

# The Comprehensive Evaluation Model of Low Carbon Benefits of the Power Planning and Its Application

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**Keywords:** low-carbon economy, the power planning, low-carbon benefits, the comprehensive cost of low-carbon, carbon emission.

**Abstract.** Analyze the formation mechanism of low carbon benefits of the low carbon power, and combine the economic and low carbon characteristics of a low carbon power by using the low carbon economic factors, redefine low carbon benefits of the power planning and form a comprehensive evaluation model of low carbon benefits. And simulationly analyze the power planning for the least low carbon comprehensive cost as the objective function according to the design case of the typical low carbon power supply, quantitatively evaluate low carbon comprehensive benefits of the power planning. The result shows that the low carbon power planning has a lot of low carbon benefits compared with the traditional power supply planning.

## Introduction

From the point of view, low carbon power planning can adapt to the development of low carbon requirements. However, the low carbon benefits of power planning has not a quantitative standard, set up low carbon benefits evaluation of power supply system, convenient for performance analysis of low carbon power supply for the promotion of low carbon power source planning and developing direction of master also has a great significance.

In recent years, the research of the low carbon power has widely spread, Comprehensive analysis of the literature [2] in a low carbon economy of electric power industry faces new situation and presents new characteristics, and set up the overall research framework of low-carbon electricity technologies; Literature [3] is analyzed for low carbon target model of the power planning. Literature[4] excavates low carbon benefits of the grid, the low carbon benefits evaluation model of the grid is set up, and puts forward the concept of low carbon electricity technology analysis. Literature [5] proposed a smart grid item to promote the development of low carbon ability, and dig deep and analyzed the coupling between each individual ability, put forward the comprehensive low carbon ability evaluation model and the final formation of the low carbon benefits comprehensive evaluation model of the smart grid. Literature[6-7] understand the concept of low carbon benefit of power grid from different angles t, and different analysis model is given.

Above all, low carbon benefits model of power planning and evaluate comprehensively low carbon benefits of the power planning are not given, this article analyzes the formation mechanism of low carbon benefits of the low carbon power, and combines the economic and low carbon characteristics of a low carbon power by using the low carbon economic factors, redefines low carbon benefits of the power planning and form a comprehensive evaluation model of low carbon benefits, and simulationly analyzes the power planning for the least low carbon comprehensive cost as the objective function according to the design case of the typical low carbon power supply, quantitatively evaluates low carbon comprehensive benefits of the power planning. The result shows that the low carbon power planning has a lot of low carbon benefits compared with the traditional power supply planning.

## The Low-carbon Comprehensive Benefit Analysis Model of Power Supply Planning

**Definition of Low-carbon Comprehensive Benefits of Power Planning.** Low-carbon comprehensive benefits of power planning includes two aspects of content, one is the benefits of

low-carbon cost, on the other hand is carbon emission reduction benefits.

First of all, define the benefits of low-carbon cost of the power planning: The impose of carbon taxes increases the cost of carbon, and carbon trading mechanism has brought the corresponding carbon earnings for the power planning. Carbon cost and carbon earnings can be integrated comprehensive carbon cost, with the numerical summing of the traditional power planning cost, namely get low-carbon comprehensive cost of low-carbon power planning. In the analysis of the benefits of low-carbon cost of the power planning, usually want to have a comparative object, under the same working conditions can be the traditional power planning. The difference value of the comparative object and the low-carbon comprehensive cost of low-carbon power planning is the benefits of low-carbon cost.

Carbon emission reduction benefits refers to the difference value between the total carbon emissions of the traditional power planning and the low-carbon power planning during the planning period.

**The Model of Low-carbon Comprehensive Cost of Low-carbon Power Planning.** Low-carbon comprehensive cost of low-carbon power planning includes the cost of investment, operation maintenance cost, power generation cost and the comprehensive carbon cost.

The cost of investment:

$$C_I^{(t)} = \sum_k Y_k^{(t)} c_{Ik}^{(t)} \quad (1)$$

The cost of operation maintenance:

$$C_O^{(t)} = \sum_k H_k^{(t)} c_{Ok}^{(t)} \quad (2)$$

The cost of power generation:

$$C_G^{(t)} = \sum_k A_k^{(t)} c_{Gk}^{(t)} \quad (3)$$

The comprehensive carbon cost:

$$C_{CO_2}^{(t)} = E_{CO_2} T_C - E_{CDM} P_T \quad (4)$$

Where  $Y_k^{(t)}$  is expanded capacity of plant set k in year t;  $H_k^{(t)}$  is the total capacity of plant set k in year t;  $A_k^{(t)}$  is yearly generation capacity to plant k in year t;  $c_{Ik}^{(t)}$ 、 $c_{Ok}^{(t)}$ 、 $c_{Gk}^{(t)}$  respectively denote the unit cost of investment, the unit cost of operation maintenance, the unit cost of power generation of plant set k in year t;  $T_C$  and  $P_T$  respectively denote carbon taxes and the price of carbon trading in year t;  $E_{CO_2}$  is the total of carbon emissions in year t,  $E_{CDM}$  is the carbon trading volume in year t.

$$E_{CO_2} = \sum_k e_k^{(t)} A_k^{(t)} \quad (5)$$

$$E_{CDM} = E_{GOV}^{(t)} - E_{CO_2} \quad (6)$$

Where  $E_{GOV}^{(t)}$  is the carbon emissions allowed of the planning in year t;  $e_k^{(t)}$  is the carbon intensity of the unit generation capacity of plant set k in year t.

In considering of the technical progress factor to carbon emissions intensity of each kind of generating set:

$$e_k^{(t)} = e_k^{(t-1)} (1 - \mu) (0 < \mu < 1) \quad (7)$$

Where  $\mu$  is the rate of technical progress .

The model of low-carbon comprehensive cost of low-carbon power planning:

$$C_S = C_I^{(t)} + C_O^{(t)} + C_G^{(t)} + C_{CO_2}^{(t)} \quad (8)$$

**The Low-carbon Comprehensive Benefit Analysis Model of Power Supply Planning**

$$\left. \begin{aligned} B_S &= C_S' - C_S \\ D_S &= E_T' - E_T \end{aligned} \right\} \quad (9)$$

Where  $B_s$  and  $D_s$  respectively denote the benefits of low-carbon cost and carbon emission reduction benefits;  $C_s$  is the comprehensive cost of traditional power planning during the planning period;  $E_T$  and  $E_T$  respectively denote the carbon emissions of traditional power planning and low-carbon power planning during the planning period.

## Low-carbon Power Optimization Based on the Model of Low-carbon Comprehensive Cost

**Objective Function.** The scheme minimizes the aggregate of the overall cost:

$$\min C = \sum_{t=1}^T C_{RF} C_S \quad (10)$$

Where  $C_{RF}$  is capital recovery factor.

**Constraint.** 1) Equation on Power Demand and Supply: Electricity that generated by plants should be equal to the anticipated power demand annually, which is

$$\sum_{k \in N_k} A_k^{(t)} = Q^t \quad (11)$$

2) Bounds on Yearly Power Generations of Plants.

$$h_{kl}^t H_k^{(t)} \leq A_k^{(t)} \leq H_k^{(t)} h_{ku}^t \quad (12)$$

Where  $h_{ku}^t$  and  $h_{kl}^t$  is the upper and lower bounds of yearly generating hour.

3) Limits on Cumulative Capacities: Cumulative capacities for every set of plants should be limited.

$$H_k^{(t)} \leq \lim Q_k^t \quad (13)$$

Where  $\lim Q_k^t$  is maximum value of cumulative capacities for every set of plants in year t.

4) Caps on Exploitable Capacity.

$$\sum_{t=1}^T Y_k^{(t)} \leq \text{Lim} T_k \quad (14)$$

Where  $\text{Lim} T_k$  is caps of exploitable capacity for resource k during the planning period;

5) Constraints on carbon emissions:

$$\sum_{k \in N_k} e_k^{(t)} A_k^{(t)} + E_S^t - E_B^t \leq E_{GOV}^t \quad (15)$$

$$\sum e_k^T A_k^T \leq E^T \quad (16)$$

The formula (15) denote constraints on carbon emission annually; The formula (16) denote constraints on carbon emissions at the end of the planning period;  $E_S^t$  and  $E_B^t$  respectively denote the selling and buying carbon quotas;  $E^T$  is the carbon emissions at the end of the planning period.

## Analysis of Examples

**Basic Data.** The optimization of power source structure on an area of our country in 2015-2024 is based on the low-carbon power planning model of this article. By the end of 2014, the province's biggest load is 84875 mw, assuming that the load increasing 10% per year during the planning period. In 2014, the intensity of carbon emissions is 0.65 kg/kWh, policy for carbon emissions requires carbon emissions fall to 0.5 kg/kWh by 2024. Assuming the inflation rate is 3%; The carbon tax price

is RMB 100 ¥/ t; The CDM trading price is 70 ¥/t. Specific datas are shown in Table 1 and Table 2.

Table.1 Relevant data of candidate power plans

Power types	Capacity of plant in 2014/GW	Available capacity of plant during the planning period/GW
Thermal power	55	—
Natural gas	2.94	—
Hydropower	9.17	8
Wind power	1	20
Nuclear power	0	5
PV	0	8

Table. 2 Parameters for different types of units

Power types	The cost of investment (¥/kW)	The cost of operation maintenance (¥/kW)	The cost of power generation (¥/kWh)	Carbon intensity (kg/kWh)	$\mu$
Thermal power	4500	135	0.25	0.85	0.01
Natural gas	3000	60	0.32	0.36	0.02
Hydropower	8500	170	0	0	—
Wind power	10000	200	0	0	—
Nuclear power	12500	250	0	0	—
PV	24000	480	0	0	—

**Result.** According to the basic data, we get all kinds of power capacity expansion plan during the planning period, as shown in Figure 1.

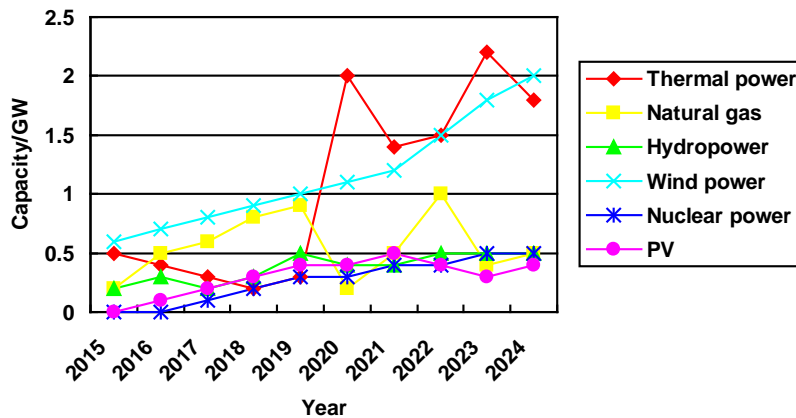


Figure.1 Capacity expansion plan

From Figure 1, on the premise of economic and environmental constraints, clean energy get to vigorously develop, in which, by in wind power technology is relatively mature, equipment investment and later operation maintenance cost is low, so the wind power becomes the development of the new energy. In carbon emissions constraints, especially at the end of the planning of carbon emissions constraints, the power structure will gradually adjust: By reducing the proportion of traditional fossil energy represented by thermal power; At the same time improve the proportion of new energy represented by wind.

The investment cost, operation maintenance cost, power cost, comprehensive carbon cost and carbon emissions of system during the planning period are shown in Table 3.

Table.3 Costs and carbon emissions for the planning period

Year	The investment cost /100million ¥	The operation cost /100million ¥	The generation cost /100million ¥	The comprehensive carbon cost /100million ¥	Low-carbon comprehensive cost /100million ¥	Carbon emissions /100million t
2015	105.5	95.9	669.6	212.2	1082.3	2.21
2016	152.5	99.1	681.3	220.4	1153.4	2.32
2017	184	103	693.3	230.1	1210.4	2.45
2018	221	106.2	707.1	245.5	1279.7	2.58
2019	262.5	110	720.5	258.2	1350.2	2.71
2020	302	115.2	725.8	278.4	1421.4	2.92
2021	358	121.4	741.9	289.5	1510.8	3.03
2022	405	126	758.2	300.6	1589.8	3.19
2023	453	133.6	776.4	320.2	1683.2	3.37
2024	497	143.7	793.8	338.8	1743.3	3.52

**The Comprehensive Evaluation of Low-carbon Benefits.** In order to quantify the power planning of low carbon benefits, introduced traditional power planning, the traditional power supply planning does not consider the carbon tax and carbon trading, wind power and other clean energy technology, and carbon emissions constraints. Getting the low-carbon comprehensive cost and carbon emissions of traditional power planning in the planning period .Two planning models of key indicators are shown in Table 4 below.

Table.4 Comparison of results under two scenarios

Model	Low-carbon comprehensive cost /billion ¥	Carbon emissions /billion t
Low-carbon planning	1402.46	2.83
Traditional planning	1412.59	3.71

According to the Table 4 and the evaluation model of low-carbon benefits:

$$B_s = D'_s - D_s = 1412.59 - 1402.46 = 10.13 \text{ billion } ¥$$

$$D_s = E'_T - E_T = 3.71 - 2.83 = 0.88 \text{ billion t}$$

Getting low-carbon cost benefits is 10.13 billion ¥, carbon emission reduction benefits is 0.88 billion t, low-carbon power planning has the huge low-carbon comprehensive benefit.

## Conclusions

This article analyzes the formation mechanism of low carbon benefits of the low carbon power, and combines the economic and low carbon characteristics of a low carbon power by using the low carbon economic factors, redefines low carbon benefits of the power planning and form a comprehensive evaluation model of low carbon benefits, and simulatedly analyzes the power planning for the least low carbon comprehensive cost as the objective function according to the design case of the typical low carbon power supply, quantitatively evaluates low carbon comprehensive benefits of the power planning. The result shows that the low carbon power planning has a lot of low carbon benefits compared with the traditional power supply planning.

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