Optimization model of a combined wind-PV-thermal dispatching system under carbon emissions trading in China

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CONTENTS

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1.Backgrounds

- **Backgrounds**
  - **Research status**
    - RES
    - CET
  - **Existing problems**
    - Uncertainty
    - Inadaptability
  - **Innovations & contributions**

1.Backgrounds

- Fossil fuels have played an unshakable role in energy consumption and will rapidly approach depletion in the first half of the 21st century.
- Environmental issues such as global warming caused by the overconsumption of traditional fossil fuels have attracted much attention.

There are two effective ways to solve the above problems, one is to use clean energy such as wind power and photovoltaic(PV) to replace fossil fuels, and the other is to use carbon emissions trading to limit its consumption.

1.1 Renewable energy sources (RES)

- Renewable energy sources have the characteristics of intermittency, randomness and fluctuation, so they can't adapt to the requirements of the power system because of their own lack of regulating capacity.
- A large amount of renewable energy integration will impact the stable operation of the power grid, thus reducing system reliability.

The key to the formation of a dispatching strategy lies in the share of power generation between thermal power and RES.

1.2 Carbon emissions trading (CET)

- Introducing CET mechanism into the power dispatching system can control the carbon emissions of the power industry.
- A change in carbon price will also affect the share of renewable energy.

The key to the formation of a trading mechanism lies in the allocation of emissions quotas and the determination of trading prices.

1.3 Existing problems-RES

Current researches involve in-depth research on the economical dispatching of integrated energy systems, but less on the issue of renewable energy abandonment.

Spillage rate（2017）	National average	Serious region
Wind	12%	More than 30%
PV	6%	More than 20%

1.3 Existing problems-CET

Due to large differences in the CET policies between China and other countries, foreign carbon trading mechanisms can't be applied easily in the case of China.

The carbon trading market in China faces problems such as a lack of functions in the carbon trading market, inaccurate quota allocation, no real-time carbon price, an imperfect trading mechanism, and a lag in legislation, making it difficult to play an effective role.

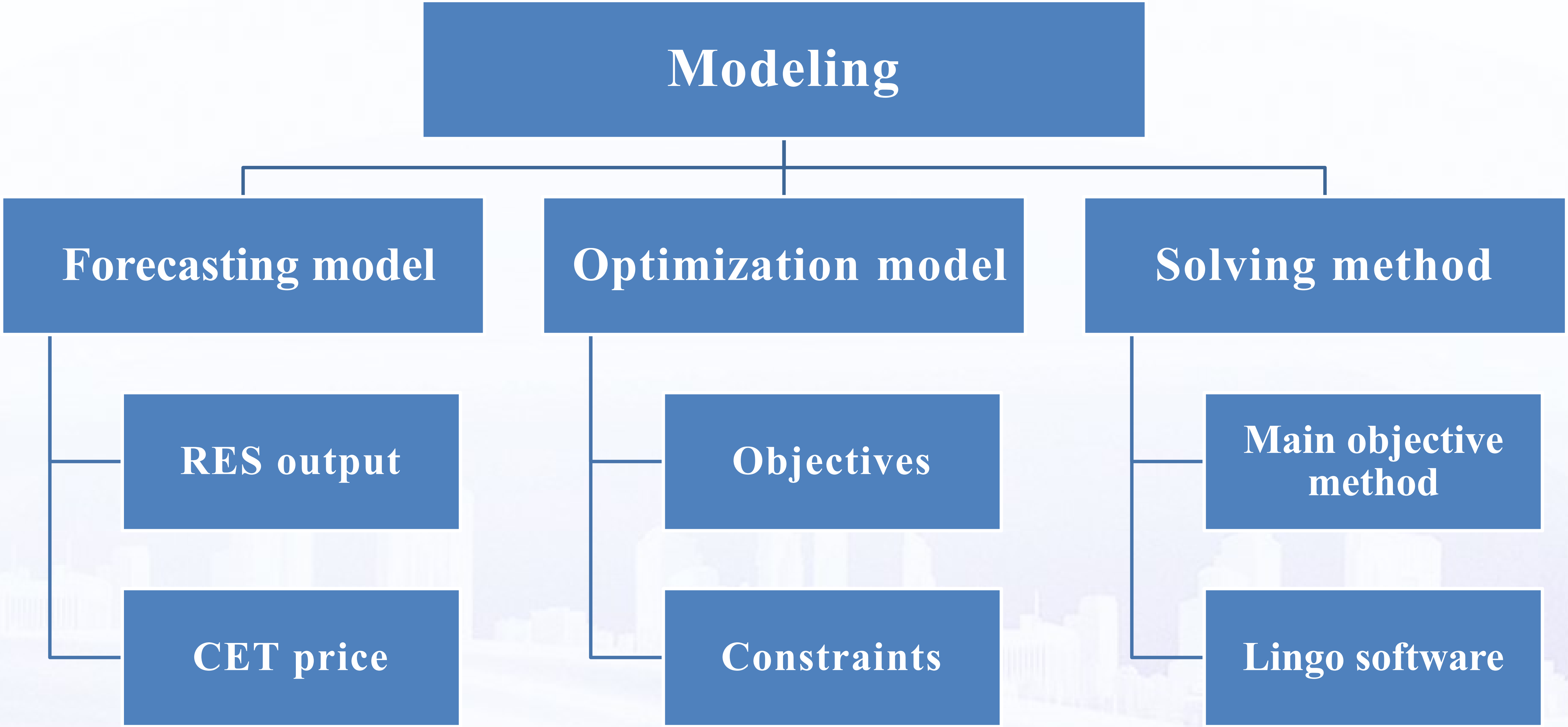
1.3 Existing problems-Dispatching strategy

- Although China has created many laws to ensure the priority dispatching of renewable energy power, they have not been effectively enforced because they do not give a clear definition of “priority dispatch”.
- The priority scheduling of renewable energy will put great economic cost pressure on grid companies, so they lack the incentive to dispatch renewable energy.

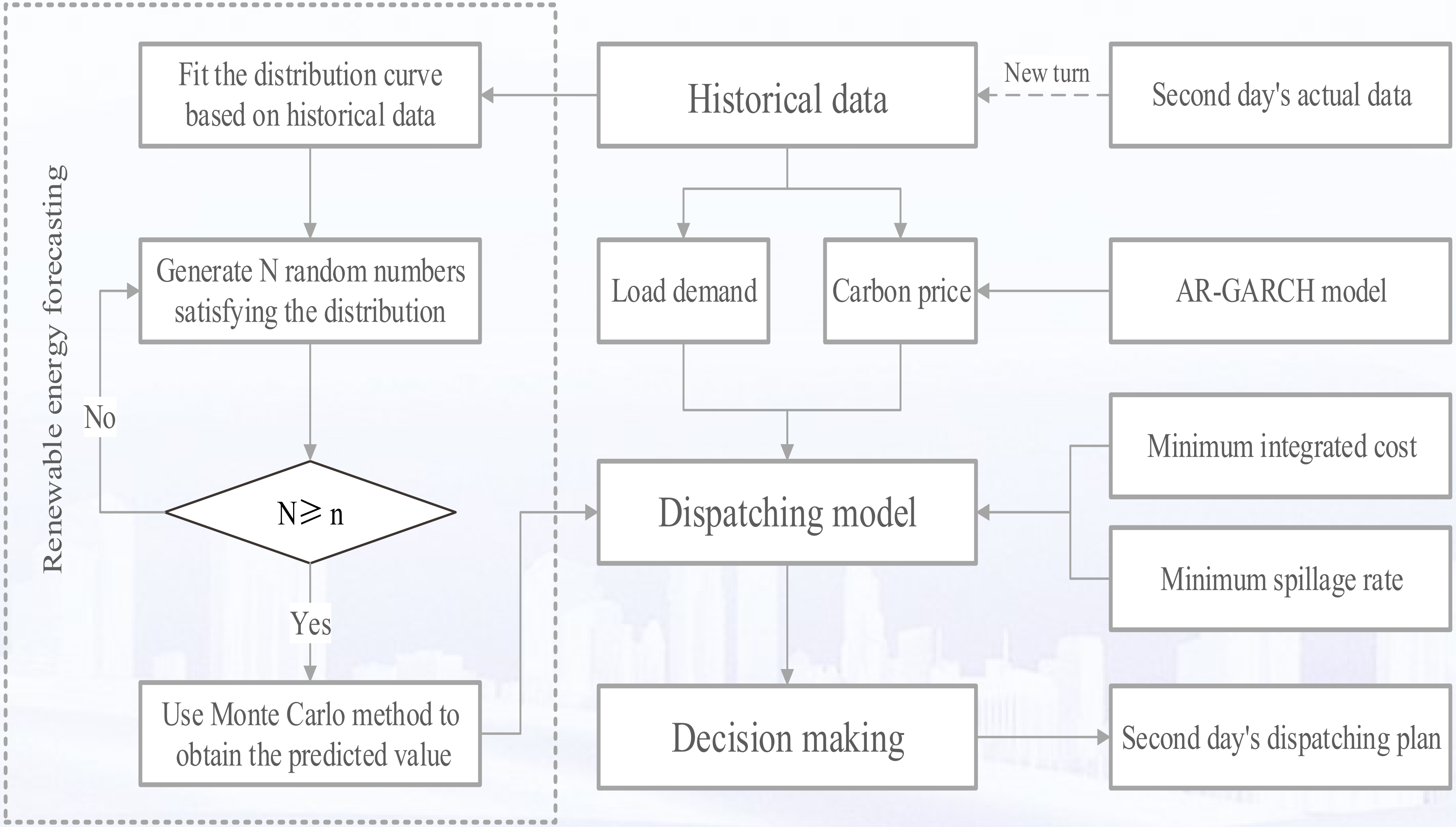
1.4 Innovations and contributions

- Introduce a CET mechanism to constrain carbon emissions while promoting the priority of renewable energy deployment, which achieves the dual purpose of energy-saving scheduling and CET.
- Use the power spillage rate to adjust the principle of joint dispatching of renewable energy and thermal power.
- Introduce the central limit theorem into renewable energy prediction to solve the problem of small sample size.

2.Modeling


Modeling
Forecasting model
Optimization model
Solving method
RES output
CET price
Objectives
Constraints
Main objective method
Lingo software

2.1 Flowchart of the optimization model



2.2 Optimization model

Objectives

- Integrated cost minimization
  - operation costs of thermal power
  - carbon emissions trading cost
- Integrated spillage rate minimization

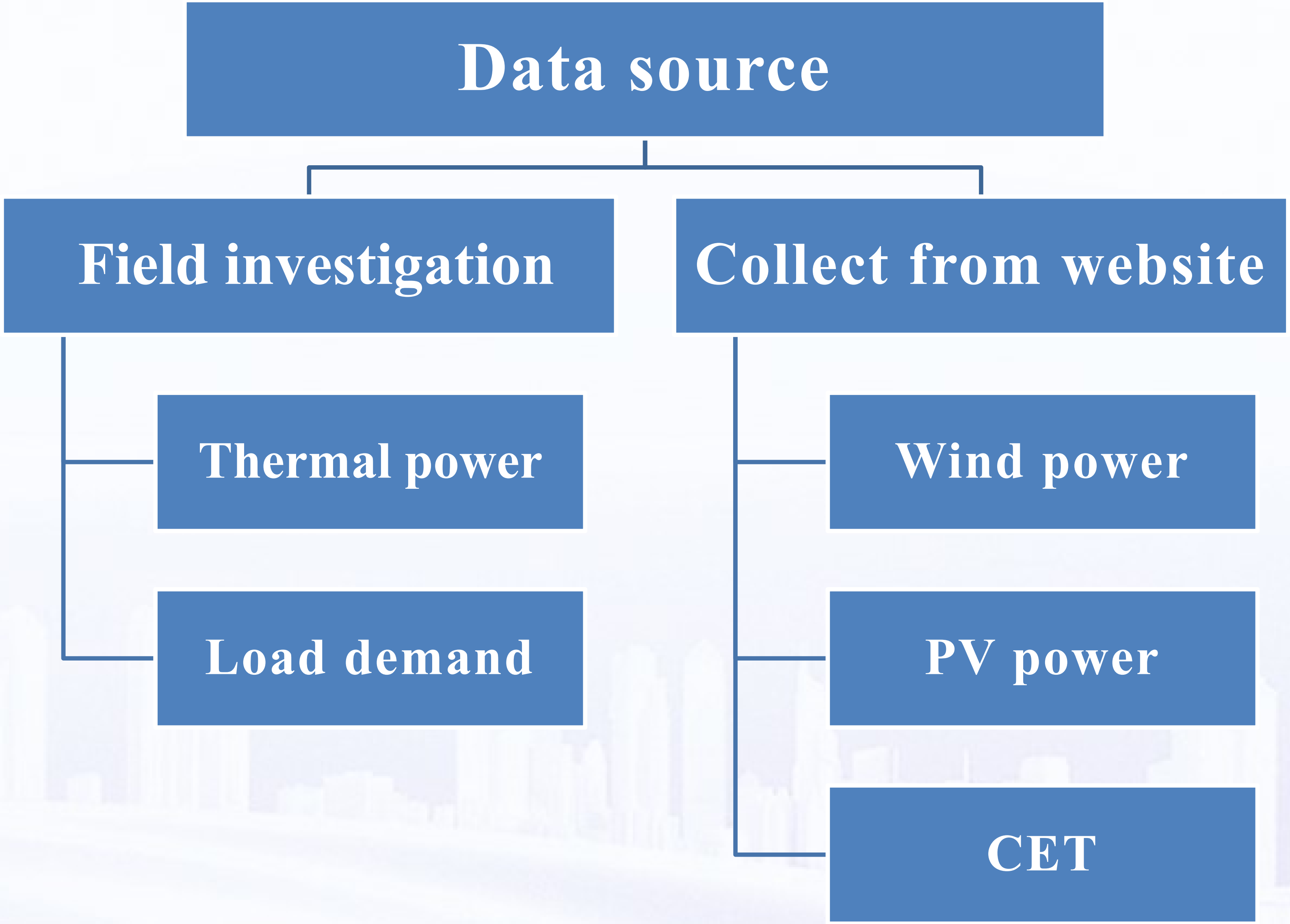
Constraints

- Equilibrium constraint of the power system
- Thermal power unit constraints
- Wind power plant constraints
- Photovoltaic power plant constraints
- penetration rate limit constraint

2.3 Solving method

The main objective method is used to transform the bi-objective problem into a single-objective, which is determining a primary objective, taking other objectives as constraint conditions and setting appropriate limit values, and then using Lingo to solve the problem.

3. Data source



3.1 Thermal power

Table 1
Technical parameters of thermal power.

Thermal power plants	Units	$Q_{i,\max}$ (MW)	$Q_{i,\max}$ (MW)	$a_{0,i}$	$a_{1,i}$	$a_{2,i}$	SD (¥)	SU (¥)
1	1#	660	270	11.71	0.274	0.644E−05	28,680	30,750
	2#	660	270	11.71	0.274	0.644E−05	28,680	30,750
	3#	660	270	11.71	0.274	0.644E−05	28,680	30,750
	4#	660	270	11.71	0.274	0.644E−05	28,680	30,750
2	5#	660	275	13.21	0.269	0.935E−05	29,300	31,170
	6#	630	250	8.8	0.268	0.944E −05	26,700	28,660
3	7#	660	250	12.68	0.272	0.631E−05	27,360	29,520
	8#	660	250	12.68	0.272	0.631E−05	27,360	29,520

Table 3
Thermal power Output parameters.

Thermal power plants	Units	$Q_{i,v}$(MW/h)	T_i^{on}(h)	T_i^{off}(h)	M_i^{on}(h)	M_i^{off}(h)
1	1#	170	7	7	7	7
	2#	170	7	7	7	7
	3#	170	7	7	7	7
	4#	170	7	7	7	7
2	5#	175	8	8	8	8
	6#	150	6	6	6	6
3	7#	165	6	6	6	6
	8#	165	6	6	6	6

3.2 Renewable energy

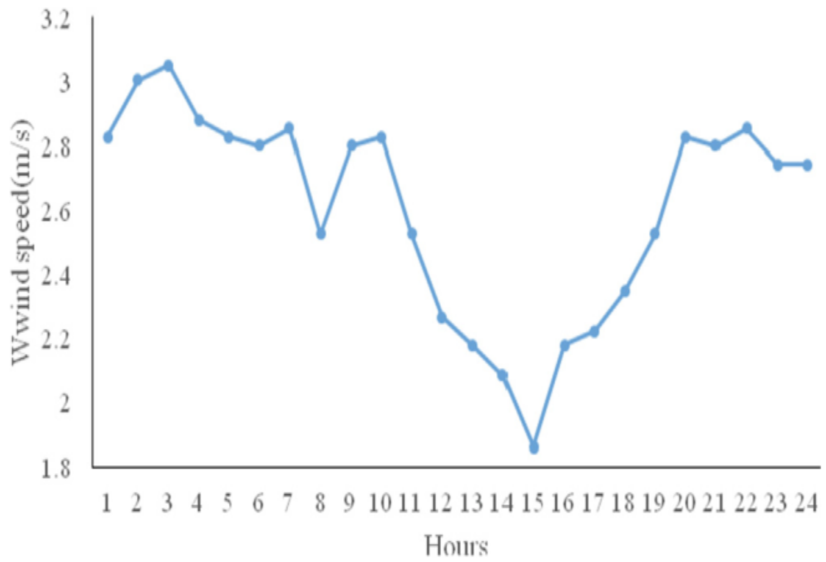


Fig. A1. Predicted value of wind speed.

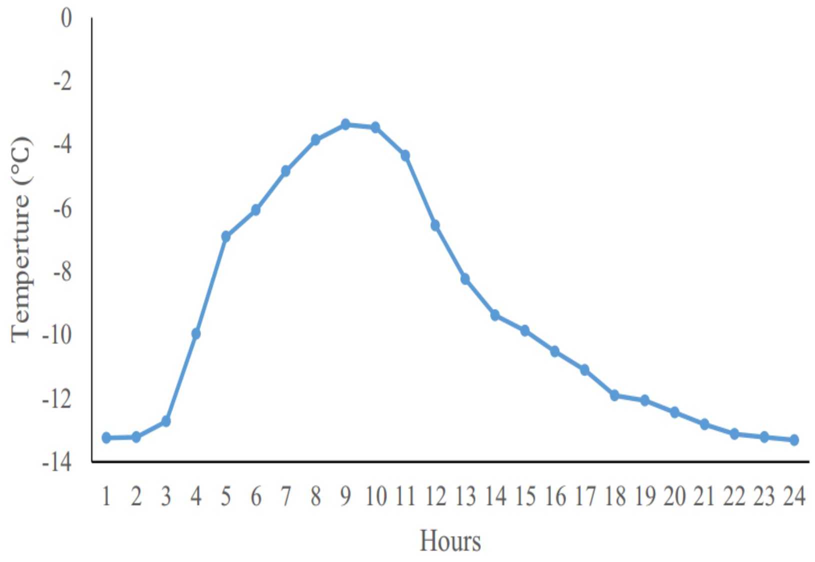


Fig. A2. Predicted value of temperature.

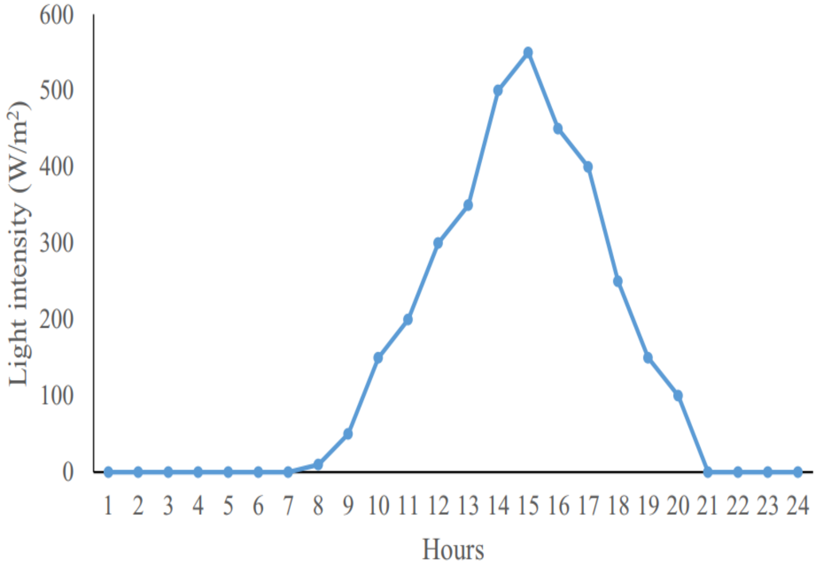


Fig. A3. Predicted value of light intensity.

（Data source：China Meteorological Administration）

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3.2 Renewable energy

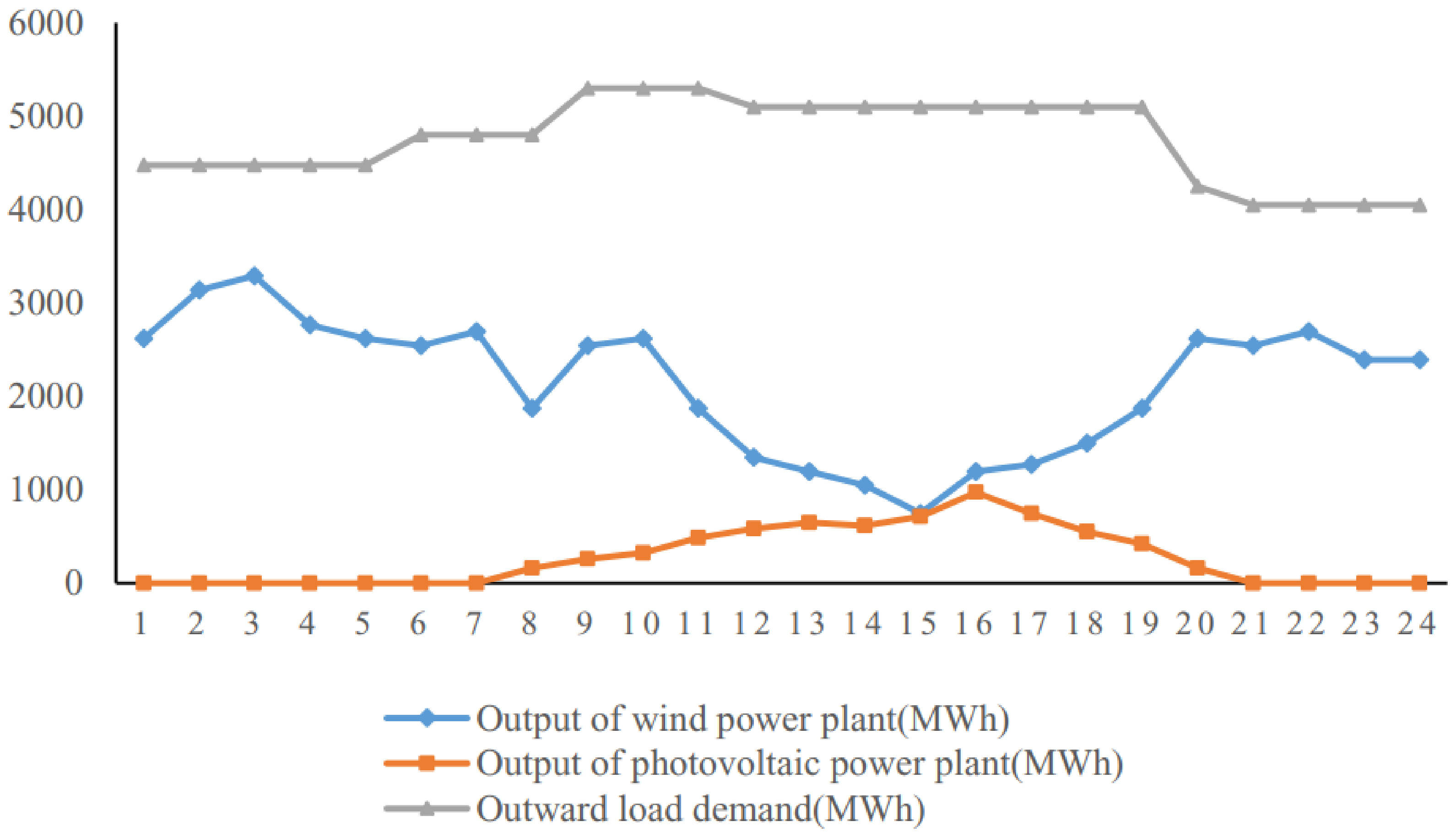

Fig. 5. Output of wind and photovoltaic power plants and outward load demand.

3.3 CET quotas and prices

A free initial carbon emission allocation model based on power generation capacity

- Load correction parameter
- Allocation of emissions per unit of electricity

（Data source：National Development and Reform Commission

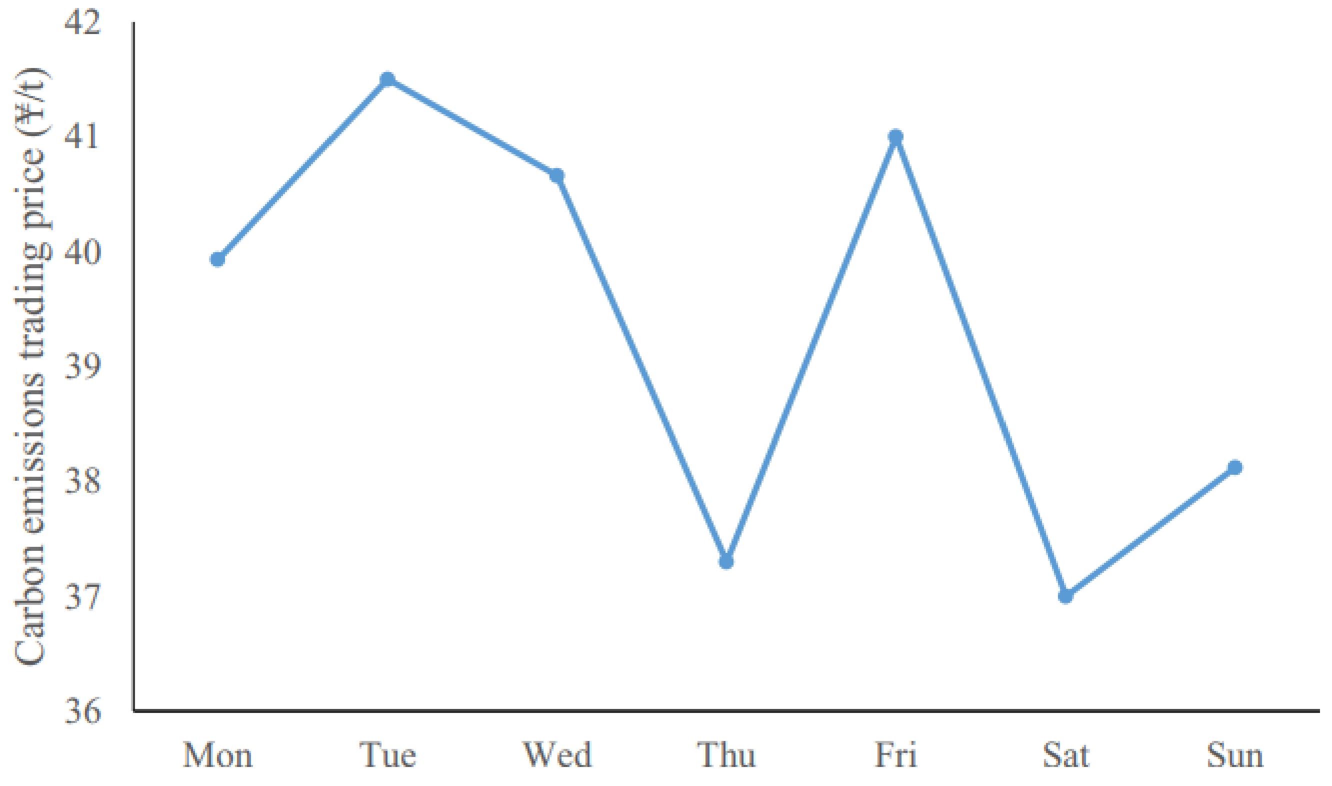

Fig. 4. Carbon emissions trading price fluctuations for one week.

4.Result Analysis

- **Result Analysis**
  - **Model comparison**
    - Forecasting model
    - Dispatching model
  - **CET**
  - **Sensitivity analysis**
    - Input data
    - Input parameters

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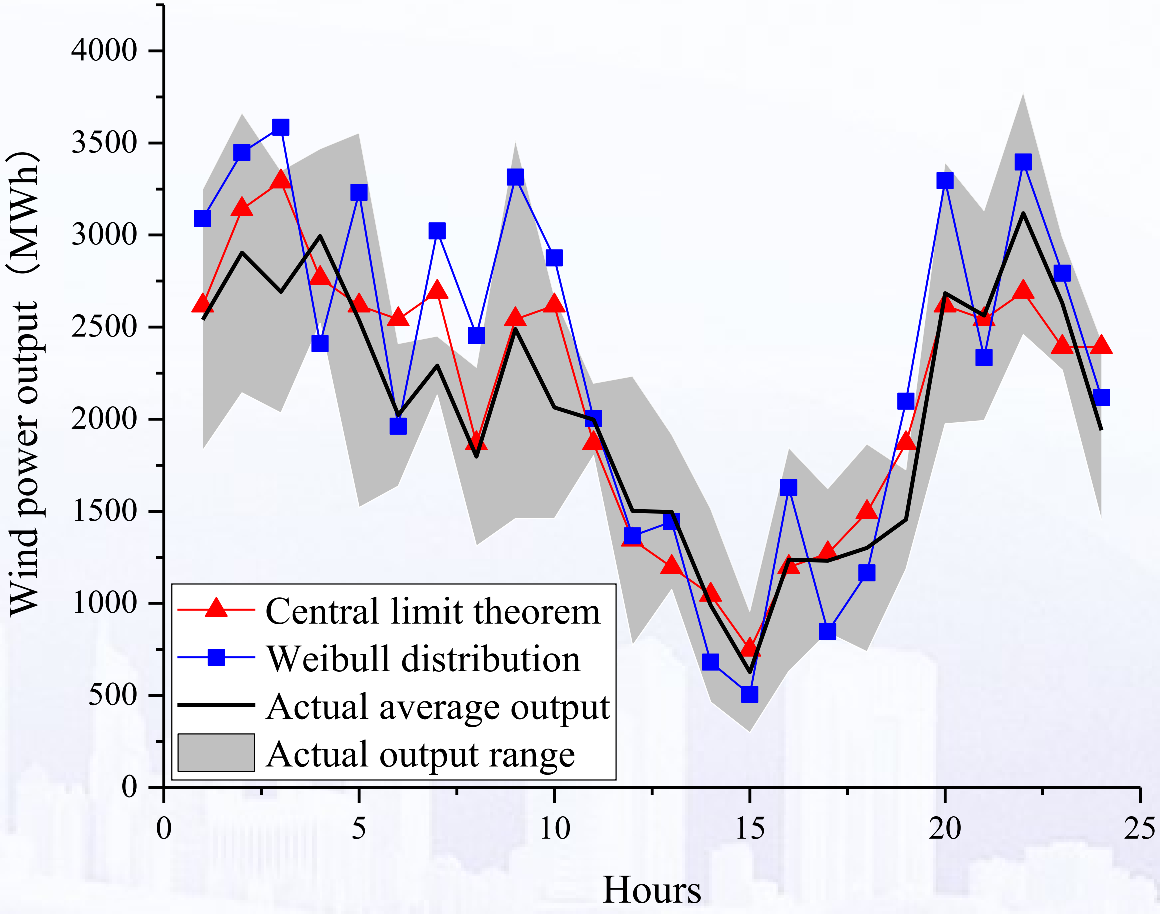
4.1 Model comparison-Forecasting model

- The wind power output predicted by the central limit theorem can basically be within the actual output range and closer to the average of the actual output.
- Better accuracy can be obtained when the sample size is small.



4.1 Model comparison-Dispatching model

- The total spillage rate is reduced from 28.86% to 25.07%.
- The increase in renewable energy consumption versus the load demand reduces the proportion of thermal power generation in the dispatch, resulting in a 3.39% reduction in the total system cost.

	No spillage optimize	Spillage optimize	Rate of change
Thermal power	83,317.68 MWh	81,272.67MWh	−2.52%
Photovoltaic power	5,305.86 MWh	5,814.27MWh	+8.74%
Wind power	35,955.29 MWh	37,645.16MWh	+4.49%
Carbon emissions	62,166.77kg	59,039.78kg	−5.03%
Total spillage rate	28.86%	25.07%	−15.12%
Total cost	¥5.49E6	¥5.31E6	-3.39%

4.2 Carbon emissions trading mechanism analysis

Three scenarios are set up to study the impacts of various mechanisms.

- Moderate scenario: free quota is set at 80% and carbon price is set at 39.6¥/t.
- Radical scenario: free quota is 10% lower than that in the Moderate scenario and the same carbon price.
- Conservative scenario: free quota is the same as that in Moderate scenario, whereas the carbon price is the half.

Scenarios	**Conservative**	**Moderate**	**Radical**
Free quota (%)	80	80	72
Carbon price (¥/t)	19.8	39.6	39.6

4.2 Carbon emissions trading mechanism analysis

Table 7
Dispatching system optimized results under different scenarios.

Scenarios	Carbon Emissions (kg/MWh)	Coal Consumption (kg/MWh)	Integrated Spillage Rate (%)	Integrated Cost (¥)
Conservative	782.85	306.16	26.71	5.46E6
Moderate	778.36	303.67	19.25	5.33E6
Radical	774.59	301.71	13.98	5.25E6

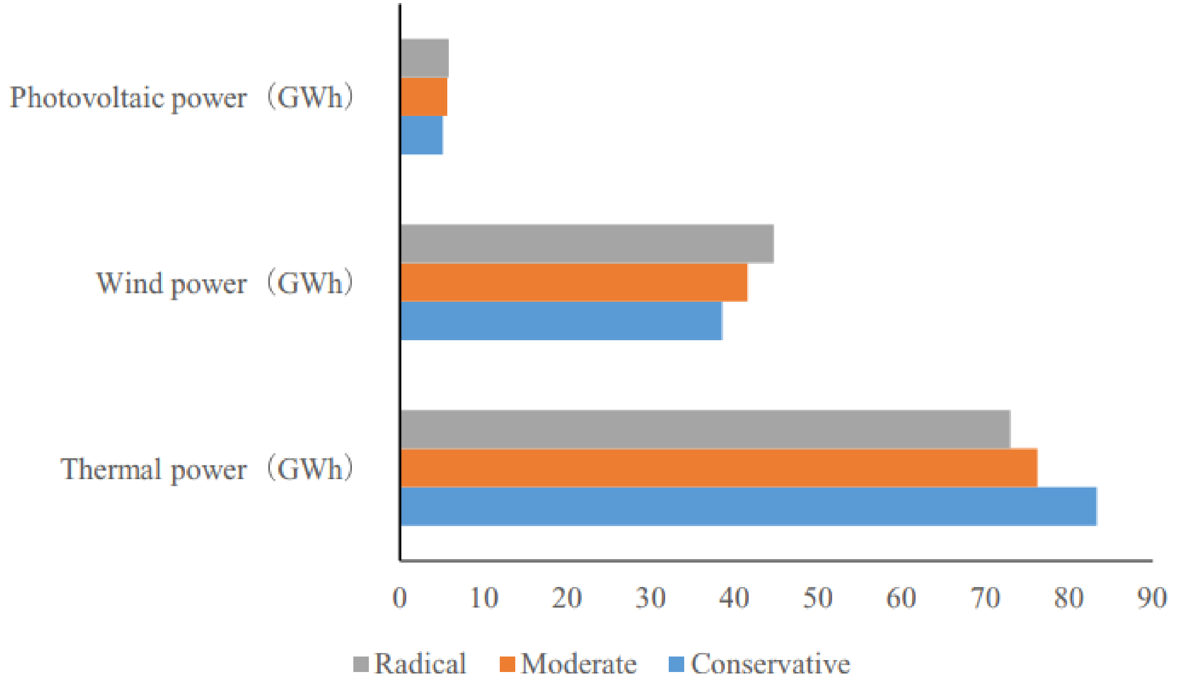
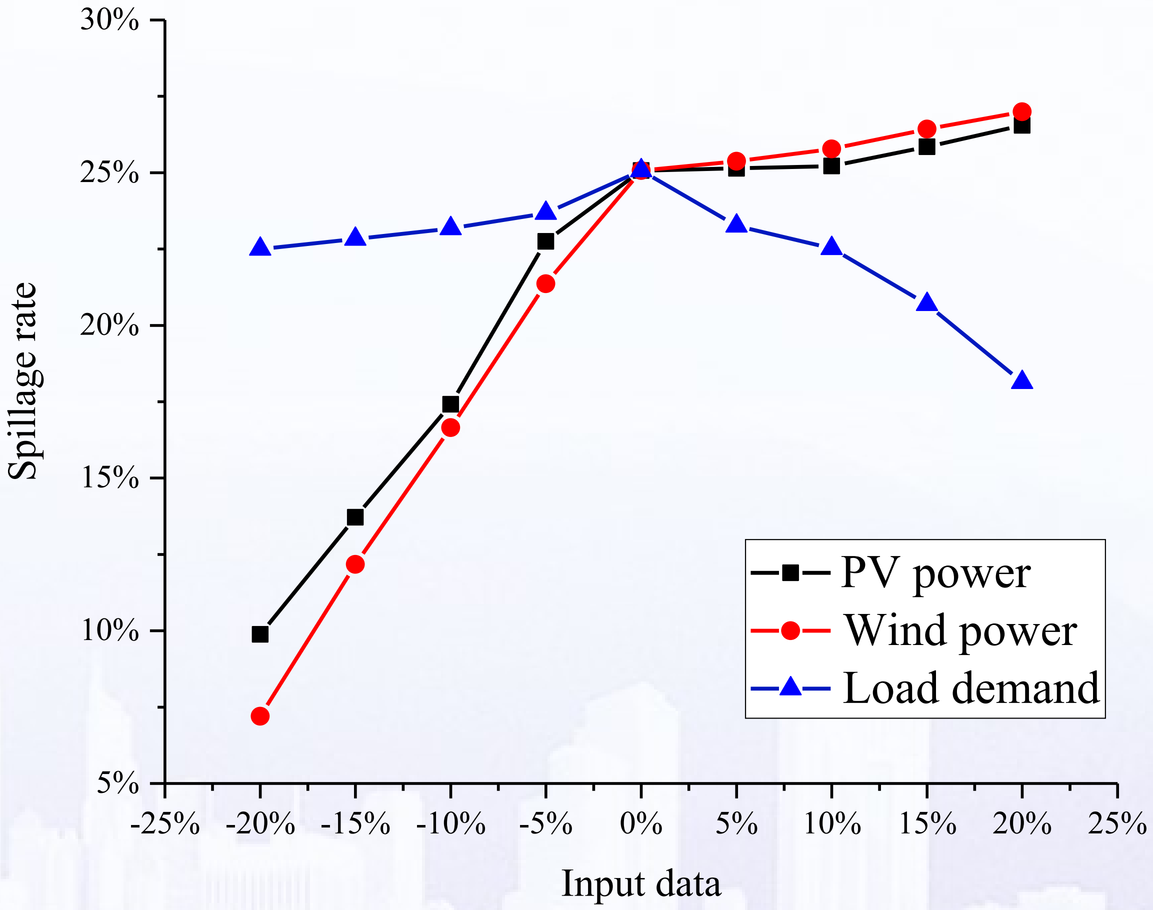


Fig. 8. Total power output under various scenarios.

A more rigorous carbon emissions trading mechanism could be effective in reducing carbon emissions as well as the integrated cost.

4.3 Sensitivity analysis-Input data

- The changes in the power rejection rate are within the acceptable range, when the input data fluctuates
- The model is more sensitive to wind power than PV power.



4.3 Sensitivity analysis-Input parameters

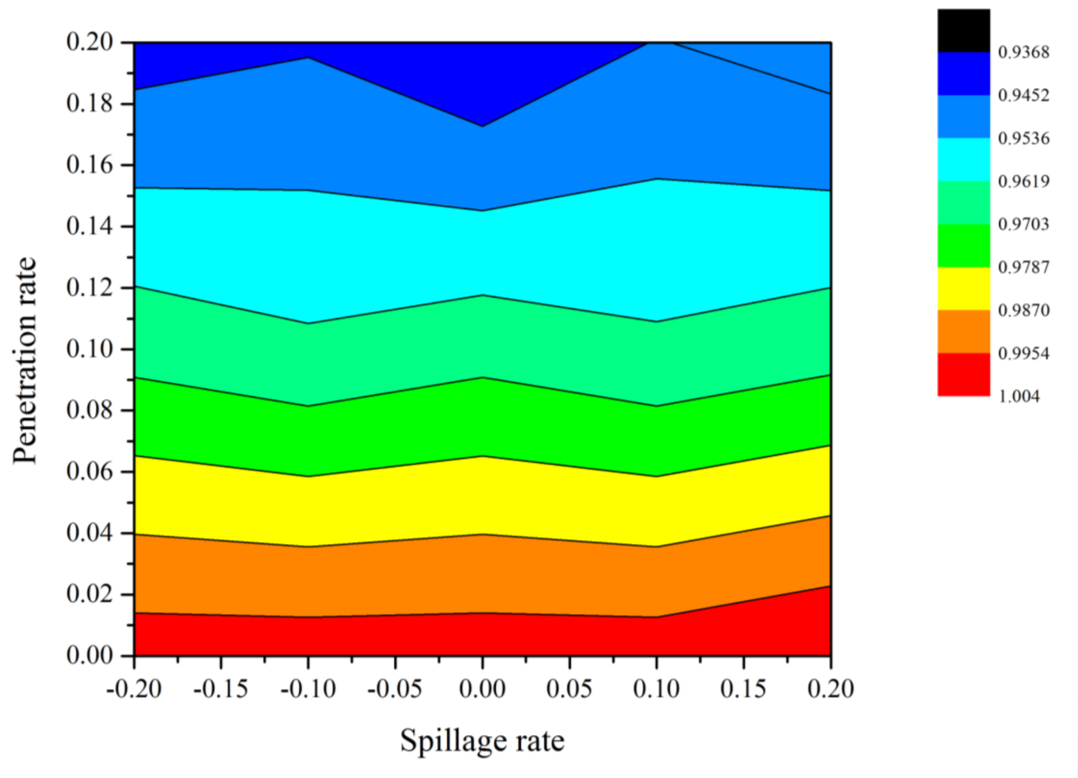
- If the penetration rate is reduced to a certain degree, the thermal power will not fully meet the load demand.
- With the increase in these two parameters, renewable energy power generation will gradually replace the share of thermal power generation, thus reducing the integrated cost.

Z \ R / ξ	−20%	−10%	0	10%	20%
−20%	-	-	-	-	-
−10%	-	-	-	5.54E6	5.54E6
0	5.31E6	5.32E6	**5.31E6***	5.31E6	5.33E6
10%	5.13E6	5.12E6	5.14E6	5.11E6	5.13E6
20%	4.99E6	5.01E6	4.97E6	5.02E6	5.00E6

(*Fig.10 is based on this data, with all other data in relative proportions.)

4.3 Sensitivity analysis-Input parameters

- Penetration rate has a greater impact on the integrated cost than spillage rate.
- Although the integrated cost fluctuates as these two parameters are increased, the overall trend is declining



The color represents the ratio of the integrated cost to 5.31E6.

4.Result Analysis

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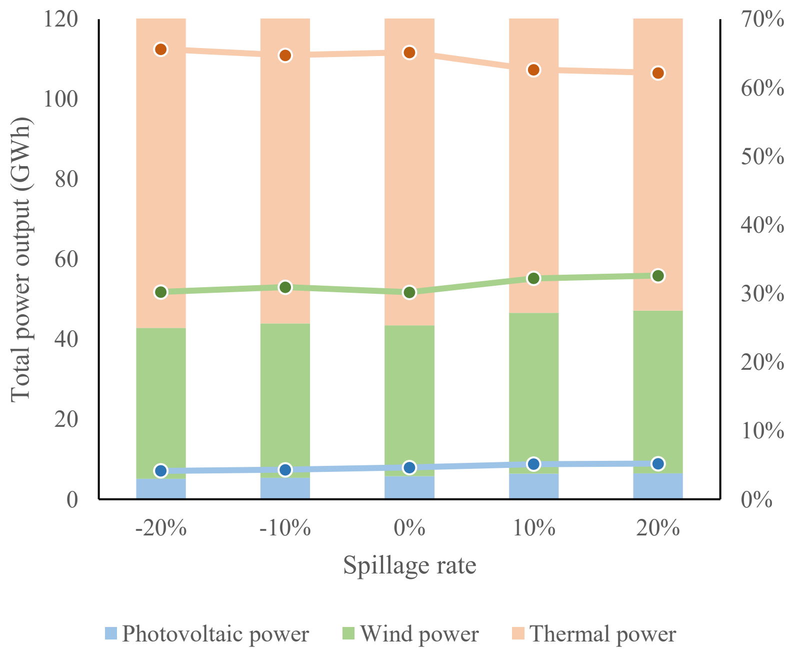
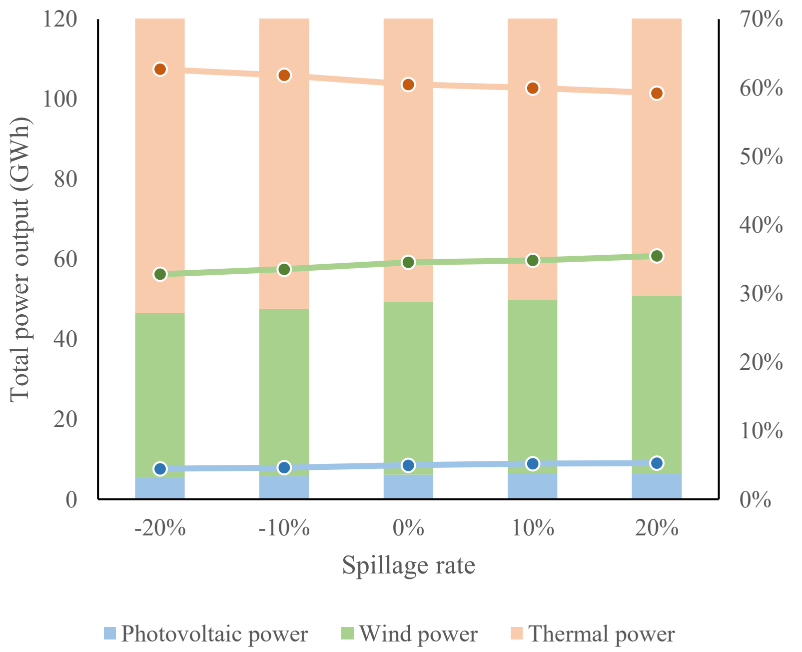
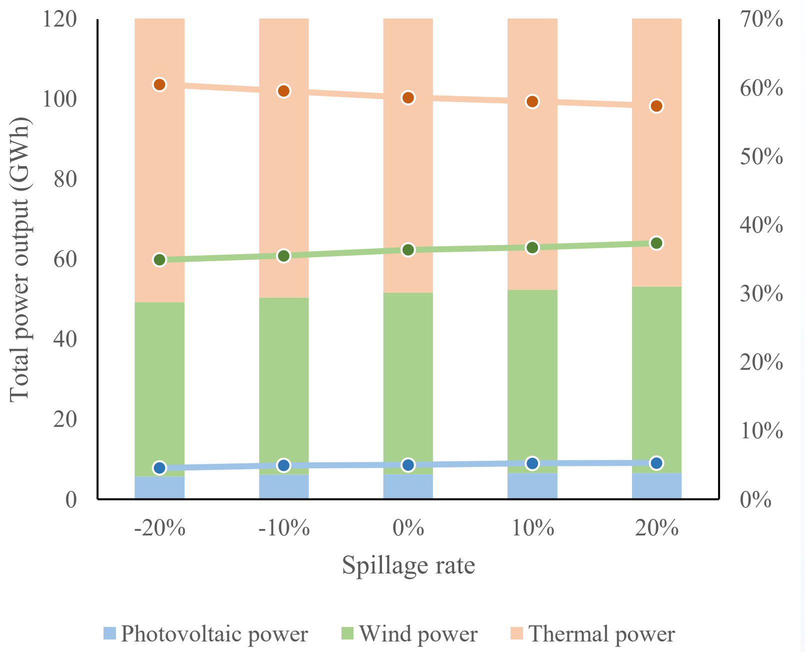
4.3 Sensitivity analysis-Input parameters



ξ=0



ξ=10%



ξ=20%

The thermal power generation changes in the opposite direction to renewable power, which means that with a gradual decline in the proportion of thermal power

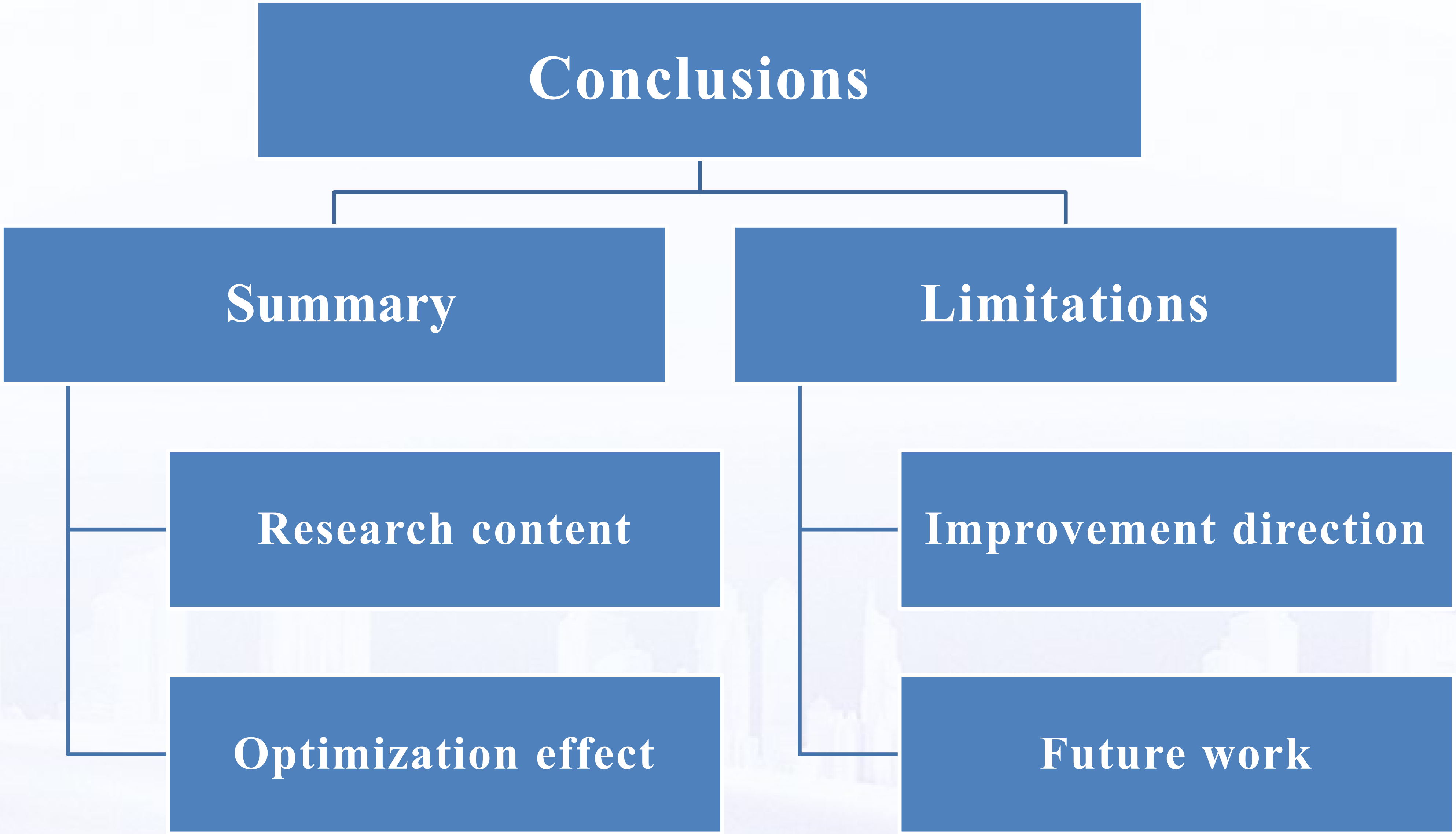
4.3 Sensitivity analysis-Input parameters

The influence of the penetration rate on the status of the thermal power units.

Penetration rate	between 40% and 50%	more than 60%	100%
Change of state	4 times	6 times	14 times
RES consumption	100% PV power	100% wind power	100% RES

An increase in the amount of grid absorption of renewable energy poses a greater challenge to the stability of the power generation system, so the thermal power unit will be forced to adjust its output at any time to ensure the stable operation of the system.

5.Conclusions



5.1 Summary

- A dispatching optimization model is proposed, which not only considers the total cost but also takes into account the impact of the renewable energy spillage rate on the dispatching system.
- As a factor affecting renewable energy consumption, a carbon emissions trading mechanism has also been introduced into the dispatching system.
- Develop a model for predicting the output of renewable energy generation.

5.2 Limitations

- The input data sensitivity analysis is only a simple simulation of the prediction error, regardless of the form of error that may occur.
- Nor does it consider the case in which prediction errors occur at the same time.
- Some technical constraints, such as transmission congestion, are not considered.

Q&A Session

Thank you