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*Research Article*

# Effects of the Green Policy Environment on Renewable Energy Investment and Effect Evaluation of Green Policies

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Investment in the renewable energy industry has huge market potential and economic benefits. In order to technologically upgrade, industrialize, and marketize renewable energy projects, it is necessary to build a good green policy environment and a reasonable green policy support system. This paper studies the effects of the green policy environment on renewable energy investment and conducts effect evaluation on the green policies. First, a coordinated energy planning and investment strategy was proposed against the green and low-carbon background, and the influence mechanism of the green policy environment on renewable energy investment was elaborated. Then, a multistage optimization model was constructed for renewable energy investment in the green policy environment, and the model reconstruction and solution were also given. After that, the steps to evaluate the effects of green policies for renewable energy power generation were also explained in detail. The experimental results verified the effectiveness of the constructed model. The relevant research results can enrich and improve the theoretical research framework of the green policy environment system, and fully promote the strategy transformation of energy and high-quality economic development.

## 1. Introduction

Clean energy has always been the focus of the energy industry development in various countries [1–9]. Due to problems like high tariffs and power shortages in many countries, clean and low-carbon energy consumption has been taking up increasingly larger share in the energy system year by year [10–15], and China is no exception. For China, investment in the renewable energy industry has huge market potential and economic benefits, and more importantly, it promotes energy transformation and high-quality economic development [16–19]. At present, the core of renewable energy investment lies in technologies and funds [20–23]. In order to technologically upgrade, industrialize, and marketize renewable energy projects, it is necessary to build a good green policy environment and a reasonable green policy support system.

Zhang et al. [24] tested the overinvestment hypothesis based on mainstream financial methods and analyzed the contribution of capital structure to the performance of renewable energy companies in China. The empirical results show that there is overinvestment in the renewable energy field. Yu et al. [25] constructed the Ordinary Least Squares (OLS) model, the fixed effect model and the random effect model to explore the effects of government subsidies on corporate R&D investment behaviors, especially those in China's renewable energy industry. Liu et al. [26] modeled the feed-in tariff policy implemented in China and analyzed its effects on the renewable energy investment in the electricity market. It simulated the Chinese electricity market with an open-loop model and described the spot electricity market with a closed-loop game. Chang et al. [27] assessed whether and how the renewable energy investment encouragement policies achieve the expected goals. It used five broadly defined standard indices, namely market, uncertainty, profitability, technology, and financial resources, to evaluate whether these policies can help create renewable energy market, maximize potential profits, reduce investment-related risks, develop and adopt new technologies, and improve access to financial resources. Zhang et al.

[28] proposed a real option model for renewable energy investment that takes into account uncertainty factors like carbon price, nonrenewable energy cost, investment cost, and electricity market price and also established a phase-out mechanism to reflect long-term changes in subsidy policies.

However, existing studies mostly focus on the decision-making principles of renewable energy investment and investment risk assessment under various uncertain factors, and little has been done on the multiangle analysis of the coordination effects of various policies in the green policy environment, nor has much effort been made to study the key elements and effects of the green policy environment and the focus and direction of renewable energy investment. Most scholars pay attention to the entirety of the green policy environment, but rarely compare the components on different levels of the green policy environment, or discuss the difference of enterprise scale and type of industry. To this end, this paper studies the effects of the green policy environment on renewable energy investment and conducts effect evaluation of various green policies. Section 2 presents the proposed coordinated energy planning and investment strategy against the green and low-carbon background, and expounds the influence mechanism of the green policy environment on renewable energy investment. Section 3 builds a multistage optimization model for renewable energy investment in the green policy environment and provides model reconstruction and solution. Section 4 explains the method to evaluate the effects of green policies for renewable energy power generation. The experimental results prove the effectiveness of the proposed model.

The relevant research results can enrich and improve the theoretical research framework of green policy environment system. Based on these results, it is possible to formulate a comprehensive green policy environment system, effectively cope with the problems arising in the development of renewable energy, as well as fully promote the strategy transformation of energy and high-quality economic development.

## 2. Coordinated Energy Planning and Investment Strategy under the Green Policy Environment

To promote the green transformation of enterprises and push forward green economy, the government has adopted a series of green policies on the environment and economy. In the green and low-carbon background and the green policy environment, the scale of investment in renewable energy power generation will gradually expand. However, disorderly investment and blind expansion will make the resources in the entire electricity market allocated in disorderly manner, and what is more, the central planning function of power grids will be weakened, the monopoly broken, and a large amount of resources inevitably wasted. Therefore, a coordinated planning and investment strategy aimed to minimize the investment and construction costs of power grids was proposed for power grids and renewable energy against the green and low-carbon background, in order to improve the economics of power energy investment planning. Figure 1 shows the schematic diagram of the coordinated energy planning and investment strategy under the green and low-carbon background. It can be learned that, starting from the overall planning of the power system, coordinated energy planning is based on the orderly investment in renewable energy, constrained by low-carbon green development, and affected by line loss and other planning costs. The objective of coordinated energy planning is to formulate a scientific and effective energy coordination plan that minimizes the investment and construction costs of power sources.

The green policy environment with coordinated energy planning and investment is a complex composed of multiple elements. Government subsidies, credit support, and environmental tax constitute the main channels that affect renewable energy investment. This paper explored the relationship between the green policy environment and renewable energy investment and the influence mechanisms of such an environment from the above three perspectives. As shown in Figure 2, moderate government subsidies can reduce the investment risks of the electricity market to a certain extent, and at the same time send positive signals to the market. Although companies benefiting from green credit support may still have the pressure of loan repayments and insufficient R&D capabilities in the early stages of development, they will see rapid development in the later stages, with optimized resource allocation, complete configuration of equipment, and high profits. Emission enterprises based on fossil energy power generation will face reduced profits and changes in resource allocation in the early stages of environmental taxation. Excessive taxing will lead to constrained resource allocation and lower social welfare.

Promoting renewable energy is naturally a green policy, which diversifies energy sources and preventing the impacts from the price and sales of nonrenewable energy. From the perspective of environmental protection, the restriction on the carbon emissions of emission enterprises imposed by green policies has a greater effect. Table 1 summarizes the incentive effects of the green policies from different aspects such as carbon emission coefficient, renewable energy power generation subsidies, and technology subsidies. It can be seen that the intensity of the above incentive effects determines the carbon emissions of the energy industry and the resulting total social welfare.

## 3. Multistage Optimization Model for Renewable Energy Investment in the Green Policy Environment

The investment decisions of renewable energy investment companies are largely affected by the uncertainties in the regulatory environment and the incentive policies. From the initial fixed feed-in tariff to the market price-based incentive mechanism in the later stage, different policies implemented at different stages are the key to promoting the healthy and orderly development of renewable energy. Considering the

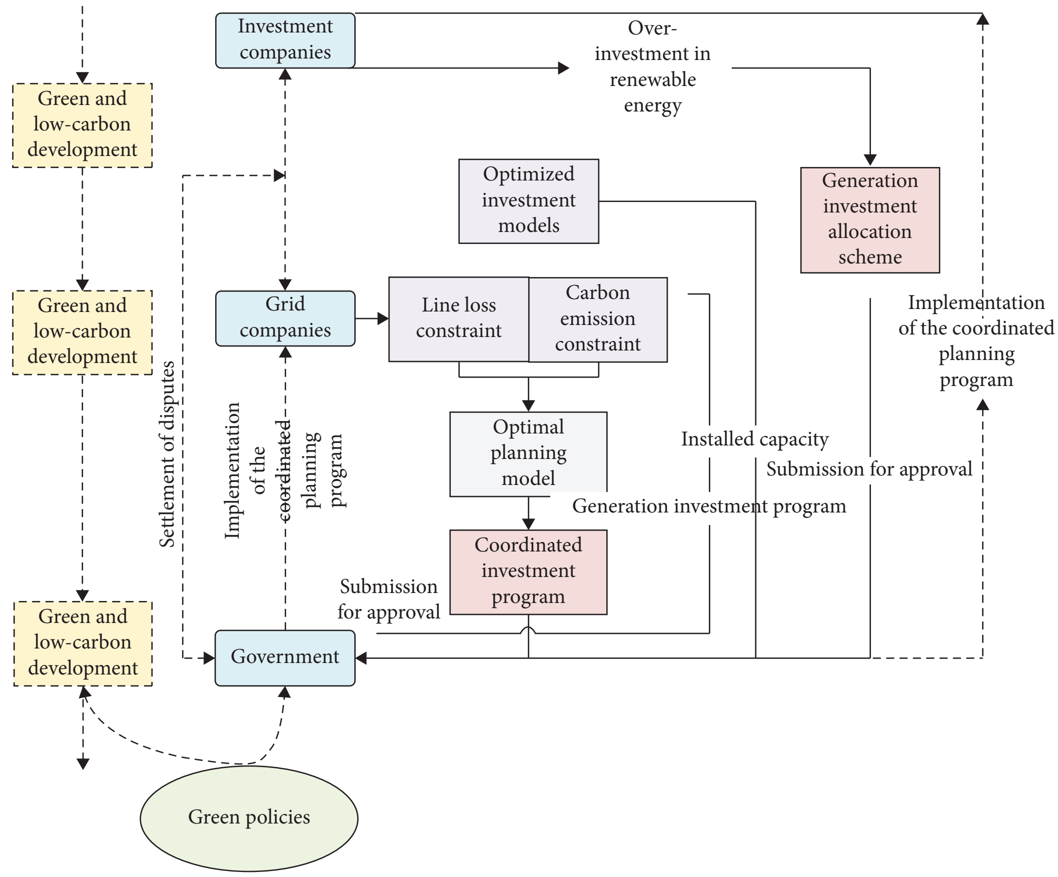



Figure 1: Diagram of the coordinated energy planning and investment strategy under the green policy environment.

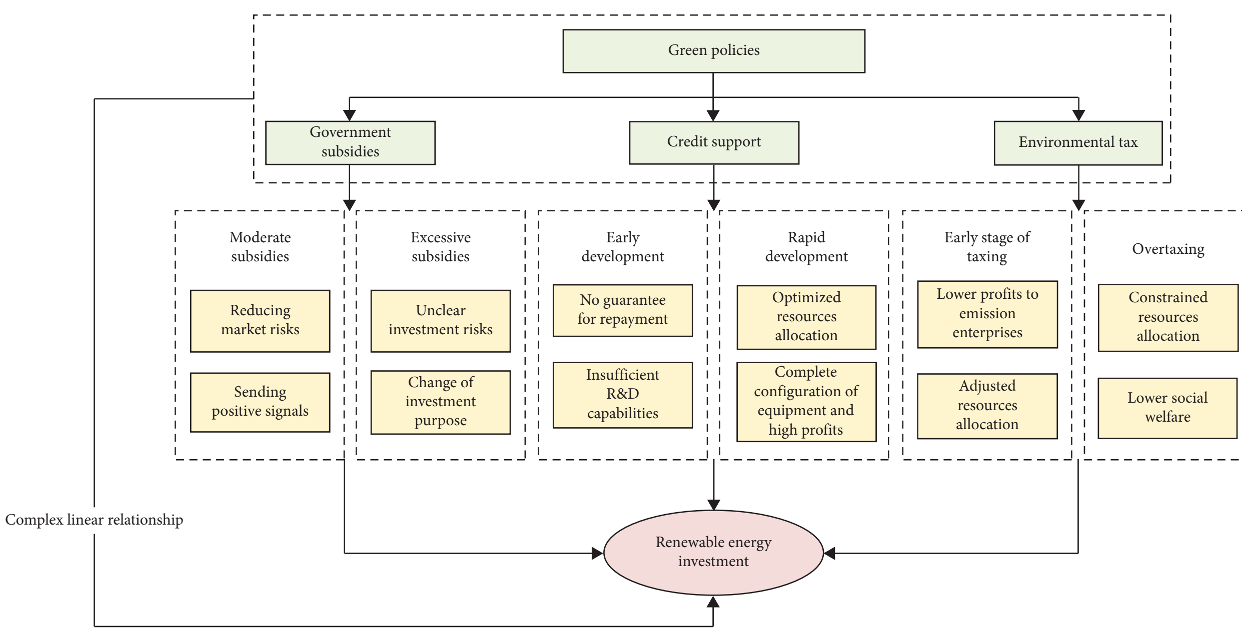



Figure 2: Influence mechanism of the green policy environment on renewable energy investment.

uncertainties in the green policy environment, there are still certain limitations to the use of real options and stochastic programming theory in related studies. To this end, this paper attempts to build a multistage stochastic dynamic programming model for renewable energy investment based on the stochastic dual dynamic programming algorithm to analyze the effects of different green policy environments on renewable energy investment.

Table 1: Summary of the green policies to encourage renewable energy development.

| | Carbon emission coefficient | Energy conservation | Extrasubsidies for renewable energy power generation | R&D investment subsidies |
|---|---|---|---|---|
| Carbon price | Yes | Yes | No | No |
| Tradable emission reduction performance | Yes | Yes (slight) | Yes (recessive) | No |
| Power generation taxes for emission enterprises | No | Yes | No | No |
| Renewable energy quota system | No | Yes (slight) | Yes (recessive) | No |
| Renewable energy generation subsidies | No | No | Yes | No |
| Renewable energy R&D subsidies | No | No | No | Yes |

*3.1. Basic Model.* This paper intends to study how to optimize the investment portfolio of $m$ renewable energy investment projects including wind power and hydropower in $\psi$ years.

To simplify the modeling process, the following hypotheses were put forward, which ensure that the model can be solved under realistic conditions:

(1) The price is uniform and comes from the same electricity market
(2) The power output from renewable energy is only related to its available quantity
(3) One investor is allowed to make a partial investment in a renewable energy investment project
(4) Once the investment share in a contract is confirmed, it cannot be changed at will in future transactions.

In this model, for a renewable energy investment project, investment decision-making stages are divided on the yearly basis. Renewable energy power generation and short-term market electricity tariff are two parameters with some stochastic behaviours, calculated on the monthly basis, and for the $t$-th month in the $i$-th project, these two parameters are denoted as $H_t^i$ and $O_t$, respectively. The binary decision variable of whether to invest in the renewable energy investment project is represented by $a_\tau$. Suppose that the net present value coefficient of the fixed investment cost of the project in year $\tau$ is represented by $e_\tau$, that the benefit coefficient of participation in the short-term electricity market by $d_\tau$, that the ratio of contracted electricity sales to available capacity by $w_\tau$, that the share purchased by the investment company by $s_\tau$, that the project construction period by $r$ months, and that the discount rate by $\sigma_d$. Based on the above assumptions, $a_\tau$, $s_\tau$, and $w_\tau$ are selected as the decision variables in the portfolio optimization problem. Let $b_\tau{:}=(w_\tau, s_\tau)\in\mathbb{R}^{m+1}$, $\tau=1, \ldots, \psi$, the following equation shows the constructed multistage stochastic programming portfolio optimization model for renewable energy:

$$\underset{a_1,b_1}{\mathrm{Max}}\ \Gamma\left[\sum_{\tau=1}^{\psi-1}\left(e_\tau^\psi b_\tau+\sum_{\tau=\tau+r}^{\tau+r+k-1} d_\tau^\psi\cdot b_\tau\left(1+\sigma_d\right)^{\tau-1}\right)a_\tau\left(1+\sigma_d\right)^{1-\tau}\right], \tag{1}$$

$$s.t.\, b_\tau\in B_\tau, \sum_{\tau=1}^{\psi-1} a_\tau\le 1, a_\tau\in\{0.1\}. \tag{2}$$

The objective function of the model is to maximize the benefits of renewable energy investment, which mainly involves two parts: the fixed and variable investment costs and the benefits of the project. The first part corresponds to the initial investment cost of the project and the electricity sales revenue from long-term contracts, and the second part corresponds to the benefit of short-term electricity purchase and sale of the project. Suppose that the contracted electricity sales is denoted as $Sw_\tau$, that the long-term contracted electricity tariff as $g_\tau$, that the investment cost of each project as $u=u(u_1,\ldots,u_m)$, the number of hours in month $t$ as $f_t$, and that the annual net present value of the project investment from the initial year to the present as $\gamma$, then the calculation formula of $e_\tau$ is as follows:

$$e_\tau=\left(\gamma\left(1+\sigma_d\right)^{-r}Sg_\tau\sum_{t=12(\tau-k+1)}^{t=12\tau} f_t, -u\right). \tag{3}$$

The calculation formula of $d_\tau$ is as follows:

$$d_\tau=\left(\sum_{t=12(\tau-k+1)}^{t=12\tau} -SO_t f_t, \sum_{t=12(\tau-k+1)}^{t=12\tau} -O_t f_t H_t\right). \tag{4}$$

Assuming that the capacity factor of the $i$-th renewable energy project is represented by $\varepsilon_i$, then $S=\varepsilon_1+\ldots+\varepsilon_m$, and the vector $(\varepsilon_1,\ldots,\varepsilon_m)$ is represented by $\varepsilon^\psi$. The following equation shows the upper limit constraint $Sw_\tau$, that is, the total investment capacity of renewable energy projects needs to be greater than $Sw_\tau$:

$$B_\tau=\left\{b_\tau\in R^{m+1}: Sw_\tau\le\varepsilon^\psi s_\tau, 0\le s_\tau\le 1, 0\le w_\tau\right\}. \tag{5}$$

After the investment contract is signed, the electricity purchase and sale benefit of the project from participation in the short-term electricity market can be calculated according to the following equation:

$$\sum_{t=12(\tau-1)+1}^{t=12\tau}\left[O_t f_t\left(s_\tau H_t^\psi - Sw_\tau\right)\right]. \tag{6}$$

Assuming that the share purchased by the investment company in the $i$-th investment project is represented by ${s_\tau}^i$, and then $H_t$ and ${H_t}^i$ satisfy the following equations:

$$\begin{aligned} E_\tau &= \left(E_\tau^1,\ldots,E_\tau^n\right), r_\tau E_\tau^T=\sum_{i=1}^{n} r_t^j\left(E_\tau^i\right)^T,\\ H_t &= \left(H_t^1,\ldots,H_t^m\right), s_t H_t^\psi=\sum_{i=1}^{m} s_\tau^j\left(H_t^i\right)^\psi. \end{aligned} \tag{7}$$

*3.2. Model Reconstruction.* Due to its nonlinearity, the above model was reconstructed in this paper. Suppose that the life cycle of the project is denoted as $\psi+k-1$ when the investment decision-making cycle is ignored. The binary variable $c_\tau$ is introduced. The renewable energy investment decision made during or before the period $\tau$ is expressed as $c_\tau = 1$, and the decision made after the period $\tau$ is expressed as $c_\tau = 0$. To simplify the model, the stochastic optimization model can be adjusted as follows:

$$\underset{a_\tau, b_\tau, c_\tau}{\text{Max}}\ \Gamma\left[\sum_{\tau=1}^{\psi-1}\left(e_\tau^\psi\left(b_\tau - b_{\tau-1}\right) + d_\tau^\psi \cdot b_{\tau-1}\right)\left(1+\sigma_d\right)^{1-\tau} + \sum_{\tau=\psi}^{\psi+k-1} d_\tau^\psi b_\psi \left(1+\sigma_d\right)^{1-\tau}\right], \quad s.t.\ b_\tau \in B_\tau. \tag{8}$$

The constraint on project investment decision is given in the following formula, that is, if $c_{\tau-1} = 1$, as both $a_\tau$ and $c_\tau$ are binary variables, there must be $a_\tau = 0$ and $c_\tau = 1$. This constraint can ensure that for the same renewable energy investment project, if $a_\tau = 1$ in a certain period of time, then $a_\tau = 0$ in the subsequent period.

$$c_\tau = a_\tau + c_{\tau-1}. \tag{9}$$

If the investment company makes an investment decision in a certain period of time, it needs to ensure that $b_\tau < 1$, that is, $w_\tau$ <1 and $s_\tau < 1$. Before the investment is completed, $b_\tau = 0$. This constraint is given in the following equation. It can be seen that for any period $\tau$, there is $a_\tau b_\tau = b_\tau$-$b_{\tau-1}$.

$$b_\tau \le c_\tau, \tag{10}$$

$$\begin{aligned} &b_\tau \le b_{\tau-1}, \\ &b_\tau \le b_{\tau-1} + 1 - c_{\tau-1}. \end{aligned} \tag{11}$$

The investment company will not make any more new investment at the end of the investment planning period of the renewable energy project, so $a_\psi = 0$ in the following equation. Substitute $a_\tau b_\tau = b_\tau$-$b_{\tau-1}$ into the objective function of the original model shown in equation (1), the nonlinear term in the model can be linearized, and then the linear reconstruction of the model is completed.

$$a_\tau, c_\tau \in \{0, 1\}. \tag{12}$$

Since there are some uncertainties in both renewable energy generation and short-term market electricity tariff, which is affected by the green policy environment, the objective of investment benefit maximization needs to be optimized under the feasibility constraint, that is, the decision variables $(a_\tau, b_\tau, c_\tau) = (a_\tau(\delta_{[\tau]}), b_\tau(\delta_{[\tau]}), c_\tau(\delta_{[\tau]})$. It can be seen that the decision variables $(a_\tau, b_\tau, c_\tau)$ are the functions of the historical data records $\delta_{[\tau]}$=($\delta$ [1], . . ., $\delta_{[\tau]}$), where:

$$\begin{aligned} &\delta_1 := \left(O_{12(\psi-1)+1,\cdots,}O_{12\tau}, H_{12(\psi-1)+1,\cdots,}H_{12\tau}\right), \tau = 1, \cdots, \psi - 1, \\ &\delta_\psi := \left(O_{12(\psi-1)+1,\cdots,}O_{12(\psi+k-1)}, H_{12(\psi-1)+1,\cdots,}H_{12(\psi+k-1)}\right). \end{aligned} \tag{13}$$

*3.3. Model Solving.* Too many scenarios may appear under the influence of the green policy environment. If enumeration is adopted in data processing, the curse of dimensionality may occur. Therefore, this paper attempts to solve the optimization problem with the stochastic dual dynamic programming algorithm.

Suppose that the stochastic process $\{\delta_\tau\}$ obeys the Markov chain, that is, for each time period $\tau$, the $\delta_\tau$ conditional distribution of $\delta_{[\tau-1]}$ and that of $\delta_{\tau-1}$ are both known and consistent. In order to better describe $\{\delta_\tau\}$, the decision model of the investment company when $\tau = \psi$ is reformulated as follows:

$$\begin{aligned} &\underset{a_\psi, b_\psi, c_\psi}{\text{Max}} \sum_{\tau=\psi}^{\psi+k-1} d_\tau^t b_\psi \left(1+\sigma_d\right)^{\psi-1} \\ &s.t.\ b_\psi \in B_\psi, c_\psi = c_{\psi-1}, b_\psi \le c_\psi, b_\psi \ge b_{\psi-1}, \\ &b_\psi \le b_{\psi-1} + 1 - c_{\psi-1}. \end{aligned} \tag{14}$$

It can be seen from the above formula that the optimal value of the optimization problem depends on the values of the stochastic vector $\delta_\psi$ and those of the decision variables $b_{\psi-1}$ and $b_{\psi-1}$, which is expressed as the "expected cost" function $W_\tau$: ($B_{\psi-1}$, $C_{\psi-1}$, $\delta_\psi$). Based on the linear representation $\Sigma^{\psi+k-1} = \psi_d{}^\psi \tau b_{\psi-1}(1+\sigma_d)^{\psi-\tau}$, the optimal solution can be estimated—$b_\psi = b_{\psi-1}$ is the optimal solution to the above optimization problem.

The optimal decision model for each stage can be constructed in the reverse order. For any time period $\tau$, the corresponding optimal value of $W_\tau$ can be obtained as follows:

$$\begin{aligned} &\underset{a_t, b_t, c_t}{\text{Max}}\ e_1^t\left(b_\tau - b_{\tau-1}\right) + d_\tau^t b_{\tau-1} + W_{\tau+1}\left(b_\tau, c_\tau, \delta_\tau\right)\left(1+\sigma_d\right)^{-1} \\ &s.t.\ b_\tau \in B_\tau, c_\tau = a_\tau + c_{\tau-1}, b_\tau \le c_\tau, b_\tau \ge b_{\tau-1}, b_\tau \le b_{\tau-1} + 1 - c_{\tau-1}, \\ &a_\tau, c_\tau \in \{0, 1\}. \end{aligned} \tag{15}$$

Assuming that the corresponding conditional expected value is represented by $\Gamma[\ldots|\delta_\tau]$, then

$$W_{\tau+1}(b_\tau, c_\tau, \delta_\tau) = \Gamma\left[W_{\tau+1}(b_\tau, c_\tau, \delta_\tau)\middle|\delta_\tau\right]. \tag{16}$$

The following equation shows the decision model for the investment company under the initial stage of renewable energy investment, i.e. $c_0 = 0$:

$$\begin{gathered}\max_{a_1, b_1, c_1} e_1^{\psi} b_1 + \Gamma[W_2(b_1, c_1, \delta_1)](1+\sigma_d)^{-1} \\ s.t.\, b_1 \in B_1, c_1 \in a_1, b_1 \le c_1, a_1 \in \{0.1\}.\end{gathered} \tag{17}$$

It can be seen from the analysis that it is $\delta_\tau$ rather than $\delta_{[\tau]}$ that determines the "expected cost" function $W_{\tau+1}$: $(B_{\tau-1}, C_{\tau-1}, \delta_\tau)$ and the expected value function $W_{\tau+1}$: $(B_\tau, C_\tau, \delta_\tau)$. If $\delta$ is independent in each stage, $W_{\tau+1}$: $(b_\tau.c_\tau)$ is not affected by the stochastically input data sequence, and the conditional expected value $\Gamma$ in (16) can also be replaced by the corresponding unconditional expected value.

## 4. Effect Evaluation of the Green Policies for Renewable Energy Power Generation

In the energy industry, the emission enterprises, which emit carbon due to fossil fuel power generation, are expressed by the superscript *DI*. The green policies that can directly affect the production and operations of the above-mentioned enterprises include carbon price and power generation tax. Let the carbon price be denoted as $g_p$, and the tax on fossil fuel power generation as $\Psi_p$. Assuming that the total power generation of the emission sector in year $p$ is denoted as $PG_p$, the emission coefficient as $\lambda_p$, the marginal production cost as $BT$, and the feed-in tariff as $FE_p$, the enterprise's profit is calculated according to the following formula:

$$\begin{aligned}P^{DI} &= m(FE_1 - BT(\lambda_1) - g_1\lambda_1 - \Psi_1)PG_1 \\ &\quad + \xi n(FE_2 - BT(\lambda_2) - g_2\lambda_2 - \Psi_2)PG_2.\end{aligned} \tag{18}$$

The first-order derivative of the enterprise's profit maximization is as follows:

$$\frac{\partial P^{DI}}{\partial \lambda_p} = 0 - BT'(\lambda_p) = g_p, \tag{19}$$

$$\frac{\partial P^{DI}}{\partial PG_p} = 0\, FE_p = BT(\lambda_p) + g_p\lambda_p + \Psi_p. \tag{20}$$

It can be seen from equation (20) that the carbon emission coefficient is determined by the carbon price. If the marginal cost of fossil fuel power generation is a constant, the competitive price of the relevant enterprise in the short-term electricity market is the total marginal cost. The following equation shows the formula of the total emission reduction:

$$JP_p = \lambda_p PG_p. \tag{21}$$

If $PG_p = 0$, the first-order derivative of the carbon emission coefficient-$BT'(\lambda_p)$ is 0 and its solution is equal to the benchmark emission price $\lambda_0$. Suppose that the corresponding benchmark power generation price is denoted as $FE_0$, then $FE_0 = BT(\lambda_0)$.

In the energy industry, the nonemission enterprises, which do not emit carbon due to nonfossil fuel power generation, are expressed by the superscript *NE*. Assuming that the annual power generation of a nonemission enterprise is denoted as $\omega_p$, and that its own knowledge stock as $L_p$. Let the increasing function and convex function of $\omega_p$ and the decreasing function and convex function of $L_p$ be the power generation cost $PC(L_p, \omega_p)$. With the increase of knowledge, the marginal cost decreases, so $PC_{\omega L} = PC_{L\omega} < 0$.

The knowledge stock $L(F_p, R_p)$ is a function of the accumulated R&D investment $F_p$ and the accumulated experience $R_p$ in renewable energy power generation technology, which satisfy $L_F \ge 0$, $L_R \ge 0$ and $L_{RF} = L_{FR}$. At each stage, the investment $F_p$ is increased by a percentage of $f_p$ on an annual basis, and $F_2 = F_1 + mf_1$. $R_p$ increases with the increase of the total power generation, and $R_2 = R_1 + mr_1$. The scientific research fund $v(f_1)$ supported by the green policy is a convex function of the increment $f$ in knowledge $F_p$, where $v_f(f_1) > 0$, $f > 0$, $v_f(0) = 0$ and $v_{ff} > 0$.

Under the influence of the green policy environment, the price-based renewable energy policies include the renewable energy power generation subsidy $x$ and the renewable energy technology R&D investment subsidy $y$. The following equation shows the formula to calculate the profit of the nonemission enterprise:

$$\begin{aligned}P^{NE} &= n((FE_1 + x_1)\omega_1 - PC(L_1, \omega_1) - (1-y)v(f_1)) \\ &\quad + \xi n((FE_2 + x_2)w_2 - PC(L_2, \omega_2)) \\ L_2 &= L(F_2, R_2).\end{aligned} \tag{22}$$

The first-order derivatives of the renewable energy generation and the profit maximization of R&D and investment enterprises at each stage are expressed in the following equation:

$$\begin{aligned}\frac{\partial P^{NE}}{\partial \omega_1} &= m(FE_1 + x_1 - PC_w(L_1, \omega_1)) \\ &\quad - \xi n(L_2, \omega_2)mL_R(F_2, W_2) = 0 \\ \frac{\partial P^{NE}}{\partial \omega_2} &= \xi n(FE_2 + x_2 - PC_\omega(L_2, w_2)) = 0 \\ \frac{\partial P^{NE}}{\partial f_1} &= m(1-y)v_f(f_1) - \xi n(L_2, \omega_2)mL_F(F_2, R_2) = 0.\end{aligned} \tag{23}$$

That is

$$PC_\omega(L_1, \omega_1) = FE_1 + x_1 - \xi nPC_l(L_2, \omega_2)L_R(F_2, R_2), \tag{24}$$

$$PC_\omega(L_2, v_2) = FE_2 + x_2, \tag{25}$$

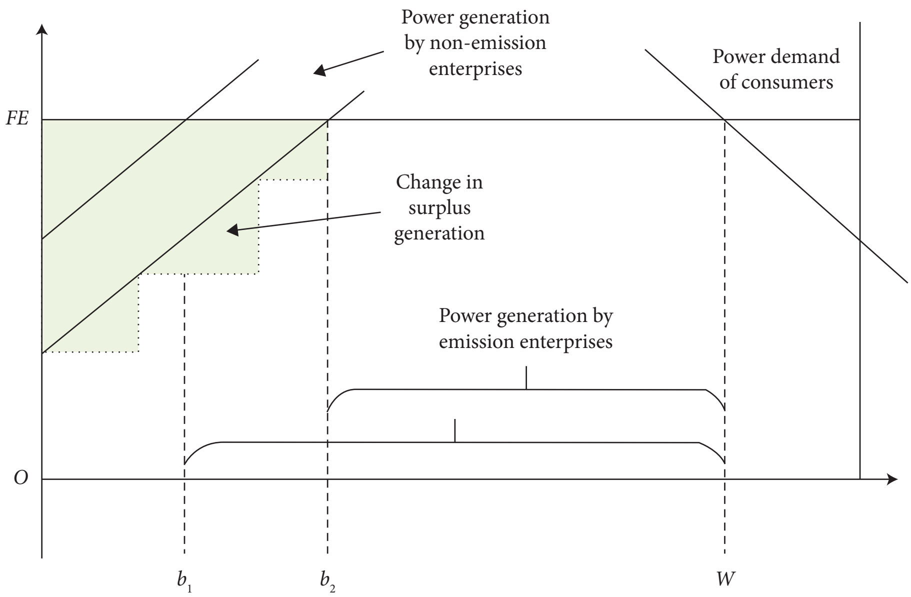



Figure 3: Green policy effect evaluation model for renewable energy power generation.

$$(1 - y)v_f(f_1) = -\xi nPC_l(L_2, \omega_2)L_F(F_2, R_2). \quad (26)$$

It can be seen from equation (24) that the renewable energy investment project will continue until the additional value resulting from the support of the green policies, including market prices and power generation subsidies, is equal to the marginal cost of power generation. Equation (25) shows that the power generation in the second stage did not bring any profit to the investment company. Equation (26) characterizes the R&D investment made by the investment company in the renewable energy power generation technology until the return on $F_p$ is equal to the marginal cost of investment.

Suppose that the power demand of consumers is denoted as $DX\ (FE)$, where $DX'(FE) < 0$. If the electricity in the market is generated by emission enterprises only, the following equation shows the calculation formula for the total annual power demand of consumers:

$$OV_0 = \int_{FE_0}^{\infty} DX(FE)\mathrm{dFE}. \quad (27)$$

With the participation of nonemission companies in renewable energy power generation, the total annual power demand of consumers is

$$OV_1 = \int_{FE_1}^{\infty} DX(FE)\mathrm{dFE}. \quad (28)$$

Under the influence of the green policies, the total change in consumers' annual power demand is

$$\Delta OV = -m\int_{FE_1}^{FE_0} DX(FE)\mathrm{dFE} - \xi n\int_{FE_0}^{FE_2} DX(FE)\mathrm{dFE}. \quad (29)$$

Equilibrium is reached when the sum of fossil fuel and renewable energy power generation is equal to the total demand of consumers, that is, $DX\ (FE_p) = PG_p + \omega_p$. Figure 3 shows the green policy effect evaluation model for renewable energy power generation incorporating emission enterprises, nonemission enterprises and the power demand of consumers.

In terms of social welfare, the green policies for renewable energy will have an impact on the government's fiscal revenue $GR$. Assuming that the government's fiscal revenue is incremental and that the return on renewable energy is one-off, the difference between taxes and subsidy costs is the increment $\Delta GR$ in the government's fiscal revenue, and the calculation formula is given in the following equation:

$$\begin{aligned}\Delta GR = m\left(\left(\Psi_1 + g_1\lambda_1\right)PG_1 - x_1\omega_1 - yv\left(f_1\right)\right) \\ + \xi n\left(\left(\Psi_2 + g_2\lambda_2\right)PG_2 - x_2\omega_2\right).\end{aligned} \quad (30)$$

The environmental damage caused by energy generation is directly related to the annual carbon emission $m$ of emission enterprises and time $n$. In order to reasonably adjust the flow and stock pollutants in accordance with the requirements of the green policies, the environmental damage function is expressed as follows:

$$\Delta EB = EB\left(JP_1, JP_2, m, n\right) - EB\left(JP_0, JP_0, m, n\right). \quad (31)$$

The change in social welfare brought about by the green policies is defined as the net change under the joint action of surplus generation, subsidies, tax revenue, and environmental damage reduction:

$$\Delta SO = \Delta OV + \Delta P^{NE} - \Delta EB + \Delta GR. \quad (32)$$

## 5. Experimental Results and Analysis

Table 2 shows the benchmark results output by the model under the no-policy scenario. The subsequent steps are as follows: first, simulate and analyze the green policies based on the effect of carbon price; then sort the effective green

Table 2: Benchmark results output by the model in the no-policy scenario.

| Parameters | Early stage | Development stage |
|---|---|---|
| Tariff | 8 | 8 |
| Carbon emission | 6.54 | 6.59 |
| Power demand of consumers | $4.21 \times 10^{12}$ | $4.21 \times 10^{12}$ |
| Carbon price | 194 | 188 |
| Power generation by emission enterprises | $2.43 \times 10^{12}$ | $2.37 \times 10^{12}$ |
| Power generation by nonemission enterprises | $6.57 \times 10^{12}$ | $6.87 \times 10^{12}$ |
| Share of power generation from renewable energy | 3.2% | 3.6% |
| R&D investment in renewable energy | 3 | — |
| Emission reduction cost ratio of renewable energy | 9.1% | — |

policies under different carbon prices and calculate the effects of green policies under the fixed total carbon emission; finally, comprehensively consider the difference between consumers' power consumption and the surplus generation, and discuss the welfare differences between various green policies.

In the simulated scenario, carbon price can effectively reduce the carbon emissions of emission enterprises, and further reduce the carbon emission coefficient and consumers' electricity consumption. So it is necessary to reduce investment in renewable energy accordingly. However, if the investment company cannot obtain benefit from the investment project, the unit price of electricity for end consumers will increase.

Under the tradable performance standard system for renewable energy power generation, consumers' fossil fuel power consumption will be reduced due to the subsidy for renewable energy power generation. If the carbon emission system is implemented simultaneously, the fossil fuel power consumption will drop even more. The taxes and subsidies under the optional green policies are shown in Table 3. It can be seen that the carbon emission coefficient of emission enterprises will be reduced in the early stage, while in the development stage, renewable energy investment and power generation will increase, and the carbon emission coefficient of emission enterprises will see less reduction—only a reduction of 3.97% compared with the baseline. For nonemission enterprises, the price of renewable energy will increase under both the carbon price and the carbon emission performance standard system in the early and development stages, although the social welfare cost under the carbon price policy is slightly lower than that under the tradable performance standard system for renewable energy power generation. In addition, the output tax of renewable energy on emission enterprises is slightly higher than the cost under the performance standard system, and the demand is more elastic. The renewable energy quota system has integrated the characteristics of power generation output tax on emission enterprises and renewable energy subsidy. The time curve of carbon emissions is greatly affected by the cost when the carbon emission reaches the quota over time. In summary, as an effective green policy for carbon emission reduction, it has relatively high cost of renewable energy subsidy. Therefore, in the development stage, investment in renewable energy generation needs to be reduced accordingly. In addition, if without an incentive green policy for emission reduction, the cost of renewable energy power generation will be further reduced.

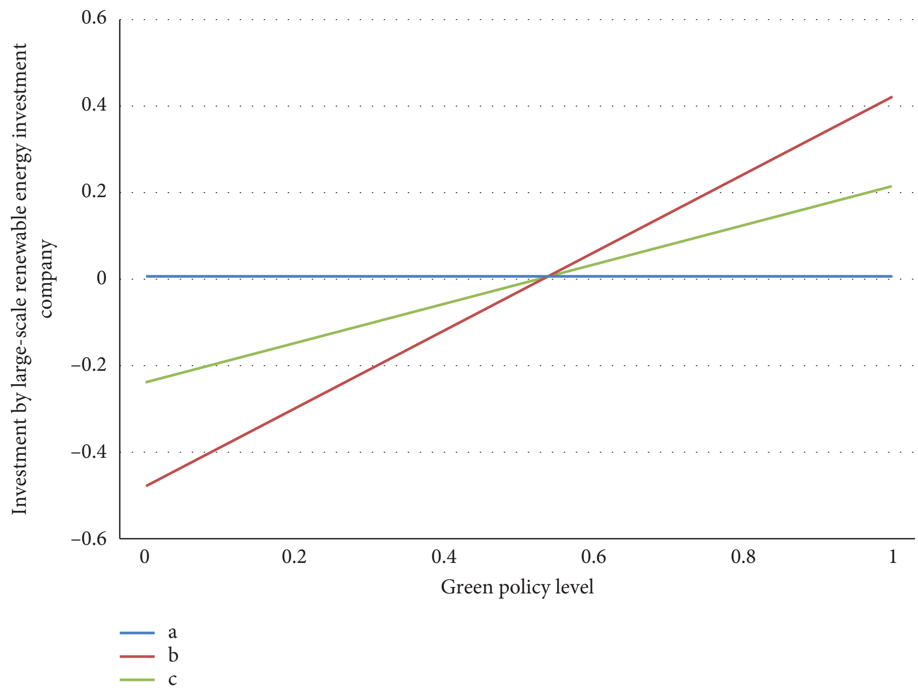
Since there are significant differences in the scale of investment in renewable energy projects by enterprises at different levels, in this paper, investment enterprises were classified into different investment capacity groups according to their operating income. Specifically, 88 domestic enterprises that have made renewable energy investments were divided into two groups: 68 large-scale enterprises in the large-scale investment group and 20 small, medium- and microenterprises in the small-scale investment group. Estimation was made using the constructed model. Figure 4 shows the relationships between the investment by enterprises at different levels and the green policy level, which are all linear.

Based on the existing research results, the effects of green policies on renewable energy power generation were further analyzed in this paper using four types of policies: credit system, carbon tax policy, power generation subsidy policy, and combined policies. Figure 5 shows the effects of various green policies on the tariff. It is intuitive that the marginal cost of power generation by fossil fuels increased with the implementation of the green policies. The power price and power demand increased accordingly. In fact, the carbon emissions from power generation by emission companies determine the cost of carbon emissions. Under the dual control through emission permit and environmental taxing, most of the carbon emission permit costs are paid by government taxes. So the earning cycle mechanism actually brings double dividends.

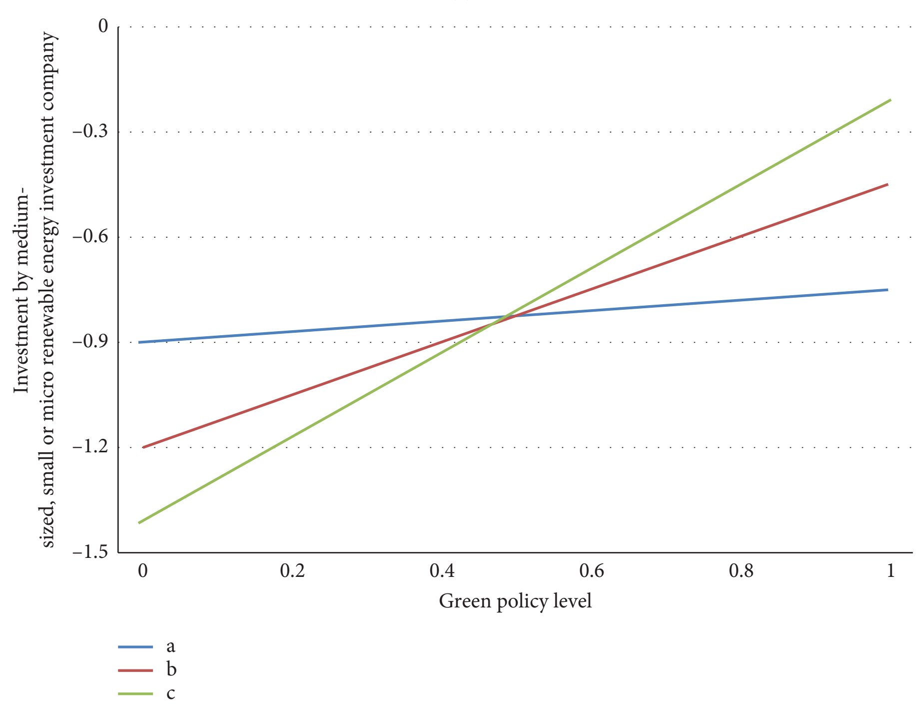
Due to the power generation subsidy received, the marginal cost of renewable energy power generation has decreased; in other words, the subsidy for renewable energy given by the green policy has directly led to the reduction of the renewable energy power generation price. In addition, the electricity tariff also shows a downward trend due to the priority in access to the grid. These two reasons together have led to a reduction in consumers' demand for electricity. In fact, the subsidy for the feed-in tariff comes from environmental taxes. In the case of combined green policies, the renewable energy power generation subsidy mechanism reduces the market share of emission enterprises, so their demand for carbon emission subsidies also decreases.

Table 3: Taxes and subsidies in optional green policies.

| Green policies | | Standing charge tariff policies | | | Price-based policies | |
|---|---|---|---|---|---|---|
| | | Carbon price | Output tax of power generation on emission enterprises | Subsidy for renewable energy power generation | Carbon emission performance standard | Renewable energy quota system |
| Taxes and subsidies | Carbon price | 26/26 | — | — | 43/37 | — |
| | Output tax of power generation on emission enterprises | — | 1.35-1.35 | — | −0.89/−0.81 | 0.53/0.32 |
| | Subsidy for renewable energy power generation | — | — | 6.54/6.54 | 0.82/0.81 | 7.31/3.75 |
| Renewable energy price | | 7.46/7.46 | 8.23/8.23 | 13.75/13.75 | 7.62/7.94 | 14.37/11.5 |




(a)




(b)

Figure 4: Relationship between the investment by enterprises at different levels and the green policy level.

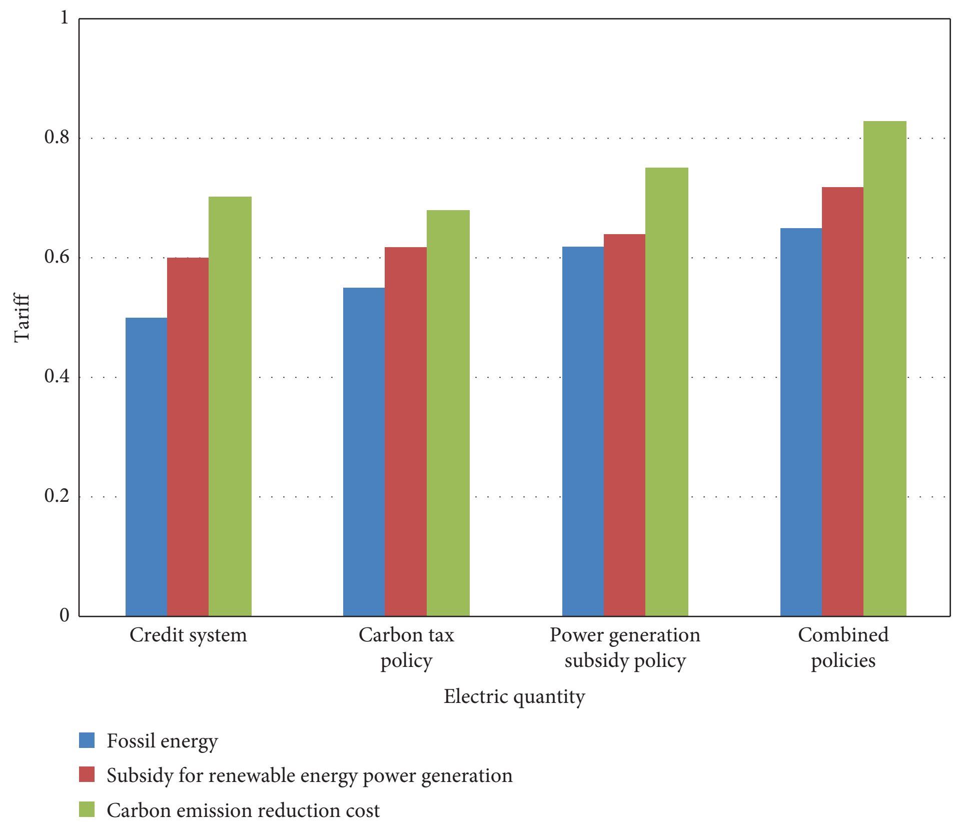



Figure 5: Effects of various green policies on the tariff.

In order to evaluate the importance of investment in technology, the two sources of technological progress - R&D investment and accumulated experience were analyzed in this paper. Tables 4 and 5 show the simulation results of the implementation of green policies. It is clear that the major changes of the benefits of all green policies have a significant impact on the rise/fall of the subsidy for renewable energy power generation, but a relatively low impact on that of the subsidy for R&D of renewable energy.

In the case of technological development subsidies, due to the complementation between technological development and accumulated experience, the renewable energy power generation will increase to a certain extent in the early stages.

Table 4: Annual effects of alternative green policies.

| | Tariff | | Carbon emission | | Renewable energy power generation | | Total power generation | | R&D investment in renewable energy (%) | Emission reduction cost of renewable energy (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Early stage (%) | Development stage (%) | Early stage (%) | Development stage (%) | Early stage (%) | Development stage (%) | Early stage (%) | Development stage (%) | | |
| Carbon price | 7.5 | 7.5 | −5.6 | −5.9 | 15.2 | 18.9 | −2.5 | −2.5 | 83 | 3.9 |
| Tradable carbon emissions | 0.8 | 0.8 | −6.1 | −5.7 | 22.5 | 26.2 | −0.3 | −0.3 | 135 | 4.5 |
| Output tax of renewable energy | 15.6 | 15.6 | −5.8 | −6.1 | 28.4 | 37.6 | −4.8 | −4.8 | 185 | 7.2 |
| Renewable energy quota system | 8.9 | 3.4 | −6.9 | −5.4 | 145.8 | 12.4.2 | −2.6 | −0.9 | 647 | 21.9 |
| Subsidy for renewable energy power generation | 0.0 | 0.0 | −5.3 | −6.2 | 126.3 | 197.3 | 0.0 | 0.0 | 1229 | 23.8 |
| Subsidy for R&D of renewable energy | 0.0 | 0.0 | −1.5 | −8.6 | 43.5 | 236.8 | 0.0 | 0.0 | 392135 | 46.8 |

Table 5: Taxes and subsidies in green policies.

| Green policies | | Standing charge tariff policies | | | Price-based policies | |
|---|---|---|---|---|---|---|
| | | Carbon price | Output tax of power generation on emission enterprises | Subsidy for renewable energy power generation | Carbon emission performance standard | Renewable energy quota system |
| Taxes and subsidies | Carbon price | 27/27 | — | — | 42/35 | — |
| | Output tax of power generation on emission enterprises | — | 1.09-1.09 | — | −0.82/-0.71 | 0.54/0.13 |
| | Subsidy for renewable energy power generation | — | — | 4.53/4.53 | 0.85/0.74 | 6.59/2.23 |
| Renewable energy price | | 7.82/7.82 | 8.13/8.13 | 11.72/11.72 | 7.95/7.85 | 14.34/9.28 |

## 6. Conclusions

This paper studied the effects of the green policy environment on renewable energy investment and conducts performance evaluation on the green policies. First, a coordinated energy planning and investment strategy was proposed against the green and low-carbon background, and the influence mechanism of the green policy environment on renewable energy investment was elaborated. Then, a multistage optimization model was constructed for renewable energy investment in the green policy environment, and the model reconstruction and solution were also presented. After that, the steps to evaluate the performance of green policies for renewable energy power generation were also explained in detail. The experimental results showed the curves of the relationships between the investment by enterprises at different levels and the green policy level and the curves of the effects of various green policies on the tariff, which verified the effectiveness of the proposed model. The sources of technological progress were also analyzed from two aspects: R&D investment and accumulated experience, which demonstrated the importance of technological investment.

Several issues in this research need to be further studied: First, green policy environment, as a novel concept, has not been fully understood. The existing studies have not quantified the theoretical system or indices of the green policy environment. Second, the proposed index system for the green policy environment is imperfect because the current information disclosure mechanism has some defects.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The author declares that there are no conflicts of interest.

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