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# Can Carbon Reduction Targets Achieve Energy Conservation and Emission Reduction?

-- Evidence From Coal-Fired Power Plants in China

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**Abstract:** The impact of environmental regulation on productivity growth and carbon reduction is crucial for a country's sustainable development. This paper examines how China's carbon reduction target policy (CRT), initiated during the 12th Five-Year Plan period, has influenced the green productivity of coal-fired power plants. Using the DEA method, we evaluated the green productivity of China's coal-fired power plants from 2005 to 2015. Additionally, we treated the CRT proposed during the 12th Five-Year Plan as a natural experiment and applied a difference-in-differences (DID) approach to estimate its effect on green productivity. The findings indicate that the green productivity of China's coal-fired power plants has been on the rise, with efficiency improvements serving as a key driver. There is heterogeneity in the green productivity of these plants. Following the implementation of the CRT, the green productivity of coal-fired power plants improved, and the positive effects of the policy have grown over time. Therefore, China's CRT plays a significant role in promoting productivity growth and carbon reduction.

**Keywords:** Coal-fired Power Plants; Green Productivity; Difference-in-differences; Carbon Reduction Target Policy.

## 1. Introduction

Over the past few decades, China has experienced a long period of high-level economic growth and has become the world's largest carbon dioxide ($CO_2$) emitter and the second-largest global economy, creating, in turn, enormous challenges related to environmental pollution. According to IEA (2020), in 2018, the carbon emissions originating from China (9.53 billion tons) have grown to reach above 25 percent of global carbon emissions. To cope with the increasingly higher carbon emissions level, China has repeatedly proposed its carbon emissions targets at global conferences. For example, at the United Nations Climate Change Conference in Copenhagen in 2009, the Chinese government announced to the world that China's carbon emissions per unit of GDP would be reduced by 40% to 45% in 2020 compared with the 2005 level, which was the first time that China proposed its carbon emissions reduction target. During the 21st United Nations Conference on Climate Change Summit in November 2015, China put forward for the second time its emissions reduction targets, that is, to peak carbon emissions around 2030 and reduce carbon emissions per unit of GDP by 60% to 65% compared with the 2005 level. Recently, in an important speech delivered at the General Debate of the 75th Session of the United Nations General Assembly in 2020, President Xi Jinping declared that China would peak carbon emissions by 2030 and achieve carbon neutrality by 2060.

To successfully meet these carbon emissions reduction targets, policymakers have carried out several emissions' mitigation programs. For instance, in the 12th Five-Year Plan (FYP), the Chinese government set an overall target of reducing carbon intensity – the amount of $CO_2$ emitted per unit of GDP – by 17% by 2015, compared with 2010 levels. Meanwhile, energy consumption per unit of GDP would be reduced by 16% during the same period. This is the first time that the Chinese government has explicitly included mandatory carbon emission control targets in its economic and social development plans. Accordingly, the national general targets and tasks were divided into provinces and municipalities, which constituted an important part of the regional 12th FYP and became a key point in the work assessment of governments. In addition, the Chinese government has also carried out pilot projects for low-carbon development (organized three batches of pilot projects for low-carbon development in provinces and cities, and finally included 87 cities, provinces, and autonomous regions) and established carbon emission trading markets (launched pilot projects for carbon emission trading in seven cities and provinces including Beijing, Tianjin, Shanghai, Chongqing, Guangdong, Hubei, and Shenzhen). There is a lot of literature on the effects of low-carbon city pilots or carbon trading pilots, working on various topics, including carbon reduction (Hu et al., 2020; Huo et al., 2022; Liu et al., 2022), energy conservation (Hong et al., 2022; Zhou et al., 2022), carbon emission efficiency (Yu and Zhang, 2021), total factor productivity (Chen et al., 2021; Cui et al., 2021), and low-carbon innovation (Pan et al., 2022; Zhu et al., 2019). However, the provincial carbon reduction target set in the 12th FYP, which is the first mandatory carbon reduction control target explicitly mentioned by the Chinese government in the economic and social development plan, has not been studied.

In addition, as the largest carbon-emitting industry in the world, the power sector, according to statistics from IEA (2020), produced 13.98 billion metric tons of $CO_2$ in 2018, accounting for 40% of total global emissions. Similarly, the power sector is also the largest carbon emitter in China. And China's coal-based primary energy structure determines that Chinese power generation is dominated by coal-fired power generation. As shown in Figures 1 and 2, during the period from 2001 to 2019, the carbon emissions of the power sector accounted for more than 40% of the total carbon emissions, and coal-fired electricity generation accounted for more than 70% of the total electricity generation in China. Therefore, carbon emissions reduction from the power sector, especially the control of carbon emissions from coal-fired power generation, is of great significance for China to achieve the medium- and long-term emission reduction targets. Nevertheless, previous studies pay little attention to the impact and mechanism of provincial carbon reduction targets (CRT) on energy conservation and emission reduction at the micro-power plant level.

In this paper, we utilize the provincial CRT set in the 12th FYP to study the influence of CRT on coal-fired power plants, which has the following advantages. First, China's rapid economic growth in recent decades has resulted in serious environmental challenges, such as the frequent occurrence of extreme weather, which is caused by excessive greenhouse gas emissions. As the world's largest carbon emitter, China's power sector accounts for more than 40% of its carbon emissions. Therefore, it is of great significance to investigate the energy-saving and carbon reduction effect of the power sector for China to achieve "dual carbon" goals. Second, different from the previous implementation of energy intensity targets to achieve carbon reduction, the provincial CRT set for the first time during the 12th FYP period reflects China's emphasis on carbon emissions, and also reflects the qualitative change of China's energy conservation and emission reduction policies. Thus, it is of practical significance to analyze the overall energy-saving and carbon-reduction effect of provincial CRT.

Based on a unique panel dataset of China's coal-fired power plants from 2005 to 2015, we adopted the difference-in-differences (DID) model to evaluate the effect of the provincial CRT on energy consumption and $CO_2$ emissions. In addition, we construct a theoretical framework to describe the impact of provincial CRT on power plants and the strategies that power plants may adopt under regulatory constraints. The results show that the provincial CRT promotes the energy conservation and emission reduction of coal-fired power plants in China, mainly through the mechanism of improving energy efficiency.

# 2. Theoretical Framework

We first assume that coal-fired power plants employ capital (*K*), labor (*L*), and energy (*E*) to produce electricity (Y), so its production function is $Y = Q(K, L, E)$. And the production function satisfies the property that the first derivative is greater than 0 (i.e., $Q_K, Q_L, Q_E > 0$) and the second derivative is less than 0 (i.e., $Q_{KK}, Q_{LL}, Q_{EE} < 0$), which means capital, labor, and energy are increasing functions of output *Y*, and their marginal outputs decrease. Meanwhile, coal-fired power plants emit carbon dioxides (*C*) when producing electricity, and the emissions mainly come from energy consumption, which is an increasing function of energy *E*. Thus, we assume that $C = C(E)$, and it satisfies the properties $C_E > 0$ and $C_{EE} > 0$. Here, we first analyze the production decisions of power plants without setting carbon reduction targets (CRT). Therefore, a power plant maximizes its profit by setting *K*, *L*, and *E* as follows:

$$\max_{K,L,E} pQ(K, L, E) - rK - wL - \theta E \tag{1}$$

where *p* represents the electricity price, *r* represents the capital price or interest rate, *w* represents the labor price or wages, and $\theta$ represents the energy price.

Then, the first-order conditions for the power plant's profit maximization problem are the following:

$$\frac{\partial \pi}{\partial K} = pQ_K - r = 0 \tag{2}$$

$$\frac{\partial \pi}{\partial L} = pQ_L - w = 0 \tag{3}$$

$$\frac{\partial \pi}{\partial E} = pQ_E - \theta = 0 \tag{4}$$

By solving equations (2), (3), and (4), we can get the equilibrium of the coal-fired power plant without regulation, that is, the equilibrium solutions are $K^*, L^*, E^*$, $Y^*$ and $C^*$.

When the government began to set provincial CRT, coal-fired power plants, as large producers of carbon emissions, would be affected by the regulation. We set a unit tax *t* on the plant's emissions, and different carbon reduction targets set by provinces represent the different regulatory intensities of carbon emissions. Therefore, under the regulation of CRT, the objective function of the power plant's profit maximization is as follows:

$$\max_{K,L,E} pQ(K, L, E) - rK - wL - \theta E - tC \tag{5}$$

Then, the first-order conditions for the power plant's profit maximization problem are the following:

$$\frac{\partial \pi}{\partial K} = pQ_K - r = 0 \tag{6}$$

$$\frac{\partial \pi}{\partial L} = pQ_L - w = 0 \tag{7}$$

$$\frac{\partial \pi}{\partial E} = pQ_E - \theta - tC_E = 0 \tag{8}$$

According to Eq. (8), we can get the equilibrium of energy consumption of the coal-fired power plant under regulation, that is $E^{crt}$. Compared to the equilibrium energy consumption (i.e., $E^*$) without regulation, the equilibrium energy consumption of the coal-fired power plant would decrease, that is, $E^{crt} < E^*$. Due to carbon emissions being an increasing function of energy, we can get $C^{crt} < C^*$. Therefore, we propose Hypothesis 1.

**Hypothesis 1.** After the initiation of provincial CRT, the carbon emissions and energy consumption of coal-fired power plants are reduced.

Based on Eq. (8), we can prove the following equations by applying the implicit function theorem:

$$pQ_{EE}\frac{\partial E}{\partial t} - C_E - tC_{EE}\frac{\partial E}{\partial t} = 0 \tag{9}$$

$$\frac{\partial E}{\partial t} = \frac{C_E}{pQ_{EE} - tC_{EE}} < 0 \tag{10}$$

As shown in Eq. (10), when the regulation is more stringer, the coal-fired power plant's energy consumption is less, which means that the intensity of provincial CRT is negatively correlated with energy use. Therefore, we can propose Hypothesis 2.

**Hypothesis 2.** The intensity of provincial CRT has a negative effect on power plants' energy use, that is, the higher the provincial CRT is set, the greater the decline in energy use of coal-fired power plants.

The above theoretical analysis found that the initiation of provincial CRT would make coal-fired power plants reduce energy use, and the higher the target, the less energy use. This indicates after the implementation of provincial CRT, power plants reduce carbon emissions by reducing energy use in response to regulations. Power plants can reduce energy use in two ways, either by reducing production or by improving energy efficiency. So here we try to explore the energy efficiency channel.

We induce the energy efficiency $\varphi$ in the production function and assume that energy efficiency is produced with capital and labor described by $\varphi = f(K_E, L_E)$ with $\frac{\partial f}{\partial K_E} > 0$ and $\frac{\partial f}{\partial L_E} > 0$. Thus, the objective function of the power plant's profit maximization can be given as:

$$\max_{K,L,K_E,L_E,E} \pi = pQ(K,L,E,\varphi) - r(K+K_E) - w(L+L_E) - \theta E - tC \quad (11)$$

To take the first-order derivative of the profit $\pi$ concerning $K, L, K_E, L_E, E$, we can get:

$$\frac{\partial \pi}{\partial K} = pQ_K - r = 0 \quad (12)$$

$$\frac{\partial \pi}{\partial L} = pQ_L - w = 0 \quad (13)$$

$$\frac{\partial \pi}{\partial K_E} = pQ_\varphi \frac{\partial f}{\partial K_E} - r = 0 \quad (14)$$

$$\frac{\partial \pi}{\partial L_E} = pQ_\varphi \frac{\partial f}{\partial L_E} - w = 0 \quad (15)$$

$$\frac{\partial \pi}{\partial E} = pQ_E - \theta - tC_E = 0 \quad (16)$$

Based on Eq. (16), we can prove the following equations by applying the implicit function theorem:

$$pQ_{EE}\frac{\partial E}{\partial t} - C_E - tC_{EE}\frac{\partial E}{\partial t} = 0 \quad (17)$$

$$\frac{\partial E}{\partial t} = \frac{C_E}{pQ_{EE} - tC_{EE}} < 0 \quad (18)$$

$$pQ_{E\varphi}\frac{\partial f}{\partial K_E}\frac{\partial K_E}{\partial t} - C_E = 0 \quad (19)$$

$$\frac{\partial K_E}{\partial t} = \frac{C_E}{pQ_{E\varphi}\frac{\partial f}{\partial K_E}} \quad (20)$$

Due to $C_E > 0$, $Q_{E\varphi} > 0$, and $\frac{\partial f}{\partial K_E} > 0$, we can get $\frac{\partial K_E}{\partial t} > 0$. This indicates that the intensity of provincial CRT would drive power plants to raise capital inputs to generate energy efficiency. Similarly, we can also prove the following equations:

$$pQ_{E\varphi}\frac{\partial f}{\partial L_E}\frac{\partial L_E}{\partial t} - C_E = 0 \quad (21)$$

$$\frac{\partial L_E}{\partial t} = \frac{C_E}{pQ_{E\varphi}\frac{\partial f}{\partial L_E}} > 0 \quad (22)$$

Eq. (22) shows that the intensity of provincial CRT would also drive power plants to increase labor inputs to improve energy efficiency. Based on these deductions, we can propose Hypothesis 3.

**Hypothesis 3.** The intensity of provincial CRT drives coal-fired power plants to improve energy efficiency.

# 3. Empirical Methodology

## 3.1. Econometric Strategy

Combining the variation in CRT across provinces with the before-and-after changes, we identify the effect of the 12th FYP (2011-2015) on carbon emissions and energy consumption of China's coal-fired power plants using a DID strategy. The specification for our DID estimation is given by:

$$y_{it} = \beta \ln(Target_p) \times Post_t + \alpha Z_{ct} + \eta_i + \delta_t + \varepsilon_{it} \quad (23)$$

where $y_{it}$ are the dependent variables, that is, the carbon emissions and energy consumption of plant *i* in year *t*. $Target_p$ is the carbon reduction target for province $p$; $Post_t$ is a dummy variable equal to 0 for 2005-2010 and 1 for 2011-2015. $Z_{ct}$ is a set of city-level control variables, and $\varepsilon_{it}$ is an error term with a mean equal to zero. $\eta_i$ denotes plant fixed effects, controlling for time-invariant plant-level characteristics, and $\delta_t$ denotes year fixed effects, capturing the plant-invariant but time-variant factors. To address the potential serial correlation and heteroskedasticity, we cluster the standard errors at the province-by-year level.

## 3.2. Data and Descriptive Statistics

We collect data on China's large coal-fired power plants with installed capacity exceeding 890 MW from the National Economic Census and the Complication of Power Industry Statistics Data. The primary dataset is a balanced panel covering 89 plants over 11 years (2005-2015) with six factors, including labor (*L*), capital (*K*), energy consumption (*E*), electricity generation (*Y*), the value of sales (*R*), and $CO_2$ emissions (*C*). The information on *L*, *K*, *E*, and *Y* is obtained from the Chinese Industry Enterprises Database, China Electric Power Yearbook, the China Electric Power Industry Statistics Analysis, and the Complication of Power Industry Statistics Data. *R* is calculated by the electricity price (*P*) and electricity generated ($R = Y \times P$). The data on *P* is the feed-in tariff of each power plant during the period between 2005 and 2015, collected from the China Power Industry Annual Development Report. Following Zhang et al. (2021), we estimate *C* from the fuel usage of each power plant via the following equation:

$$CO_{2i} = \sum_{j=1}^{J} E_{j,i} \times NCV_j \times CC_j \times COF_j \times \left(\frac{44}{12}\right) \quad (24)$$

where *i* is the *i*th power plant, *j* indicates the fuel types, *E* is the energy consumption of different fuel types, *CF* represents the transformation factor, *CC* is the carbon content, and *COF* indicates the carbon oxidation factor. The term $\left(\frac{44}{12}\right)$ is the ratio of the mass of a $CO_2$ atom to the mass of carbon atom. Table 1 presents the descriptive statistics for each variable from 2005 to 2015.

Data on provincial CRT are collected on the official website of the State Council. Figure 3 shows the distribution of provincial CRT in the 12th FYP.

Regions more economically developed or more heavily industry centered – such as Guangdong, Shanghai, Jiangsu, Zhejiang, and Tianjin – are required to meet higher goals. The average reduction target for carbon intensity is 15.53% with a standard deviation of 2.33%.

# 4. Empirical Results

As shown in columns (1) and (2) of Table 2, controlling for plant and year fixed effects, the results show that the provincial CRT can reduce carbon emissions and energy consumption of coal-fired power plants. Column (3) indicates that the establishment of provincial CRT can promote the energy efficiency of coal-fired power plants.

## 4.1. Figures

See following Fig 1, 2 and 3.

# 5. Conclusion

Existing literature has paid limited attention to the impact of provincial carbon reduction targets on the green productivity of China's coal-fired power plants. Based on data from China's coal-fired power plants from 2005 to 2015, this study first employs the DEA method to estimate green productivity and then uses the DID method to analyze the impact of provincial carbon reduction targets on green productivity. The findings reveal that the green productivity of China's coal-fired power plants has been on the rise, with efficiency improvements serving as the key driving force. There is heterogeneity in the green productivity of these power plants. After the implementation of provincial carbon reduction targets, the green productivity of coal-fired power plants improved, and the positive effects of this policy have grown over time. Therefore, the current provincial carbon reduction targets in China are effective in reducing carbon emissions and promoting green productivity.

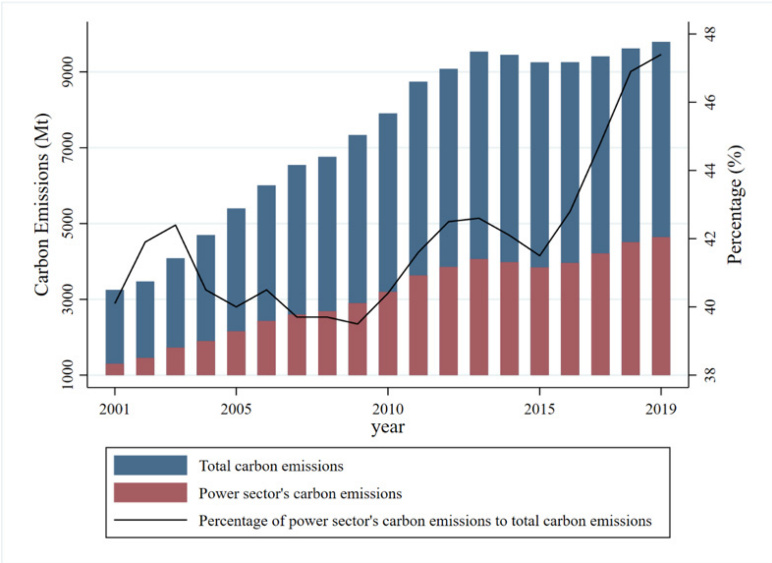


**Figure 1.** Carbon emissions and proportion changes
Note: The data were collected from Carbon Emission Accounts and Datasets (CEADs).

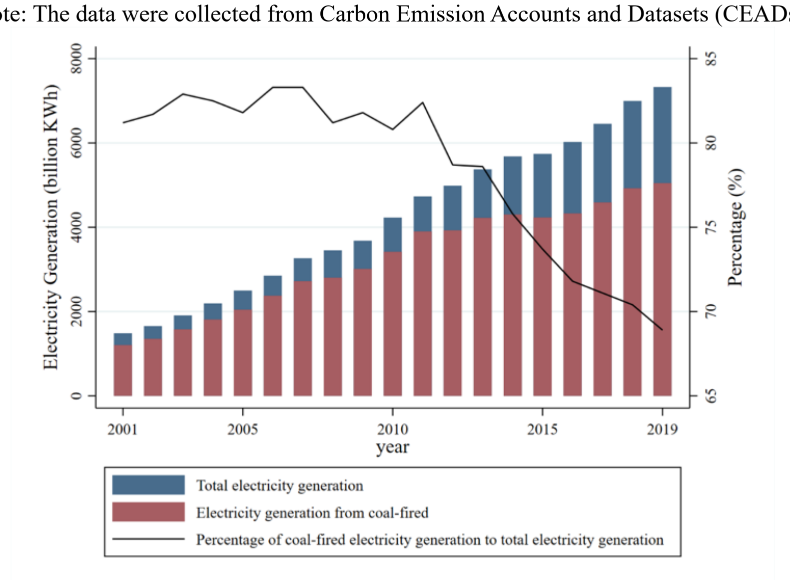


**Figure 2.** Electricity generation and proportion changes
Note: The data were collected from China Electric Power Statistical Yearbook.

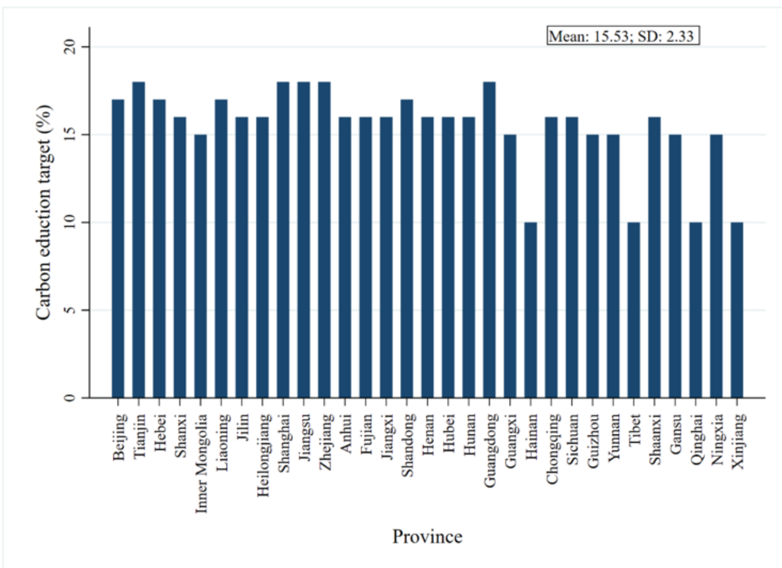


**Figure 3.** Distribution of provincial carbon intensity targets in 12th FYP
Note: The data were collected from the official website of the State Council

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