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The Impacts of Chinese Renewable Energy Policies: A Dynamic General Equilibrium Analysis

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Abstract: Developing renewable energy is an important strategy to respond to carbon neutrality, contributing to energy transition and sustainable development in China. A dynamic computable general equilibrium model is employed to study the impacts of renewable energy policies on emission reductions and economic development. The basic data is the Chinese input-output table in 2015. The results show that the expansion of renewable energy can reduce emissions and that the power sectors face significant decreases in emissions compared to other sectors; the high economic growth is more conducive to the optimization of energy consumption structure and creates more favorable conditions for renewable electricity adoption; and the share of renewable electricity will reach 48.88% and 50.02% by 2030 under low and high GDP growth paths, respectively. The increased clean electricity derives mainly from wind power and solar power.

Keywords: Renewable energy; Feed-in tariff; CO_2 emission reductions; Dynamic CGE model

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1. Introduction

Driven by concerns about environmental problems, many countries regard renewable energy development as an important energy strategy and an effective way to respond to climate change. Renewable energy plays a key role in the process of energy transition, and accelerating the development of renewable energy in China contributes to reducing greenhouse gas (GHG) emissions and air pollution, creating employment, and ensuring the security of the energy supply. China possesses massive potential to harness a diverse range of renewable sources and technologies for power generation, and the Chinese government already has a basket of policy strategies leading in the direction of sustainability and a low-carbon energy system. China has pledged to increase the proportion of non-fossil energy in primary energy consumption to approximately 25% by 2030.

In 2021, non-fossil energy consumption accounted for 16.6% of the total primary energy consumption in China. In the power sector, renewable energy accounted for 33% of the total power generation in 2021, coal for 60% of the power generation, and natural gas for the remaining 3.4%. This paper will make an integrated comprehensive evaluation of renewable energy development by quantifying the environmental benefits and economic impacts of China's renewable energy target, which is of significant interest to policymakers in China. The research lays the foundation for future studies of the effects of renewable energy policies.

The rest of the paper is organized as follows. Section 2 reviews the existing literature on the impacts of renewable energy development. Section 3 describes the model, data sources, and mechanism of renewable energy on the environment and economy. Section 4 presents the scenario settings, and Section 5 discusses the main results. Section 6 offers conclusions.

2. Literature review

Renewable energy policies have aroused extensive attention in the academic field. Currently, five primary methods are used to study renewable energy policies: the computable general equilibrium (CGE) model; input-output (I-O) analysis [1–2]; the econometric model [3–4]; the bottom-up models [5–6]; and the real options approach [7]. Of these, the CGE model is widely used to assess the environmental and economic impacts of renewable energy policies. Scholars have combined the CGE model framework with data to study renewable energy, energy investment, energy efficiency, and pollution taxes [8]. Compared with the I-O model, the CGE model can use nonlinear functions and allow the substitution between production inputs; compared with the econometric model, the CGE model connects the producers' demands for produced inputs and primary factors, producers' supplies of commodities, demands for inputs to capital formation, and investigates the economic behaviors of households, enterprises, and government.

In the existing studies based on the CGE model, the renewable energy policies can be summarized as three categories: renewable feed-in tariff [9–10]; subsidies to power production from renewable energy [11–12]; and tax on fossil fuels [13]. Tabatabaei et al. explore the impacts of a feed-in tariff in Iran on the economy, welfare, and the environment by employing the Economic-Energy-Environmental model, and their results show how government finances subsidies can affect the results of a feed-in tariff [10]. Bohringer et al. designed a static CGE model to analyze the impacts of power production subsidies from renewable energy in Germany [12]. Rivers builds a three-sector CGE model to assess the impacts of renewable electricity support schema (tax on fossil fuels) on the rate of unemployment in the US [13].

Moreover, a static CGE model is applied to analyze the impacts of renewable energy promotion in Portugal [14]. Hwang and Lee examine electricity industry reform in Korea [15]. Cai and Arora assess a clean power plan in the US by disaggregating the electricity sector under the CGE framework [16]. Ruamsuke et al. explore the impacts of carbon limits in Southeast Asia and find that the largest emissions reduction potentials are the electricity and energy-intensive sectors [17]. Kalkuhl et al. evaluate various policy instrument portfolios, including carbon taxes, renewable energy subsidies, and feed-in tariffs, by establishing a global CGE model [18]. Morris et al. also compare a set of support policy portfolios of renewable energy based on an EPPA model [19].

Several studies have provided a basis for China's renewable energy policy. Dai et al. employ a static CGE model to analyze the role of China's non-fossil energy strategy in achieving the country's Copenhagen Commitments [20]. Wu et al. explore China's renewable support scheme based on a multi-regional CGE model [21]. However, the model is still static. Although Qi et al. use a dynamic China-in-Global Energy Model to discuss the impacts of renewable energy promotion on CO_2 emissions in China, the evaluation of economic impacts is omitted [22].

This paper contributes to the existing studies on China's renewable energy policy in one way—the high and low GDP growth paths are set to capture the uncertainty of China's economy in the future, which is also an important design to understand the development of renewable energy under different economic growth conditions.

3. Model and data

3.1. Dynamic CGE model

A Chinese dynamic CGE model is established based on the ORANI-G model [23]. The model includes production, household, government, international trade, emissions, and dynamics modules. A brief description of the main module is introduced as follows.

3.1.1. Production

The production structure is shown in **Figure 1**. At the top level of the production module, the total output is composed of three inputs through the Leontief function (**Equations 1** and **2**). The three inputs are commodity composites (intermediate inputs), an energy-factor composite, and a primary-factor composite.

$$XOUT_i = min\left(\frac{XCOM_i}{a_{ci}}, \frac{XENE_i}{a_{ei}}, \frac{XFAC_i}{a_{fi}}\right) \tag{1}$$

$$POUT_i * XOUT_i = PCOM_i * XCOM_i + PENE_i * XENE_i + PFAC_i * XFAC_i \tag{2}$$

Where $XOUT_i$ is the total output of industry *i*, and $POUT_i$ is the output price. $XCOM_i$, $XENE_i$, and $XFAC_i$ are the intermediate inputs composite, energy-factor composite, and primary-factor composite in industry *i*, respectively; $PCOM_i$, $PENE_i$, and $PFAC_i$ are the corresponding prices. a_{ci}, a_{ei}, and a_{fi} are input-output coefficients, and $a_{ci} + a_{ei} + a_{fi} = 1$.

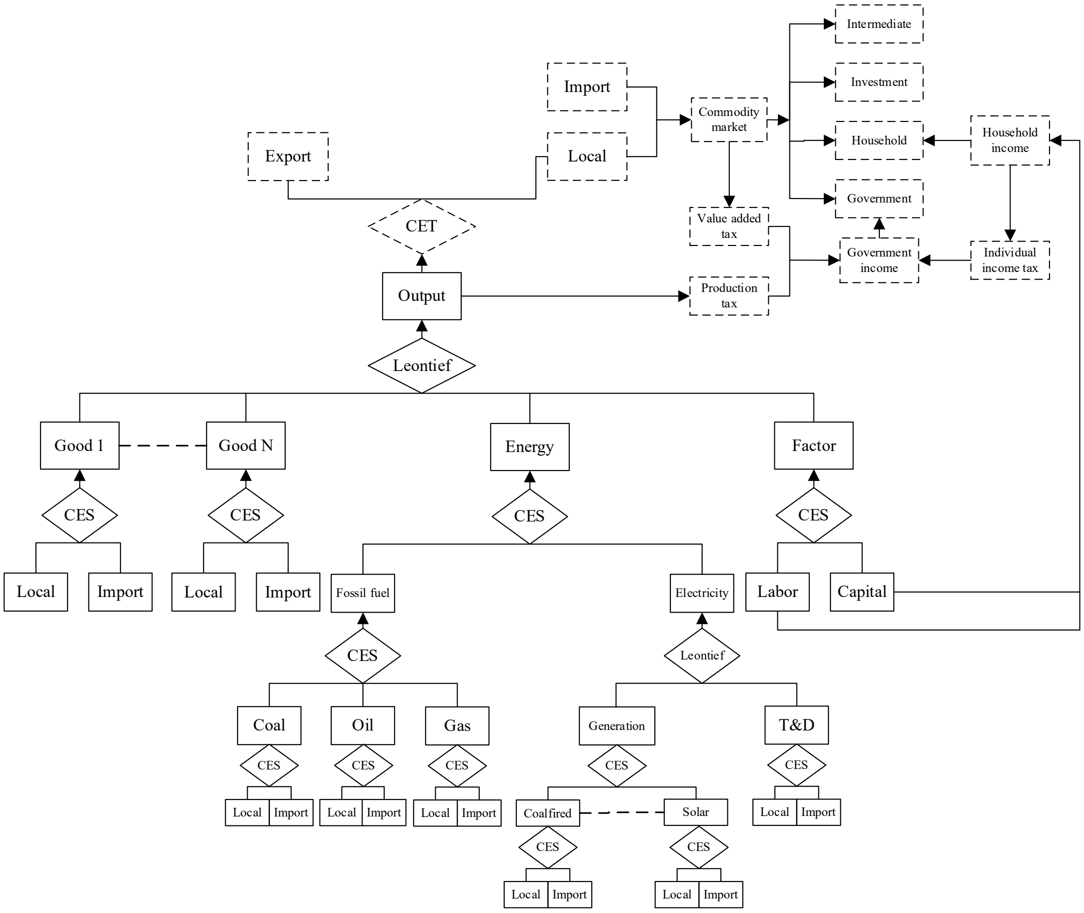

Figure 1. Production structure

In the second nest, the energy-factor composite is composed of compound fossil fuel and compound electricity through a constant elasticity of substitution (CES) function (**Equations 3** and **4**); each intermediate input composite is the CES aggregate of local good and imported good; the primary-factor composite is also the CES aggregate of labor and capital.

$$XENE_i = A_i\left(\delta_{fi} XFOS_i^{\rho} + \delta_{ei} XELE_i^{\rho}\right)^{\frac{1}{\rho}} \tag{3}$$

$$PENE_i * XENE_i = PFOS_i * XFOS_i + PELE_i * XELE_i \tag{4}$$

Where $XFOS_i$ and $XELE_i$ are the compound fossil fuel and compound electricity in industry *i*, respectively; $PFOS_i$ and $PELE_i$ are the corresponding prices. δ_{fi} and δ_{ei} are share parameters, meeting $\delta_{fi} + \delta_{ei} = 1$. P is a parameter related to elasticity σ, and the relationship between them is $P = 1-(1/\sigma)$. A_i is the technical parameter.

In the third tier, coal, oil, and natural gas are nested into compound fossil fuel by the CES function; the power generation and the power supply are nested into electricity composite by the Leontief function. In the fourth tier, the power generation is composed of various types of electricity (**Equations 5** and **6**); In the fifth tier, various types of energy are divided into domestic and imported parts nested by the CES function.

$$XELE_i = \left[\sum\nolimits_k \delta_{ki}\left(\frac{X_{ki}}{A_{ki}}\right)^{\rho_i}\right]^{1/\rho_i} \tag{5}$$

$$PELE_i * XELE_i = \sum\nolimits_k P_{ki} * X_{ki} \tag{6}$$

Where X_{ki} is the input of electricity *k* in industry *i*, and P_{ki} is the price of electricity *k*. *k* represents various types of electricity. δ_{ki} and A_{ki} share technical parameters, respectively.

3.1.2. Pollutant emissions and pollution tax

The widespread use of fossil fuels is the culprit behind emissions of GHG (CO_2) and air pollutants (SO_2). The CO_2 and SO_2 emissions caused by fossil energy in each industry are equal to the inputs of fossil energy in this industry multiplied by the emissions factor and then by the clean technological parameter (**Equation 7**); summing up the emissions for each fossil energy in each industry yields the total emissions (**Equation 8**).

$$EMI_{fi} = X_{fi} * FAC_f * CLE_i \tag{7}$$

$$EMI = \sum\nolimits_i \sum\nolimits_f EMI_{fi} \tag{8}$$

Where EMI_{fi} is emissions caused by fossil energy *f* used in industry *i*, EMI is total emissions. X_{fi} is the demand for fossil energy *f* by industry *i*. FAC_f is the emission coefficient of fossil energy *f*, which is assumed to be the same in each industry. CLE_i is the clean technological parameter in the industry *i*.

If a pollution tax on emissions of GHG and pollutants is levied, the tax due is equal to the number of emissions multiplied by the tax rate imposed on each unit of emissions (**Equation 9**); the total tax due is the sum of the tax for each fossil energy in each industry (**Equation 10**).

$$EMI = \sum\nolimits_i \sum\nolimits_f EMI_{fi} \tag{9}$$

$$ETAX = \sum\nolimits_i \sum\nolimits_f ETAX_{fi} \tag{10}$$

Where $ETAX_{fi}$ is the pollution tax levied on fossil energy *f* by industry *i*, ETAX is total pollution tax revenue, *and t* is the rate of pollution tax.

3.1.3. Feed-in tariff and the source of subsidy

Feed-in tariff is introduced into the model. **Equation 11** reflects that the renewable powers' purchase price of users is lower than the initial market price under the subsidy. Power generation from renewable energy is more competitive when the feed-in tariff is applied.

$$P_k = \frac{P_{0,k}}{1+s} \tag{11}$$

Where P_k is renewable powers purchase price of users, and $P_{0,k}$ is renewable powers' initial market price. *k* represents the renewable powers needed to be subsidized, and *s* is the subsidy rate.

It is assumed that the subsidy comes from the tax revenue, which is reflected in **Equation 12**. In the CGE model, the sales tax for producers, investors, households, and the government are set and the total tax revenue is produced by aggregating sales tax plus the production tax, then subtracting the amount of the subsidy. That is to say, subsidy is equivalent to negative tax revenue.

$$TTAX = PTAX + ITAX + HTAX + GTAX + PTX + ETAX - SUB \tag{12}$$

where $TTAX$ is the total tax revenue, and PTAX, ITAX, HTAX, and GTAX represent total intermediate, investment, household, and government tax revenue respectively. PTX is the total production tax. SUB is the total amount of the subsidies.

3.1.4. Household

The representative household income comes from labor wages and capital rent, and the objective of household consumption is to maximize utility. The household utility is subject to the Klein-Rubin function (**Equation 8**), which is used to derive linear expenditure demand functions.

$$U = \prod_c (X_c - XSUB_c)^{SLUX_c} \tag{13}$$

Where *U* is the utility level of the household, X_c is the total consumption of commodity *c*. $XSUB_c$ is the minimum demand for commodity *c* and is not affected by the commodity price and the household income. The utility will not be produced if consumption is less than $XSUB_c$. $SLUX_c$ is the marginal coefficient, and $SLUX_c$ must sum to the unity.

3.1.5. Dynamic module

This study adopts a recursive dynamic method, and the equations are shown as follows. **Equation 14** is the equation of capital accumulation, which shows that capital stock in the current period first subtracts depreciation and then adds the current new investment, equal to capital stock in the next period. **Equation 15** shows that the gross rate of capital growth is the ratio of new investment to capital stock. It is hypothesized that capital growth follows a logistic function. **Equation 16** shows that the real gross rate of return is the capital rental price divided by capital cost. **Equation 17** shows that the expected gross rate of return is adjusted according to both the expected gross rate of return in the previous period and the real gross rate of return.

$$K_{i,t+1} = I_{i.t} + （1 - \delta） K_{i,t} \tag{14}$$

$$G_{i,t} = I_{i,t}/K_{i,t} \tag{15}$$

$$R_{i,t} = PK_{i,t}/PI_{i,t} \tag{16}$$

$$E_{i,t} = (1-\alpha)E_{i,t-1} + \alpha R_{i,t} \tag{17}$$

Where $K_{i,t+1}$ is the capital stock of the subsequent period, $K_{i,t}$ is the current capital stock, I_{it} is the current investment, and δ is the depreciation rate. $G_{i,t}$ is the gross rate of capital growth and $R_{i,t}$ is the real gross rate of return. $PK_{i,t}$ and $PI_{i,t}$ are the capital rental price and the user cost, respectively. $E_{i,t}$ is the expected gross rate of return, and α is the exogenous coefficient, which represents the adjusting speed of the expected gross rate of return based on the real gross rate of return.

3.2. Data

The basic data used in this paper is the Chinese I-O table in 2015. The 42 sectors in the I-O table are either merged or dismantled for research. The final 17 sectors include agriculture, light industry, heavy industry, construction, transportation, services, three fossil energy sectors (coal, oil, and natural gas), and eight electricity sectors (coal-fired power, gas-fired power, oil-fired power, hydropower, nuclear power, wind power, solar power, and power supply sectors). The disaggregation of the electricity sector in the I-O table will be introduced in detail in the following sections.

This study split the power sector of the I-O table into eight new sectors: seven power production sectors and one power supply sector (Transmission and Distribution, T&D). Firstly, the power sector is disaggregated into the power generation sectors and the T&D sector. Here, this study refers to Lindner et al. and assumes that the split ratio of row and column is equal, and this value is determined according to the share of investment to power generation and T&D. As shown in **Table 1**, the electricity statistics data for 2015 issued by the China Electricity Council give the share of investment to power generation and T&D. Further, the power generation sector is disaggregated into coal-fired power, gas-fired power, oil-fired power, hydropower, nuclear power, wind power, and solar power according to Vennemo et al. [24].

Table 1. Investment in the power sector in 2015

	Total	Power generation	T&D
Amount (bill. RMB)	857.6	393.6	464.0
Share (%)	100	46	54

Various parameters for substitution elasticity are set as follows: the substitution elasticity among electricity is 5 [25]; among fossil energy is 1.2 [26]; the substitution elasticity between fossil energy and electricity is 1.2 [26]; the elasticity parameter between labor and capital vary across different industries and Armington elasticity vary across different commodities, as shown in **Table 2** [27].

Table 2. Settings of substitution elasticity

Industry/Commodity	Labor-capital	Armington
Coal	0.20	3.05
Oil	0.20	5.20
Gas	0.20	5.20
Coal-fired power	1.26	2.80
Gas-fired power	1.26	2.80
Oil-fired power	1.26	2.80
Hydropower	1.26	2.80
Nuclear power	1.26	2.80
Wind power	1.26	2.80
Solar power	1.26	2.80
T&D	1.26	2.80
Agriculture	0.26	3.25
Light industry	1.12	2.00
Heavy industry	1.26	2.95
Construction	1.40	1.90
Transportation	1.68	1.90
Services	1.26	1.90

4. Scenario settings

4.1. Business as usual

Business as usual (BAU) refers to the reference criteria for future policy simulation. Here, it refers to the natural state of China’s economic development without policy support for renewable energy generation. The GDP growth rate and the labor force growth rate are usually set in the baseline scenario (**Table 3**).

Table 3. Settings of BAU

Year	GDP growth rate (%) high/low	Labor force growth rate (%)
2023	5.8/5.6	-0.33
2024	5.8/4.6	-0.33
2025	5.8/4.4	-0.33
2026	4.8/4.0	-0.79
2027	4.8/4.0	-0.79
2028	4.8/4.0	-0.79
2029	4.8/4.0	-0.79
2030	4.8/4.0	-0.79

This study sets high and low GDP growth paths to capture the uncertainty of China's economy in the future. The high GDP growth rate is from Zhang et al. [28]. The low GDP growth rate refers to the predictive value of the IMF. The labor force growth rate is set according to Ma et al. [8].

4.2. Simulation scenarios

Four policy scenarios are set in this paper. S1 simulates the renewable electricity subsidies. Under S1, the subsidy rate is shocked. The study calculates the subsidy rate according to the Chinese tariff's additional standard for renewable energy. The subsidy rate in 2015 was 3.85% and in 2016 was 5.28%. The subsidy rate needs to be continuously improved to achieve the power generation goal of renewable energy. According to China Renewable Energy Outlook 2017, the subsidy policy will gradually withdraw from 2025, and so will the policy simulation.

Both S2 and S3 continue to simulate based on S1; S2 adds a sulfur tax policy based on S1, while S3 adds a carbon tax policy based on S1. S4 adds sulfur tax and carbon tax simultaneously based on S1. That is to say, S2, S3, and S4 are policy combinations of subsidies and taxes. The assignment of the carbon tax rate is based on Dong et al., which is a carbon tax imposed on production with 200 RMB/ton CO_2 [27]. Referring to Wei et al., the study set the sulfur tax rate as 1000 RMB/ton SO_2 [29]. The settings of the simulation scenarios are summarized in **Table 4**.

Table 4. Settings of simulation scenarios

Signs	Scenario description
S1	Increase the subsidy rate of renewable electricity.
S2	Add a sulfur tax policy based on S1.
S3	Adds a carbon tax policy based on S1.
S4	Add sulfur tax and carbon tax simultaneously based on S1.

5. Results

5.1. Impacts on the total emission reductions

Table 5 shows that the total emissions in each scenario decrease relative to the BAU under the low GDP growth assumption; the S4 scenario is the most effective, followed by the S3 scenario. Because the development of renewable energy means the tightening of fossil energy; hence, structures of the primary energy consumption and the power consumption are cleaner. As polluted gas and GHG come from the consumption of fossil energy, the reduction of fossil energy generation brings the benefits of emission reductions.

Concern about GHG emission reductions and the energy-related CO_2 emission trends under high GDP growth assumption are shown in **Figure 2**. Only the energy-related CO_2 emissions can be captured by the CGE model and the energy-related CO_2 emissions in China account for about 93%–94% of the total emission [17]. CO_2 emissions of each scenario are decreasing year by year and the S4 scenario is the most obvious. Hence, the combination of renewable energy subsidies and fossil energy pollution taxes is an optimal choice for achieving both the renewable energy target and the emission reduction target.

Table 5. Total emission reductions relative to the BAU (%)

	2023	2024	2025	2026	2027	2028	2029	2030
LS1-SO2	-0.51	-0.59	-0.67	-0.67	-0.69	-0.71	-0.73	-0.77
LS1-CO2	-0.51	-0.47	-0.41	-0.38	-0.37	-0.37	-0.38	-0.41
LS2-SO2	-1.32	-1.35	-1.39	-1.34	-1.31	-1.29	-1.28	-1.28
LS2-CO2	-1.27	-1.16	-1.01	-0.92	-0.85	-0.79	-0.74	-0.71
LS3-SO2	-4.96	-4.84	-4.71	-4.48	-4.23	-3.97	-3.72	-3.49
LS3-CO2	-4.83	-4.49	-4.07	-3.74	-3.39	-3.03	-2.68	-2.34
LS4-SO2	-7.07	-6.99	-6.86	-6.59	-6.25	-5.86	-5.46	-5.05
LS4-CO2	-6.90	-6.58	-6.12	-5.73	-5.26	-4.75	-4.21	-3.67

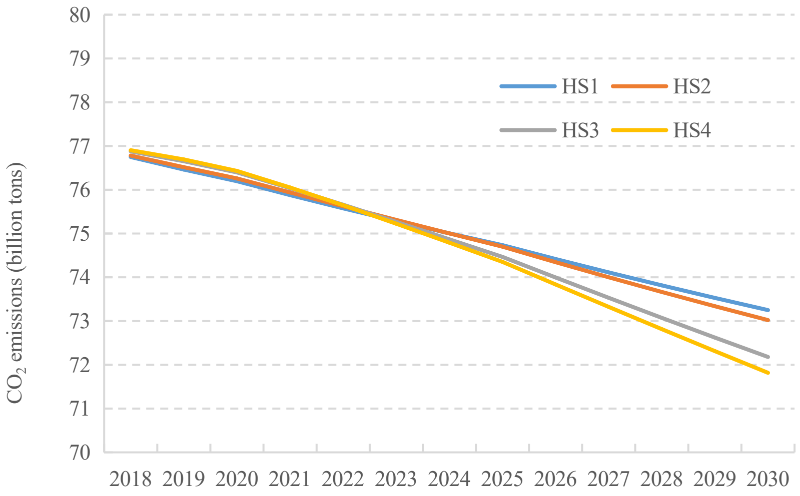

Figure 2. Energy-related CO_2 emission trends

5.2. Impacts on the sectoral emission reductions

Table 6 shows the CO_2 emission reductions of industries in the S1 and S4 scenarios relative to the BAU under the low GDP growth assumption. On the whole, due to the transition from fossil technologies to renewable energy generation, the thermal power sectors face significant decreases in emissions compared to other sectors under both S1 and S4, followed by the coal sector. The output of gas-fired power increases over time because of the promotion of natural gas, so emissions from natural gas and gas-fired power sectors increase relative to the BAU.

In terms of emission reductions of other non-energy sectors, the emissions of agriculture, light industry, heavy industry, construction, transportation, and services under S1 increase relative to the BAU. Because subsidy policy (S1) stimulates the output of the above-related industries, the increase in output causes the increase in fossil energy factors demand. Under the S4 scenario, the emissions of agriculture, light industry, heavy industry, construction, transportation, and service reduce relative to the BAU due to the sulfur tax and carbon tax having been implemented based on a feed-in tariff. The contribution of the construction sector to emission reductions is the most outstanding, followed by the services, transportation, agriculture, light industry, and heavy industry.

Table 6. Sectoral emission reductions of CO_2 relative to the BAU under S1 and S4 (%)

Scenarios	Industries	2023	2024	2025	2026	2027	2028	2029	2030
LS1	Coal	-0.24	-0.19	-0.14	-0.09	-0.06	-0.03	-0.02	-0.02
	Oil	1.47	2.15	2.92	3.09	3.24	3.37	3.47	3.55
	Gas	2.48	3.09	3.80	3.86	3.92	3.97	4.01	4.03
	Coal-fired power	-6.53	-7.97	-9.53	-10.12	-10.76	-11.45	-12.21	-13.03
	Gas-fired power	37.94	51.72	67.12	69.45	71.30	72.69	73.64	74.14
	Oil-fired power	-15.42	-19.95	-24.82	-27.08	-29.30	-31.47	-33.61	-35.72
	Agriculture	1.58	1.97	2.32	2.29	2.22	2.12	1.99	1.83
	Light industry	1.51	2.07	2.62	2.71	2.76	2.77	2.73	2.64
	Heavy industry	2.02	2.84	3.81	4.20	4.59	4.98	5.38	5.78
	Construction	2.70	2.16	1.44	0.72	0.02	-0.63	-1.23	-1.78
	Transportation	2.00	2.53	3.07	3.14	3.20	3.26	3.30	3.34
	Service	1.73	2.03	2.29	2.23	2.16	2.08	1.99	1.89
LS4	Coal	-8.36	-8.16	-7.89	-7.55	-7.14	-6.68	-6.21	-5.74
	Oil	-3.63	-2.52	-1.14	-0.47	0.29	1.09	1.93	2.77
	Gas	-2.62	-1.57	-0.25	0.33	0.99	1.72	2.49	3.29
	Coal-fired power	-12.18	-13.43	-14.79	-15.18	-15.58	-16.01	-16.50	-17.08
	Gas-fired power	38.68	53.38	69.84	72.98	75.64	77.80	79.41	80.46
	Oil-fired power	-21.98	-26.58	-31.44	-33.89	-36.23	-38.47	-40.66	-42.83
	Agriculture	-6.56	-6.05	-5.53	-5.33	-5.08	-4.84	-4.61	-4.43
	Light industry	-4.54	-4.10	-3.58	-3.43	-3.26	-3.09	-2.94	-2.82
	Heavy industry	-3.59	-2.37	-0.81	0.06	1.07	2.16	3.33	4.54
	Construction	-17.58	-16.31	-15.30	-14.41	-13.37	-12.28	-11.26	-10.41
	Transportation	-6.46	-5.78	-5.04	-4.70	-4.31	-3.91	-3.52	-3.16
	Service	-7.87	-7.26	-6.65	-6.31	-5.92	-5.50	-5.12	-4.78

5.3. Impacts on the energy and electricity structure

In the future, the share of renewable energy will increase significantly, as shown in **Figure 3**. Under the low GDP growth path, the LS4 scenario shows that, by 2030, the proportion of renewable energy to the total will reach 24.33%, while the share of natural gas will reach 17.23%, and the proportion of coal consumption in the total energy mix will decrease to 40.21%. Subsidy and pollution tax reduce the price of renewable energy relative to that of fossil energy, which leads to the latter being substituted by the former. The above substitution effect is the result of the optimal decision-making behavior of the economic entity.

Under the high GDP growth path, the HS4 scenario shows that renewable energy will account for 25.16% of the total energy mix by 2030. Hence, high economic growth is more conducive to the development of renewable energy and the optimization of the energy consumption structure. High economic growth results in higher energy demand, which creates more favorable conditions for renewable electricity adoption.

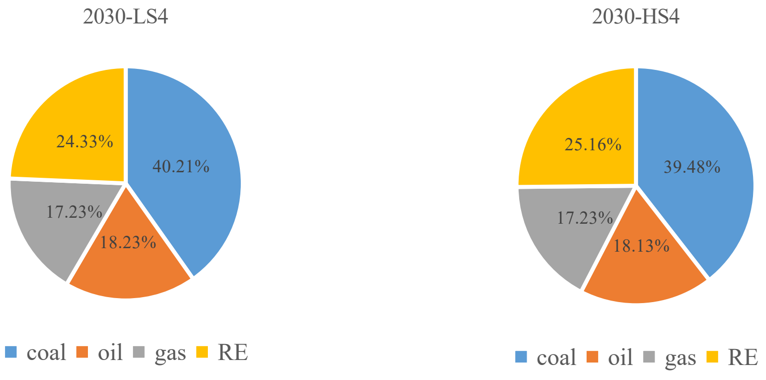

Figure 3. Energy structure of S4 in 2030 under low and high GDP growth

Subsidizing renewable electricity will not only optimize China's energy system by making the energy consumption structure cleaner but also will help achieve the target of increasing the proportion of power generation from non-fossil energy to 50% of total power generation by 2030, which is proposed in the Strategy for Energy Production and Consumption Revolution (2016–2030).

Table 7 shows the proportion of renewable electricity in different years under low and high GDP growth paths of S1. The simulation results show that the share of renewable electricity increases from 42.77% in 2025 to 48.88% in 2030 under the low GDP growth path; under the high GDP growth path, this proportion increases from 43.09% in 2025 to 50.02% in 2030. **Figure 4** shows that the added clean electricity is mainly contributed by wind power and solar power due to the limited potential of hydropower development. Hence, wind power and solar power will develop rapidly in the early stage of energy transition before 2030.

Table 7. Share of renewable electricity (%)

	2025	**2030**
LS1	42.77	48.88
HS1	43.09	50.02

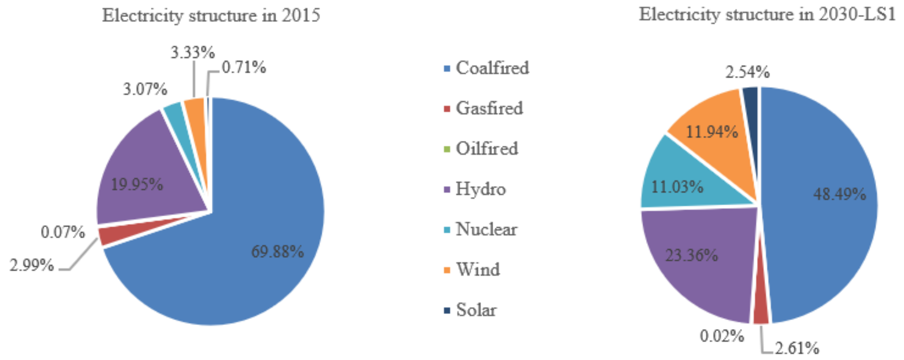

Figure 4. The change in the electricity structure

5.4. Impacts on the economy

As shown in **Table 8**, the feed-in tariff policy (S1) has positive impacts on China's real GDP and employment, and the positive effects on employment increase year by year. The reason is that subsidies stimulate the development of the entire renewable energy industry and the related upstream and downstream industries, creating economic output and employment. As mentioned by Dai et al., developing renewable energy requires the purchase of special equipment, such as wind turbines and silicon plates, which is a huge investment, aside from that incurred in building fossil-fired power plants, and one that creates output from upstream industries, green growth points, and employment [16].

Based on the S1 scenario, if a sulfur tax policy is added (S2), the increase of real GDP and employment is lower than that of S1 compared to the BAU, and the values are negative in the first two years. Under the S4 scenario, i.e., adding sulfur tax and carbon tax simultaneously based on S1, the negative impacts of real GDP and employment are further increased. The impact path of taxation is to increase the production cost through energy prices and promote the enterprises to adjust the production scale under the new cost constraints.

Table 8. Changes in real GDP and employment relative to the BAU (%)

Year	Real GDP				Employment			
	S1	S2	S3	S4	S1	S2	S3	S4
2023	1.09	0.87	-1.07	-2.66	2.35	2.05	-0.36	-2.26
2024	1.04	0.86	-0.77	-2.37	2.69	2.43	0.41	-1.48
2025	0.94	0.77	-0.62	-2.16	3.06	2.82	1.09	-0.70
2026	0.83	0.67	-0.54	-1.99	3.11	2.88	1.38	-0.30
2027	0.73	0.58	-0.48	-1.79	3.18	2.96	1.65	0.16
2028	0.63	0.49	-0.44	-1.58	3.28	3.06	1.92	0.64
2029	0.54	0.40	-0.42	-1.38	3.41	3.20	2.19	1.13
2030	0.46	0.33	-0.41	-1.21	3.57	3.37	2.46	1.61

6. Conclusions

This paper establishes a dynamic CGE model to study the impacts of China's renewable energy policies on emission reductions, energy and electricity structure, and economy. The main conclusions are drawn as follows.

China is currently promoting environmental governance, especially air pollution control. The development of renewable energy is an inevitable choice to achieve air pollution control. The dynamic simulation results capture the changes in emission reductions relative to the BAU each year and the dynamic trajectory of emissions. The expansion of renewable energy can bring emission reductions by significantly reducing the consumption of fossil energy, and the power sectors face significant decreases in emissions compared to other sectors due to the transition from fossil technologies to renewable energy generation. The results will provide valuable references for policy-making and lay the foundation for the subsequent related research of renewable energy policies.

The simulation benchmark can better reflect the current situation of renewable energy in China by using the input-output data, which makes recursive results closer to reality. By 2030, the share of renewable electricity will reach 48.88% under a low GDP growth path and 50.02% under a high GDP growth path. The increased share of clean electricity is mainly contributed by wind power and solar power. As both of these will develop rapidly in the early stage of energy transition before 2030, relevant safeguards should be put on the agenda.

High economic growth is more conducive to renewable energy development and the optimization of the energy consumption structure. Moreover, a sulfur tax and carbon tax policy can indirectly promote the deployment of renewable energy by restraining the consumption of fossil energy. The main way that carbon tax can influence renewable energy development is by increasing the cost of fossil energy consumption, thereby changing the renewable energy and fossil energy comparative advantages. Therefore, the government can gradually improve the construction of the carbon market, making the carbon market an increasingly important driving force for renewable energy development.

Developing renewable energy can have positive impacts on China's real GDP and employment, but the impacts on real GDP and employment are negative if a sulfur tax and a carbon tax are added simultaneously based on subsidies. The environmental tax policy has a significant positive effect on emission reductions, but it cannot achieve the dual objectives of environmental protection and economic growth. Hence, policymakers should weigh the pros and cons constantly and adjust relevant measures according to the development goals.

In summary, developing renewable energy is a key aspect of China's environmental governance due to its huge environmental benefits and vital role in global GHG emission reductions. Hence, this study proposes that the Chinese government takes the development of renewable energy as an important national strategy and offers support in funding, technology, and policies.

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Author contributions

Study conceptualization: Yurong Zhao
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