CHINA'S CO2 EMISSIONS PEAK WITH A DYNAMIC NONLINEAR ARTIFICIAL NEURAL NETWORK APPROACH AND SCENARIO ANALYSIS

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Overview

The international community and the academic world have paid great attention to if and when China's carbon dioxide (CO2) emissions will peak. Most studies analyze this issue with a linear framework of the economy-energy-environment system. Despite the similar underlying approaches, they have not reached an agreement on the year and level of the peak. Our study empirically investigates the peak of China's CO2 emissions with a dynamic nonlinear artificial neural network named Nonlinear Auto Regressive model with exogenous input (NARX), which considers feedback mechanisms and nonlinear prediction issues based on the coupling relationship of the economy-energy-environment system. The results show that the peak of China's CO2 emissions occurs in 2031, 2035 and 2029 at the level of 10.78, 11.63 and 10.08 billion tonnes under benchmark growth, high-growth, and low-growth scenarios respectively. CO2 emissions per capita peak in 2029 and 2028 at the level of 7.3 tonnes and 6.8 tonnes under the benchmark and low-growth scenarios, but it will not peak under the high-growth scenario. Considering the complex nonlinear system relationship between China's future economic development, energy consumption and carbon dioxide emissions, we suggest that China can choose the medium-speed development road and achieve its peak target in 2031. Based on the methodology of the mean impact value (MIV), we differentiate the importance of the influence factors to CO2 emissions: industrialization, urbanization, gross economic output, economic structure, total population, energy consumption and structure, energy productivity, and environmental governance. China is able to develop an optimal peaking pathway and corresponding policies by comprehensively considering the direction and contribution of these influence factors.

Methods

This paper analyzes the peak of China's CO2 emissions comprehensively by integrating the NARX model, scenario analysis, and MIV. We develop a system of factors affecting China's CO2 emissions, which includes industrialization, urbanization, gross economic output, economic structure, total population, energy consumption and structure, energy productivity, and environmental governance. Industrialization, measured by GDP per capita (in yuan), captures the effects of industrial development on the level of CO2 emissions. Urbanization, measured by the proportion of urban population, explains the influences on CO2 emissions from the development of cities. Gross economic output, measured by GDP (in 100 million yuan), shows the effects of economic scale on the peak of CO2 emissions. The proportions of the secondary and tertiary sectors of China's economy (in %) measure the effects of economic structure on the peak of CO2 emissions. Total population (in 10 thousand) shows the influence of population on the CO2 emissions peak. Total energy consumption (in 10 thousand tonnes of coal equivalent (tce)) and the percentages of coal and non-fossil energy consumption measure the respective effects on CO2 emissions from energy consumption and its structure. GDP per unit of energy use (in 10 thousand yuan per tce) measures the effect on CO2 emissions from energy productivity. Total investment in environmental governance (in 100 million yuan) measures China's efforts to manage carbon emissions.

Based on the settings in other studies, we present three scenarios. Under the benchmark scenario, all influence factors change with the average rates of the past ten years and with consideration of the characteristics of each stage in the Chinese mid-long term socioeconomic development process. The high-growth and low-growth scenarios are developed based on the benchmark scenario with the adjustment of the influence factors caused by the dynamic changes of the socioeconomic development process.

The equation of the NARX model is:

$$y(t) = f[y(t-1), y(t-2),..., y(t-n), x(t-1), x(t-2),..., x(t-n)] \quad (1)$$

where $f[\bullet]$ is a nonlinear function, $y(t)$ is output, which is the targeted variable, $x(t)$ is the network input, $y(t-1), y(t-2),..., y(t-n), x(t-1), x(t-2),..., x(t-n)$ are time lags for the output and input variables.

The data, from the 2017 China Statistical Yearbook, span 1978 to 2016, and include CO2 emissions and the eleven influence factors. The quantity of CO2 emissions is estimated using a method developed by Xu and Song (2010). It is calculated by multiplying primary energies (coal, oil, natural gas, and non-fossil) by their respective carbon emissions coefficients:

$$C = \sum_i \frac{E_i}{E} * \frac{C_i}{E_i} * E = \sum_i S_i * F_i * E * 44/12$$ **Error! Reference source not found.**

where C is CO2 emissions, E is total energy consumption, E_i is the consumption quantity of energy i, C_i is the percentage of the i-th energy source in the total energy consumption, S_i denotes energy as a percentage of the total energy consumption, F_i is the carbon emission coefficients for each energy source, and 44/12 is the ratio of carbon transformed into CO2.

Results

The peak occurs in 2031, 2035, and 2029 under the benchmark, high-growth, and low-growth scenarios respectively. The peak levels are 10.78, 11.63, and 10.08 billion tonnes respectively. We also find China's CO2 emissions per capita occurs in 2029 and 2028 at the level of 7.3 and 6.8 tonnes under the benchmark and the low-growth scenarios, but CO2 emissions per capita will not peak under the high-growth scenario.

Based on the results, the importance of the influence factors, from highest to lowest, is: economic scale (GDP), the proportion of the secondary sector (manufacturing industry and construction), the proportion of coal consumption, industrialization, energy productivity, non-fossil energy consumption, total energy consumption, urbanization, total population, the proportion of the tertiary sector (sevices), and the investment in environmental governance.

Conclusions

The main conclusions are:

First, the dynamic machine learning framework is able to accomplish medium and long term prediction. A dynamic neural network considers and is able to reveal patterns among the past, present, and the future. Thus, it overcomes the shortcomings of the conventional linear analysis. It describes the development paths and the influence factors of China's CO2 emissions, and helps us further understand the complexity of the economy-energy-environment system.

Second, the peak of China's CO2 emissions is a result of the coupling evolution of the economy, energy, and environment. Rapid economic growth caused by industrialization and urbanization stimulates a rapid increase in energy demand. China's CO2 emissions therefore increase quickly with the domination of fossil energy. Nevertheless, China's CO2 emissions are able to peak with the changing economic structure towards service, energy consumption structure towards low-carbon fuels, increasing energy productivity, and effective environmental governance. Not only does this paper contribute to the study of China's CO2 emissions, the results of this paper also encourage us to believe a peak will occur. The peak occurs first in 2029 under the low-growth scenario. The latest occurrence is in 2035 under the high-growth scenario. China's CO2 emissions will peak in 2031 under the benchmark scenario, and its level is between 10 and 11.7 billion tonnes.

Third, China needs to scientifically choose a coordinated development path for CO2 emissions peaking. China needs to match the CO2 emissions peaking path with the contribution and direction of the influence factors of the CO2 emissions. This analysis method of using MIV and contribution helps us recognize and understand the influence factors of China's CO2 emissions. For achieving the peak goal of CO2 emissions, China needs to explore the cooperation between low-carbon industrialization and low-carbon urbanization; keep consciously making technological innovation a priority for economic structure reform; and further reduce the reliance on coal for economic growth (Qi et al. 2016). In addition, improving energy productivity sufficiently, utilizing environmental governance consistently, and imbuing low-carbon governance into the administration of the national and local governments play a substantial role in reforming a high-carbon economy.

References

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