World Energy 2017-2050: Annual Report

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This Annual Report evaluates the future development of world energy supply and its impact on the global economy as well as climate change. The report projects the world energy supply and gross world product (global economic output) from 2017 to 2050. It also projects carbon dioxide emissions from fossil fuels burning and the implied global average surface temperature from 2017 to 2100.

To project the future oil and natural gas production, this report uses Hubbert Linearization as the primary analytical tool. Hubbert Linearization was first proposed by American geologist M. King Hubbert (Hubbert 1982). It plots the current production to cumulative production ratio against the historical cumulative production. It uses the downward linear trend of the current production to cumulative production ratio to determine the ultimately recoverable resources.

Past experience suggests that Hubbert Linearization exercise tends to underestimate the ultimately recoverable oil and natural gas resources. Despite its limitations, Hubbert Linearization provides a useful tool helping to indicate the likely level of ultimately recoverable resources under the existing trends of technology, economics, and geopolitics. To mitigate this "pessimistic" bias, I use the US Energy Information Administration (EIA)'s official projection for the US oil and natural gas production from 2017 to 2050 (EIA 2017, Table A1), which may prove to be too optimistic.

There is a high level of uncertainty regarding the future of the world coal production that may be influenced by economics, climate stabilization requirements, as well as resources constraints. This report uses the "proved coal reserves" reported by the BP *Statistical Review of World Energy* (BP 2017) to evaluate the future coal production in China and India, currently the first and second largest coal producer in the world. I use EIA's official projection for the US coal production from 2017 to 2050 (EIA 2017, Table A1). To project the rest of the world's future coal production, I apply Hubbert Linearization to the rest of the world's historical coal production data.

For the future wind and solar electricity consumption, I do not impose a definite limit on their future potential. However, I assume that the annual installation of wind and solar generating capacity will grow at a progressively slower rate and eventually approach a certain level of maximum.

For the future production (consumption) of biofuels, nuclear electricity, hydro electricity, geothermal electricity, biomass electricity, I use the projections made by EIA's *International Energy Outlook* (EIA 2016).

The previous Annual Report, "World Energy 2016-2050", was posted at *Peak Oil Barrel* (Political Economist 2016): http://peakoilbarrel.com/world-energy-2016-2050-annual-report/

Figures and tables are placed at the end of each section.

World Energy 2005-2016

According to BP's *Statistical Review of World Energy*, world primary energy consumption reached 13,276 million tons of oil equivalent in 2016 (BP 2017). From 2005 to 2016, world primary energy consumption grew at an average annual rate of 1.8 percent.

World oil consumption (including biofuels) was 4,418 million tons in 2016, accounting for 33.3 percent of the world energy consumption. From 2005 to 2016, world oil consumption grew at an average annual rate of 1.1 percent.

World natural gas consumption was 3,204 million tons of oil equivalent in 2016, accounting for 24.1 percent of the world energy consumption. From 2005 to 2016, world natural gas consumption grew at an average annual rate of 2.3 percent.

World coal consumption was 3,732 million tons of oil equivalent in 2016, accounting for 28.1 percent of the world energy consumption. From 2005 to 2016, world coal consumption grew at an average annual rate of 1.6 percent.

World consumption of nuclear electricity was 592 million tons of oil equivalent in 2016, accounting for 4.5 percent of the world energy consumption. From 2005 to 2016, world consumption of nuclear electricity declined at an average annual rate of 0.5 percent.

World consumption of hydro electricity was 910 million tons of oil equivalent in 2016, accounting for 6.9 percent of the world energy consumption. From 2005 to 2016, world consumption of hydro electricity grew at an average annual rate of 3.0 percent.

World consumption of wind and solar electricity was 292 million tons of oil equivalent in 2016, accounting for 2.2 percent of the world energy consumption. From 2005 to 2016, world consumption of wind and solar electricity grew at an average annual rate of 25.3 percent.

World consumption of geothermal, biomass and other renewable electricity was 127 million tons of oil equivalent in 2016, accounting for 1.0 percent of the world energy consumption. From 2005 to 2016, world consumption of geothermal, biomass and other renewable electricity grew at an average annual rate of 7.4 percent.

According to the World Bank and IMF data, gross world product (global economic output) was 111.5 trillion dollars (in constant 2011 international dollars) in 2016 (World Bank 2017; IMF 2017). From 2005 to 2016, global economic output grew at an average annual rate of 3.5 percent.

World average energy efficiency was 8,401 dollars per ton of oil equivalent in 2016. From 2005 to 2016, world average energy efficiency grew at an average annual rate of 1.7 percent.

According to the BP *Statistical Review of World Energy*, world carbon dioxide emissions from fossil fuels burning reached 33.4 billion tons in 2016. From 2005 to 2016, world carbon dioxide emissions grew at an average annual rate of 1.4 percent.

World average emission intensity of primary energy consumption was 2.52 tons of carbon dioxide emissions per ton of oil equivalent. From 2005 to 2016, world average emission intensity of primary energy consumption declined at an average annual rate of 0.3 percent.

Figure 1 compares the historical world economic growth rates and the primary energy consumption growth rates from 2005 to 2016. The primary energy consumption growth rate has an intercept of -0.0157 at zero economic growth rate and a slope of 0.959. That is, primary energy consumption has an “autonomous” tendency to fall by about 1.6 percent a year when economic growth rate is zero. When economic growth rate rises above zero, an increase in economic growth rate by one percentage point is associated with an increase in primary energy consumption by 0.96 percent. R-square for the linear trend is 0.860.

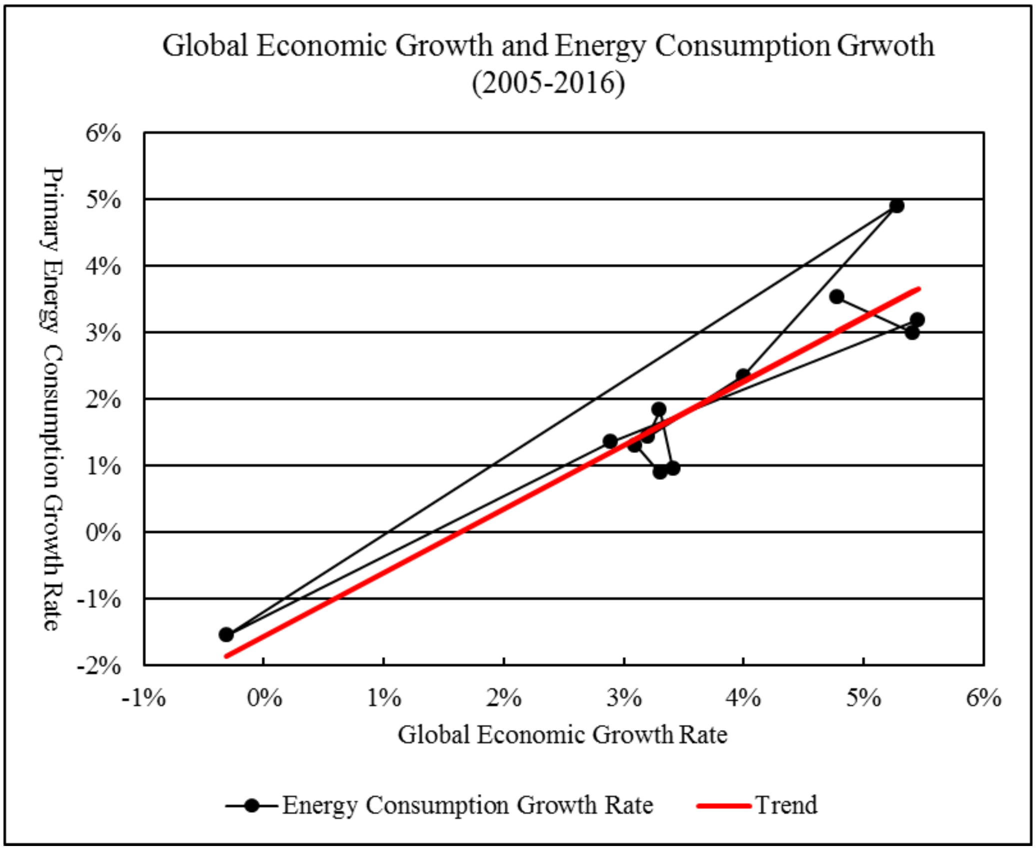

Figure 1

Sources: Gross world product in constant 2011 international dollars from 2005 to 2015 is from World Bank (2017), extended to 2016 using data from IMF (2017, Statistical Appendix, Table A1); world primary energy consumption from 2005 to 2016 is from BP (2017).

Oil

World oil production (including crude oil and natural gas liquids) was 4,382 million tons (92.2 million barrels per day) in 2016, 0.5 percent higher than world oil production in 2015.

In 2016, Saudi Arabia was the world's largest oil producer by energy content; Saudi Arabia produced 586 million tons of crude oil and natural gas liquids (12.3 million barrels per day), accounting for 13.4 percent of the world oil production.

The United States was the world's largest oil producer by volume; the US produced 543 million tons of crude oil and natural gas liquids (12.4 million barrels per day), accounting for 12.4 percent of the world oil production.

The Russian Federation was the world's second largest oil producer by energy content or the third largest oil producer by volume; Russia produced 554 million tons of crude oil and natural gas liquids (11.2 million barrels per day), accounting for 12.6 percent of the world oil production.

Figure 2 shows the historical and projected US oil production from 1950 to 2050. The projection is based on the US Energy Information Administration's reference case scenario of the US oil production from 2017 to 2050 (EIA 2017, Table A1).

The US cumulative oil production up to 2016 was 33 billion tons. According to EIA's current projection, the US oil production will peak in 2026 with a production level of 670 million tons and the US cumulative oil production will be 55 billion tons by 2050. Hubbert Linearization applied to the EIA projection from 2041 to 2050 implies that the US ultimately recoverable oil resources will be 90 billion tons.

Figure 3 applies the Hubbert Linearization analysis to the world (excluding the US) oil production. The world (excluding the US) cumulative oil production up to 2016 was 156 billion tons. The linear trend from 2009 to 2015 indicates that the world (excluding the US) ultimately recoverable oil resources will be 356 billion tons. Regression R-square is 0.960. Year 2009 was the year of "Great Recession". Other things being equal, using a recession year as the initial year in Hubbert Linearization leads to a larger amount of estimated ultimately recoverable resources than using a regular year.

Figure 4 shows the historical and projected world (excluding the US) oil production from 1950 to 2050. The world (excluding the US) oil production is projected to peak in 2022, with a production level of 3,861 million tons.

Figure 5 shows the historical and projected world production of liquid fuels. The world production of liquid fuels is the sum of the US oil production, the world (excluding the US) oil production, and the biofuels production. Projection of world biofuels production from 2017 to 2040 is from EIA (2016, Table G3), extended to 2050 based on the linear trend from 2030 to 2040. The world production of liquid fuels is projected to peak in 2024, with a production level of 4,614 million tons.

By comparison, in “World Energy 2016-2050” (the last Annual Report), world production of liquid fuels was projected to peak in 2023, with a production level of 4,540 million tons.

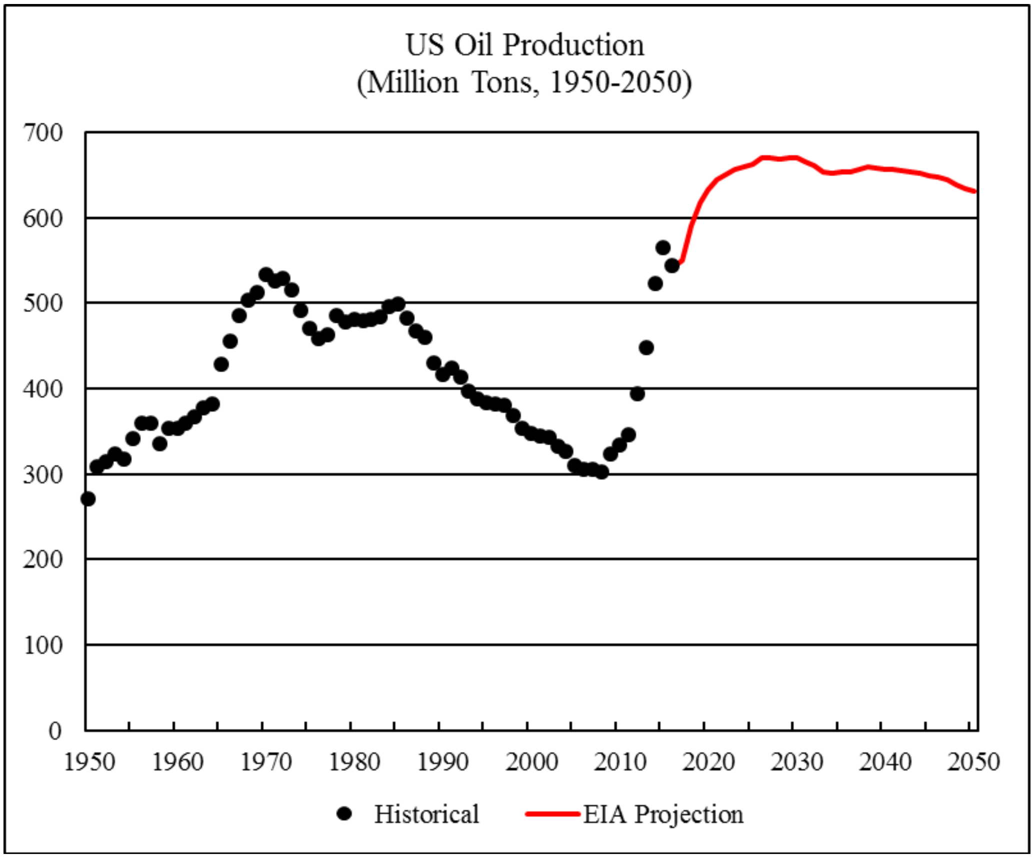

Figure 2
Sources: US historical oil production from 1950 to 1964 is from Rutledge (2008); US oil production from 1965 to 2016 is from BP (2017). Projected US oil production from 2017 to 2050 is from EIA (2017, Table A1).

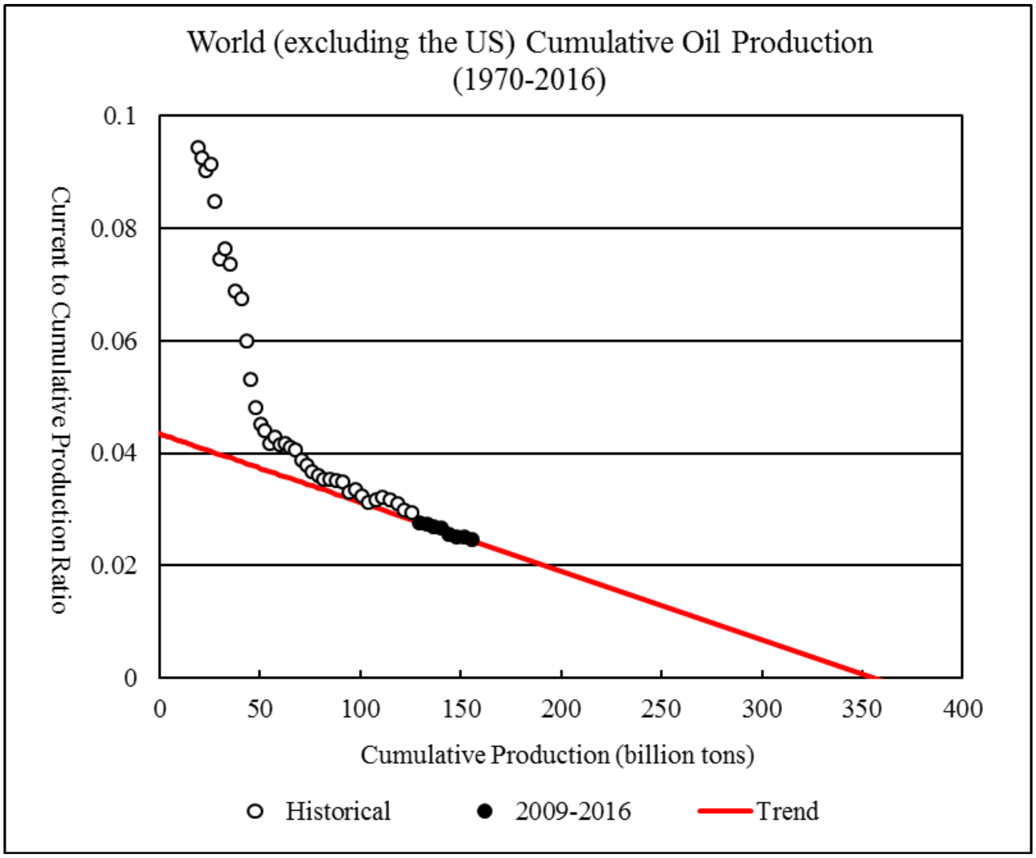

Figure 3
Sources: World historical cumulative oil production is from Rutledge (2008); world oil production from 1965 to 2016 is from BP (2017).

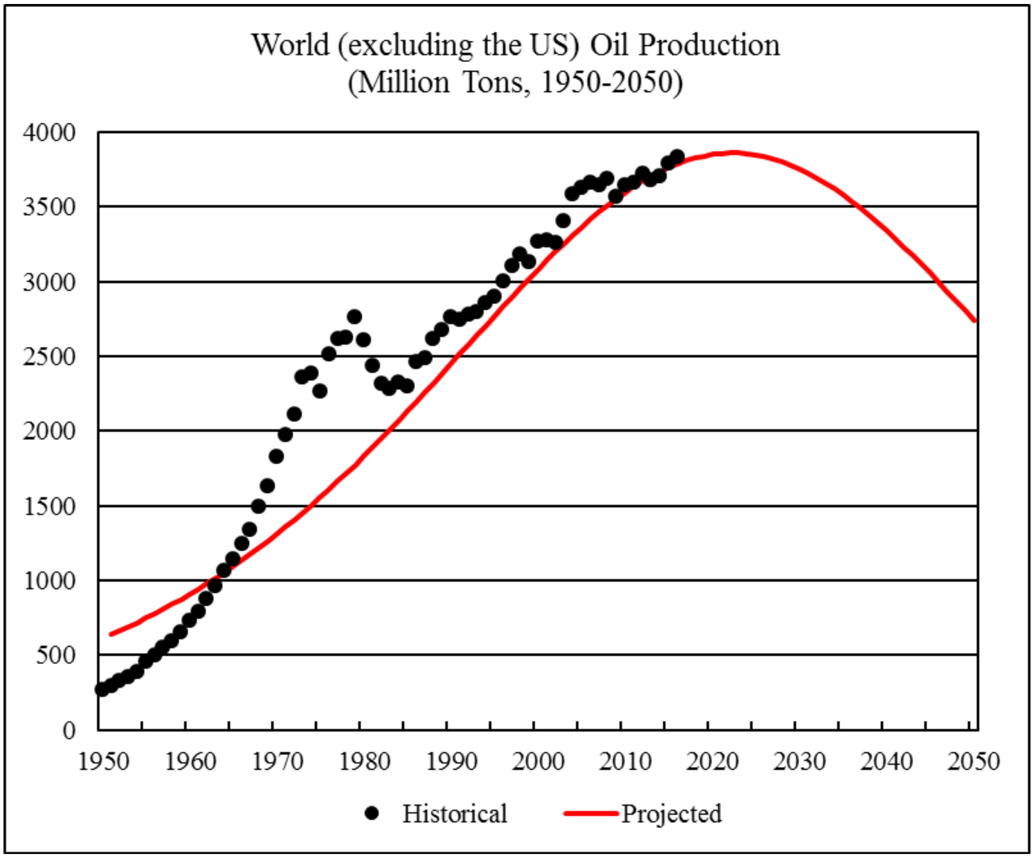

Figure 4
Sources: World historical oil production from 1950 to 1964 is from Rutledge (2008); world oil production from 1965 to 2016 is from BP (2017).

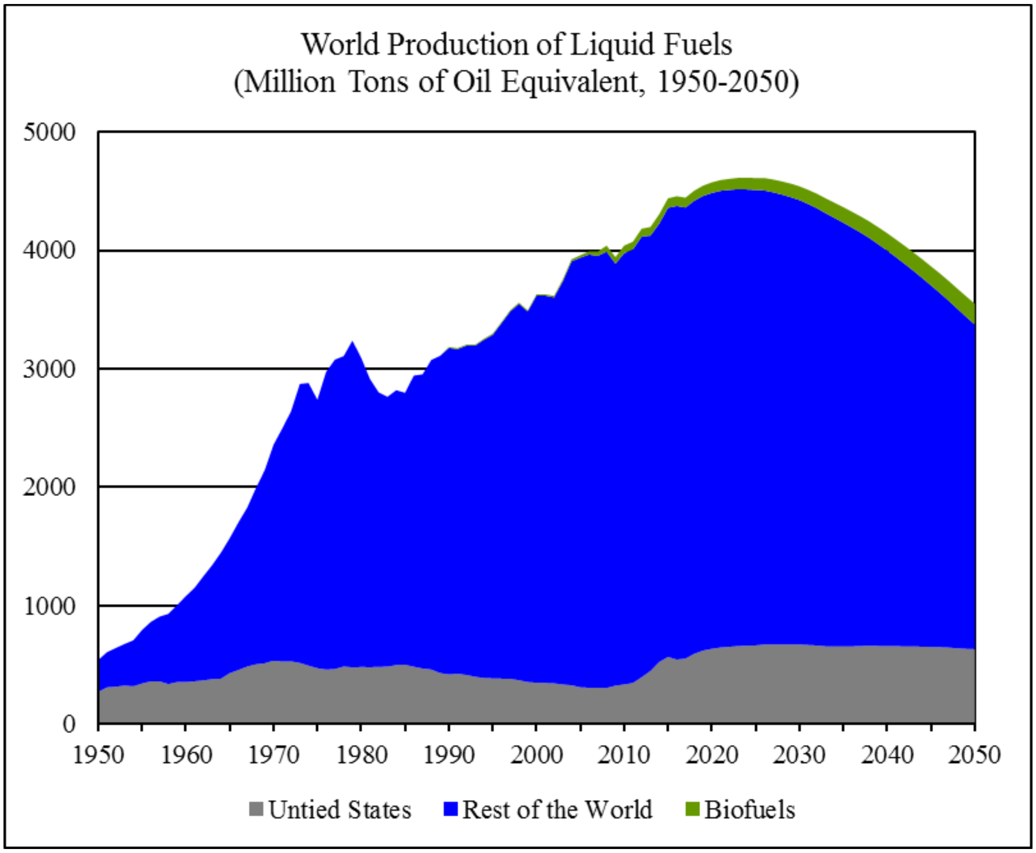

Figure 5
Sources: See Figure 2 and 4 for the US and the world (excluding the US) oil production. World biofuels production from 1990 to 2016 is from BP (2017). Projection of world biofuels production from 2016 to 2040 is from EIA (2016, Table G3), extended to 2050 based on the linear trend from 2030 to 2040.

Natural Gas

World natural gas production was 3,552 billion cubic meters (3,213 million tons of oil equivalent) in 2016, 0.6 percent higher than world natural gas production in 2015.

In 2016, the United States was the world's largest natural gas producer; the US produced 749 billion cubic meters of natural gas (691 million tons of oil equivalent), accounting for 21.1 percent of the world natural gas production.

The Russian Federation was the world's second largest natural gas producer; Russia produced 573 billion cubic meters of natural gas (522 million tons of oil equivalent), accounting for 16.3 percent of the world natural gas production.

Iran was the world's third largest natural gas producer; Iran produced 202 billion cubic meters of natural gas (182 million tons of oil equivalent), accounting for 5.7 percent of the world natural gas production.

Figure 6 shows the historical and projected US natural gas production from 1950 to 2050. The projection is based on the US Energy Information Administration's reference case scenario of the US natural gas production from 2017 to 2050 (EIA 2017, Table A1).

The US cumulative natural gas production up to 2016 was 32 billion tons of oil equivalent. EIA's current projection implies that the US cumulative natural gas production will be 64 billion tons of oil equivalent by 2050 and the US ultimately recoverable natural gas resources will be 153 billion tons of oil equivalent.

Figure 7 applies the Hubbert Linearization analysis to the world (excluding the US) natural gas production. The world (excluding the US) cumulative natural gas production up to 2016 was 74 billion tons of oil equivalent. The linear trend from 2009 to 2016 indicates that the world (excluding the US) ultimately recoverable natural gas resources will be 195 billion tons of oil equivalent. Regression R-square is 0.843.

Figure 8 shows the historical and projected world (excluding the US) natural gas production from 1960 to 2050. The world (excluding the US) natural gas production is projected to peak in 2027, with a production level of 2,706 million tons of oil equivalent.

Figure 9 shows the historical and projected world natural gas production. World natural gas production is projected to peak in 2029, with a production level of 3,596 million tons of oil equivalent.

By comparison, in “World Energy 2016-2050” (the last Annual Report), world natural gas production was projected to peak in 2030, with a production level of 3,694 million tons of oil equivalent.

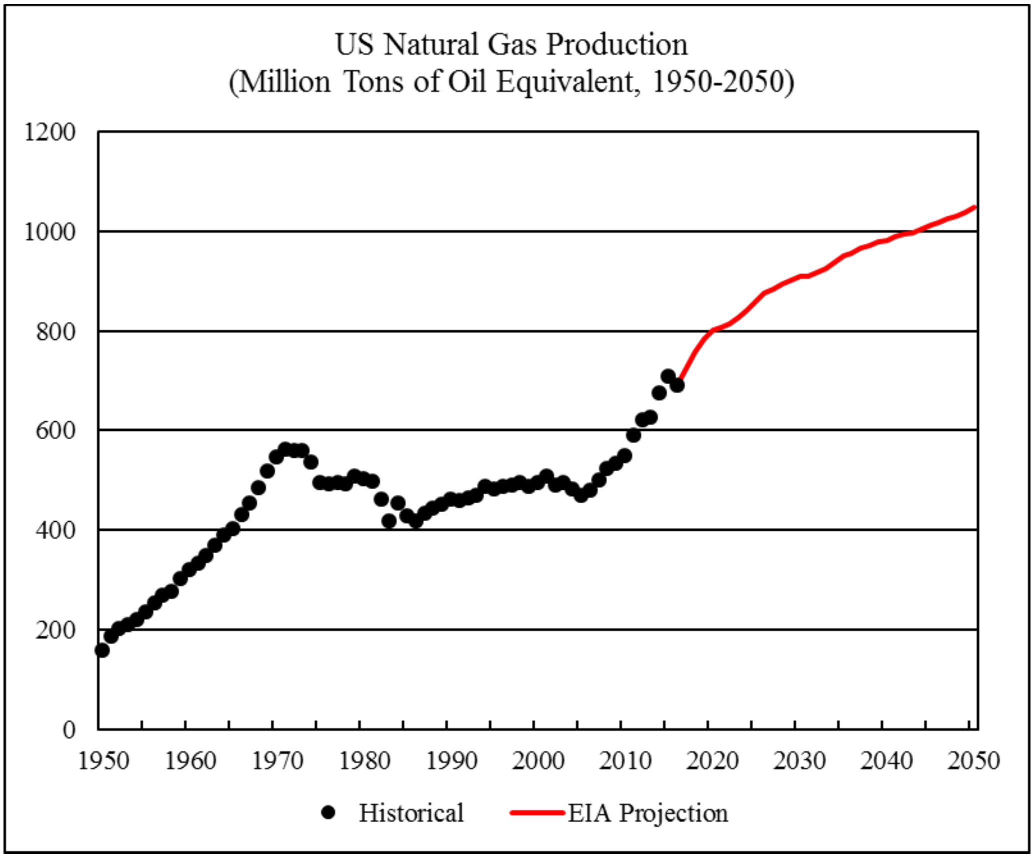

Figure 6
Sources: US historical natural gas production from 1950 to 1969 is from the US Energy Information Administration, Natural Gas Data, Natural Gas Gross Withdrawals and Production, "U.S. Natural Gas Marketed Production"; US natural gas production from 1970 to 2016 is from BP (2017). Projected US natural gas production from 2017 to 2050 is from EIA (2017, Table A1).

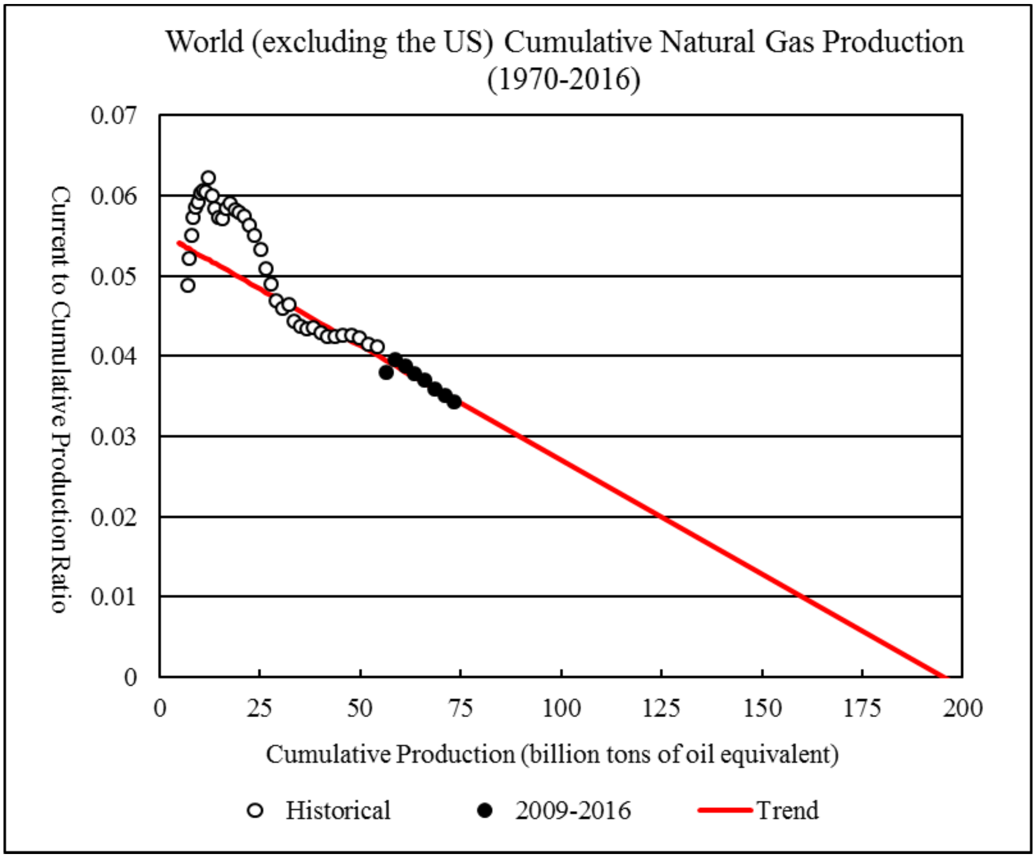

Figure 7
Sources: World historical cumulative natural gas production is from Rutledge (2008); world natural gas production from 1970 to 2016 is from BP (2017).

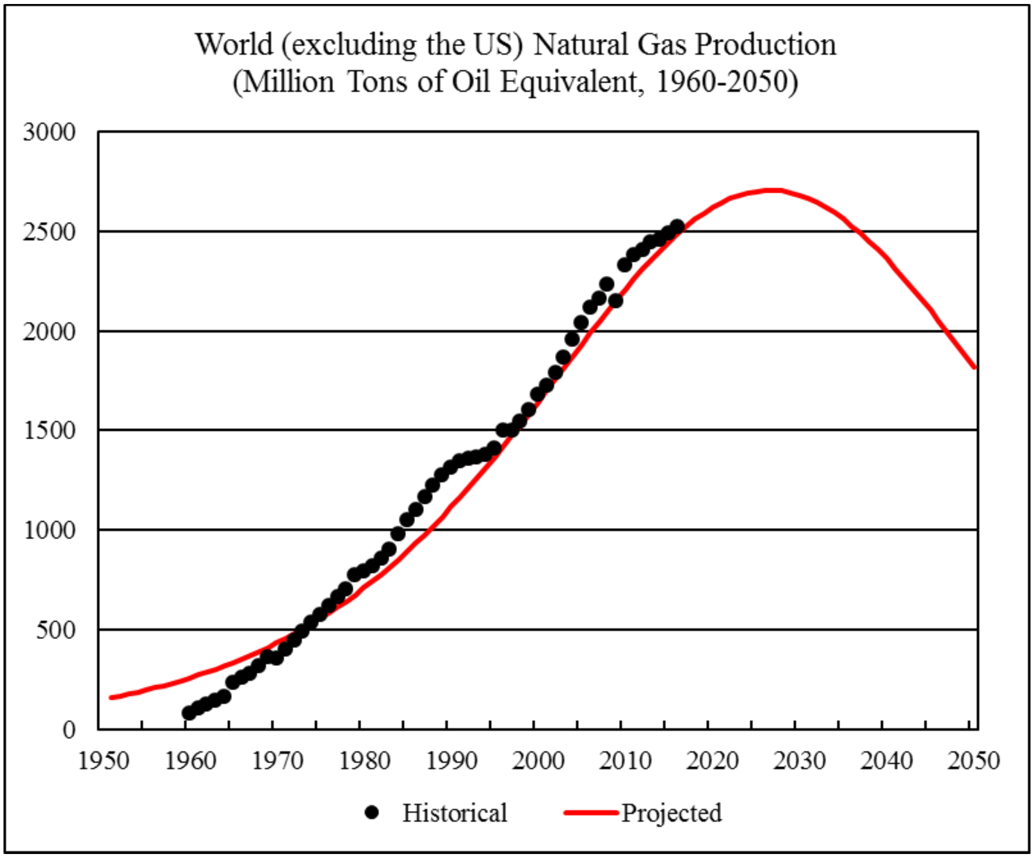

Figure 8
Sources: World historical natural gas production from 1960 to 1969 is from Rutledge (2008); world natural gas production from 1970 to 2016 is from BP (2017).

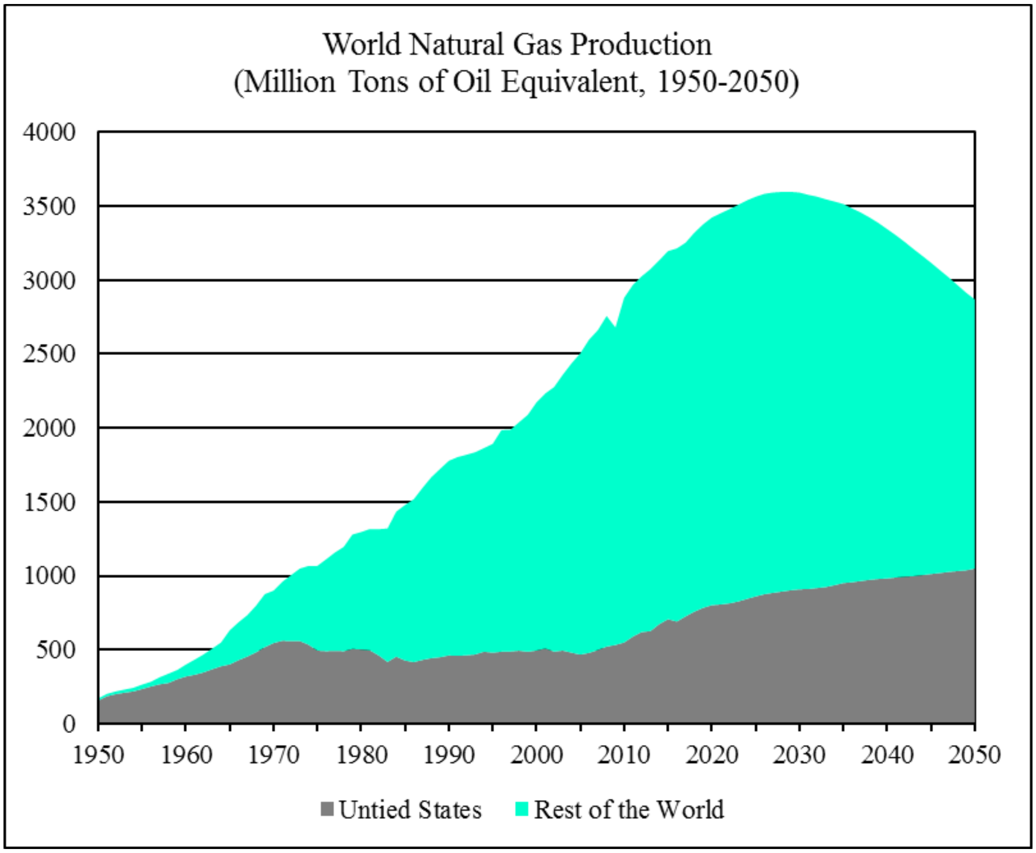

Figure 9
Sources: See Figure 6 and 8 for the US and the world (excluding the US) natural gas production. World historical natural gas production from 1950 to 1959 is estimated using carbon dioxide emissions from natural gas consumption (Boden, Marland, and Andres 2017).

Coal

World coal production was 7,460 million tons (3,656 million tons of oil equivalent) in 2016, 6.3 percent lower than world coal production in 2015.

In 2016, China was the world's largest coal producer; China produced 3,411 million tons of coal (1,686 million tons of oil equivalent), accounting for 45.7 percent of the world coal production.

India was the world's second largest coal producer by volume (but the fourth largest coal producer by energy content); India produced 692 million tons of coal (289 million tons of oil equivalent), accounting for 9.3 percent of the world coal production.

The United States was the world's second largest coal producer by energy content and the third largest coal producer by volume; the US produced 661 million tons of coal (365 million tons of oil equivalent), accounting for 8.9 percent of the world coal production.

Figure 10 shows China's historical and projected coal production from 1950 to 2050. China's cumulative coal production up to 2016 was 79 billion tons. According to BP *Statistical Review of World Energy*, China's coal reserves were 244 billion tons by the end of 2016. China's implied ultimately recoverable coal resources are 323 billion tons. China's coal production is projected to peak in 2036, with a production level of 4,699 million tons.

Figure 11 shows India's historical and projected coal production from 1950 to 2050. India's cumulative coal production up to 2016 was 16 billion tons. According to BP *Statistical Review of World Energy*, India's coal reserves were 95 billion tons by the end of 2016. India's implied ultimately recoverable coal resources are 111 billion tons. India's coal production is projected to peak in 2051, with a production level of 1,396 million tons.

Figure 12 shows the historical and projected US coal production from 1950 to 2050. The projection is based on the US Energy Information Administration's reference case scenario of the US coal production from 2017 to 2050 (EIA 2017, Table A1).

The US cumulative coal production up to 2016 was 76 billion tons. EIA's current projection implies that the US cumulative coal production will be 96 billion tons by 2050 and the

US ultimately recoverable coal resources will be 138 billion tons. The US coal production peaked in 2008, with a production level of 1,063 million tons.

Figure 13 applies the Hubbert Linearization analysis to the rest of the world's (world excluding China, India, and the US) coal production. Despite wide fluctuations of the current production to cumulative production ratio over the past century, a long-term downward trend can be identified. The rest of the world's cumulative coal production up to 2016 was 197 billion tons. The linear trend from 1915 to 2016 indicates that the rest of the world's ultimately recoverable coal resources will be 382 billion tons. Regression R-square is 0.699.

Figure 14 shows the rest of the world's historical and projected coal production from 1950 to 2050. In 2013, the rest of the world's coal production reached 2,798 million tons, which has been the highest level on record.

Figure 15 shows the historical and projected world coal production. World coal production is projected to peak in 2036, with a production level of 8,844 million tons.

By comparison, in "World Energy 2016-2050" (the last Annual Report), world coal production was projected to peak in 2039, with a production level of 8,695 million tons.

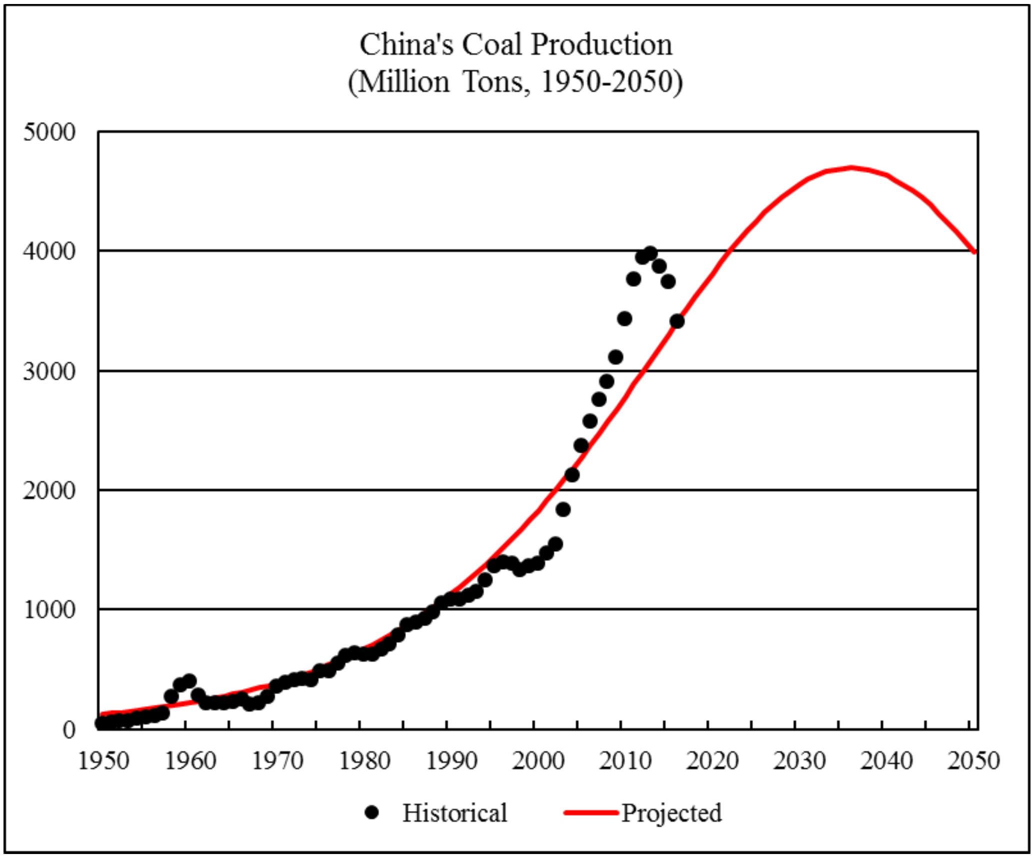

Figure 10
Sources: China's historical coal production from 1950 to 1980 is from Rutledge (2011); China's coal production from 1981 to 2016 is from BP (2017). China's projected coal production from 2017 to 2050 is calculated by this author using the assumption that China's ultimately recoverable coal resources equal the sum of historical cumulative production and the coal reserves reported by BP (2017).

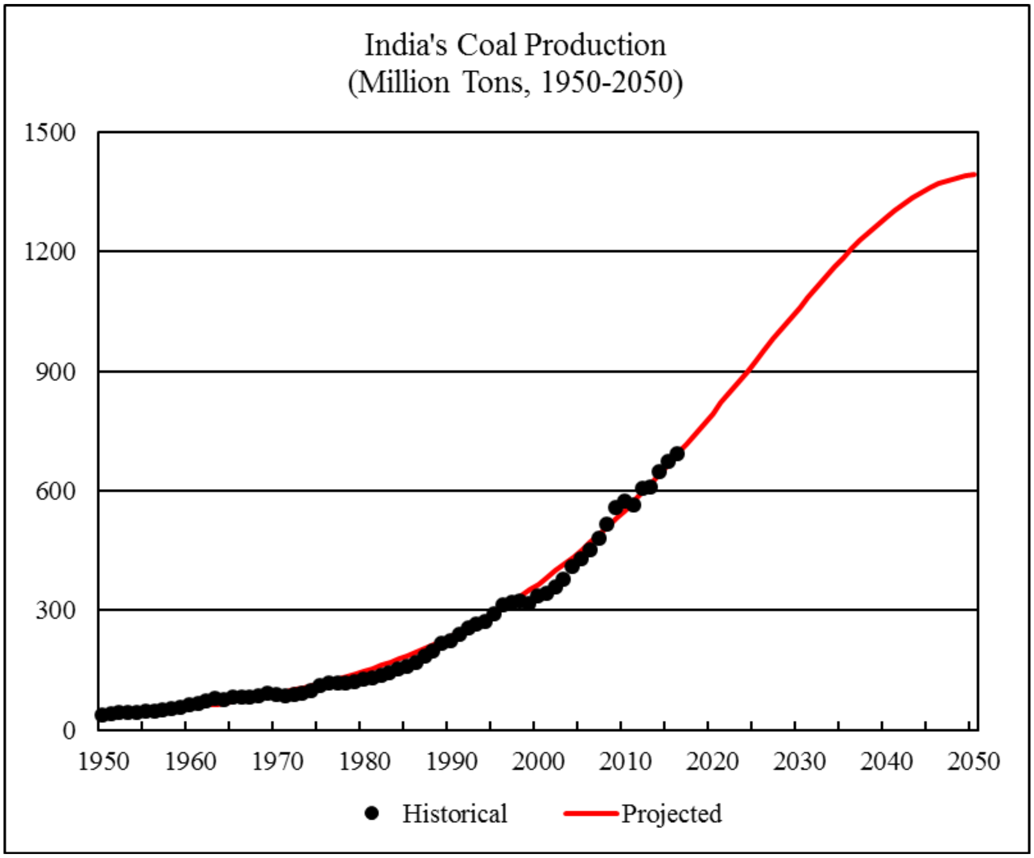

Figure 11
Sources: South Asia’s historical coal production (used as a proxy for India’s coal production) from 1950 to 1980 is from Rutledge (2011); India’s coal production from 1981 to 2016 is from BP (2017). India’s projected coal production from 2017 to 2050 is calculated by this author using the assumption that India’s ultimately recoverable coal resources equal the sum of historical cumulative production and the coal reserves reported by BP (2017).

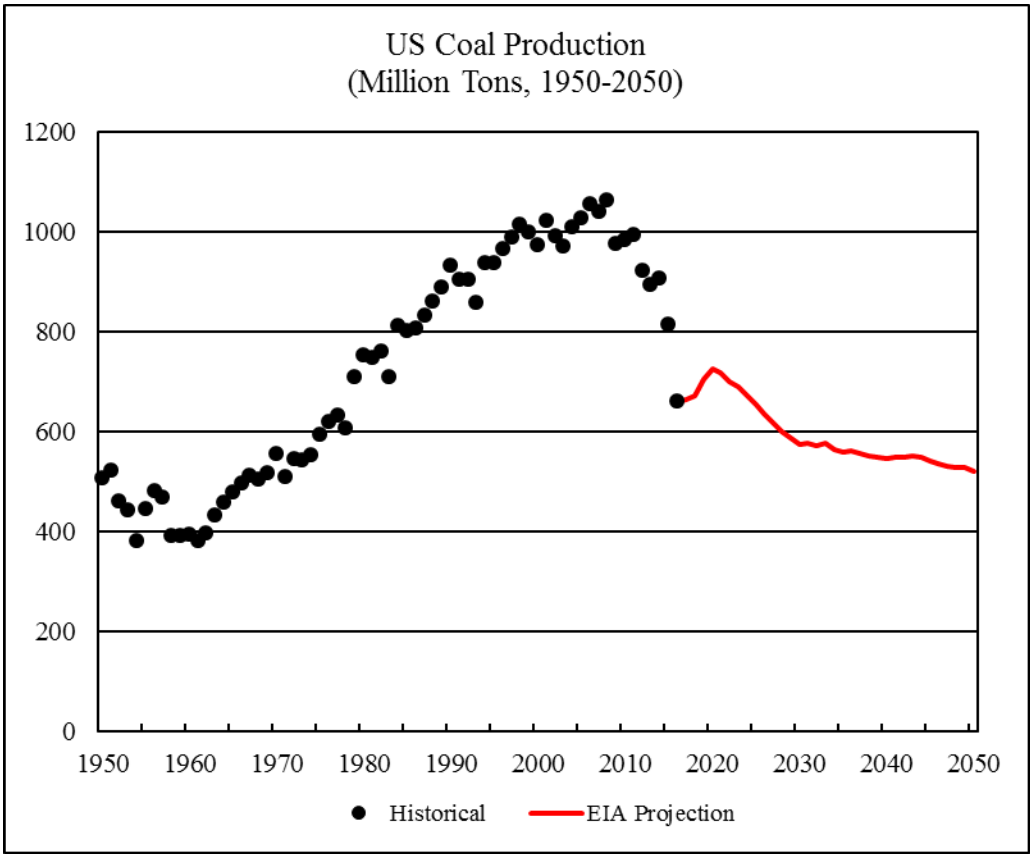

Figure 12
Sources: US historical coal production from 1950 to 1980 is from Rutledge (2011); US coal production from 1981 to 2016 is from BP (2017). Projected US coal production from 2017 to 2050 is from EIA (2017, Table A1).

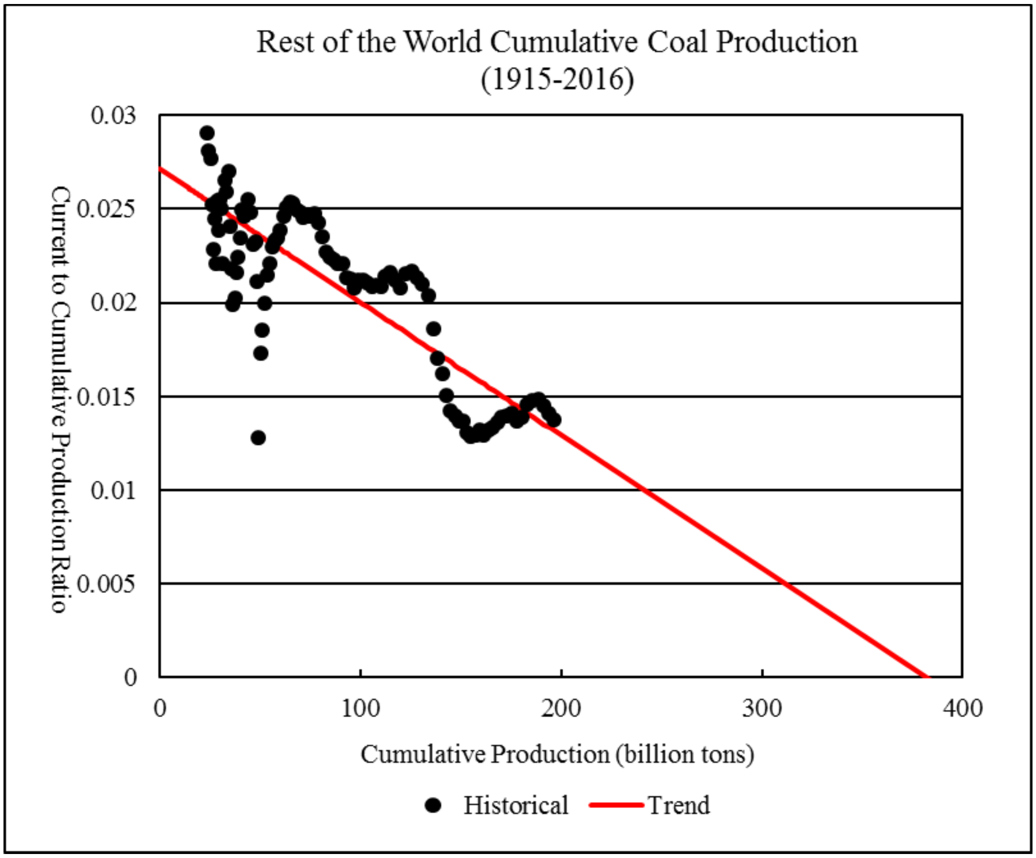

Figure 13

Sources: The rest of the world's coal production is the world coal production less the sum of China's, India, and the US coal production. World historical cumulative coal production is from Rutledge (2011); world coal production from 1981 to 2016 is from BP (2017).

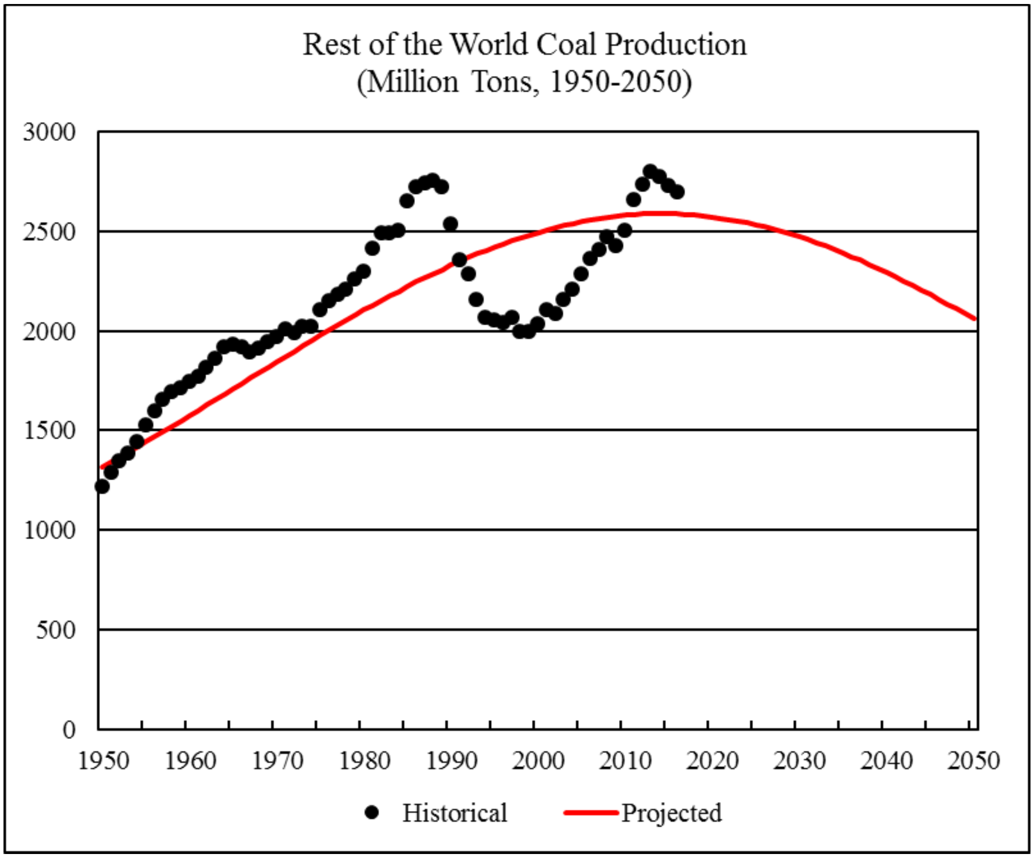

Figure 14
Sources: The rest of the world's coal production is the world coal production less the sum of China's, India, and the US coal production. World historical coal production from 1950 to 1980 is from Rutledge (2011); world coal production from 1981 to 2016 is from BP (2017).

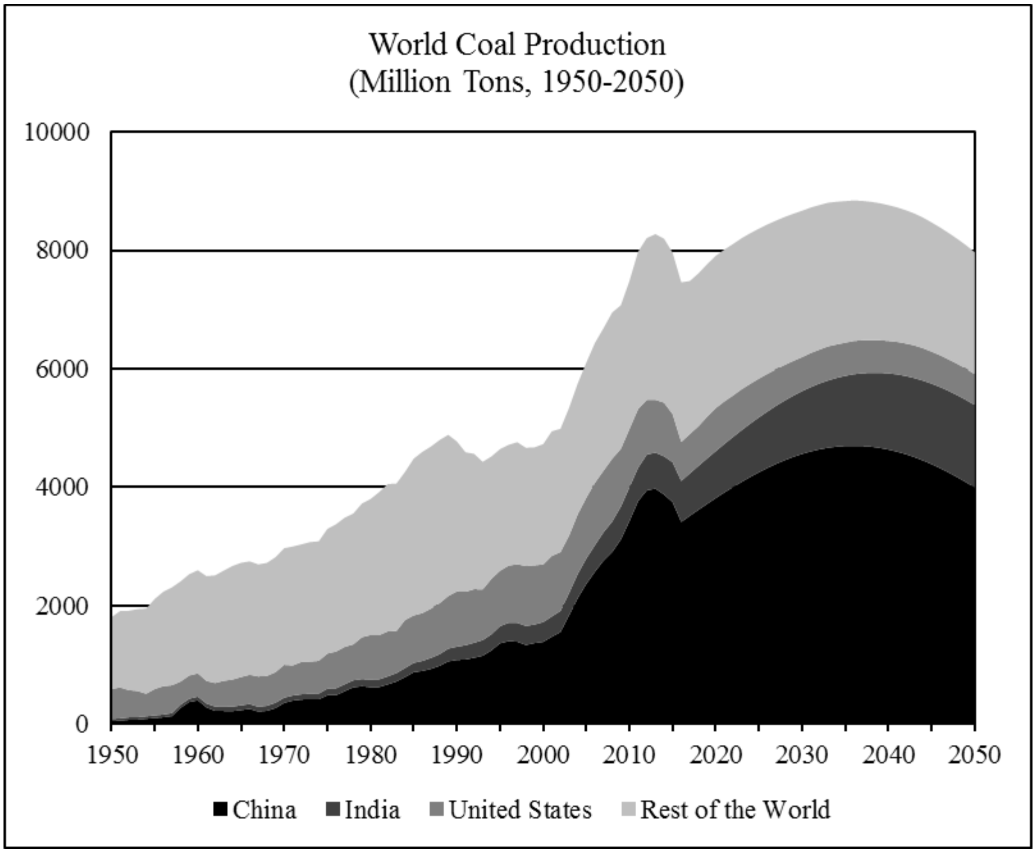

Figure 15
Sources: See Figure 10, 11, 12, and 14 for China's, India, the US's, and the rest of the world's coal production.

Wind and Solar Electricity

World consumption of wind and solar electricity was 1,293 terawatt-hours in 2016 (292 million tons of oil equivalent), 19.2 percent higher than world consumption of wind and solar electricity in 2015.

Wind and solar are renewable energy resources. However, wind and solar electricity is intermittent. Incorporation of wind and solar electricity into electric grids requires maintaining a large backup generating capacity and poses challenges to grid reliability. Curtailing of excess wind and solar electricity when surges of wind and solar generation exceed demand may impose limits on how much wind and solar electricity can be absorbed by a given system of electric grids. In the long run, wind electricity and solar electricity are also limited by the availability of land and mineral resources (Castro et al. 2011 and 2013).

In 2016, the world installed 50 gigawatts of wind generating capacity and 75 gigawatts of solar generating capacity. Figure 16 compares the historical relationship between the annual installation of wind and solar generating capacity and the annual growth to the annual installation ratio (that is, the ratio of the growth of the annual installation to the annual installation) from 1999 to 2016. The downward linear trend indicates that the annual installation of wind and solar generating capacity should eventually approach the maximum of 282 gigawatts (where the linear trend meets the zero horizontal line).

However, the annual growth to the annual installation ratios have fluctuated widely and the R-square for the linear trend is very low (0.071). Wind and solar electricity is still in the early phase of their development. In the future, as data accumulate, one can hope that a more clear and reliable pattern may emerge that can help to illustrate the potential limits to wind and solar development.

The parameters of the linear trend shown in Figure 16 can be used to project the future installation of wind and solar generating capacity. The world's cumulative installation of wind and solar generating capacity is projected to rise to about 9,400 gigawatts by 2050 (Figure 17). By comparison, in "World Energy 2016-2050" (the last Annual Report), the world's cumulative installation of wind and solar generating capacity was projected to rise to about 6,600 gigawatts by 2050.

The future wind and solar electricity generation can be estimated using the following formula:

Electricity Generation (current year)

= (Beginning-of-year Generating Capacity + End-of-year Generating Capacity) / 2 * 8760 Hours * Capacity Utilization Rate

In 2016, the observed world average wind electric power capacity utilization rate was 24.7 percent; the observed world average solar electric power capacity utilization rate was 14.4 percent; the observed world average wind and solar electric power capacity utilization rate was 20.8 percent. From 2005 to 2016, the world average wind and solar electric power capacity utilization rate averaged 21.6 percent. These capacity utilization rates are calculated using wind and solar electricity consumption and generating capacity data provided by BP (2017).

I assume that from 2017 to 2050, the world average wind and solar electric power capacity utilization rate will be 22 percent.

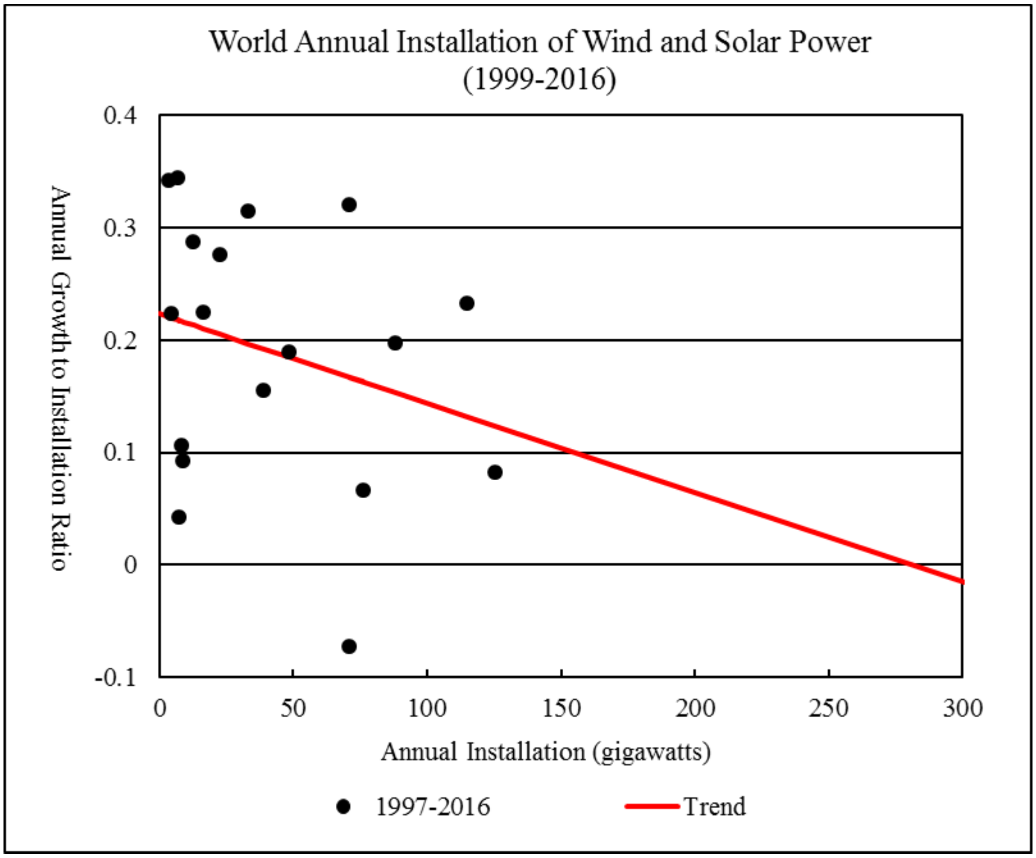

Figure 16
Sources: Annual installation of wind and solar generating capacity from 1998 to 2016 is from BP (2017).

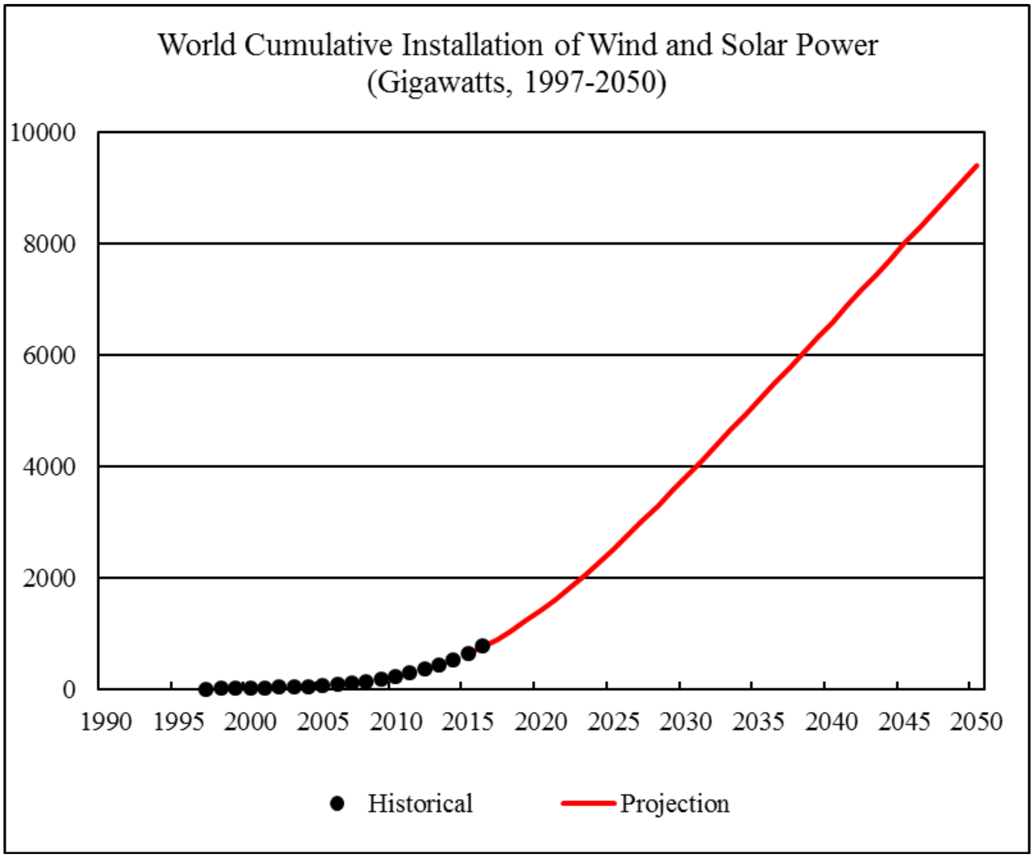

Figure 17
Sources: Cumulative installation of wind and solar generating capacity from 1997 to 2016 is from BP (2017).

Nuclear, Hydro, Geothermal, Biomass, and Other Renewable Electricity

World consumption of nuclear electricity was 2,617 terawatt-hours in 2016, 1.6 percent higher than world nuclear electricity consumption in 2015.

To project the future nuclear electricity consumption, I use the US Energy Information Administration's projection of net nuclear electricity generation from 2017 to 2040 (EIA 2016, Table H16), extended to 2050 based on the linear trend from 2031 to 2040. I adjusted the EIA's projection downwards to match the projected net nuclear electricity generation in 2016 with the nuclear electricity consumption in 2016 reported by BP (2016).

World consumption of hydro electricity was 4,023 terawatt-hours in 2016, 3.1 percent higher than world hydro electricity consumption in 2015.

To project the future hydro electricity consumption, I use the US Energy Information Administration's projection of net hydro electricity generation from 2017 to 2040 (EIA 2016, Table H18), extended to 2050 based on the linear trend from 2031 to 2040. I adjusted the EIA's projection upwards to match the projected net hydro electricity generation in 2016 with the hydro electricity consumption in 2016 reported by BP (2016).

World consumption of geothermal, biomass, and other renewable electricity was 561.7 terawatt-hours in 2016, 4.7 percent higher than world consumption of geothermal, biomass, and other renewable electricity in 2015.

To project the future consumption of geothermal, biomass, and other renewable electricity, I use the US Energy Information Administration's projection of net geothermal electricity generation and net other renewable electricity generation from 2017 to 2040 (EIA 2016, Table H20 and H22), extended to 2050 based on the linear trend from 2031 to 2040. I adjusted the EIA's projection downwards to match the projected net generation of geothermal, biomass, and other renewable electricity in 2016 with the consumption of geothermal, biomass, and other renewable electricity in 2016 reported by BP (2016).

World Energy 2017-2050

Figure 18 shows the historical and projected world primary energy consumption from 1950 to 2050.

World historical consumption of oil, natural gas, and coal from 1950 to 1964 is estimated from carbon dioxide emissions from fossil fuels burning (Boden, Marland, and Andres 2017).

World primary energy consumption and its composition from 1965 to 2016 is from BP (2017).

World consumption of oil, natural gas, and coal from 2017 to 2050 is assumed to be the same as production. Oil consumption includes biofuels production. Coal production in tons is converted to coal production in tons of oil equivalent using the formula: 2.04 tons of coal = 1 ton of oil equivalent (based on the observed world average ratio in 2016).

World consumption of wind, solar, nuclear, hydro, geothermal, biomass, and other renewable electricity from 2017 to 2050 is converted to their thermal equivalent based on the formula: 4.4194 terawatt-hours = 1 million tons of oil equivalent.

World primary energy consumption is projected to rise to 17,347 million tons of oil equivalent by 2050, effectively reaching a plateau by the late 2040s.

For 2017-2050, global economic growth rate is estimated by using the linear relationship between the primary energy consumption growth rate and the economic growth rate observed for the period 2005-2016:

Economic Growth Rate = (Primary Energy Consumption Growth Rate + 0.0157) / 0.959

Figure 19 shows the historical and projected world economic growth rates from 1991 to 2050. World average economic growth rate is projected to fall from 3.8 percent in 2001-2010 and 3.5 percent in 2011-2020, to 3.0 percent in 2021-2030, 2.2 percent in 2031-2040, and 1.7 percent in 2041-2050.

Since the end of the Second World War, global economic growth rate has fallen below 2 percent only in several occasions. During 1913-1950, when the global capitalist system suffered from major wars, revolutions, and the Great Depression, world economy actually grew at an average annual rate of 1.8 percent (Maddison 2010). Thus, by the mid-21st century, although the global economy will continue to grow, world economic growth rate may become too low for the global capitalist system to maintain basic economic and social stability.

Nevertheless, gross world product (in constant 2011 international dollars) is projected to rise to 257 trillion dollars by 2050. By comparison, in “World Energy 2016-2050” (the last Annual Report), gross world product was projected to rise to 207 trillion dollars by 2050.

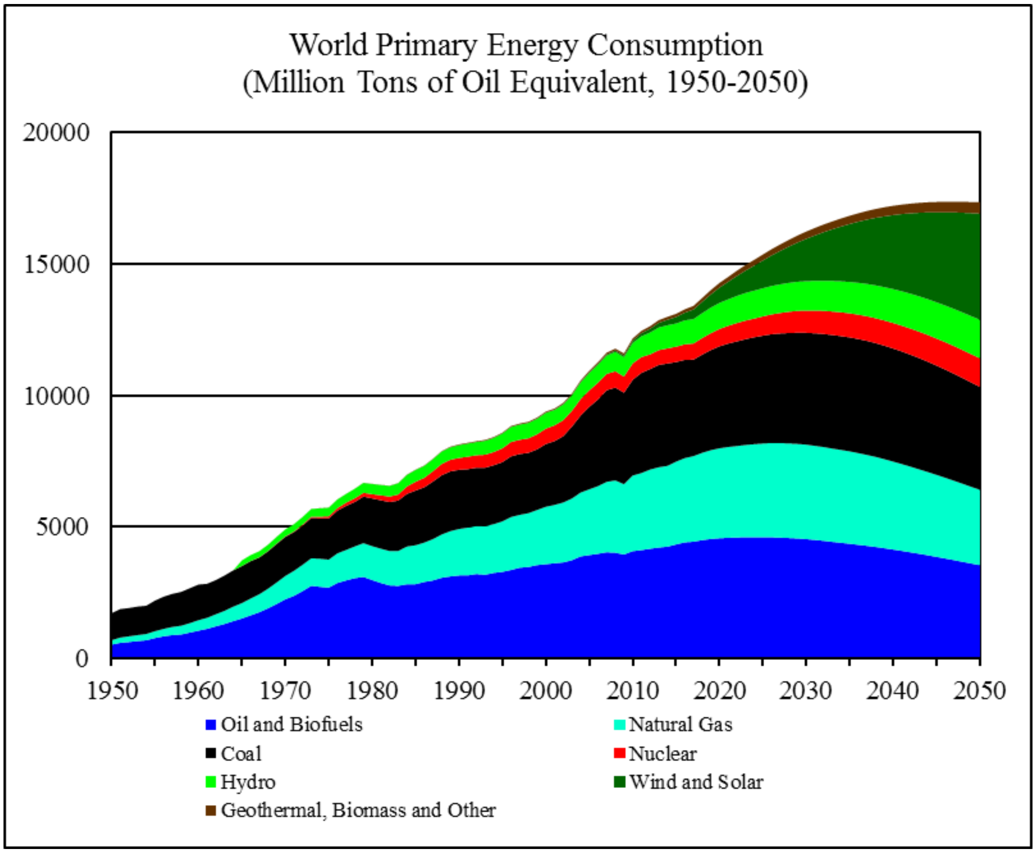

Figure 18
Sources: World historical oil, natural gas, and coal consumption from 1950 to 1964 is estimated from carbon dioxide emissions (Boden, Marland, and Andres 2017); world primary energy consumption and its composition from 1965 to 2016 is from BP (2017); world primary energy consumption and its composition from 2017 to 2050 is based on this report's projections.

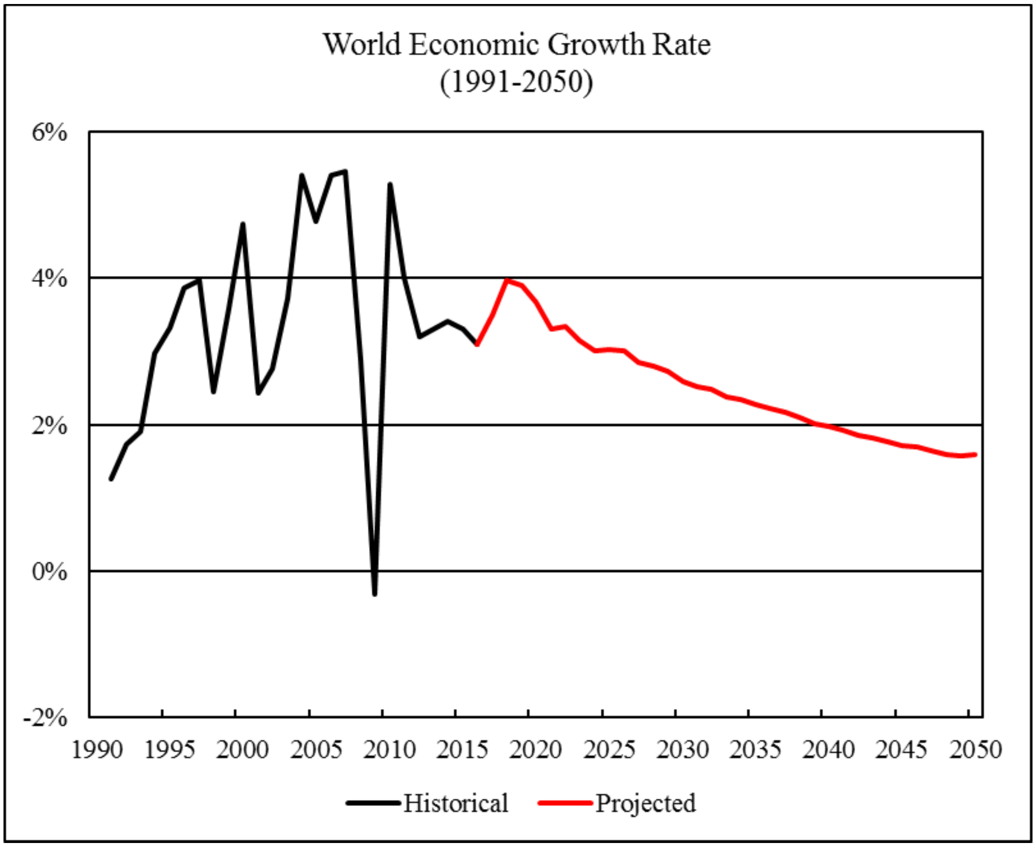

Figure 17
Sources: World economic growth rates from 1991 to 2015 are from World Bank (2017); world economic growth rates in 2016 and 2017 are from IMF (2017, Statistical Appendix, Table A1); world economic growth rates from 2018 to 2050 are based on this report's projections.

Carbon Dioxide Emissions and Climate Change, 2017-2100

Figure 20 shows the world carbon dioxide emissions from fossil fuels burning from 1950 to 2100.

Historical carbon dioxide emissions from the burning of solid, liquid, and gaseous fuels from 1751 to 2014 are from Boden, Marland and Andres (2017). For 2015-2100, I estimate the carbon dioxide emissions from oil, natural gas, and coal consumption by assuming that each ton of oil consumption (excluding biofuels) emits 2.881 tons of carbon dioxide, each ton of oil equivalent of natural gas consumption emits 2.175 tons of carbon dioxide, and each ton of oil equivalent of coal consumption emits 3.882 tons of carbon dioxide. These conversion factors are based on the observed relationship between carbon dioxide emissions and fuel consumption in 2014.

World carbon dioxide emissions are projected to peak in 2030 at 37.1 billion tons. By comparison, in "World Energy 2016-2050" (the last Annual Report), world carbon dioxide emissions were projected to peak in 2029 at 36.0 billion tons.

Cumulative world carbon dioxide emissions from fossil fuels burning from 1751 to 2100 will be 3,584 billion tons. These are emissions from direct fossil fuels combustion only and do not include emissions from cement production and gas flaring.

According to Intergovernmental Panel on Climate Change's Fifth Assessment Report, cumulative carbon dioxide emissions will largely determine the global mean surface warming by the late 21st century and beyond (IPCC 2013: 27-29). Figure 21 shows the historical relationship between the cumulative carbon dioxide emission from fossil fuels burning (not including emissions from cement production and gas flaring) and the global surface temperature anomaly. Global surface temperature anomaly is measured as the difference between the global average surface temperature and the average global surface temperature in 1880-1920. The latter is used as a proxy for the pre-industrial global temperature (Hansen and Sato 2016). Global surface temperature anomalies are shown in ten-year trailing averages to smooth out short-term effects from El Nino and solar irradiance cycles. The linear relationship between historical cumulative carbon dioxide emissions and the ten-year average global surface temperature anomalies indicate that for an increase of cumulative carbon dioxide emissions by one trillion tons, global surface temperature will rise by 0.68 degrees Celsius.

Figure 22 shows the historical and projected global surface temperature anomaly from 1889 to 2100. Global surface temperature anomalies are shown in ten-year trailing averages to smooth out short-term fluctuations. For the period 2007-2016, the average global surface temperature was 0.97 degrees Celsius higher than the 1880-1920 average; in 2016, the global average surface temperature was 1.25 degrees Celsius higher than the 1880-1920 average. The future temperature projections are based on the future carbon dioxide emissions projected by this report and the linear relationship between cumulative carbon dioxide emissions and the global surface temperature shown in Figure 21. Under the current trend, the global surface temperature is projected to rise to 2.43 degrees Celsius above the 1880-1920 average.

According to Hansen et al. (2016), global warming by more than two degrees may lead to the melting of West Antarctica ice sheets, causing sea level to rise by 5-9 meters over the next 50-200 years. Bangladesh, European lowlands, the US eastern coast, North China plains, and many coastal cities will be submerged. This will lead to the end of civilization as we know it.

Table 1 summarizes the results of this Annual Report.

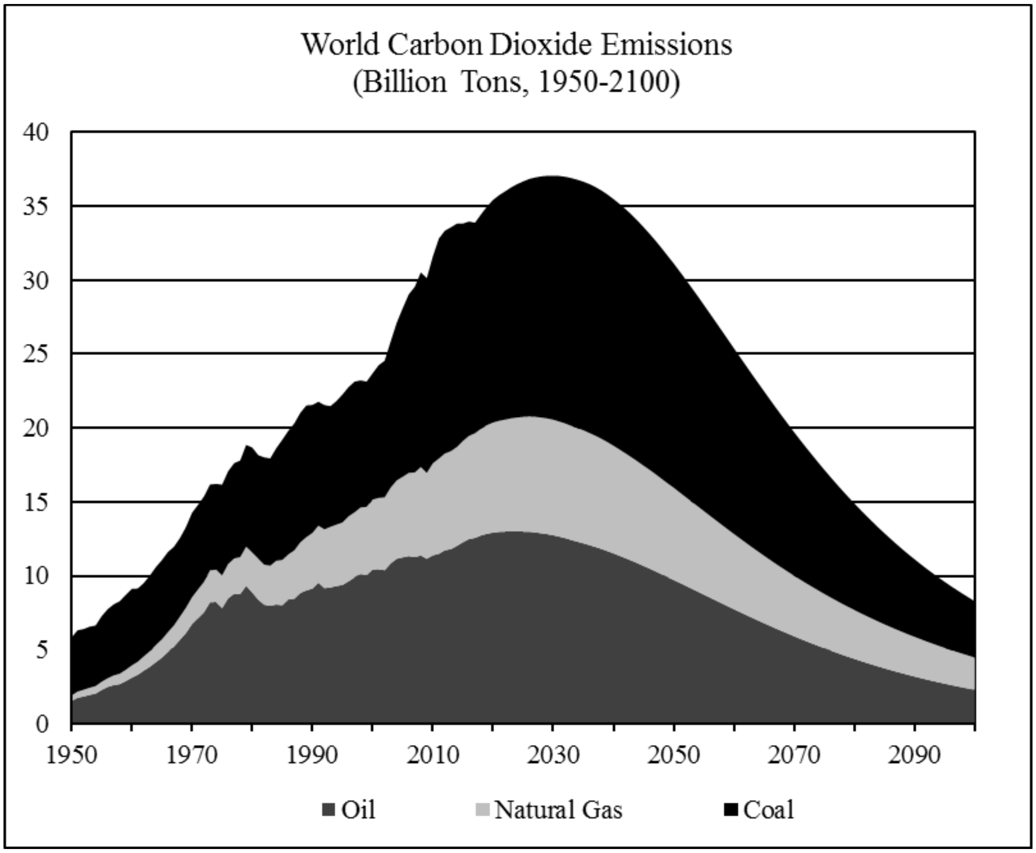

Figure 20
Sources: World carbon dioxide emissions from fossil fuels burning for 1950-2014 are from Boden, Marland, and Andres (2017); world carbon dioxide emissions from 2015 to 2100 are estimated using oil, natural gas, and coal consumption projected by this report.

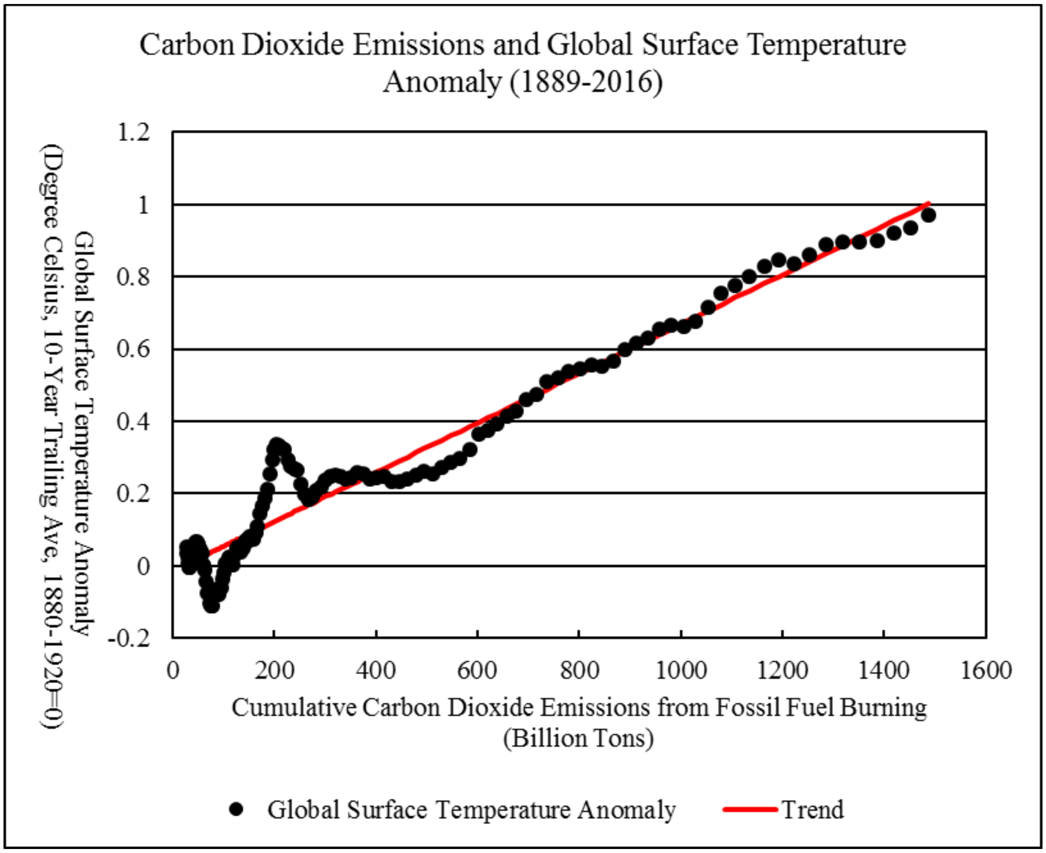

Figure 21
Sources: Historical carbon dioxide emissions from 1751 to 2014 are from Boden, Marland, and Andres (2017), extended to 2016 using fossil fuels consumption data from BP (2017). Global surface temperature anomaly from 1880 to 2016 is from NASA (2017).

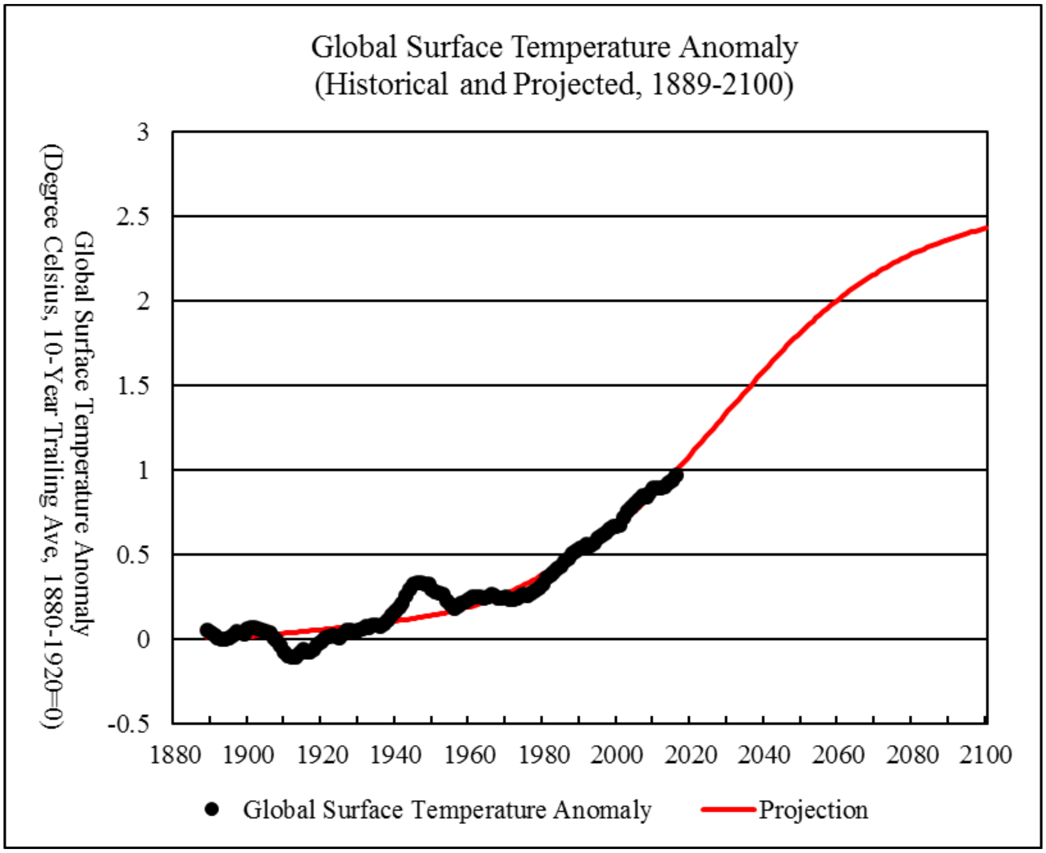

Figure 22
Sources: Global surface temperature anomaly from 1880 to 2016 is from NASA (2017). Future temperature projection is based on the projected future carbon dioxide emissions (see Figure 20) and the historical relationship between cumulative carbon dioxide emissions and global surface temperature (see Figure 21).

Table 1 World Energy, Economy, and Climate Change: 2000-2050 (2017 Scenario)

	2000	2010	2020	2030	2040	2050
World Energy Consumption (Mtoe):						
Oil and Biofuels	3,590	4,085	4,574	4,542	4,145	3,550
Natural Gas	2,182	2,874	3,422	3,591	3,344	2,869
Coal	2,385	3,636	3,876	4,249	4,296	3,906
Nuclear	584	626	657	850	969	1,089
Hydro	601	779	994	1,115	1,290	1,465
Wind and Solar	7	85	581	1,611	2,814	4,039
Geothermal, Biomass and Other	42	85	176	275	353	430
Total	9,390	12,170	14,281	16,234	17,211	17,347
Gross World Product (trillion $)	63.1	91.3	129.3	173.5	216.7	256.9
Carbon Dioxide Emissions (Gt)	23.7	31.6	35.4	37.1	35.5	31.1
Global Temperature Anomaly (ºC)	0.67	0.86	1.10	1.35	1.59	1.82

Mtoe: million metric tons of oil-equivalent.
$: constant 2011 international dollars.
Gt: giga-tons or billion metric tons.
Global Temperature Anomaly: ten-year trailing average of the difference between the global average surface temperature and the 1880-1920 global average surface temperature.

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