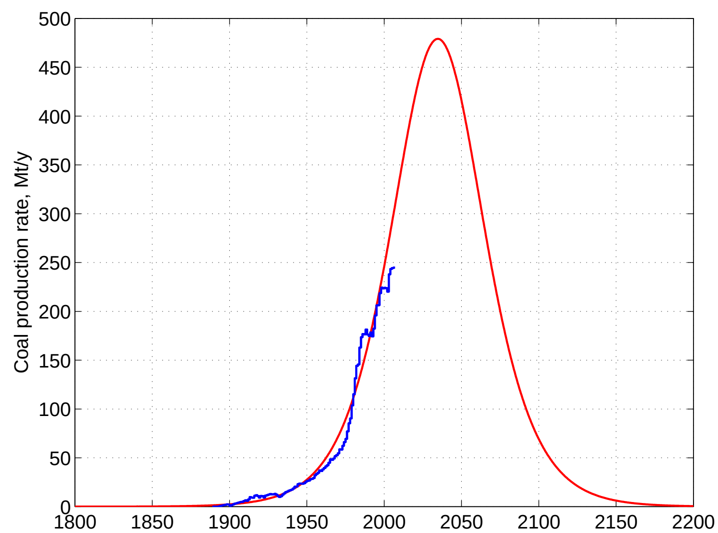

Figure 36: A high single-Hubbert cycle match of the historical rate production of anthracite and bituminous coal in South Africa. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

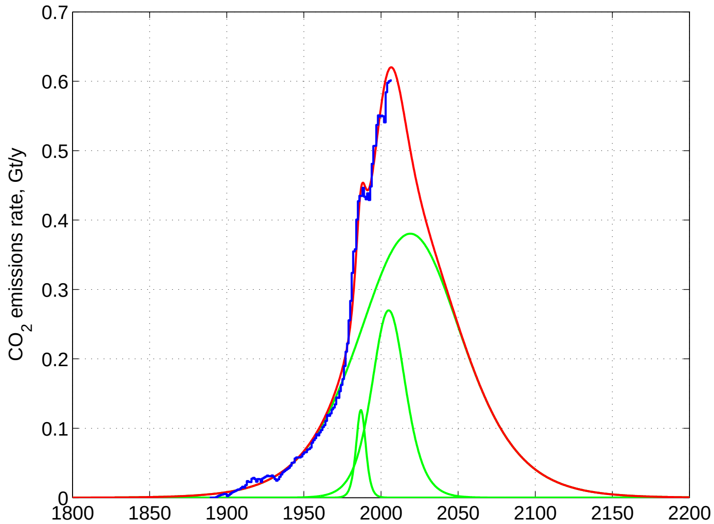

Figure 37: The best multi-Hubbert cycle match of the historical rate of CO_2 emissions in South Africa. The predicted emission peak in the year 2008 is 0.6 Gt CO_2/y. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

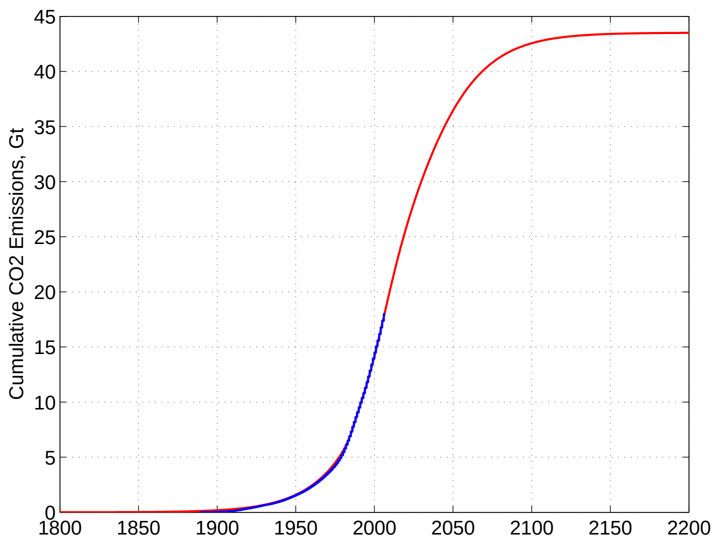

Figure 38: The best multi-Hubbert cycle match of the historical cumulative CO_2 emissions in South Africa. The year of peak emissions is 2008, and the ultimate emissions are 44 Gt of CO_2. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

9. Indonesia

Indonesia has two coal-producing regions, the islands of Sumatra and Borneo. Coal from Sumatra is largely consumed by power generation and coal from Kalimantan (the Indonesian part of the island of Borneo) is largely exported. The coal is entirely Tertiary in age and ranges from lignite to anthracite [3]. Seams are up to 10 meters thick in East and South Kalimantan, where igneous activity has locally increased the rank of the coal. Seams of sub-bituminous coal are up to 12 meters thick at Bukit Asam, southeastern Sumatra [4].

Thick coal seems, shallow mining depths, and low labor costs make Indonesia a very low-cost coal producer. The presence of substantial low-cost coal reserves that are close to ports along a major shipping route has made Kalimantan a major source of thermal coal exports. Borneo Coal Indonesia exports five grades, ranging from 22 to 26 MJ per kilogram. All coals are less than 1 percent sulfur, and the 22 and 24 MJ/kg grades are less than 7 percent ash [21].

The best single Hubbert cycle fit of Indonesia's total coal production is shown in **Figures 39** and **40**. The production data for anthracite and bituminous coals are from the Supplemental Materials to [9]. We predict the peak of production in 2014, and the ultimate coal recovery of 5.6 Gt. Our estimate is identical to the "Reserves + Cumulative Production" ($R+C = 5.6$ Gt) and the "Best Guess" ($BG = 5.6$ Gt) in Table B.1 in [9].

The corresponding match of the rate and cumulative emissions of CO_2 in Indonesia is shown in **Figures 41** and **42**. The peak emissions of CO_2 of 0.54 Gt/y are predicted in the year 2014, and the ultimate emissions are 12.2 Gt of CO_2.

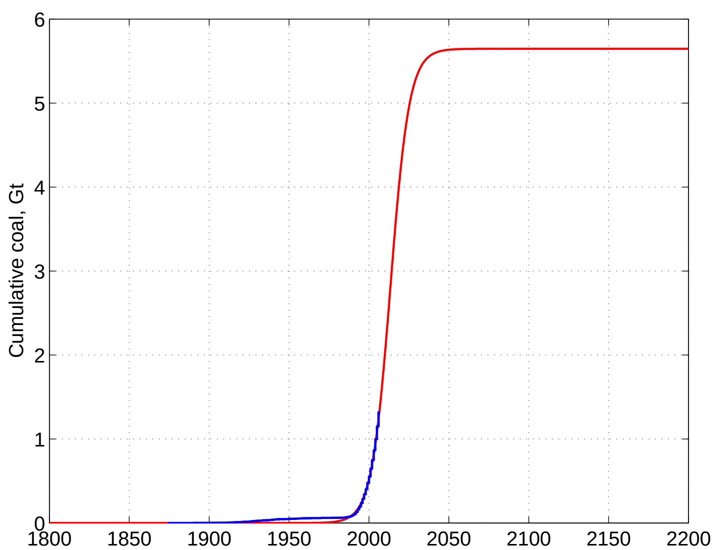

Figure 39: The best single Hubbert cycle match of the historical cumulative production of anthracite and bituminous coal in Indonesia. The year of peak production is 2014, and the ultimate coal production is 5.6 Gt. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

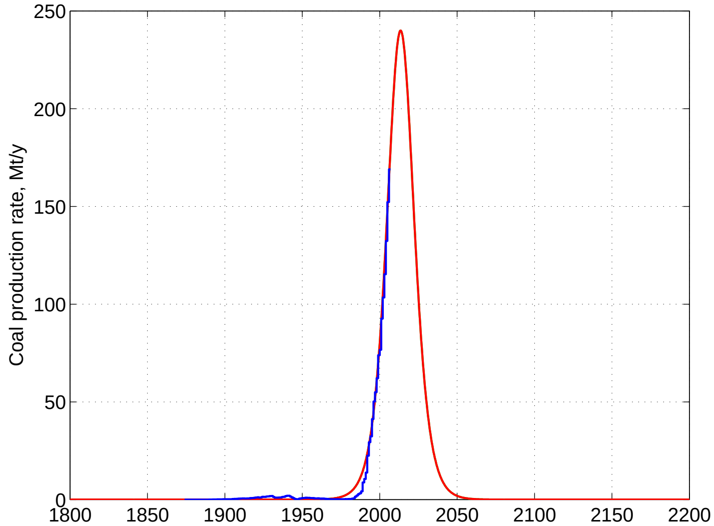

Figure 40: The best single Hubbert cycle match of the historical rate of production of anthracite and bituminous coal in Indonesia. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

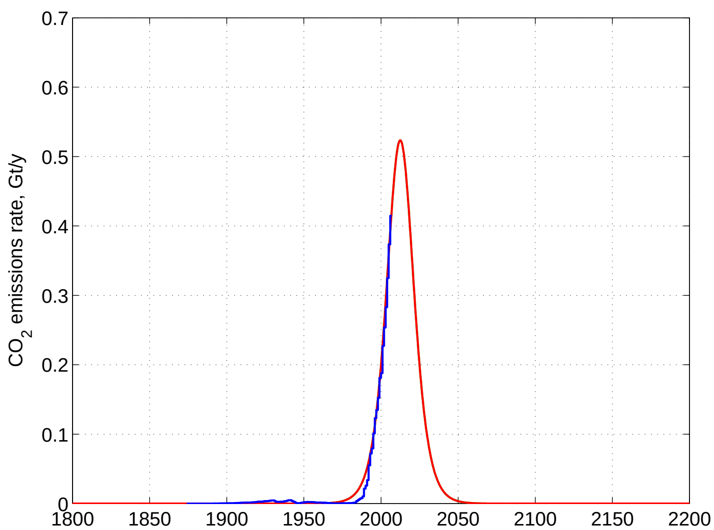

Figure 41: The best multi-Hubbert cycle match of the historical rate of CO_2 emissions in Indonesia. The predicted emission peak in the year 2014 is 0.54 Gt CO_2/y. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

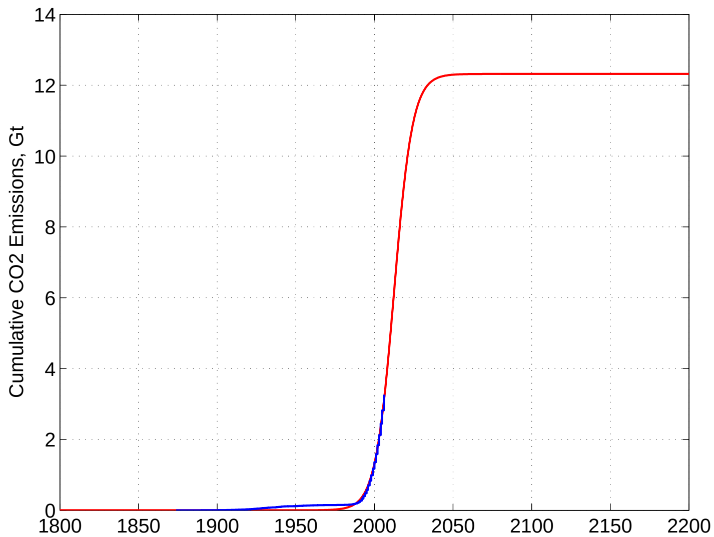

Figure 42: The best multi-Hubbert cycle match of the historical cumulative CO_2 emissions in Indonesia. The year of peak emissions is 2014, and the ultimate emissions are 12.2 Gt of CO_2. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

10. Mongolia

Most of Mongolia's coal resources are located in the north of the country. The Baganuur coal field in northern Mongolia contains low-sulfur, Cretaceous coals up to 25 meters thick. Other coalfields in northern Mongolia are Sharin Gol, Nalayh, Achit Nuur, and Khartarbagat. Also in northern Mongolia, highly tectonized Paleozoic coals are found in numerous small, isolated deposits. These are anthracite or low-volatile bituminous [4].

The Tavan Tolgoi deposit in the Permian Southern Gobi Basin of southern Mongolia contains an estimated 6 billion tons of bituminous coal, about one-third of which is coking-quality, but its remote location prevented development until 2003. Production reached 1 million metric tons in 2007 and the coal is exported to China. The mine contains 16 major coal seams totaling 74.9 meters in thickness [22].

The best multi-Hubbert cycle fit of Mongolia's total coal production is shown in **Figures 43** and **44**. The production data for bituminous and lignite coals are from the Supplemental Materials to [9]. We predict the peak of production in 2100, and the ultimate coal recovery of 15.7 Gt. The peak of the small Hubbert cycle was in the year 1988. Our production-based estimate is 6 times less than the "Reserves + Cumulative Production" ($R + C = 100.2$ Gt) and is equal to the "Best Guess" ($BG = 15.2$ Gt) in Table B.1 in [9]. The higher prediction is from an advertising section for Mongolia's Business Opportunities.[3]

The corresponding match of the rate and cumulative emissions of CO_2 in Mongolia is shown in **Figures 45** and **46**. The peak emissions of CO_2 of 0.3 Gt/y are predicted in the year 2100, and the ultimate emissions are 25 Gt of CO_2.

[3] *Mongolia: Business Opportunities for 2005, Special Advertising Section*, Fortune Magazine, www.timeinc.net/fortune/services/sections/fortune/intl/ media/2005_09mongolia.pdf, September 2005. Accessed on 07.04.2009.

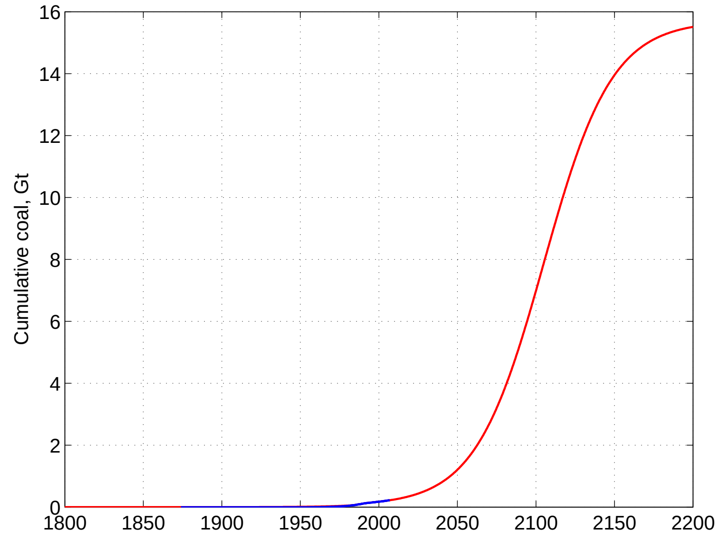

Figure 43: The best multi-Hubbert cycle match of the historical cumulative production of bituminous and lignite coal in Mongolia. The year of peak production is 2100, and the ultimate coal production is 15.7 Gt. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

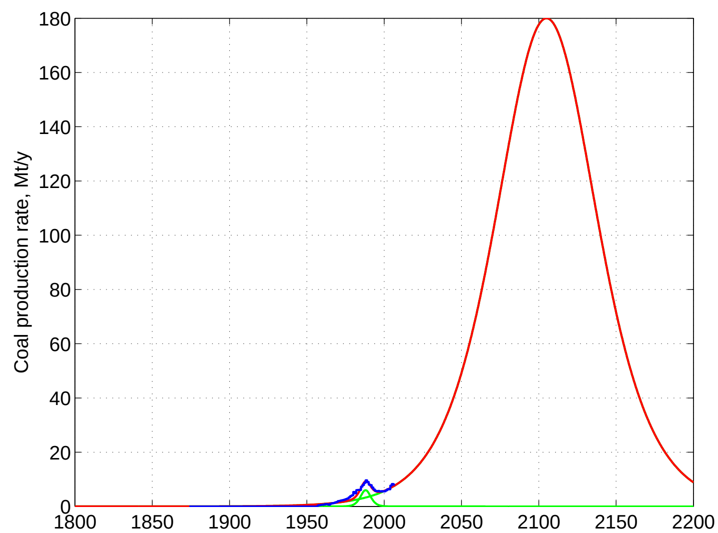

Figure 44: The best multi-Hubbert cycle match of the historical rate of production of bituminous, and lignite coal in Mongolia. The small peak is in the year 1998. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

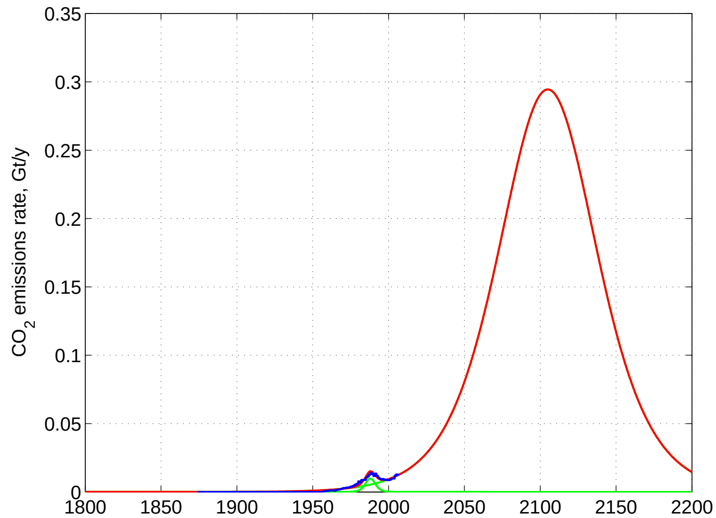

Figure 45: The best multi-Hubbert cycle match of the historical rate of CO_2 emissions in Mongolia. The predicted emission peak in the year 2100 is 0.3 Gt CO_2/y. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

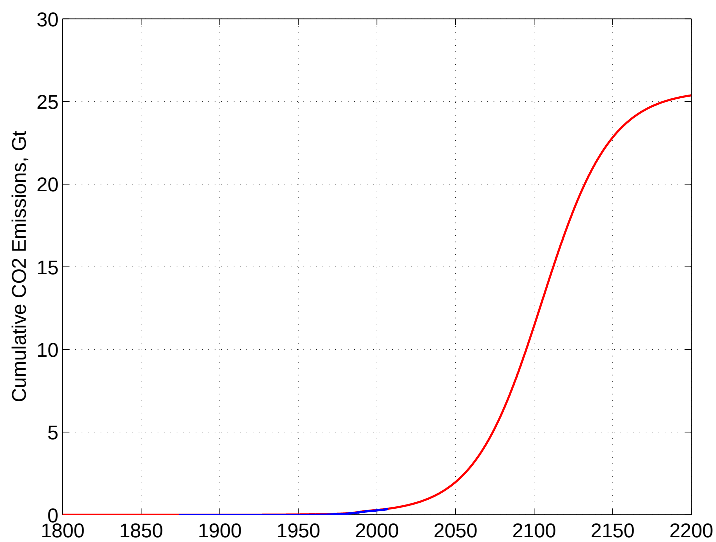

Figure 46: The best multi-Hubbert cycle match of the historical cumulative CO_2 emissions in Mongolia. The year of peak emissions is 2100, and the ultimate emissions are 25 Gt of CO_2. Data source: Supplemental Materials to Mohr and Evans (2009) [9].

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