Empirical Study on China's Energy Development under the Target of Carbon Emissions

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Abstract. Carbon dioxide is the inevitable product of the use of fossil fuels and is the main cause of global warming. In 2018, global carbon dioxide emissions reached 33.89 billion tons. Under the Kyoto protocol, countries are taking measures to reduce carbon emissions. China has pledged to peak its carbon emissions by 2030 and will work hard to reach the peak as soon as possible. This paper studies the development trend of fossil energy and the development space of renewable energy in China under the constraint of carbon emission by using mathematical models from an empirical perspective, and briefly analyzes its feasibility, and obtained preliminary conclusions. By 2030, total energy consumption will increase by 34 percent, fossil energy by 17 percent and non-fossil energy by 116 percent, accounting for about 24.4 percent of total energy consumption. This paper will forecast the total energy consumption from 2019 to 2030 according to the calculation model.

1. Introduction
In 2018, China's primary energy consumption totaled 4.64 billion tons of standard coal, which consumed 23.6% of the total global energy. Non-fossil energy accounts for 14.7%; from a per capita perspective, China is 96.9 GJ in 2018, which is 1.28 times the world average, but only 32.9% of the US. In 2018, China's carbon emissions reached 9.429 billion tons, accounting for 27.8% of the world. Within fossil energy, in terms of carbon emissions, the positive contribution of controlling coal emission reduction is basically offset by rising oil. In the past five years, China’s total coal consumption control has achieved results, with zero total carbon dioxide emissions growth, while carbon dioxide emissions increased by 2% and 3% in 2017 and 2018, mainly because the increase in oil consumption offset the decline caused by coal. In the past five years, the carbon emissions from coal have fallen from 80% to 75%, compared with a 3% increase in oil contribution. Most of the oil consumption emissions come from fuel vehicles. In 2018, carbon dioxide emissions from fuel vehicles accounted for 63% of oil consumption emissions, 6 percentage points higher than in 2015. Therefore, while the emission reduction targets are concentrated in coal in the industry, it is also necessary to pay attention to oil and natural gas.

2. Energy development measuring model and method

2.1. Measuring method

2.1.1. Total energy consumption. According to the macroscopic population and GDP forecast energy consumption intensity coefficient, the proportion factor of energy demand growth is determined, and
the total amount of primary energy consumption is calculated. For simple calculation, the total energy consumption is determined according to a certain proportion of GDP growth.

\[
A_i = a_i A_i; \quad a_i = \alpha / r; \quad r = \frac{1}{n} \sum_{i=1}^{n} r_i
\]  

(1)

\(A_i\) is the total energy consumption of I year, and \(a_i\) is the relationship coefficient between energy and GDP; \(\alpha\) is GDP growth rate, \(r\) is the ratio of GDP growth to energy growth; The calculation period of this paper is from 2000 to 2018.

2.1.2. The proportion of each energy source. According to the average annual growth rate of oil, coal, natural gas and non-fossil energy in primary energy in the past 10 years, and according to the total control targets of natural gas, coal and non-fossil energy, the corresponding coefficient adjustment is carried out.

\[
\begin{align*}
O &= \rho_O \frac{1}{n} \sum_{i=1}^{n} O_i; \quad C = \rho_C \frac{1}{n} \sum_{i=1}^{n} C_i; \quad G = \rho_G \frac{1}{n} \sum_{i=1}^{n} G_i; \quad R = \rho_R \frac{1}{n} \sum_{i=1}^{n} R_i \\
\rho_O, \quad \rho_C, \quad \rho_G, \quad \rho_R \text{ is the growth rate of oil, coal, natural gas and renewable energy in primary energy.}
\end{align*}
\]

(2)

2.1.3. Classification calculation. According to the proportion of energy in each year, and the total amount of primary energy in that year, the consumption can be calculated.

\[
\begin{align*}
A_{O(i)} &= R_{O(i-1)} \cdot (1 + O) \cdot A_i; \quad A_{C(i)} = R_{C(i-1)} \cdot (1 + C) \cdot A_i \\
A_{G(i)} &= R_{G(i-1)} \cdot (1 + G) \cdot A_i; \quad A_{R(i)} = R_{R(i-1)} \cdot (1 + R) \cdot A_i
\end{align*}
\]

(3)

\(A_{O(i)} \cdot A_{C(i)} \cdot A_{G(i)} \cdot A_{R(i)}\) is the proportion of oil, coal, natural gas and renewable energy in the I year; and \(A_{O(i)} + A_{c(i)} + A_{G(i)} + A_{R(i)} = A_i; \quad R_O, \quad R_C, \quad R_G, \quad R_R\) is the proportion of oil, coal, natural gas and renewable energy in primary energy.

2.1.4. Non-fossil energy allocation. For non-fossil energy sources, including hydropower, nuclear power, wind power, and solar energy, they are subdivided and adjusted according to their respective development rules in the total amount of non-fossil energy.

\[
A_H = R_H A_R; \quad A_N = R_N A_R; \quad A_W = R_W A_R; \quad A_S = R_S A_R; \quad A_H + A_N + A_W + A_S = A_R
\]

(5)

\(A_H, \ A_N, \ A_W, \ A_S\) are capacity of hydro, nuclear, wind and solar; \(R_H, \ R_N, \ R_W, \ R_S\) are the proportion of all forms of energy in renewable energy.

2.1.5. Carbon emission calculation. According to the carbon emission intensity of fossil energy, the annual carbon emission value is calculated in the same proportion based on 2018.

\[
C_i = a A_{c(i)} + b A_{O(i)} + c A_{G(i)}
\]

(6)

\(C_i\) is the total carbon emissions, and \(a, b, c\) are respectively carbon emission coefficients of coal, oil and natural gas.

The check method is as follows: calculate the relationship between the growth proportion of fossil fuels and the growth proportion of carbon emissions in the past years, deduce the growth of carbon emissions based on the growth of fossil fuels in 2018 and 2030, and then obtain the carbon emission value.

\[
\begin{align*}
R_F &= A_{F(N)} / A_{F(M)}; \quad R_C = C_{F(N)} / C_{F(M)}; \quad \tau_{FC} = R_F / R_C; \\
C_{2030} &= C_F(2018) \cdot (A_F(2030) / A_F(2018)) / \tau_{FC}
\end{align*}
\]

(7)

(8)

\(R_F\) is the ratio of fossil fuel consumption in year N to year M; \(R_C\) is the ratio of carbon emission in the NTH year to that in the MTH year; \(\tau_{FC}\) is the ratio of fossil fuel increments to carbon emissions increments; \(C_{2030}, \ C_{2018}\) are respectively the carbon emission values of 2030 and 2018.
2.2. Quantity calculation

2.2.1. Total amount. The comparison of China's GDP growth rate and energy consumption growth rate in the past 30 years is shown in Figure 1. From 2005 to 2013, China's GDP grew at an average annual rate of 10.2%, energy consumption elasticity was 0.59, GDP annual growth rate was 6.9% in 2013-2018, and energy consumption elasticity was 0.32. The average ratio of China's GDP growth rate to energy consumption growth since 2000 is \( r = \frac{1}{n} \sum_{i=1}^{n} r_i = 2.9 \), so the energy consumption elasticity is 0.29. At the same time, considering the annual average energy reduction factor, the growth rate of total energy consumption is measured.

![Figure 1. Comparison of GDP growth rate and energy consumption growth rate in the past 30 years](image)

According to the process of gradually decreasing GDP growth from 6.5% to 3%-5%, and taking into account factors such as lower energy consumption, the growth rate of energy consumption will decrease year by year based on 2018, from the current 3.3% year-on-year decrease of 0.15 percentage points. The growth rate will be 1.5% by 2030, the total energy consumption in China \( A_{t+1} = \alpha_t/r \cdot A_t \). The calculation is shown in Table 1.

| Year | Speed Increase \( a \) | Total Amount \( A \) |
|------|--------------------------|---------------------|
| 2018 | 3.30%                    | 3243.6              | 46.4 |
| 2019 | 3.2%                     | 3345.8              | 47.8 |
| 2020 | 3.0%                     | 3446.1              | 49.3 |
| 2021 | 2.9%                     | 3544.4              | 50.7 |
| 2022 | 2.7%                     | 3640.1              | 52.1 |
| 2023 | 2.6%                     | 3732.9              | 53.4 |
| 2024 | 2.4%                     | 3822.5              | 54.7 |
| 2025 | 2.3%                     | 3908.5              | 55.9 |
| 2026 | 2.1%                     | 3990.6              | 57.1 |
| 2027 | 2.0%                     | 4068.4              | 58.2 |
| 2028 | 1.8%                     | 4141.6              | 59.2 |
| 2029 | 1.7%                     | 4209.9              | 60.2 |
| 2030 | 1.5%                     | 4273.1              | 61.1 |

2.2.2. Classification energy measurement parameters. In the past ten years, oil has decreased by 0.06% annually from 21.50% in 2009 to 19.75% in 2018. On this basis, the proportion of oil in primary energy will be adjusted by 4.5 times intensity coefficient to determine by 2030. Natural gas from 2% in 2009 to 6.5% in 2018, with an average annual growth rate of 0.15%. Considering the macro target, that is, by 2030, natural gas accounts for 15% of the total consumption share, so it is adjusted by 4.5 times the
intensity coefficient. Coal from 70.6% in 2009 to 59% in 2018, with an average annual reduction of 0.37%. With the promotion of renewable energy, and taking into account the peak of carbon emissions in 2030, adjusted by a factor of 3.2: The proportion of non-fossil energy in energy consumption increased from 5.9% in 2009 to 14.7%, with an average annual growth rate of 0.28%. Considering the macro target of non-fossil energy in 2030, the coefficient was adjusted according to 2.8, and the proportion of non-fossil energy in 2030 was predicted to be 24.4%.

2.2.3. Carbon emission calculation parameters. Energy emission factors according to relevant standards, coal \( a = 0.755 \), Oil comprehensive \( b = 0.584 \), Natural gas \( c = 0.448 \). Based on 2018, the value is predicted to be 2030.

2.2.4. Classification prediction result. 1) The development trend of various types of energy is shown in Table 2.

| Year | Ratio of 2009 | Ratio of 2018 | \( \rho \) | annual growth rate |
|------|--------------|--------------|----------|-------------------|
| Oil  | 21.50%       | 19.75%       | -0.06%   | 4.50              |
| Natural Gas | 2.00%       | 6.55%       | 0.15%    | 4.50              |
| Coal | 70.60%       | 59.00%       | -0.37%   | 3.20              |
| Non-fossil | 5.90%       | 14.70%       | 0.28%    | 2.80              |

2) The annual growth rate of various types of energy is measured as shown in Table 3.

| Year | Oil | Natural Gas | Coal | Non-fossil |
|------|-----|-------------|------|------------|
| 2018 | 3.40% | 1.82%       | 0.90% | 10.10%     |
| 2019 | 1.82% | 13.45%      | 1.05% | 8.67%      |
| 2020 | 1.66% | 12.35%      | 0.86% | 8.23%      |
| 2021 | 1.49% | 11.41%      | 0.67% | 7.82%      |
| 2022 | 1.32% | 10.59%      | 0.47% | 7.43%      |
| 2023 | 1.16% | 9.87%       | 0.28% | 7.07%      |
| 2024 | 0.99% | 9.22%       | 0.08% | 6.72%      |
| 2025 | 0.82% | 8.64%       | -0.12% | 6.39%     |
| 2026 | 0.66% | 8.10%       | -0.33% | 6.07%      |
| 2027 | 0.49% | 7.61%       | -0.53% | 5.77%      |
| 2028 | 0.32% | 7.15%       | -0.74% | 5.48%      |
| 2029 | 0.15% | 6.73%       | -0.95% | 5.19%      |
| 2030 | -0.02% | 6.33%       | -1.16% | 4.92%      |

3. China's energy industry development trend model results

3.1. Total energy consumption and classification results
It is predicted that by 2030, China's total energy consumption will be 4,273 million toe, equivalent to 6.11 billion tons of standard coal. Compared with 2018, the increase will be 1115 million toe, an increase of 35%, fossil energy will increase by 17%, and oil will increase by 11.39%. It will reach its peak by 2029. Assuming domestic production remains unchanged, the dependence on oil will increase slightly from 70% to 73%; natural gas will increase by 190%, and by 2030 it will account for 14.5% of total consumption. Assuming domestic production remains unchanged, external dependence will rise from 43% to 80%; coal will decrease slightly by 0.46% to reach its peak in 2024; non-fossil energy will grow by 116%, accounting for 24.4% of total consumption. The calculation results of China's energy development are shown in Table 4.
Table 4. China's energy development forecast results (million toe)

| Year | Total Count | Oil $A_O$ | Natural Gas $A_G$ | Coal $A_C$ | Non-fossil $A_R$ |
|------|-------------|-----------|-----------------|-----------|---------------|
| 2018 | 3243.6      | 640       | 214.5           | 1907      | 482.1         |
| 2019 | 3345.8      | 651.7     | 243.4           | 1927      | 523.9         |
| 2020 | 3446.1      | 662.5     | 273.4           | 1943.6    | 567           |
| 2021 | 3544.4      | 673.3     | 304.6           | 1956.5    | 611.3         |
| 2022 | 3640.1      | 681.2     | 336.9           | 1965.7    | 656.8         |
| 2023 | 3732.9      | 689.1     | 370.1           | 1971.2    | 703.2         |
| 2024 | 3822.5      | 696       | 404.3           | 1972.7    | 750.4         |
| 2025 | 3908.5      | 701.7     | 439.2           | 1970.3    | 798.4         |
| 2026 | 3990.6      | 706.3     | 474.8           | 1963.9    | 846.9         |
| 2027 | 4068.4      | 709.7     | 510.9           | 1953.5    | 895.7         |
| 2028 | 4141.6      | 712       | 547.4           | 1939      | 944.8         |
| 2029 | 4209.9      | 713       | 584.3           | 1920.6    | 993.8         |
| 2030 | 4273.1      | 712.9     | 621.3           | 1898.3    | 1042.7        |

| Ratio to 2018 | 35.2% | 11.39% | 189.63% | -0.46% | 116.28% |

3.2. Carbon Emission

Carbon emissions are calculated according to the following mathematical model: determine the emission coefficient of coal, oil and natural gas, and calculate the ratio according to various energy consumption and carbon emissions in 2018. $C_i = aA_{Ci} + bA_{Oi} + cA_{Gi} = 0.755A_{Ci} + 0.584A_{Oi} + 0.448A_{Gi}$. In this paper, oil and natural gas are converted into coal equivalents for calculation. The calculation results are shown in Table 6. Combined with the results of Table 5, China's carbon emissions reached a peak of 10.508 billion tons by 2029. Carbon emission trends are shown in Figure 2.

Table 5. Carbon emission calculation results (100 million tons)

| Year | carbon emission $C$ | Total fossil energy emissions | Integrated emission coefficient | Standard coal emission coefficient | Oil equivalent standard coal coefficient | Natural gas equivalent standard coal coefficient |
|------|---------------------|-------------------------------|---------------------------------|-----------------------------------|------------------------------------------|-----------------------------------------------|
| 2018 | 94.29               | 2529.32583                   | 0.03727871                     | 1                                 | 0.77350993                               | 0.593377483                                  |
| 2019 | 96.0122             | 2575.5245                    | 0.03727871                     | 1                                 | 0.77350993                               | 0.593377483                                  |
| 2020 | 97.6061             | 2618.27974                   | 0.03727871                     | 1                                 | 0.77350993                               | 0.593377483                                  |
| 2021 | 99.0597             | 2657.27351                   | 0.03727871                     | 1                                 | 0.77350993                               | 0.593377483                                  |
| 2022 | 100.374             | 2692.52384                   | 0.03727871                     | 1                                 | 0.77350993                               | 0.593377483                                  |
| 2023 | 101.541             | 2723.8347                    | 0.03727871                     | 1                                 | 0.77350993                               | 0.593377483                                  |
| 2024 | 102.552             | 2750.96543                   | 0.03727871                     | 1                                 | 0.77350993                               | 0.593377483                                  |
| 2025 | 103.399             | 2773.68333                   | 0.03727871                     | 1                                 | 0.77350993                               | 0.593377483                                  |
| 2026 | 104.081             | 2791.9657                    | 0.03727871                     | 1                                 | 0.77350993                               | 0.593377483                                  |
| 2027 | 104.59              | 2805.61656                   | 0.03727871                     | 1                                 | 0.77350993                               | 0.593377483                                  |
| 2028 | 104.923             | 2814.55391                   | 0.03727871                     | 1                                 | 0.77350993                               | 0.593377483                                  |
| 2029 | 105.082             | 2818.82305                   | 0.03727871                     | 1                                 | 0.77350993                               | 0.593377483                                  |
| 2030 | 105.066             | 2818.40066                   | 0.03727871                     | 1                                 | 0.77350993                               | 0.593377483                                  |
4. Conclusion
Based on the mathematical model, this paper measures the energy development trend of China under the constraint of carbon emission. By 2030, total energy consumption will increase by 34 percent, fossil energy by 17 percent and non-fossil energy by 116 percent, accounting for about 24.4 percent of total energy consumption. From the perspective of carbon emissions, oil consumption will peak in 2029 and coal in 2024, and carbon emissions will reach a peak of 10.5 billion tons in 2029. Assuming that domestic supply remains unchanged, oil's external dependence on natural gas will rise slightly from the current 70% to 73%, and the surge in natural gas use will increase its external dependence on natural gas from 43% to 80%. Therefore, the development of non-fossil energy sources is an urgent task.

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