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Energy Policy, Market Environment and Renewable Energy Development: Quantitative Evaluation Based on CGE Model

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ABSTRACT: In order to investigate the impacts of government policy and market environment on the development of renewable energy, this paper constructs a computable general equilibrium (CGE) model to simulate the impacts of policy scenarios, market scenarios and policy-market scenarios on renewable energy output and investment, energy structure, economy and environment based on China's input-output extension table in 2020. The results show that: the subsidy can optimize the energy structure and power structure, and non-hydropower renewable energy represented by wind power and solar power will become a new force of energy supply in China; the market environment of traditional energy price rising will increase the output and investment of renewable energy, and the energy policy can offset the negative impacts of traditional energy price downward on renewable energy; the impacts of subsidy on GDP, employment and emission reduction is positive; the GDP and employment is benefit from the market environment of traditional energy price downward, but the environment is damaged due to stimulating energy consumption. Finally, the government should support the renewable energy through energy policy, and monitor the market risk of the price fluctuation of traditional energy, so as to make the renewable energy become the key force of the transition of economic development mode and the focus of the breakthrough of energy environment dilemma. The novelty of this paper lies in simultaneously constructing policy scenarios, market scenarios, and integrated policy-market scenarios to examine the development of renewable energy and its corresponding economic and environmental impacts under each type of scenario, while also validating the effectiveness of energy policies in mitigating market risks.

KEYWORDS: Renewable energy; subsidy; emission reduction; CGE model

1 Introduction

Global energy will increasingly shift toward low-carbon and zero-carbon sources. Vigorously developing renewable energy has become a common consensus and collective action worldwide in advancing the energy revolution and addressing climate change. As the economy fully recovers, China's energy demand will continue to grow. Expanding renewable energy is an essential step to strengthen national energy security and gradually achieve energy independence. It is also an objective requirement for ecological conservation and sustainable development. China's roadmap for fulfilling its dual carbon commitments centers on two key 2030 milestones: sourcing roughly 25% of its primary energy from non-fossil fuels and scaling up its combined wind and solar power capacity to more than 1.2 billion kilowatts. The China's 2035 Nationally Determined Contributions Report proposes that by 2035, the share of non-fossil fuels in total energy consumption should reach over 30%, and the total installed capacity of wind and solar power should be at least six times the 2020 level, striving to reach 3.6 billion kilowatts. Therefore, renewable energy will play

a key role in achieving the carbon peak and carbon neutrality targets, leading the mainstream direction of energy production and consumption revolution.

The development of renewable energy is influenced by both government planning and technological innovation, but it is also inevitably affected by market mechanisms. From a policy perspective, renewable energy subsidies and mandatory quota policies will play important roles. From a market perspective, price fluctuations of traditional fossil fuels are one of the uncertainties in renewable energy development, with oil being the most representative fossil fuel. In the process of renewable energy development, a critical factor to consider is whether oil prices will significantly impact its progress [1].

During the energy transition, how will renewable energy policies affect renewable energy itself, the energy mix, the economy, and the environment? How will market factors promote or hinder the development of renewable energy? What effects will the combined influence of policy and market factors generate? The findings of this study are expected to offer valuable insights and decision-making references for the Chinese government in coordinating the development of renewable energy and implementing the “dual carbon” goals.

2 Literature Review

In the realm of policy research aimed at promoting renewable energy development, the first category focuses on subsidies. Existing studies predominantly employ input-output or CGE models to quantify the impact of subsidy policies on carbon emissions, energy structure and GDP [2–4]. The results indicate that renewable energy subsidy policies effectively alter the substitution elasticity between fossil fuels and renewable energy, leading to reduced energy prices, optimized energy consumption structure, lower carbon dioxide emissions, and promoted economic growth. Furthermore, the analysis in reference [5] indicates that, in contrast to energy finance policies, renewable energy subsidies can moderate the subsequent effects on GDP within a carbon peaking context. Utilizing an 11-year panel dataset (2011–2021) covering 114 listed companies in China’s renewable energy sector, reference [6] demonstrates that subsidies have promoted investment in renewable energy.

The second category of policy research addresses renewable portfolio standards (RPS). The findings of reference [7] demonstrate the significant potential of China’s RPS policies to not only stimulate renewable power generation but also improve the environmental performance of the entire power supply chain, as evidenced by a power supply chain network equilibrium model. Using the increase in solar energy consumption in Iowa as a proxy for the RPS, the findings of reference [8] based on the Autoregressive Distributed Lag model reveal that the renewable portfolio standards can significantly reduce carbon emissions. Additionally, reference [9] builds an environmental dynamic stochastic general equilibrium model to evaluate China’s climate policy mix, which includes the RPS, and determines that the optimal proportion of renewable energy is 62.4%.

Studies of the market factors that influence renewable energy development have predominantly examined the interaction between oil prices and renewable energy. Reference [1] examines the linkage between renewable energy investment, oil prices, macroeconomic conditions, and policies in Norway, the UAS, and the UK by employing the VAR methodology, finding that the interplay between renewable energy and oil prices varies depending on a nation’s status as a net oil importer or exporter and its level of renewable energy support. Based on data spanning from 22 February 2022, to 15 July 2024, the application of Wavelet Quantile Correlation analysis in reference [10] reveals that indicates that oil price uncertainty exerts adverse long-term effects on the European renewable energy sector. The empirical analysis in reference [11], using a Bayesian Vector Autoregression model, shows that a positive oil price shock promotes renewable energy consumption with a lagged effect in Bangladesh. Reference [12] confirms that rising oil prices act as a driver for increased

renewable energy consumption in China, but reference [13] failed to establish a significant causal relationship between real oil prices and the deployment of renewable energy.

The above content is summarized in Table 1 as shown below.

Table 1: Summary table of literature review.

Dimension	Research Category	Representative Literature	Core Methodology	Key Findings/Focus	Research Gaps/Limitations
Policy Factors	Subsidy Policy Studies	[2–6]	Input-Output Model, CGE Model, Panel Data Analysis	Subsidies can optimize the energy structure, reduce carbon emissions, promote economic growth and renewable energy investment.	Few dynamically assess the interplay with market price fluctuations.
	Renewable Portfolio Standards (RPS)	[7–9]	Power Supply Chain Network Equilibrium Model, ARDL Model, Environmental DSGE Model	RPS can incentivize renewable power generation, improve the environmental performance of the power supply chain, and aid emission reduction.	Lacking systematic assessment of overall macroeconomic and employment.
Market Factors	Oil Price & Renewable Energy Linkage	[1,10–13]	VAR Model, Wavelet Quantile Correlation, Bayesian VAR Model	The relationship between oil prices and renewable energy varies depending on a country's energy structure and policy support level; oil price uncertainty exerts adverse long-term effects on renewable energy; rising oil prices have a lagged positive effect on renewable energy consumption in certain contexts.	Most studies rely on econometric methods.

In summary, while there is a substantial body of research examining the influence of either policy or market factors on renewable energy in isolation, integrated analyses that combine these two dimensions are relatively scarce. Moreover, the existing literature primarily relies on econometric methods to explore the relationship between traditional energy prices—as represented by oil prices—and renewable energy. Through establishing policy, market, and integrated policy-market scenarios, this study will simulate renewable energy development and its associated socioeconomic and environmental impacts under each scenario using a CGE model. The marginal contributions are: (1) Under a dynamic CGE model framework, setting policy scenarios represented by subsidies and market scenarios represented by bidirectional fluctuations in oil prices, while also establishing combined policy and market scenarios, to simulate and analyze the impacts under each type of scenario; (2) To reveal the influence patterns of traditional energy price volatility on the dynamics of renewable energy and verify the effectiveness of energy policies in mitigating market risks.

The remainder of this paper is organized as follows: Section 3 describes the model and data, Section 4 presents the scenarios setting, Section 5 discusses the results and Section 6 concludes the paper.

3 Research Design

3.1 CGE Model

The basic framework of the CGE model as shown in Fig. 1. The CGE model constructed in this paper comprises the production module, the environmental and subsidy module, the investment, consumption, and export demand module, and the dynamic module.

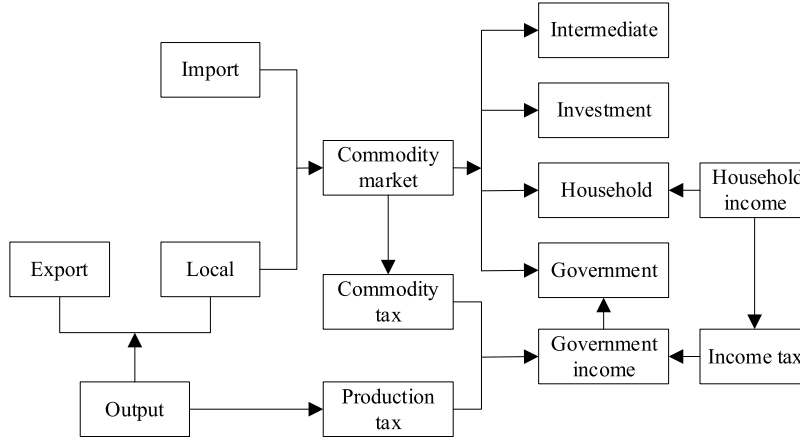


Figure 1: Basic framework of the CGE model.

3.1.1 Production

Fig. 2 illustrates the structure of the production module. At the top level, intermediate inputs, energy composite goods, and initial factor composite goods are aggregated into total output via the Leontief function, as depicted in Eqs. (1) and (2).

$$X1TOT_i = \min \left(\frac{XCOM_i}{a_{ci}}, \frac{XENE_i}{a_{ei}}, \frac{XFAC_i}{a_{fi}} \right) \quad (1)$$

$$P1TOT_i * X1TOT_i = PCOM_i * XCOM_i + PENE_i * XENE_i + PFAC_i * XFAC_i \quad (2)$$

Eq. (1) is a Leontief production function, while Eq. (2) can be interpreted as a budget constraint. Based on Eqs. (1) and (2), the demand for various inputs ($XCOM$, $XENE$, $XFAC$) is derived. Here, $X1TOT$ is the gross output of the industry, $P1TOT_i$ is the corresponding output price; $XCOM_i$, $XENE_i$ and $XFAC_i$ are the intermediate input, energy composite, and primary factor composite, respectively, $PCOM_i$, $PENE_i$ and $PFAC_i$ are the corresponding prices; a_{ci} , a_{ei} and a_{fi} are the input-output coefficients satisfying $a_{ci} + a_{ei} + a_{fi} = 1$.

At the second level, the intermediate input composite is nested from domestic and imported goods using a CES production function, as shown in Eqs. (3) and (4). The energy composite is nested from the fossil energy composite and the electricity composite using a CES production function. The primary factor composite is nested from labor and capital using a CES production function. The functional forms are not repeated here.

$$XCOM_i = A_{com,i} \left(\delta_{dom,i} XDOM_i^{\rho_{com,i}} + \delta_{imp,i} XIMP_i^{\rho_{com,i}} \right)^{\frac{1}{\rho_{com,i}}} \quad (3)$$

$$PCOM_i * XCOM_i = PDOM_i * XDOM_i + PIMP_i * XIMP_i \quad (4)$$

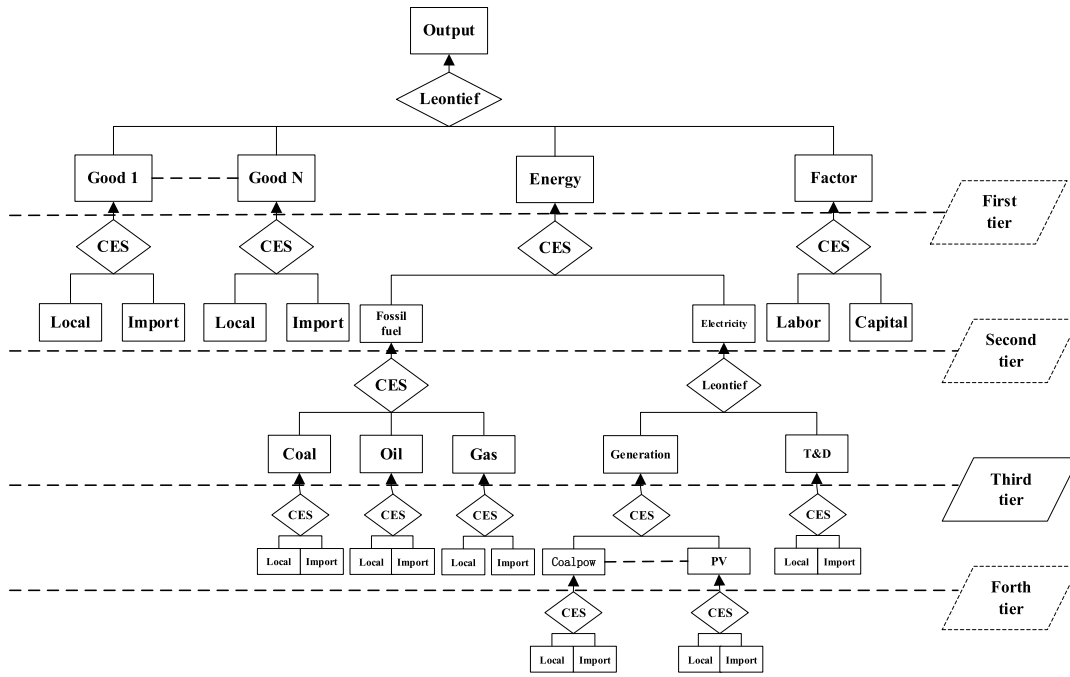


Figure 2: Production module.

Eq. (3) is a CES production function, while Eq. (4) can be interpreted as a budget constraint. Based on Eqs. (3) and (4), the demand for various inputs (X_{DOM} , X_{IMP}) is derived. Here, X_{DOM_i} and X_{IMP_i} are the domestic product and imported product, respectively; P_{DOM_i} and P_{IMP_i} are the corresponding prices; $\delta_{dom,i}$ and $\delta_{imp,i}$ are the share parameters satisfying $\delta_{dom,i} + \delta_{imp,i} = 1$; $\rho_{com,i}$ is the parameter related to the elasticity of substitution; $A_{com,i}$ is the technology parameter.

At the third level, fossil energy is defined as a CES composite of coal, oil, and natural gas. Electricity supply and electricity production are combined into electricity using a Leontief function. At the fourth level, electricity production is composed of various types of power, namely coal-fired power, gas-fired power, oil-fired power, hydropower, nuclear power, wind power, and solar power, combined using a CES function. The relevant functional forms are not repeated here.

3.1.2 Environment and Subsidy

The pollutant emissions from an industry caused by fossil energy use equal the industry's fossil energy input multiplied by the emission factor of the fossil energy and then multiplied by the industry's clean technology parameter, as shown in Eq. (5). An industry's total pollutant emissions are defined in Eq. (6) as the sum of emissions from all fossil energy sources used. The total pollutant emissions are the sum of production, household, and government emissions, which is given by Eq. (7).

$$EMI_{fi} = X_{fi} * EMIF_f * CLE_i \quad (5)$$

$$EMI_i = \sum_f EMI_{fi} \quad (6)$$

$$EMIT = \sum_i EMI_i + HEMI + GEMI \quad (7)$$

Here, EMI_{fi} denotes the emissions caused by industry i 's use of fossil energy f ; X_{fi} quantifies the consumption of fossil energy f by industry i ; $EMIF_f$ denotes the emission factor of fossil energy f ; CLE_i is the clean technology parameter of industry i ; EMI_i refers to the aggregate emissions of industry i ; $EMIT$ denotes the total emissions; $HEMI$ and $GEMI$ represent the total household emissions and total government emissions, respectively.

Renewable energy subsidies lower the purchase price of renewable electricity for consumers, as shown in Eq. (8).

$$P_k = \frac{P_{0,k}}{1+s} \quad (8)$$

Here, P_k is the consumer's purchase price for renewable electricity; $P_{0,k}$ is the market price of renewable electricity; k represents a range of renewable electricity eligible for subsidies; s is the subsidy rate.

3.1.3 Investment, Consumption, and Export

At the top level, new capital formation is governed by a Leontief function that combines various investment goods. The second tier models the composition of each input commodity using a CES function to nest domestic and imported products. The specific functional forms are not repeated here.

In the household consumption module, the top level employs the Klein-Rubin utility function, as shown in Eq. (9), to derive the linear expenditure demand function under budget constraints. A CES function is applied at the second level to model each consumption commodity as a nest of domestic and imported variants.

$$U = \prod_c (X3_c - X3SUB_c)^{SLUX_c} \quad (9)$$

Here, U represents utility; $X3_c$ denotes the household consumption quantity of product c ; $X3SUB_c$ is the minimum subsistence demand for product c (where no utility is generated if consumption falls below $X3SUB_c$); $SLUX_c$ represents the marginal consumption share of product c , satisfying the condition $\sum_c SLUX_c = 1$.

Exports are influenced by export prices, foreign prices, and foreign income, as shown in Eq. (10). Higher export prices lead to lower export volumes, indicating a negative correlation between the two. Higher foreign income leads to increased export volumes, while foreign prices, foreign income, and the exchange rate are positively correlated with export volumes.

$$X4_c = F4_c * \left(\frac{P4_c}{PHI * PWD_c} \right)^{\sigma 4_c} \quad (10)$$

Here, $X4_c$ represents the export volume, $F4_c$ denotes variables affecting foreign income, $P4_c$ is the exchange rate; PWD_c is the world price, $\sigma 4_c$ is the export elasticity.

3.1.4 Dynamic Module

This paper utilizes a recursive dynamic framework. The change in the capital stock follows Eq. (11), where the stock at $t + 1$ is derived from the previous stock plus net investment (new investment minus depreciation). The gross growth rate of the capital stock in period t is defined as the ratio of new investment to the existing capital stock, as specified in Eq. (12). The actual gross return on capital in period t is defined

as the ratio of its rental price to its cost, as given in Eq. (13). The expected rate of return on capital is updated from its value in period $t - 1$ and the actual gross return, as shown in Eq. (14).

$$\Delta K_{i,t+1} = I_{i,t} - \delta K_{i,t} \quad (11)$$

$$G_{i,t} = I_{i,t} / K_{i,t} \quad (12)$$

$$R_{i,t} = PK_{i,t} / PI_{i,t} \quad (13)$$

$$E_{i,t} = (1 - \alpha) E_{i,t-1} + \alpha R_{i,t} \quad (14)$$

Here, $\Delta K_{i,t+1}$, $I_{i,t}$ and $K_{i,t}$ denotes the change in the capital stock occurring in period $t + 1$, the new investment for period t , and the capital stock in period t , respectively. δ is the depreciation rate. $G_{i,t}$ and $R_{i,t}$ denote the gross growth rate of the capital stock for period t and the actual gross return on capital in period t , respectively. $PK_{i,t}$ and $PI_{i,t}$ represent the rental price of capital in period t and the cost of capital at time t , respectively. $E_{i,t}$ denotes the expected rate of return on capital, and α represents the speed at which the expected return adjusts to the actual gross return.

3.2 Data

This study employs China's 2020 extended input-output table as its primary dataset. The original 42 sectors are merged and disaggregated into 17 sectors. Sector merging follows their industrial attributes. The disaggregation of energy sectors is described below. First, the oil and natural gas sectors are separated. Their production cost structures and sales destinations differ significantly. The columns of the input-output table are split based on the relative proportion of their production shares in 2020. The rows are split based on the relative proportion of their consumption shares. Second, the power sector is disaggregated, following the approaches of reference [14] and reference [15]. The first step involves disaggregating the power sector into two distinct components: power generation, and transmission & distribution (T&D), using the same splitting ratio for both rows and columns. This ratio is determined based on the 2020 share of power source investment (46%) and grid investment (54%) in total power investment. The former represents investment in power generation, while the latter represents investment in T&D. In the second step, the power generation is further disaggregated into coal-fired, gas-fired, oil-fired, hydropower, nuclear power, wind power, and solar power generation.

Furthermore, various elasticity parameters are set according to relevant studies. The substitution elasticity among clean power sources is set at 5 [16]. The substitution elasticity between clean and thermal power is parameterized with a value of 2 [17]. The elasticity among fossil energy sources, and between fossil energy and electricity, are both set at 1.2 [17]. The labor-capital substitution elasticity and the Armington elasticity differ significantly across industries [18].

4 Scenarios Setting

This study primarily establishes a baseline scenario and simulation scenarios. The baseline scenario serves as a reference standard for the simulation scenarios, representing the natural state of economic development in the absence of energy policies and market shocks. The model's baseline scenario assumes specific trajectories for GDP and labor force growth. According to OECD Economic Outlook, China's GDP growth rate is forecasted to be 4.4% in 2026 and 4.3% in 2027. Based on this trend, we assume that the GDP growth rates for 2028 to 2030 will be 4.2%, 4.1%, and 4.0%, respectively. The labor growth rate is based on the projections in reference [19].

The simulation scenarios mainly include policy scenarios, market scenarios, and policy-market scenarios. The policy scenario is designed to meet the 2030 target of 25% renewable energy in primary energy

consumption through subsidies. The market scenario is represented by typical international oil price shocks. Given the numerous and uncertain factors influencing international oil price fluctuations, simulating small fluctuations is more informative than simulating large ones [20]. Additionally, since this study aims to simulate the impact of oil price fluctuations rather than to predict oil prices, setting oil price fluctuation amplitudes based on relevant studies is both feasible and reasonable. Therefore, the market scenarios simulate annual average increases and decreases of 3% (derived based on data calculations from the Commodity Markets Outlook of World Bank Group in 2024) in international oil prices, projected until 2030. The policy-market scenario is designed to account for the potential adverse effects of falling oil prices on renewable energy development. It combines falling oil prices with subsidy policies to examine the combined impact of policy and market factors, as well as the role of policies in mitigating market risks.

The specific settings for the baseline scenario and simulated scenarios are shown in [Table 2](#).

Table 2: Baseline scenario and simulation scenario settings.

	Year	GDP Growth Rate	Labor Growth Rate
Base Scenario	2026	4.4	−0.79
	2027	4.3	−0.79
	2028–2030	4.0	−0.79
Scenario Code		Scenario Description	
Simulated Scenario	Policy Scenario	SUB	The subsidy policy aims to achieve a 25% share of renewable energy in primary energy consumption by 2030 (the subsidy rate should increase by 2% annually)
	Market Scenario	OP+3	International oil prices have increased by an average of 3% annually.
		OP-3	International oil prices decline by an average of 3% annually.
	Policy-Market Scenarios	SUB & OP-3	International oil prices decline by an average of 3% annually plus subsidy policies

5 Results

5.1 Renewable Energy

Under the policy scenario, which aims to achieve the target of 25% renewable energy in primary energy mix by 2030 through subsidies, the energy mix and power structure become cleaner and greener, as shown in [Fig. 3](#). By 2030, the primary energy mix is expected to be redistributed, with coal, oil, and natural gas constituting 43%, 17%, and 15%, respectively. The results under this scenario show that the share of renewable energy generation in total electricity generation will reach 57% by 2030. [Fig. 4](#) presents the power structure in 2030 under the policy scenario. Wind and solar power will account for 15% and 3%, respectively, with non-hydro renewable energy becoming a new force in China's clean energy supply.

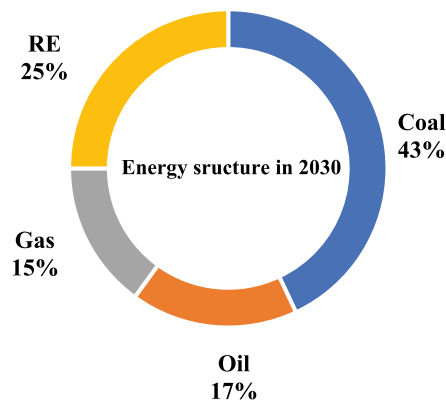


Figure 3: Energy structure in 2030.

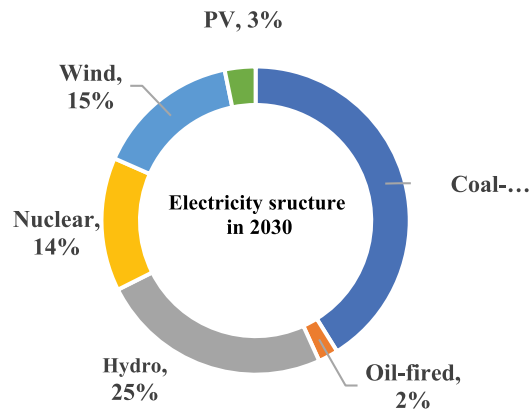


Figure 4: Electricity structure in 2030.

It is noteworthy that coal remains the largest single energy source, indicating the need for more innovative balancing strategies between “energy security” and “accelerated low-carbon transition.” Furthermore, the increasing share of variable renewable energy exponentially amplifies the demand for system flexibility, urgently calling for simultaneous advancements in energy storage technology and innovations in electricity market mechanisms. Therefore, achieving the 25% renewable energy target is not merely about meeting a quantitative goal but represents a critical opportunity to drive the transformation of China’s energy governance system from “scale expansion” to “quality and efficiency”.

The changes in renewable energy output and investment growth rate relative to the baseline scenario under different scenarios are shown in [Table 3](#). Under the policy scenario, subsidies lead to a year-by-year increase in renewable energy output compared to the baseline. By 2030, renewable energy output increases by 21.39% compared to the baseline. The increase in the renewable energy investment growth rate relative to the baseline peaks in 2027 at 29.19%. This demonstrates that targeted subsidies can not only effectively stimulate short-term investment enthusiasm but also, through the formation of scale effects, provide sustained momentum for the long-term sustainable development of renewable energy.

Table 3: Change in renewable energy output and investment growth rate relative to the baseline scenario (%).

Scenario	Variable	2026	2027	2028	2029	2030
SUB	Output	10.25	12.11	14.57	17.18	21.39
	Investment Growth Rate	28.31	29.19	27.11	23.24	19.58
OP+3	Output	0.78	0.97	1.23	1.69	1.91
	Investment Growth Rate	1.82	2.25	2.53	2.61	2.72
OP-3	Output	−0.82	−1.20	−1.53	−1.96	−2.31
	Investment Growth Rate	−2.21	−2.82	−3.27	−3.43	−3.56
SUB&OP-3	Output	3.41	4.35	5.14	6.07	6.98
	Investment Growth Rate	13.55	14.37	14.27	13.35	11.93

Under the market scenario with oil price shocks, rising international oil prices lead to increases in both renewable energy output and investment growth rate. By 2030, with an average annual oil price increase of 3%, renewable energy output rises by 1.91% relative to the baseline, while the investment growth rate increases by 2.72%. The opposite occurs when international oil prices fall, but the effect of rising vs. falling oil prices on renewable energy output and investment growth is asymmetric, with a greater impact observed during price declines. This asymmetry reflects the continued structural vulnerability in the cost competitiveness of renewable energy. When oil prices rise, although increased costs of conventional energy can promote substitution, the transmission effect is constrained by rigid energy demand and technological transition lags. Conversely, when oil prices fall, the price advantage of conventional energy rapidly squeezes the market space for renewables, exerting a stronger suppressive effect.

Falling oil prices negatively impact renewable energy output and investment. However, simulation results from the policy-market scenario show that when a 3% average annual oil price decrease is combined with subsidy policies, the impact on renewable energy output and investment growth turns from negative to positive. By 2030, renewable energy output increases by 6.98% relative to the baseline, and the investment growth rate increases by 11.93%. This further demonstrates that, against the backdrop of increasing uncertainty in renewable energy development due to external market shocks, proactive and well-structured policy interventions can not only mitigate negative impacts but also serve as strategic levers to drive the transformation of the energy structure. Therefore, building a resilient renewable energy policy system requires a focus on the dynamic coordination between policy instruments and market signals.

Fig. 5 presents the deviation in the return on renewable energy investment from the baseline under a portfolio of scenarios. Overall, over time, the gap in investment return rates between various scenarios and the baseline scenario shows a widening trend, yet the direction and underlying mechanisms of these changes differ significantly. Specifically, under scenarios involving subsidy policies alone or rising international oil prices, the investment return rate for renewable energy continues to improve relative to the baseline scenario. This is primarily driven by two factors: subsidy policies directly reduce project development costs and operational risks, thereby enhancing capital's expected returns, while rising oil prices indirectly strengthen the market competitiveness and profitability of renewable energy by increasing the comparative cost of fossil fuels. Notably, in scenarios where oil prices decline, the investment return rate significantly drops relative to the baseline scenario, reflecting the direct suppressive effect of the price advantage of traditional energy on the economic viability of renewables. However, when subsidy policies are introduced alongside declining oil prices, the investment return rate shifts from negative to positive, achieving a structural reversal. This phenomenon reveals that, in adverse market conditions, targeted policy interventions can effectively hedge

against price shocks and sustain the commercial appeal of renewable energy investments by reshaping the relative price dynamics of energy sources.

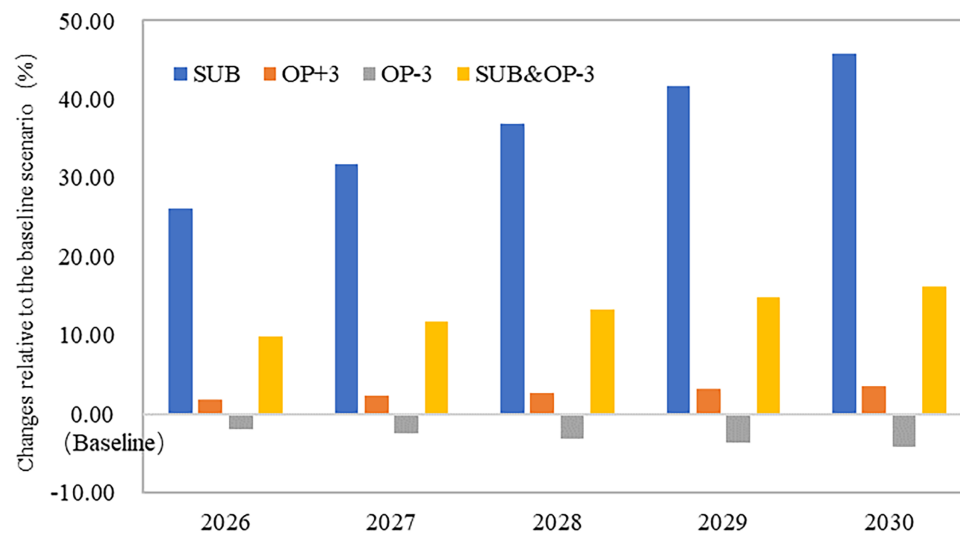


Figure 5: Variation in renewable energy investment returns relative to the baseline scenario.

5.2 Macroeconomics

The changes in GDP and employment relative to the baseline scenario under different scenarios are shown in Table 4. Subsidy policies generate positive effects on both GDP and employment. By 2030, GDP exceeds the baseline level by 1.08%, while employment is 4.13% higher. Developing renewable energy requires the procurement of specialized equipment, and such investments help stimulate economic output in upstream and downstream industries while creating jobs.

Table 4: Impact on GDP and employment relative to the baseline (%).

Scenario	Macroeconomic Variables	2026	2027	2028	2029	2030
SUB	GDP	1.05	1.13	1.20	1.15	1.08
	Employment	1.44	1.88	2.49	3.20	4.13
OP+3	GDP	-0.07	-0.13	-0.19	-0.28	-0.41
	Employment	-0.20	-0.34	-0.51	-0.69	-0.95
OP-3	GDP	0.08	0.13	0.21	0.31	0.45
	Employment	0.19	0.35	0.53	0.78	1.03
SUB&OP-3	GDP	0.72	0.83	0.95	1.02	1.12
	Employment	0.98	1.21	1.78	2.16	2.70

Simulation results under the market scenario indicate that rising oil prices lead to declines in both GDP and employment. By 2030, with an average annual oil price increase of 3%, GDP decreases by 0.41% and employment decreases by 0.95% relative to the baseline. Falling oil prices exert opposing effects on GDP and employment. Lower international oil prices reduce China's oil import costs, thereby lowering costs across the petrochemical industry. This ultimately reduces overall macroeconomic operating costs through industrial chain transmission and promotes economic development. By 2030, with an average annual oil price decrease

of 3%, GDP increases by 0.45% and employment increases by 1.03% relative to the baseline. The effects of oil price increases and decreases on GDP and employment are asymmetric, with price declines having a more pronounced impact than increases.

Under the policy-market scenario, where subsidy policies are implemented alongside falling oil prices, the positive effects on GDP and employment are further strengthened. By 2030, under the SUB&OP-3 scenario, GDP increases by 1.12% and employment increases by 2.70% relative to the baseline. This dual-growth trend highlights the critical value of policy intervention in counter-cyclical adjustment. When the market faces downward pressure on traditional energy prices, targeted subsidies not only cushion the impact on the renewable energy sector but also generate a net positive pull on the overall economy by stimulating investment vitality across the industrial chain and fostering the diffusion of technological innovation.

5.3 Carbon Emission Reduction

In the energy sector, promoting renewable energy through subsidy policies implies a reduction in fossil fuel use. This leads to a cleaner structure in both primary energy consumption and electricity consumption. Since pollutant and greenhouse gas emissions originate from fossil fuel combustion, reduced fossil fuel usage brings emission reduction benefits. Moreover, decreased use of thermal power further reduces fossil fuel consumption. As shown in Table 5, carbon emissions under the policy scenario decrease compared to the baseline. Carbon emissions in 2026 decreased by 0.75% compared to the baseline scenario, while by 2030, they decreased by 1.73%. The magnitude of emission reductions relative to the baseline scenario increases year by year.

Table 5: Changes in carbon emissions relative to the baseline (%).

Scenario	2026	2027	2028	2029	2030
SUB	-0.75	-1.01	-1.25	-1.51	-1.73
OP+3	-0.10	-0.21	-0.301	-0.40	-0.51
OP-3	0.11	0.20	0.32	0.45	0.61
SUB&OP-3	-0.14	-0.11	-0.09	-0.06	0.04

Under the market scenario, the sustained rise in oil prices also leads to an increasing reduction in carbon emissions relative to the baseline scenario each year. Carbon emissions are 0.10% lower than the baseline in 2026, decreasing to 0.51% lower by 2030. On one hand, rising oil prices increase economic operating costs, suppress energy consumption, and consequently reduce carbon emissions, improving air quality. On the other hand, as mentioned earlier, rising oil prices favor the expansion of renewable energy, which also contributes to improved air quality. Conversely, under persistently falling oil prices, economic operating costs decrease accordingly, stimulating energy consumption and worsening air quality. Carbon emissions are 0.11% higher than the baseline in 2026, increasing to 0.61% higher by 2030. If the policy scenario is introduced alongside falling oil prices, carbon emissions remain lower than the baseline up until 2029, after which they increase. However, the magnitude of this increase is significantly reduced, reaching only 0.04% above the baseline by 2030 (compared to the original 0.61%). This indicates that subsidy policies can mitigate the environmental damage caused by falling oil prices. The subsidies enhance the relative competitive advantage of renewable energy, displacing some fossil fuel consumption. However, due to the limited nature of this substitution effect, carbon emissions eventually increase compared to the baseline over time.

5.4 Sensitivity Analysis

To enhance the robustness of the results, we conducted sensitivity tests on key uncertain parameters. The tests confirm that while the magnitude of certain outcomes shows moderate sensitivity, the core qualitative conclusions—such as the feasibility of achieving the 2030 renewable target and the direction of macroeconomic impacts—remain consistent across all parameter ranges. This supports the structural reliability of the model despite inherent parametric uncertainties. As shown in Table 6, when the substitution elasticity between fossil energy and electricity varies within the range of (1–1.5), the variations in key results such as renewable energy output, GDP, and employment remain relatively minor. This indicates that the model demonstrates good stability under these parameter changes.

Table 6: Robustness check results (%).

Index (2030)	E = 1	E = 1.2 (baseline)	E = 1.5	Maximum Variation Amplitude
Change in Renewable Energy Output Relative to the Baseline Scenario under SUB&OP-3	6.87	6.98	7.11	0.13 percentage points
Change in GDP Relative to the Baseline under SUB&OP-3	1.02	1.12	1.23	0.11 percentage points
Change in Employment Relative to the Baseline under SUB&OP-3	2.58	2.70	2.85	0.15 percentage points

6 Conclusions and Discussion

Renewable energy development plays a pivotal role in addressing the dual challenges of energy constraints and climate change, yet it is influenced by both government policies and market conditions. This study develops a CGE model to evaluate the implications of energy policy measures, represented by subsidies, and market shocks, represented by oil price fluctuations, on renewable energy output and investment, as well as their effects on the energy structure, macroeconomy, and carbon emission reduction. The main findings and corresponding implications are as follows:

First, subsidy policies play a significant and targeted guiding role in optimizing the energy structure. Research findings indicate that targeted subsidies can directly increase the share of renewable energy in the power generation mix (projected to reach 57% by 2030), with wind and photovoltaic power emerging as the primary contributors to this growth. It is recommended to implement a differentiated subsidy mechanism: for photovoltaic projects nearing grid parity, gradually transition to a “green certificate + premium” model, while maintaining substantial subsidies for technologies still in the developmental stage, such as offshore wind power. Additionally, a dynamic adjustment formula should be established to link subsidy phase-outs with reductions in power generation costs. Furthermore, a provincial-level assessment system for renewable energy power consumption should be introduced to enforce consumption responsibilities on local grid operators and key enterprises.

Second, policy interventions can effectively hedge against market risks arising from fluctuations in traditional energy prices. Rising traditional energy prices favor renewable energy development, while falling prices hinder it. Renewable energy policies can, to some extent, offset the adverse effect of lower traditional energy prices on the renewable sector. It is recommended to establish an energy price volatility early warning and response mechanism: when international oil prices fall by more than 15% in a single quarter, temporary

electricity price adjustments or tax credits for renewable energy projects should be automatically triggered. Simultaneously, a renewable energy industrial chain resilience fund could be introduced to provide targeted support for critical equipment manufacturing and energy storage technology R&D during periods of low traditional energy prices.

Third, the development of renewable energy stimulates the economy through dual pathways: industrial chain expansion and reduced energy costs. Subsidy policies and a market environment of declining traditional energy prices have positive impacts on GDP and employment. The former generates output and jobs by fostering related industries through renewable energy development, while the latter lowers overall economic operating costs. This reflects that the energy transition is not merely a technological substitution but also a process of restructuring economic growth drivers. Therefore, promoting energy transition and making renewable energy development a key force in transforming the economic development model is essential. Measures such as implementing “Renewable Energy Replacement Incentives for High-Energy-Consuming Enterprises” could be introduced, offering tiered carbon quota rewards or export tax rebate benefits to industries like steel and chemicals that exceed baseline thresholds for green electricity usage. This would synergize energy transition with industrial upgrading.

Fourth, policy-driven measures are the key guarantee for the continuous expansion of emission reduction benefits from renewable energy. Promoting renewable energy through subsidy policies yields significant emission reduction benefits. In contrast, declining traditional energy prices stimulate energy consumption and are unfavorable for emission reduction. However, subsidy policies can mitigate the environmental damage caused by falling traditional energy prices by enhancing the competitive advantage of renewable energy. Therefore, addressing ecological and environmental issues such as air pollution and climate change ultimately depends on replacing more traditional fossil fuels with renewable energy. A mandatory “Renewable Energy Substitution Rate” disclosure system could be implemented, requiring key emitters to progressively increase their proportion of green electricity usage. Simultaneously, a linkage mechanism between the carbon emission rights market and the green certificate trading market should be established, allowing enterprises to offset part of their carbon quotas through the consumption of green electricity, thereby amplifying policy synergies.

This paper still holds potential for further expansion and refinement. The study focuses solely on renewable energy subsidies as a representative case, yet renewable energy policies also include renewable portfolio standards. The CGE modeling framework can be applied to further study the environmental and economic impacts of quota policies, thereby enriching the findings. Additionally, energy system, future research could incorporate domestic coal price volatility to better capture the complexity of China’s energy economy. Additionally, current technological innovation is driving the development of the renewable energy market, yet the CGE model has limitations in measuring the impact of technology in this area, which has not been addressed in this study.

This study acknowledges several limitations inherent in the modeling approach. First, the analysis relies on the 2020 input-output table as the primary dataset. While this choice aligns with data availability and structural consistency for the base year, it may not fully capture recent economic shifts or sectoral transformations post-2020. Second, as with most CGE applications, the results are sensitive to key elasticities and parameters. Although these values are drawn from established literature, their inherent uncertainty could influence the magnitude—though not necessarily the direction—of simulated outcomes. Finally, the model simplifies real-world market dynamics by assuming perfect competition, frictionless adjustment, and exogenous behavioral rules. These simplifications enhance analytical tractability but may overlook nuanced interactions in rapidly evolving markets.

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