

**Study on RE integration mechanisms  
in Northwest China**

Summary

**Xi'an Jiaotong University**

**March 2019**

**Project manager: Prof. Xiuli Wang**

**Technical manager: Prof. Jianxue Wang**

**Project participants: Yunpeng Xiao**

**Wei Zhang**

**Siyang Liu**

**Yongxi Huang**

**Yanan Wang**

**Min Zhang**

**Hongyang Zhao**

**Zhengting Jiang**

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# 1. Preface

## 1.1 Introduction

In order to grasp the development of renewable energy (RE) consumption mechanism in Northwest China better, and promote the scientific and rational development of the mechanism, in 2018, the Northwest Energy Administration (NWEA) has carried out a study on the mechanism to better RE integration. This subject is studied by the Electrical Engineering Department of Xi'an Jiaotong University. The research studied the development of different mechanisms to improve RE integration, promoting inter-provincial and inter-regional power trade, explore the potential of dispatch and ancillary service.

In recent years, RE in the northwest region has achieved leap-forward development. The RE installed capacity and power generation have grown rapidly, making Northwest China the region with the largest RE proportion among all business regions of the State Grid. Along with the rising proportion of RE generation capacity, the problems of RE curtailment has become increasingly prominent.

It is particularly significant for the northwest region, accounting for the largest RE proportion among the RE in China, to study the RE consumption mechanism and path. In 2017, the quantity of RE curtailment in this region is 29.812 billion kWh with a corresponding rate at 20.3%, which is a decrease of 8.6% compared with the same period last year. Problems that restrict the RE consumption in northwest region are very complicated, which result from the historical reasons and will change along with the development of the plan. Therefore, we need to do the research on mechanisms in different aspects to better RE integration.

## 1.2 Research Progress

Time Period	Research Progress
January 2018- February 2018	Project beginning
March 2018- July 2018	(1) Conduct the research of <b>Task 1-4</b> (2) Some project participators in NWEA and XJTU conduct the investigations in Ningxia on <b>June 26th</b> (3) submit the following deliverables: Task 1 report: Analysis of RE integration mechanisms in northwest region Task 2 report: Analysis of inter-provincial and inter-regional

Time Period	Research Progress
	power trading in northwest region
August 2018- December 2018	<p>(1) Invite a number of well-known experts and hold mid-term review meeting on <b>August 29th in Beijing</b></p> <p>(2) Conduct the research of Task 3 and 4</p> <p>(3) Some project participators of NWEA and XJTU participate in the official start-up meeting of the Ningxia Auxiliary Service Market on <b>November 30th</b></p> <p>(4) Hold annual discussion meeting on <b>December 27th</b> with experts in World Bank, NWEA and XJTU</p> <p>(5) submit the following deliverables:</p> <p>Task 3 report: Impacts analysis of dispatch models to RE integration in Ningxia</p> <p>Task 4 report: Monitoring report on operation of pilot ancillary service market in Ningxia</p>
January 2019- March 2019	<p>(1) Hold a discussion meeting on <b>March 2nd</b> with experts of World Bank, NWEA and XJTU</p> <p>(2) Modify and improve each part of the report to form a general report</p>

The following papers have been published in the research process of this subject:

- 1) Xiao Y, Wang X, Wang X, et al. Review on Electricity Market Towards High Proportion of Renewable Energy[J], Proceedings of the CSEE, 2018,38(3):663-674.
- 2) Zhang W, Wang X, Wu X, et al. Enhanced long-run incremental cost charging considering the impact of demand response[J]. IET Generation, Transmission & Distribution, 2018, 12(22): 6011-6020.
- 3) Wang Y, Wang X and Zhao H. Analysis of Dispatch Methods in Northwest Area[C]. ACPEE,2019, accepted.

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## 1.3 Main Research Works

The project conducted the study in following four aspects: (1) analyze the development of different mechanisms to improve RE integration in northwest China; (2) study the inter-provincial and inter-regional transaction mechanism to promote RE generation in northwest China; (3) simulate to analyze the impact of RE integration using different dispatch models and (4) support to pilot ancillary service market in a selected province (Ningxia).

### Task 1 RE development Route

The project analyzed the main factors restricting the RE consumption in Northwest China. They can be summarized as the inadequate local electricity demand, the potential of power transmission isn't fully utilized, the inadequate peaking regulation capability, the insufficient accuracy of RE output prediction, the imperfect market and dispatching mechanisms. Based on the analysis of the status and constraints of RE consumption in the Northwest China, and the analysis of RE consumption mechanisms and effects at home and abroad, this study believes that those areas with difficulties in RE consumption should start from the above aspects and reflect on the deficiencies. Finding the corresponding improvement measures finally. From the aspects of power generation, transmission, using, and the mechanisms of market and dispatching, the project has pointed out the development direction and framework from the short-term to long-term, covering the RE plants planning, transmission planning, demand response management, and the promotion market and dispatching mechanisms. The project proposed “promoting the transition of RE planning toward comprehensive resource assessment by independent decision-making”, “establishing a mechanism for optimal allocation of peaking resources”, “achieving the dual development of expanding the scope of system resource allocation and promoting the rational pricing of transmission resources as well”, “realizing the transition from the stage of excavating demand side flexibility to the stage that demand side can flexibly and actively follow the RE output”, which have certain guiding significance for other areas having the RE curtailment problems. The works of **Task 1** included:

a) Review existing studies to figure out major factors that constrain the RE integration in northwest region, and analyze the reasons behind these factors;

b) Analyze different measures and mechanisms, including both government coordination and development of power markets, that can eliminate or reduce the impacts of various factors to improve RE integration, based on both international and domestic experience and lessons, and then assess the applicability of the measures and mechanisms in northwest region as well;

c) Recommend various mechanism arrangements that can promote the RE integration in northwest region, together with the development path of these mechanisms in short-term, medium and long-term (e.g. stage-by-stage arrangement for the transition from effective intervention of the government to the market mechanism). The consultant will sort out the objectives, actions and conditions precedent for every

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stage;

d) the project consult extensively the external experts in the industry, solicit their opinions and suggestions from different stakeholders, and include the appropriate suggestions in the final report.

## **Task 2 Study the transaction mechanism to promote RE generation**

China's resource-rich areas are far from the load center. In order to meet the electricity demand, China has built lots of inter-regional transmission channels. The utilization of those channels plays an important role in the RE consumption of the resource areas. The project focus on the Northwest China and analyzes the current mechanism and status of cross-province (regional) transaction. The study found that "the overall utilization rate of cross-provincial and cross-regional transmission channels in Northwest China still has considerable potential for improvement". "the transmission channels play an important role in the RE consumption", "cross-provincial and cross-regional trading mechanism is basically established but the trading types remain to be improved". At the same time, it's found that "cross-provincial and cross-regional transaction terminal areas are not willing to further increase in trading electricity quantity". In view of the problems found in the study of cross-provincial (regional) trading mechanisms, the project proposes that "the cross-provincial (regional) trading mechanisms should enrich the trading varieties and activate the thermal power plants to participate in the RE consumption", which has certain reference for the trading mechanisms improvement of the national cross-regional transmission channels. The works of **Task 2** included:

a) Survey and analyze current power transmission capacities of major inter-provincial (inter-regional) passages (cross-sections) as well as the volume of power transmission based on the actual operations in 2015-2017, and survey related market mechanisms and absorption policies to arrange the inter-provincial (inter-regional) power exchange;

b) Survey and research receiving provincial (regional) markets of inter-provincial (inter-regional) power transmission regarding their willingness, pricing, policies, barrier and other aspects;

c) Analyze various mechanisms and measures for inter-provincial (inter-regional) power transmission (including government planned transaction, generation right trading, market bidding and other mechanisms), categorized by different time lengths (annual, quarterly, monthly and daily transactions), assess the implementation effects, constraint factors and options for improvement for these mechanisms and measures, aiming to increase the ratio of RE export;

d) Investigate the methods used to determine the actual transmission capacities of major inter-provincial (inter-regional) passages (cross sections), analyze major factors used to determine the actual transmission capacities, compare the actual capacities with their technical potential, and put forward suggestions of exploring the market mechanism to make use of the transmission potentials;

e) Study the methods of breaking through inter-provincial barriers, and propose options to benefit all stakeholders from the inter-provincial (inter-regional) power

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transactions, particularly focusing on mechanisms and relevant policies that will increase the RE integration through inter-provincial (inter-regional) power trading.

### **Task 3: Study on different dispatch models**

At this stage, thermal power units take up the highest proportion in China. Under the background of severe RE curtailment, establishing a peaking auxiliary service market will help inspire the enthusiasm of market players and dig the peaking resources within the system, which can effectively promote the RE consumption and ensure the safe operation of power system. Focus on Ningxia, the project investigated and analyzed the operation status of the Ningxia auxiliary service market, and concluded that “the thermal power plants are willing to take part in the real-time deep peaking market”, “the development of peaking auxiliary market can effectively promote the RE consumption”, “the current rules of Ningxia peaking auxiliary market are reasonable overall”. In response to the problem found in the operation of Ningxia market, the project proposed “allowing the RE plants to participate in the quotation”, “differing the upper limit of the thermal power plants’ quotation between the heating and non-heating period”, “using the two-part quotation”, “allowing hydropower and pumped storage power plants to participate in the market”, and “allowing the users to share cost of peaking auxiliary service”, which is of great significance to the reform of China’s power system at the stage of piloting the peaking auxiliary service market is being explored throughout the country. The works of **Task 3** included:

a) Survey the existing fairness-focused dispatch rules in northwest power grid (fairness, equality and openness), and identify major factors of the existing dispatch rules that constraint RE integration;

b) Compare other different dispatch models, including economic dispatch, energy-saving dispatch and low-carbon dispatch in the context of a rising weight of RE capacity in northwest power grid;

c) Simulate the power system operation for target planning years (2016, 2020 and 2030) using different dispatch models, and provide quantitative results of RE integration;

d) Align current dispatch rules in the provincial power grids and the reality that increasing RE capacity has been connected into the power grids, put forward improvement suggestions and opinions for the dispatch rules.

### **Task 4 Study on ancillary service**

The impartiality dispatch is the main dispatching mode in China. However, with the continuous improvement of RE penetration rate, the current dispatching mode faces some difficulties. The improvement of dispatching mode becomes an important factors affecting the RE consumption. In order to further explore the potential of the current dispatching mode, the project takes the Ningxia as an example to analyze the current operation status of the impartiality dispatch. Through comparative analysis of the numerical experiments, it’s found that “the impartiality dispatch is less economical than other dispatching modes, and the RE consumption capability is poor”. In view of the problems found in the research of dispatching modes, the project proposed “adopting

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the appropriate dispatching mode according to local conditions”, “encouraging the captive power plants to participate in system dispatch”, “digging the potential peaking capacity of thermal units by combining with the depth peaking auxiliary service market”, “abolishing the mode of ‘determining power generation by heat’ in cogeneration power plants to improve the flexible”, which has certain reference value for the dispatching agencies in other regions. The works of **Task 4** included:

a) Survey the implementation progress of the “Two Implementation Rules” in 2015-2017, and evaluate the implementation results.

b) Support NWEA to pilot the first ancillary service market in Ningxia Autonomous Region, particularly assess how the ancillary service market will influence the RE integration in Ningxia.

c) Track the implementation of the pilot ancillary service market in Ningxia for at least three months, and evaluate its implementation results, particularly its impacts on RE integration in Ningxia.

d) Summarize the operation experience of the ancillary service market in Ningxia, and provide opinions to replicate the practices in other provinces in northwest region.

After the implementation of the project outcomes, the RE consumption mechanisms of Northwest China has been improved and developed. The project assisted the start-up and trial operation of the Northwest auxiliary service market. The application effect was good and the social benefits were significant. It played a positive role in promoting the reform of the power system in the Northwest China and the whole country.

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## **2. Task 1: Analyze the development of different mechanisms to improve RE integration in northwest China**

### **2.1 Technical Route**

Task 1 explores the advanced experience from foreign countries, compares and analyzes differences between the domestic mechanism and effect of RE consumption and that abroad, and at the same time, the applicability of the advanced foreign experience used in Northwest China. Furthermore, it covers six dimensions and puts forward the rolling mechanism path arrangement of the RE development in Northwest China, according to the latest information of the future development plan based on the three cycles of "13th Five-Year Plan", "14th Five-Year Plan" and "15th Five-Year Plan". The research results have practical significance for grasping the development status of RE consumption mechanism in Northwest China, learning advanced foreign experience, promoting the rolling development of RE consumption mechanism. The technical route of Task 1 is shown in figure 2-1.

The practice of improving the mechanism and optimizing the allocation of resources is the important means to achieve efficient RE consumption. What needs to be mentioned is that, the improvement of the mechanism cannot be achieved overnight, instead, we should fully consider the national policies and the actual development of the industry, to establish a rolling development path from short-term to medium-long-term. This kind of establishment should not only promote the RE consumption, but also fully consider the fairness and efficiency of market operation as well as the overall benefits of social and economic development, so as to reduce negative externalities. Specifically speaking, the research methods are given as follows:

- (1) To analyze the main constraints of RE consumption in northwest region: The constraints come from different levels of policy, system and technology; therefore, it is necessary to consult experts of the related areas extensively and take the suggestions from various areas. Additionally, in terms of the factors that restrict the RE consumption (e.g., the weakness of local power demand, inadequate inter-provincial and inter-regional power transmission and inadequate peak regulation capacity), it is significant to figure out the historical causes of these factors and the fundamental mechanism of their inadaptability to the development of RE. Then, the next step is to quantitate their restrictions to RE under the planning levels at the present stage and future stage.
- (2) To investigate advanced foreign experience: There is no doubt that countries and regions with relatively high-level RE consumption have experienced or are experiencing difficulties of RE consumption. As a result, it is valuable to investigate and study the experiences and lessons of the development of energy-dependent industries, government policies, market mechanism, RE delivery, dispatching and trading associations in these countries and regions, what's more, to clarify the functions of the government, the market, the grid company and other

social sectors in promoting the RE consumption.

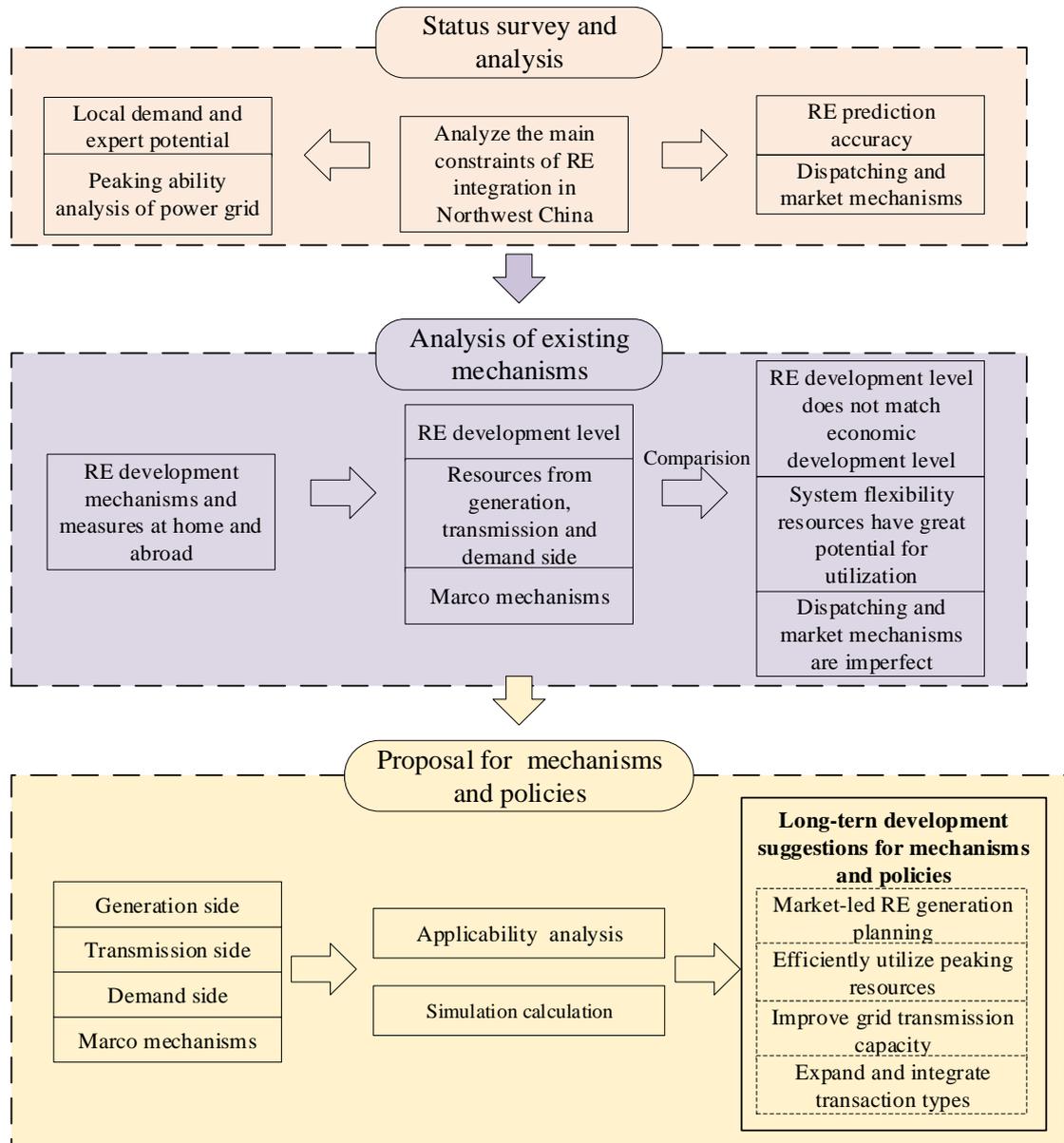


Figure 2-1 Technical route of Task 1

- (3) To evaluate the effectiveness of each mechanism and its applicability in Northwest China: In views of the conclusions drawn from the investigation and analysis, this project studies and analyzes the institutional mechanism for eliminating or weakening various constraints under the coordination of market and government. Then, it evaluates the applicability of various mechanisms in Northwest China, so as to put forward the new development thoughts for the RE of the region for the future.
- (4) To propose the arrangement of the rolling mechanism path in northwest region: the suggestions of RE consumption with relatively low cost and strong application are proposed according to the evaluation of the applicable results of various mechanisms and the characteristics of the RE, power grid and economic social

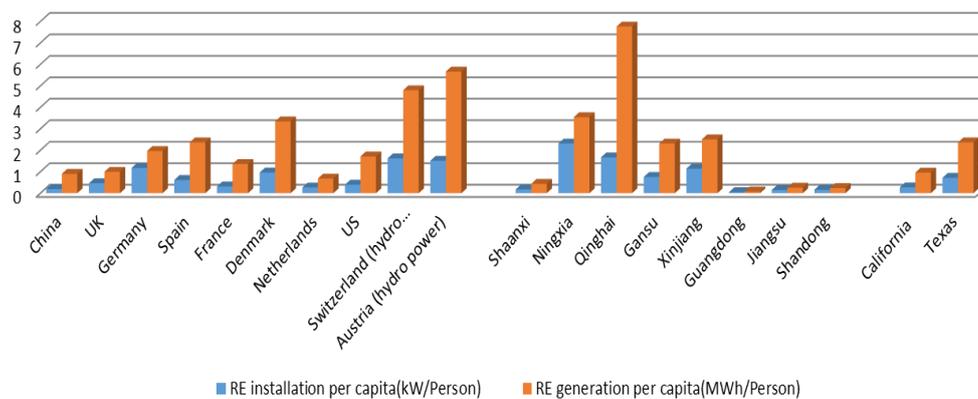
development in northwest region in current years. In addition, this project also puts forward the rolling development path from short-term to medium-long-term, (e.g., the phased arrangement for transition from effective administrative intervention to marketization, from centralized and unified dispatching of power grids to coexistence of multi-transaction modes). At the same time, it sorts out the development of RE consumption at each stage, the target, the overall goal of electricity market reform, the forecast level of social and economic development, as well as the specific anticipated goal, concrete action, preconditions and transitional arrangements for the development of RE policy and electricity market mechanism.

## 2.2 Analysis of RE Consumption Mechanism

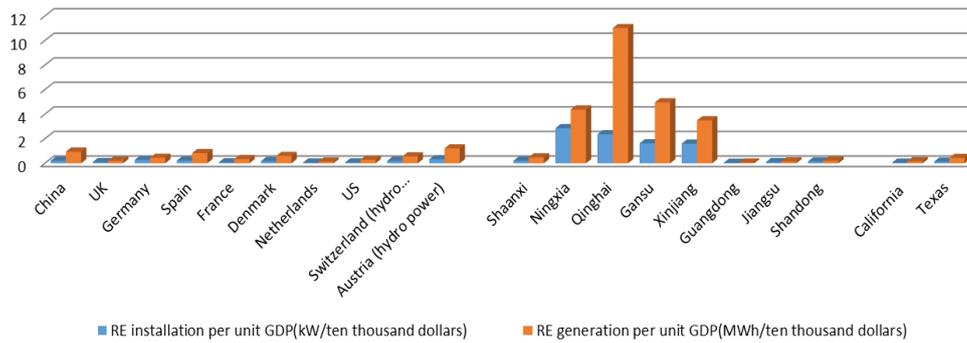
Task 1 investigates and analyzes the current situation and problems of new energy absorption in Northwest China, and compares the mechanism and effect of new energy absorption at home and abroad, as well as the applicability of advanced foreign experience in Northwest China. The conclusions are given in the following:

**(1) The local electricity demand in the northwest region is insufficient, so it is necessary to expand the electricity demand both internally and externally.**

The northwest region is rich in RE, and the construction of RE power generation projects is rapid. However, the local electricity demand is insufficient compared with the RE power generation resources. Figure 2-2 and 2-3 illustrate the relationship between RE installed and power generation together with the population and economic development level in some countries and regions. It suggests that the regional economic level in Northwest China is not balanced compared with the level of RE development, which is an important reason for the difficulty of RE consumption.



**Figure 2-2 Relationship between economic levels and RE development in some countries (or regions)**



**Figure 2-3 Relationship between economic levels and RE development in some countries (or regions)**

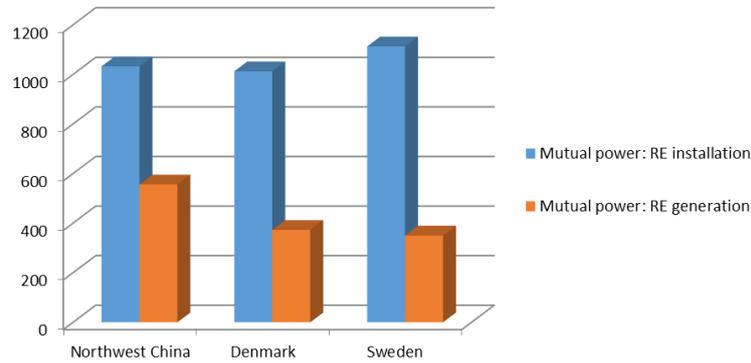
The economic level of the major European and American countries is comparatively consistent with the level of RE development, which means that RE can be used efficiently. On the contrary, the level of RE development in Chinese provinces and regions does not match the level of economic development. To be specific, the level of regional economic development in Northwest China is relatively backward while the RE resources are abundant. Therefore, the northwest region needs to allocate new energy on a larger scale.

In addition, the northwest region itself needs to speed up economic transformation and industrial restructure, and at the same time, increasing demand-side flexibility through demand-side management, development of electric vehicles and energy storage, etc.

**(2) The export potential has not been fully exploited, and the utilization rate of RE needs to be further improved.**

The northwest power grid is interconnected with the central, eastern, northern and central Tibetan power grids through seven DC channels whose theoretical transmission capacity reaches more than 30 million kilowatts. However, in actual operation, the potential of power transmission in Northwest China has not been developed fully due to some factors such as system security and acceptance capacity of terminal provinces.

Compared with the interconnected power grids in Europe, the northwest region has realized interconnection of power grids and established a large number of outgoing channels, but the potential of interconnection has not been realized fully. In other word, in terms of relative proportion, the ratio between the transmission capacity of outgoing channels and the RE installation capacity in Northwest China is less than 50% compared with that in Denmark, which has reached 122.64%. It suggests that although the capacity of outgoing channels is large, there is still potential for prompting the relative proportion.



**Figure 2-4 Comparison of renewable energy installation (MW) with annual average hourly mutual power transfer (MWh)**

**(3) Power transmission capacity in Northwest China needs to be improved**

The limited peak regulation capacity of the Northwest Regional System lays out mainly in the shortage of peak regulation capacity of thermal power units during the period of new energy concentration. For example, the peak regulation capacity of some thermal power units in the northwest region cannot meet the requirements of "using 50% or more of rated capacity", proposed in the "two rules", and the peak regulation capacity cannot meet the needs of power grid operation. There are three important factors to improve the level of new energy absorption in Northwest China, including increasing the flexibility of thermal power units, increasing the capacity of peak shaving system and improving the allocation mechanism of power transmission resources.

**(4) The accuracy of RE forecasting in Northwest China needs to be improved from the technical and institutional level**

The short-term wind power forecasting accuracy of a province in Northwest China is about 75%, and the photovoltaic forecasting accuracy is about 80%, which still falls behind the international advanced level. In terms of the problem that the prediction accuracy of RE output in Northwest China is inadequate, we should not only pay attention to the technical level, but also stimulate and improve the prediction accuracy from the institutional level, combining with the improvement of market and dispatching mechanism, and improving the prediction accuracy of RE from the institutional level.

**(5) Imperfect market and dispatching mechanism**

In recent years, in order to improve the RE consumption, the trading market system in Northwest China is gradually improving, so does the proportion of market-oriented trading power. However, from the perspective of transaction type and flexibility, the growth of trading power is still limited, resulting from the following two reasons. For one thing, most of the trading mechanisms fail to achieve competitive market transactions and trading prices are relatively fixed, making the market allocation of new energy not fully utilized. For another, the power balance of the power system mainly depends on the traditional dispatching agencies, relying on the traditional "three public" dispatching mode, with a low degree of marketization. Therefore, to solve these problems, we should handle the relationship between dispatching and market properly, clarify the responsibilities of dispatching and market in the allocation of RE, and take full advantages of the market in the allocation of RE.

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## **2.3 Rolling Mechanism Path and Supervision Suggestions for Medium-long-term RE Consumption in Northwest China**

In view of the reality of Northwest China, the opinions and viewpoints of experts in this field have been widely collected. Based on the analysis of successful experience of RE consumption abroad, suggestions on the rolling mechanism path arrangement and supervision of RE development in Northwest China are given as follows.

### **2.3.1 Medium-long-term rolling mechanism path of RE consumption in Northwest regions**

Considered from three aspects including system planning, operating and transaction are designed from four dimensions including power generation, transmission, consumption and general mechanism, the rolling mechanism path is formed in six dimensions. To be more intuitive, the logical relationship of different rolling mechanism paths arrangement is shown in figure 2-5 as follows.

Each rolling mechanism path provides the specific actions in different layers based on the time nodes of the year 2020, 2025 and 2030. These time nodes represent the short-term, medium-term and long-term development planning respectively. Among them, the long-term development has the expectation to establish a sustainable mechanism in terms of proposing development direction while the short-term and medium-term development considers the current situation by using some temporary rolling mechanism, which is regarded as the transition to the development of the long term. In the following, the brief explanation for each rolling mechanism path will be given and the specific contents are shown in table 1-6 in the appendix.

#### **(1) RE Generation Planning**

RE generation planning belongs to the planning problem on the generation side and its rolling path mechanism arrangement should consider the following two factors: one is the explosive growth of RE generation brought by the technological innovation and the other is the impact of the RE planning and construction on the ecological environment. The general idea of the path is: the transition from the plan-oriented new energy generation planning to the market-oriented new energy generation planning, from the planning decision-making scheme based on power generation resources assessment to the scheme based on comprehensive resources (including resource, networks, load and storage) assessment, and the market profit assessment of the power plant itself. The details of rolling path arrangement are shown in table 1 in the appendix.

#### **(2) Peak regulation capacity and mechanism in the RE power system**

Peak regulation capacity and mechanism belong to the problems on the generation side and its rolling path arrangement should be considered from two aspects including increasing the peak regulation capacity and improve the mechanism. The general idea of the path is to transfer from fully utilize peak regulation resources to efficiently use these resources. The key to the former solution is to solve the problem of the lack of peak regulation capacity, focusing on increasing the peak regulation capacity and expanding the allocation scope of peak regulation resources. While for the latter, it depends on the accurate pricing of the peak regulation resources, thus, needs a rational

market mechanism. The specific practice of rolling path arrangement is shown in table 2 in the appendix.

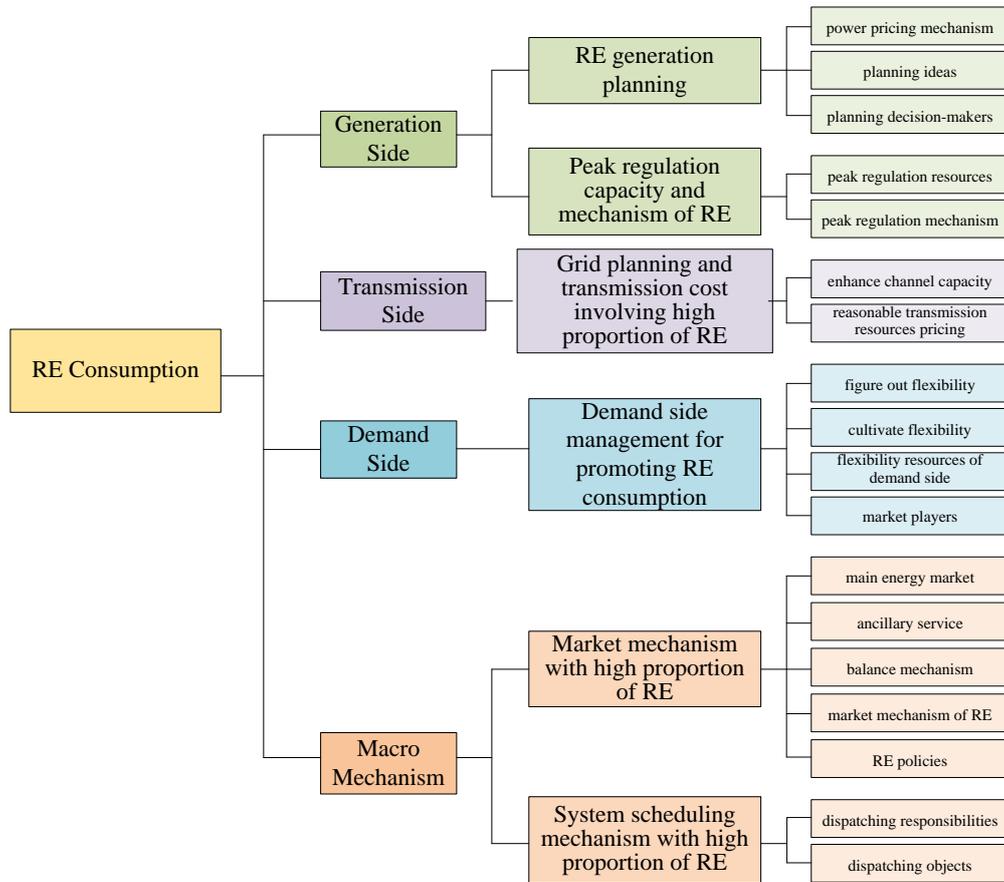


Figure 2-5 Logical relationship of different rolling mechanism paths arrangement

### (3) Grid planning and transmission cost involving high proportion of RE

The grid planning and transmission cost belong to the content of transmission dimension and its rolling mechanism path should be considered from two aspects: network planning and transmission cost. The overall idea is to enhance the power grid interconnection capacity and reasonable pricing of transmission resources, aiming at expanding the scope of system resource allocation and promoting the dual development of reasonable pricing of transmission resources. The specific practice of rolling path arrangement is shown in table 3 in the appendix.

### (4) Demand side management for promoting RE consumption

The demand side management belongs to the content of load side and its rolling path arrangement should be considered from the two aspects: increasing the flexibility resources and establishing a reasonable market mechanism for invoking flexibility resources. The overall idea is to transfer from figuring out flexibility to utilizing flexibility to follow the RE accurately and improve the predictability and controllability of demand response during the development. The specific practice of rolling path arrangement is shown in table 4 in the appendix.

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### **(5) Market mechanism with high proportion of RE**

Market mechanism belongs to the content of macro mechanism dimension. Its rolling path arrangement should be considered from four aspects: trading mode, price system, settlement mechanism and RE policy. The general idea is to expand the types of transactions and integrate the types of transactions simultaneously, and ultimately achieve efficient transactions and provide rich means of risk management. The aim is to gradually increase the proportion of trading power in market-oriented transactions, reach more than 95% in the long run, and gradually play the role of market allocation of resources, cost sharing and benefit distribution. The details of rolling path arrangement are shown in table 5 in the appendix.

### **(6) System scheduling mechanism with high proportion of RE**

Market mechanism belongs to the content of macro mechanism dimension. Its rolling path arrangement should be considered from two aspects: scheduling mechanism and scheduling object. The general idea is to clarify the process of dispatching and market responsibility and expand the demand side schedulable resources. The details of rolling path arrangement are shown in table 6 in the appendix.

### **2.3.2 Supervisory Suggestions**

The rolling development of RE consumption consists of power generation, transmission, consumption, combined with general mechanism. In order to promote the RE consumption in northwest regions, this project provides the following suggestions to change the RE consumption supervisory methods based on the rolling mechanism path.

#### **(1) Promote the conversion of leading factor of generation planning**

The mode of current RE generation planning mainly includes supply demanding promotion and government approval. With the deepening of the electricity reform and the electricity market, the mode of RE generation planning should be converted into the practice of “overall planning and market impulse”. To be more specifically, the leading factor of planning decision is supposed to transit from generation resources assessment to comprehensive assessment with multiple links of generation, transmission, distribution and storage and at the same time. As for the power generation plants, they need to evaluate the profits they can obtain under the market regime and decide the planning decisions themselves. By contrast, the government only play the role of supervisor.

#### **(2) Promote full utilizations of peak regulation resources**

Firstly, it is necessary to search for the peak regulation resources from different aspects to implement the following two actions. One is to lead the flexibility reform of current units while the other is to stimulate the promotion of unit flexibility by market mechanism. Then, it is also important to supervise the development of peak regulation ancillary service market, expand the scope of market mechanism application in the medium and long term, and eventually gradually transform the function of allocating peak regulation resources from peak regulation ancillary service to spot market and capacity market.

#### **(3) Focus on the power grid planning and transmission cost**

RE transmission in Northwest China is greatly affected by transmission channel

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obstruction, so we should focus on channel obstruction during planning and design of power grid, and formulate the transmission channel planning plan considering the specific situation of source and load comprehensively. In addition, as the benefit mechanism of power grid utilization, transmission cost also needs to be reasonably guided. That is to say, it is necessary to focus on the improvement of transmission cost evaluation system and allocation mechanism, leading the formation of a transmission cost pricing mechanism based on comprehensive cost.

**(4) Figure out the flexibility resources on the demand side**

There are two solutions that can be done to promote the RE consumption from the demanding side. One is to stimulate the increase of load further and the other solution is to find out and cultivate the load flexibility, in order to adapt to the uncertainty of power generation side. In addition, the demand side management needs effective incentives and guided measures from government regulations and policies. On one hand, it is necessary to establish the demanding policies according to the different development time nodes and search for the flexibility of demand side. On the other hand, for new flexible resources such as distributed energy storage and electric vehicles (EVs), we should guide them to cultivate flexibility and gradually expand the market participants, so that all kinds of energy users have opportunities to participate in demand response projects.

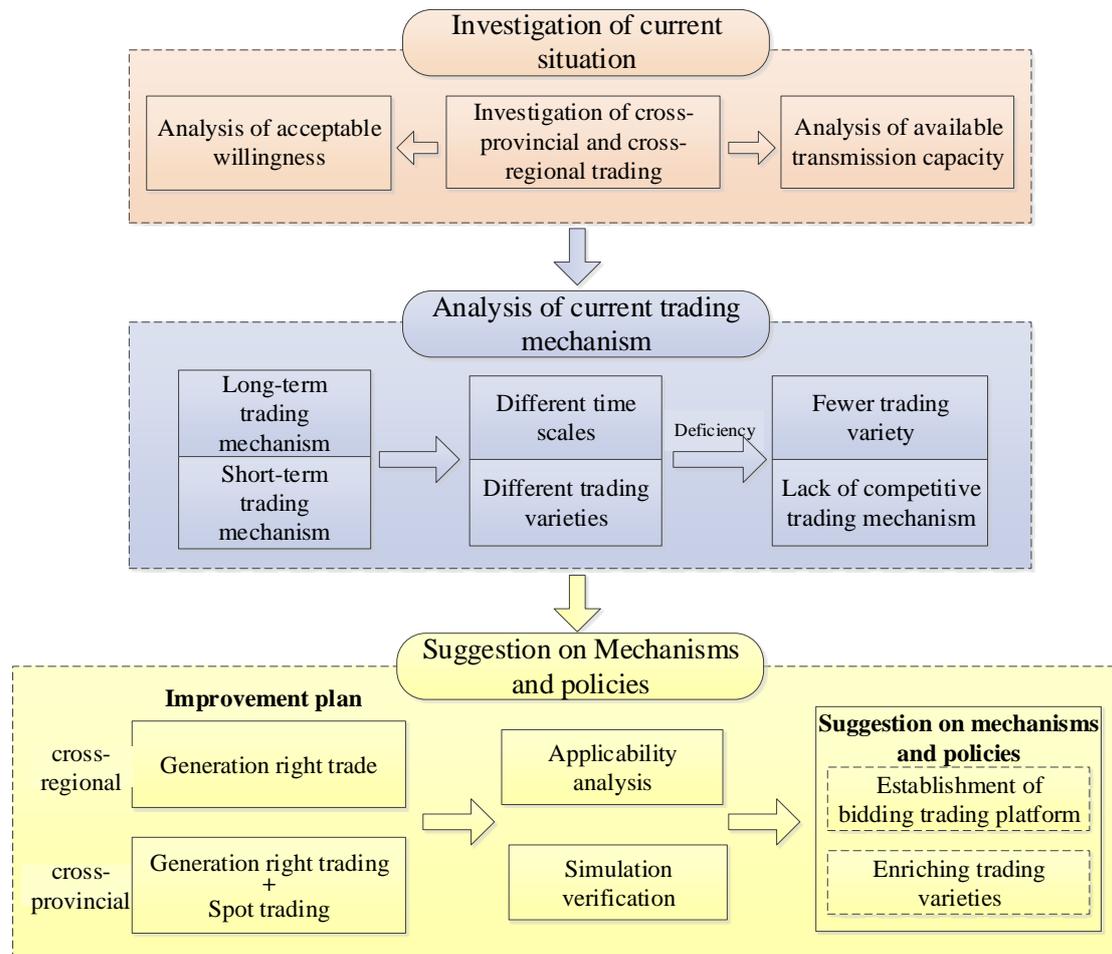
**(5) Clarify responsibilities and the relationship between market and dispatching**

On the one hand, it is necessary to guide the power market to expand and integrate transaction types, expand market scope, and ultimately establish a multi-level power market; on the other hand, in the process of market development, it is vital to guide dispatching to make functional changes and clarify dispatching responsibilities. At the same time, we need to guide dispatching to gradually expand dispatching objects, and clarify the relationship between market and dispatching. Furthermore, it is necessary to change the dispatching responsibility to implement market transaction results and ensure the safe and economic operation of the system.

### 3. Task 2: Study the inter-provincial and inter-regional transaction mechanism to promote RE generation in northwest China

#### 3.1 Technical Route

Task 2 explores the available capability and restricted factors of the cross-provincial or cross-regional transmission channel and the acceptable willingness of terminals for cross-provincial and cross-regional trades. Furthermore, it studies the advanced experience from foreign countries, compares and analyzes differences between the domestic cross-provincial and cross-regional trading mechanism and that abroad, and at the same time, the applicability of the advanced foreign experience used in Northwest China. As a result, a trading mechanism of promoting cross-provincial and cross-regional RE consumption is proposed based on the conclusions. The research results have practical significance for grasping the development status of cross-provincial and cross-regional RE consumption in Northwest China, learning advanced foreign experience, promoting the trading quantities and RE consumption. The technical route of this project is shown in figure 3-1 as follows:



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**Figure 3-1 Technical route of Task 2**

The quantity of cross-regional and cross-provincial transaction electricity in Northwest China is increasing gradually, which has become an important factor for the stable operation of regional power grid and the effective consumption of electricity. In order to promote the development of cross-provincial and cross-regional transactions and solve the problem of RE consumption in Northwest China, it is necessary to study the cross-provincial and cross-regional transmission channels and trading mechanisms, analyze the constraints of cross-provincial and cross-regional transactions, and put forward a more perfect market mechanism. Therefore, the specific research ideas are given in the following six aspects according to the principle mentioned above:

- (1) To investigate the current situation of cross-provincial and cross-regional trading and RE consumption in northwest region: there are different characteristics and situations in views of cross-provincial and cross-regional trading in this area. This project investigates the current situation of cross-provincial and cross-regional transactions from different aspects such as trading power quantity, trading varieties and trading modes and analyzes the existing problems and drawbacks according to the characteristics in northwest area, establishing a foundation for the subsequent research. In the meanwhile, in order to promote the RE consumption in this area, it is necessary to investigate and analyze the situation inside, then find the time nodes and regions that are difficult to consume to put up with a more targeted solution to the problem of RE consumption.
- (2) To study the available transmission capacity of cross-provincial and cross-regional transmission channels: Effective utilization of transmission channels is the basis of developing cross-provincial and cross-regional transmission. This project sorts out each transmission channel in the area, analyzes its current usage and studies the constraints of effective utilization of channel capacity, so as to further find out the utilization potential of channel capacity.
- (3) To analyze the acceptable willingness of cross-provincial and cross-regional trading terminals: in views of the DC cross-regional transmission line and the cross-provincial trading inside a region in Northwest China, this project comprehensively analyzes the acceptable willingness of cross-provincial and cross-regional trading terminals from several aspects, including transaction economy, acceptable ability of terminal areas and obstacles to the transaction, thus, studies the influence of acceptable willingness of terminals on cross-provincial and cross-regional transactions.
- (4) To analyze the cross-provincial and cross-regional trading mechanism: it is of great importance to do research on the adaptability of the typical foreign electricity market mechanism based on the investigation of it. To be more specifically, this project will sort out the current cross-provincial and cross-regional trading rules and the corresponding mechanism in northwest area, so as to analyze the characteristics and existing problem of them.
- (5) To propose a comprehensive cross-provincial and cross-regional trading mechanism of promoting RE consumption: based on the comprehensive analysis several factors, including the trading situations, the transmission channel capacity

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and the willingness of terminals, this project puts forward a comprehensive trading mechanism of promoting RE consumption. To be more precise, it demonstrates the applicability of the transaction from different aspects and proposes the specific implementation process of the transaction mechanism.

- (6) To validate the implementation effect of the trading mechanism: based on the comprehensive mechanism proposed in this project, a model is established to simulate cross-provincial and cross-regional transactions with actual data of the northwest power grid, in terms of different scenarios of RE consumption in this area. Then, this project calculates the improved effect of the comprehensive trading mechanism on RE consumption to verify the effectiveness of the proposed mechanism, based on the trading results.

## **3.2 Analysis of Cross-provincial and Cross-regional Trading**

### **Mechanism in Northwest Region**

This project studies and analyzes the current situation of cross-provincial and cross regional transactions, the utilization of transmission channels and market trading mechanism in five provinces (or regions) of Northwest China, whose relevant conclusions are shown as follows:

#### **3.2.1 Cross-regional transactions in Northwest China are developing rapidly while there is further improvement for cross-provincial transactions**

##### **(1) Cross-regional transactions**

In recent years, the cross-regional trade in Northwest China has been growing rapidly. In 2017, the quantity of power transactions has exceeded by 15% of the total annual power generation in the area and has been more than the annual consumption in Gansu, Ningxia and Qinghai, becoming an important means to consume the surplus electricity in Northwest China.

Cross-regional transactions in Northwest China are mainly medium-long-term transactions, combined with short-term cross-regional spot transactions of surplus RE. It is necessary for the medium-long-term transactions to form a stable output through building thermal units with RE, however, the proportion of RE is less than 30% in the cross-regional power transmission in Northwest China in 2017. By contrast, short-term cross-regional spot trading of surplus RE has strong pertinence and obvious effect. What is to say is that the RE consumption of cross-regional trading has been increased by more than 20%, which increases the proportion of RE accounting for the total outgoing power of cross-regional trading.

##### **(2) Cross-provincial transactions**

Gansu Province is located in the middle of five provinces (or regions) among northwest region, resulting in the fact that the cross-provincial transactions are realized through its grid. In addition, the cross-provincial transactions in Northwest China are mainly from Gansu, Ningxia and Xinjiang to Qinghai. In 2017, the short-term real-time cross-provincial transactions accounted for nearly 80% of the total cross-provincial power transactions. However, the problem is, the cross-provincial transactions were frequent, but the quantity of electricity transaction was not large, accounting for less

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than 5% of the total power consumption. Therefore, there is still great potential of further improvement for cross-provincial cooperation in Northwest China.

### **3.2.2 The overall utilization rate of cross-provincial and cross-regional outbound corridors in Northwest China still has considerable potential for improvement.**

In Northwest China, the DC transmission channel has high voltage level and large transmission capacity, and the utilization of each line is different. Among those lines, the average annual load rate of three DC lines is over 75%, whose utilization rate is high. However, for other four lines among all, the average load rate is 30% to 45%, which have a relatively lower utilization rate.

The provincial cross-sections in northwest region mainly include Shaanxi-Gansu cross-section, Gansu-Ningxia cross-section, Gansu-Qinghai cross-section and Gansu-Xinjiang cross-section. The operation mode in this area is complex, which will change the power flow mode of provincial section. As for the current situation, the transmission capacity of cross-provincial channels is sufficient from general views. In 2017, the average load rate of the channel varies from 10% to 20%, that is to say, the cross-provincial transmission channels are maintained at a low load rate. In the meanwhile, based on the maximum power exchange calculation in 2017, almost all the lines still have large capacity to be utilized except that Gansu-Qinghai channel is close to full power transmission.

The cross-provincial and cross-regional channel transmission capacity is restricted by many factors, such as generator output characteristics, power grid structure, power grid security and stability constraints, power system load characteristics and so on. As the same time, the transmission capacity of Qishao DC, Zhaoyi DC and Jiquan DC transmission channel, which have been constructed in recent year, are restricted to a certain extent due to the uncompleted construction of the corresponding power supply and control equipment, resulting in the fact that they cannot reach the designed rated power for the time being.

As for cross-regional DC transmission channels, with the operation of auxiliary power supply and the abundance of transaction contracts, the transmission power of some lines with low utilization rate is expected to be further improved. As for cross-provincial transactions, there is potential for further improvement of cross-provincial mutual benefit in terms of trading mechanism because of the small volume of overall transactions.

### **3.2.3 Cross-provincial and cross-regional transaction terminal areas are not willing to further increase in trading electricity quantity.**

#### **(1) Cross-regional trading**

The cross-regional power transmission in Northwest China has a price advantage of about 10% to 40% compared with the power price of the receiving terminal provinces. In the meanwhile, the spot trade of surplus RE often competes with the low price of 0.05-0.2 yuan/kWh, which has strong economy.

The cross-regional power transmission has become an important source of power supply for the receiving terminal areas. However, the acceptable capacity of terminals

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is limited and a large amount of outgoing power will affect the utilization hours of local generating units in terminal areas to an extent, the receiving areas, thus, tend to have a relatively low willingness to accept more power from northwest region if there is no substantial increase in load.

## **(2) Cross-provincial trading**

Northwest China is a vast region, which has differences in the distribution of resources among different provinces as well as the cost of power generation. Therefore, it has advantages over cross-provincial energy optimal allocation. However, in this area, there is a shortage of electricity due to the fact that the consumption exceeds the generation in Qinghai Province while other provinces have different degrees of surplus. This situation makes the provinces with surplus electricity have stronger willingness to send electricity, while the neighbor provinces have relatively weaker willingness. What's more, the cross-provincial barriers still exist and some provinces even limit the scale of electricity trading with other provinces.

In conclusion, the willingness of cross-provincial and cross-regional transaction terminal areas to further increase the scale of transactions is weak. In terms of this phenomenon, we should consider establishing more flexible trading methods from the perspective of trading mechanism to stimulate the development of cross-provincial and cross-regional transactions.

### **3.2.4 Cross-provincial and cross-regional trading mechanism is basically established, but the trading types remain to be improved.**

At present, the cross-provincial and cross-regional transaction mechanism in Northwest China includes two forms: medium-long term and short term. The medium-long term includes bilateral negotiation, priority power generation and planned electricity consumption while the short-term transaction mainly includes the spot transaction mechanism of surplus RE, the framework agreement and the electricity replacement transaction, etc.

The medium-long-term trading, acting as a way to lock the trading volume and stabilize the price of electricity, covers most of the electricity generation. Priority power generation ensures the priority implementation of the national plan and local government agreements. First of all, it ensures the implementation of the national energy development strategy, enabling priority delivery of clean energy, and the development planning among local governments. However, under the existing medium and long-term trading mechanism, the new energy absorption capacity of the whole network may not be fully utilized. Bilateral bargaining can indeed introduce market competition and provide more free choices for both parties. However, under the constraints of preferential generation and planned electricity, the market's resource regulation capacity may not be reflected. On this basis, we need to improve the existing trading mechanism, gradually reduce the proportion of planned electricity, and open up market competition. At the same time, it is difficult to predict the output of new energy in advance accurately, so it is impossible to participate in the medium-long-term power contracts in depth. At present, the medium-long-term cross-regional power delivery contracts in Northwest China only account for about 30% of the total power output from new energy sources. Therefore, the medium-long-term trading mechanism should be

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more in line with the characteristics of new energy output when determining the trading curve. At the same time, with the continuous strengthening of inter-provincial mutual aid capacity, the power supply of neighboring provinces can be considered as the backup support of the province. With the system reliability guaranteed, the proportion of new energy in power transmission can be further increased, and the new energy absorption capacity can be improved.

Currently, short-term cross-provincial transactions mainly depend on the execution ability of Northwest Network Dispatch, which brings great pressure to daily dispatch and operation. The characteristics of new energy consumption in Northwest China are different. We should find a more flexible market trading mechanism and establish a unified competitive trading platform.

### **3.3 Construction and Supervisory Suggestions of Cross-provincial and Cross-regional Trading Mechanism**

Based on the current situation of cross-provincial and cross-regional trade in Northwest China and the advanced experience of RE consumption at home and abroad, this paper puts forward the construction scheme of cross-provincial and cross-regional comprehensive trade mechanism to promote RE consumption, and gives corresponding regulatory suggestions.

#### **3.3.1 Cross-provincial and cross-regional trading mechanism construction**

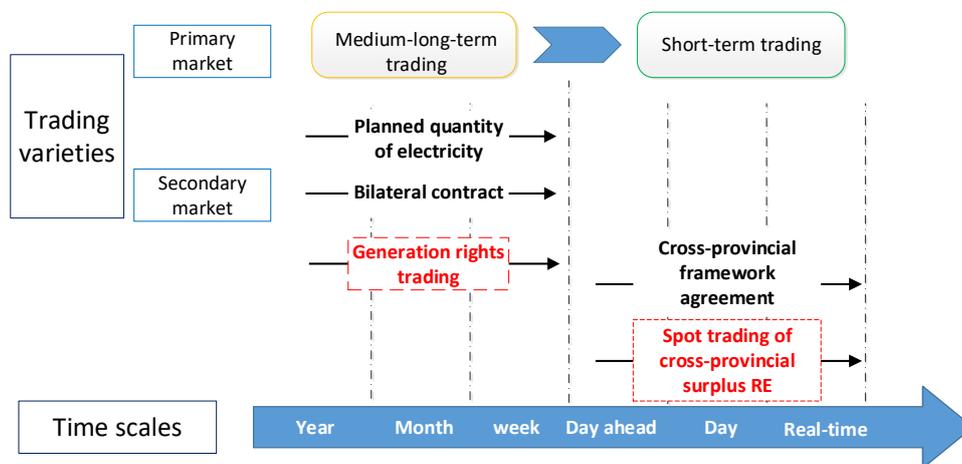
##### **(1) Cross-regional trading mechanism**

Cross-regional trading still has a long way to go and faces many challenges. At present, the main factors affecting the further development of cross-regional transactions are the receiving capacity and willingness of the receiving provinces. In the case of the contradiction between guaranteeing the benefits of local power generation enterprises and receiving low-priced electricity from foreign provinces, we should seek flexible market mechanism to alleviate trade barriers. To be more specifically, the Northwest cross-regional transmission trading mechanism proposes to join the power generation rights trading mechanism between the RE units in sending areas and the thermal power units in receiving areas on the basis of the existing bilateral negotiations in the medium-long term. RE in Northwest China can gradually attempt to trade power generation rights across regions with thermal power units in provinces where transmission channels are located. Power generation rights trading can tap potentials of the acceptable capacity of the cross-regional transmission receiving provinces, and further promote RE consumption on the basis of guaranteeing the interests of both RE and ceasefire power units.

##### **(2) Cross-provincial trading mechanism**

At present, this part of the work has been fruitful and the next step is to enhance the degree of marketization. The current problem that the overall power generation in Northwest China is relatively surplus, which affects the development of cross-provincial transactions. Therefore, it is considered to mitigate trade barriers by seeking flexible market mechanisms without affecting the efficiency of local power generation enterprises. Considering the characteristics of all kinds of market transaction modes, it

is suggested that the medium-long-term cross-provincial power generation rights trading and short-term cross-provincial spot trading of surplus RE should be added on the basis of the existing mechanism to promote the consumption of RE by utilizing the internal resources of the Northwest China.



**Figure 3-2 Cross-provincial (cross-regional) electricity market trading mechanism structure**

In terms of medium-long-term transactions, the RE in the provinces (districts) of Northwest China with difficulties in consumption can gradually try to carry out cross-provincial power generation rights transactions with the thermal power units in the provinces (districts) with a high proportion of adjacent thermal power. Power generation rights trading can further tap the local RE acceptable capacity in Northwest China, and promote RE consumption on the basis of guaranteeing the interests of both RE and cease-fire power units.

In terms of short-term transactions, the provinces in Northwest China carry out cross-provincial spot transactions of surplus RE in the period of imminent curtailment of RE power and the provinces with high proportion of adjacent thermal power and surplus peak-shaving capacity. The cross-provincial spot trading of surplus RE has improved the existing cross-provincial short-term trading mechanism in Northwest China, and promoted the consumption of RE on the basis of guaranteeing the interests of both RE and thermal power units.

### 3.3.2 Supervisory suggestions

Cross-provincial and cross-regional trade is an important way to optimize the allocation of resources, and an important way to promote RE consumption in Northwest China. In order to develop cross-provincial and cross-regional electricity trading further, it is necessary to carry out work from the aspects of system optimization and market mechanism construction. Based on the research foundation mentioned above, there are some suggestions given as follows:

#### (1) To increase the proportion of RE power accounting for cross-regional outgoing power supply

The large cross-regional electricity trade in Northwest China can provide strong support for RE consumption. However, due to the inadequate accuracy of RE forecasting, the proportion of RE generation in cross-regional power transmission is less than 30%. In order to make effective use of cross-regional transactions to help

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consume RE, it is necessary to further increase the proportion of RE in outgoing electricity.

On one hand, it is necessary to strengthen the accuracy of RE forecasting. Due to the inadequate accuracy of RE forecasting, there is a big error between actual output and forecasting output, which brings great difficulties to the formulation of power generation plan, and will restrict the proportion of RE power delivered across regions. It is advisable that a reasonable forecasting reward and punishment mechanism should be set up for RE power plants to encourage them to improve the forecasting accuracy. In the meanwhile, the power grid dispatching and operation departments should strengthen the optimization of generation plans to achieve multi-energy coordination and complementarity.

On the other hand, system flexibility needs strengthening. Due to the uncertainty of RE output, there will be deviation between the actual operation output and the plan. Adequate system availability and flexibility will make more RE added to the formulation of cross-regional outgoing power plans. It is advisable to strengthen the reserve margin of the system and the mutual aid between provinces and to tap the potential of cross-provincial reserve fully.

## **(2) To improve the cross-provincial and cross-regional transaction mechanism**

The cross-provincial and cross-regional trading mechanism has been initially established, but the varieties of trading still need to be further improved. A more comprehensive cross-provincial and cross-regional trading platform should be established based on the operation characteristics of the northwest regional power grid and the current situation of RE consumption.

Cross-regional transactions should combine the characteristics of RE output, optimize the trading curve and increase the proportion of RE electricity. It is advisable that power generation rights should be traded gradually in medium-long-term transactions, and the potential of cross-regional energy optimal allocation should be further tapped. At the same time, in short-term transactions, we should improve the trading system, encourage RE power plants in all provinces to actively participate in spot transactions, and reduce the amount of abandoned electricity.

Cross-provincial transactions should establish short-term spot trading platforms, promote cross-provincial mutual assistance within the region, and assist in the consumption of RE. In the meanwhile, we should enrich the medium-long-term trading varieties, consider setting up a power generation rights trading mechanism, and promote the provinces with higher proportion of thermal power units to participate more actively in the coordinated RE consumption in the northwest region.

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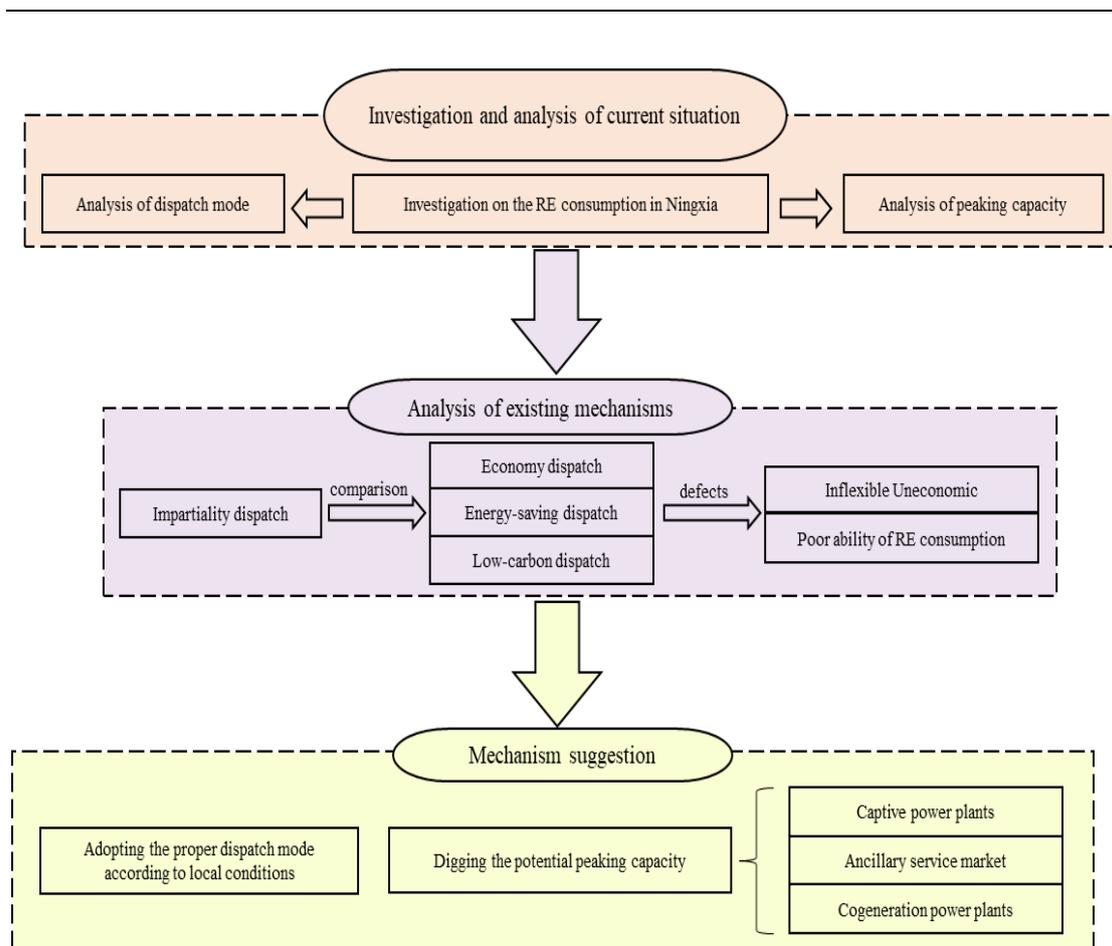
## **4. Task 3: Simulate to analyze the impact of RE integration using different dispatch models**

### **4.1 Technical Route**

Task 3 studied the current dispatch method and the problems encountered in Ningxia operation. It comparatively analyzed the impact of different dispatch methods on the RE consumption in Ningxia, and investigated the factors which could be used to promote the RE consumption. Based on the survey and analysis results, this research proposed dispatch mechanism optimization proposals. The research results have practical significance for grasping the development status of the dispatch methods, finding the problems and drawbacks in dispatch mechanism, promoting the improvement and optimization of the dispatch mechanism and RE consumption. The technical route of this project is shown in figure 4-1. It is foreseeable that the installed capacity of RE in Ningxia will increase rapidly in the next few years. In order to promote the output of RE units, solve the problem of RE consumption, it is necessary to study current dispatch mode, analyze the influence of different dispatch modes on power system, investigate the key factors which restrict RE consumption. Based on the survey and analysis results, the proposals of optimization and improvement measures are proposed. Therefore, the specific research ideas are given in the following four aspects according to the principle mentioned above:

(1) To investigate the current dispatch mode in Ningxia: Combined with the load demand, power supply and cross-provincial transmission channels in Ningxia, investigating the current dispatch mode, analyzing the problems and disadvantages of the current mode, which could build the foundation for the follow-up research. Finding out the key factors which restrict RE consumption in this dispatch mode, digging the potential peaking capacity. Then this research can propose the solution to solve the problem of RE consumption.

(2) To analyze contrastively the impact of various dispatch modes on RE consumption: Different dispatch mechanisms have different emphases. This research builds the models of economic dispatch mode, impartiality dispatch mode, energy-saving dispatch mode, and low-carbon dispatch mode. Based on those models and the actual data of the Ningxia's power system in typical day, the numerical experiment analyzed contrastively the performance and difference of various dispatch modes. According to the actual dispatch situation in Ningxia, the feasibility of continuing to dig potential peaking capacity to promote RE consumption is analyzed.



**Figure 4-1** Technical route of Task 3

- (3) To analyze the benefit of various dispatch modes: According to the emphases of different dispatch modes, different indicators are establishing to quantify and visually reflect the performance of different dispatch modes. It is convenient for decision makers to compare different dispatch modes or to weigh different performance according to actual needs.
- (4) To propose the suggestions on optimization of dispatch mode to promote RE consumption: Based on the analysis results, relevant literature and the actual situation of Ningxia, evaluating the current dispatch mode in Ningxia, and the reasonable optimization suggestions on dispatch mode are proposed to promote the RE consumption.

## 4.2 Contrastive analysis of various dispatch modes

This project analyzes contrastively the performance of different dispatch modes in several typical days. The relevant conclusions are shown as follows:

### (1) Different dispatch modes have different emphases

This research analyzed the performance of different dispatch modes in typical day. Table 4-1 and 4-2 shows the performance differences of different dispatch modes in typical February day and typical August day. In this table, IF means *the index of fairness*, this indicator reflects the degree of deviation in the compliance of different power plants. IE means *the index of economic*, this indicator reflects the cost of power system operation. IES means *the index of energy-saving*, this indicator reflects the coal

consumption of power system operation. ILC means *the index of low-carbon*, this indicator reflects the carbon emission cost of power system operation.

**Table 4-1.** The comparisons of operation index in typical February day

	Impartiality dispatch	Economy dispatch	Energy-saving dispatch	Low-carbon dispatch
IF	<b>0.2919</b>	0.7285	0.7357	0.7122
IE/mil. yuan	45.12	<b>43.03</b>	43.04	43.04
IES/t	73723.8	70617.6	<b>70464.0</b>	70642.5
ILC/mil. yuan	11.95	11.26	12.93	<b>11.26</b>

**Table 4-2** The comparisons of operation index in typical August day

	Impartiality dispatch	Economy dispatch	Energy-saving dispatch	Low-carbon dispatch
IF	<b>0.1255</b>	0.5354	0.5354	0.5322
IE/mil. yuan	53.86	<b>50.94</b>	50.96	50.97
IES/t	88935.5	84517.5	<b>84506.0</b>	84705.7
ILC/mil. yuan	13.84	12.91	12.93	<b>12.86</b>

As seen in the table 4-1 and 4-2, the output of plants in impartiality dispatch mode compared with the deviation of the contracted energy and the discrete situation is relatively the best. The dispatch mode considers the fairness among the plants, ensuring that the plant can complete the contract power with similar progress. It can be seen that the operation cost of economic dispatch is the least. The operation scheduling of the impartiality dispatch mode doesn't make the system run in an economical state, which means the economy is bad. For the comparison of energy efficiency, it can be seen that among the modes, the index of energy-saving dispatch mode is the least compared to other modes. For the comparison of the index of low-carbon, it can be seen that among the modes, the indicator of low-carbon dispatch mode is the best.

## (2) The performance of impartiality dispatch mode is comparatively bad

Compared with economy, energy-saving and low-carbon dispatch modes, the impartiality dispatch mode emphasizes fairness more, while its performance in RE consumption is bad.

It can be seen in the table 4-1 and 4-2, the impartiality dispatch mode is less economical, the operation cost is about 5% higher than that of other dispatch modes on average. According to the table 4-3, the curtailment rate of the impartiality dispatch mode increases by about 1 percentage point compared with other dispatch modes.

**Table 4-3.** The comparisons of curtailment in various dispatch modes

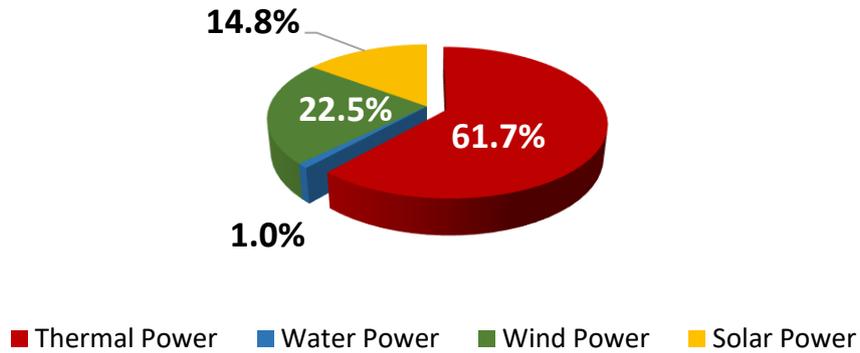
	Impartiality dispatch	Economy dispatch	Energy-saving dispatch	Low-carbon dispatch
Curtailment/bn. KWh	1.08	0.65	0.74	0.61
Rate/%	3.33	1.98	2.56	1.86

**(3) The current dispatch mode has some shortcomings**

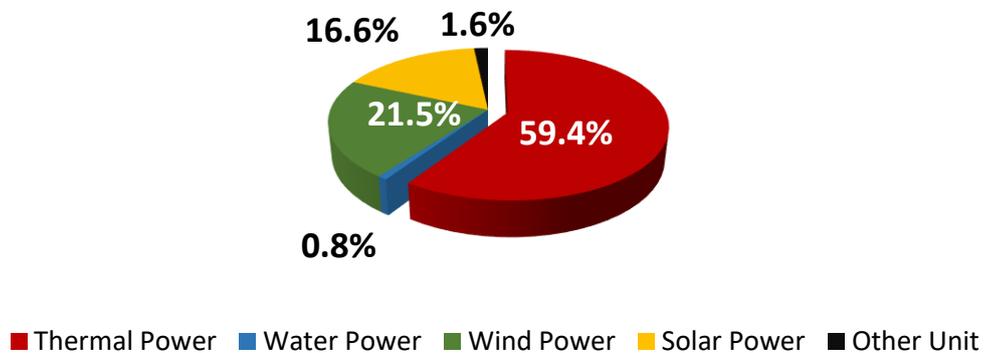
Through the numerical experiment, it can be seen that the load demand is low and the power supply is sufficient in Ningxia. The current dispatch mode can meet the social demand for electricity. But the economy of this mode is bad compared with other dispatch modes, the ability of saving energy and reducing emission is weak. It is suggested to improve the current dispatch mode according to these problems. The problem of RE curtailment can be alleviated and solved by optimizing the dispatch method.

**(4) RE in Ningxia is expected to develop well in future**

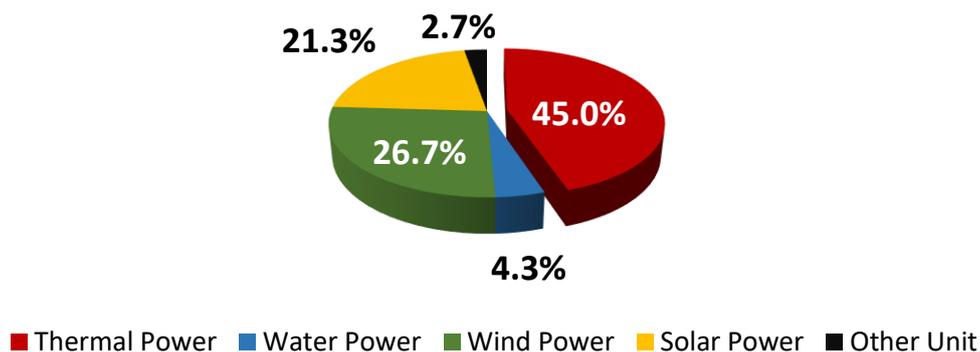
According to relevant planning and forecast data, the wind and photovoltaic power generation will continue to increase. The figure 4-2 to 4-4 show the variation tendency of the proportion of installed capacity of different types of generation units in 2017, 2020, and 2030.



**Figure 4-2** The proportion of installed capacity in 2017



**Figure 4-3** The proportion of installed capacity in 2020



**Figure 4-4** The proportion of installed capacity in 2030

Compared with 2017, the proportion of wind and photovoltaic power generation to the Ningxia social electricity consumption will increase by about 1 percentage point and the proportion of non-fossil energy power generation will be about 20% in 2020. The RE consumption problem in 13<sup>th</sup> Five-Year Plan of Ningxia will be basically completed. But in the next few years, the Ningxia power grid still faces the problem of RE curtailment. In 2030, the renewable energy in Ningxia will continue to develop. Compared with 2020, the proportion of wind and photovoltaic power generation to social electricity consumption will increase by 7 and 3 percentage points respectively. The proportion of non-fossil energy power generation will reach more than 30%. With the optimization of power supply and the development of power market, it is expected to completely solve the problem of RE consumption.

#### **(5) Ningxia still faces the problem of RE curtailment**

It can be seen that according to relevant prediction and analysis, the third DC transmission line and the supporting projects are still in commissioning. It is hard to live up to its full potential. And the power supply structure will not change in the short term, the flexibility of power supply is still insufficient and the peaking capacity is still limited. Ningxia still faces the problem of RE curtailment in next few years. It should be noted that solving problems are not only related to technical measures, such as the optimization of dispatch mode, but also closely related to relevant policies, the development of power market and management mechanism. Solving the problem of RE curtailment needs the cooperation of relevant functional departments and enterprises.

### **4.3 Suggestions on improvement and optimization of dispatch modes**

Based on the analysis results, relevant literature, the actual situation and the practical dispatch procedures of Ningxia power system, the reasonable optimization suggestions on dispatch mode are proposed to promote the RE consumption.

#### **(1) Encouraging the captive power plants to participate in system dispatch**

The captive power plant is the power plant invested by enterprises to meet the energy consumption demand of electricity. In the actual dispatch of power system in Ningxia, some captive power plants and local power plants only track the load demand of their own users and fail to fulfill the system's peaking obligations, resulting in inadequate peaking capacity. The lack of peaking capacity makes it hard to solve the

problem of RE consumption. Through the numerical experiment, we find the effect is obvious. In typical February day, the maximum RE curtailment power is 1352MW, the peaking capacity of captive power plant can provide is 772MW. In typical August day, the maximum RE curtailment power is 725MW, the peaking capacity of captive power plant can provide is 507MW. If the captive power plants can take part in system dispatch, the RE curtailment power will drop dramatically. The table 4-4 shows the comparison of the RE curtailment rate in the case that captive power plants take part in system peaking and the case that the plants don't in typical February day.

**Table 4-4** The comparison of RE curtailment rate in typical February day

	Impartiality dispatch	Economy dispatch	Energy-saving dispatch	Low-carbon dispatch
Peaking	0.98	0.83	0.83	0.53
Not peaking	4.72	3.52	4.03	3.49

It is suggested that the preferential power price and compensatory power price should be adopted to encourage captive power plants to participate in the power system peaking regulation so as to provide more flexibility for power system dispatch.

**(2) Adopting the appropriate dispatch mode according to local conditions**

China has a vast territory, and there is a gap between energy and load conditions in different regions. The dispatch mode should be formulated in accordance with local conditions. This research takes Ningxia as an example to study the impact of different dispatch modes on RE consumption, which has certain reference value for the provinces which have the same or similar conditions in Northwest China. For other provinces with rich water resources, hydropower plants can be used as peaking power supply. The requirements for RE consumption can be relaxed as appropriate to ensure the power system's demand of reserve in those areas where power allocation is relatively inadequate. The dispatch agencies in different regions can also choose different dispatch modes according to the actual development of the local areas and the construction of power markets.

**(3) Digging the potential peaking capacity of thermal units by combining with the depth peak-regulation ancillary service market**

Except the cogeneration units and gas-fired units, the ordinary coal-fired thermal units' peaking regulation measures are low-load peaking, which is every easy to achieve, the unit doesn't need to carry out large scale renovation, and the frequent start-up and shutdown of unit can be avoided. Normally, it is required that the unit should reach 50% of the nominal capacity without being paid. If the ancillary service market could be implemented, it will encourage those units whose peaking capacity is more than 50% of the nominal capacity to provide peaking service as sellers. It can promote the absorption of clean energy and can stimulate the enthusiasm of coal-fired units to provide ancillary service.

**(4) Abolishing the mode of “Determining Power generation by heat” in cogeneration power plants to improve the flexible of dispatch**

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In the actual situation and practical dispatch procedures in Ningxia power grid, the local cogeneration power plants determine power generation by heat in winter, which cause the lack of peaking capacity, so the RE generation will be curtailed when it does not match with the load demand. Relevant research points out that the thermal hysteresis of heating system can be used to make the cogeneration units run more flexibly by configuring heat storage equipment. For units whose heat load is close to their maximum heat capacity, the output of the cogeneration units can be reduced by configuring electric boiler when the RE generation power exceed the prediction. At the same time, the electric boiler in the power plants can consume the excess clean energy output to compensate for the insufficient heat caused by the cogeneration units reduce output. Which can promote the RE consumption.

## 5. Task 4: Support to pilot ancillary service market in Ningxia

### 5.1 Technical Route

Task 4 monitors the development of Ningxia ancillary service market, and assesses the impact to RE integration in the province. According to the ancillary service market rules of Ningxia, a clearing model of the deep peaking market has been constructed to simulate this market, which considers thermal power plant quotations, renewable energy subsidies and other factors. The research results have practical significance for summarizing the operation experience of the ancillary service market in Ningxia, and provide opinions to replicate the practices in other provinces in northwest region, promoting the development of RE consumption mechanism. The technical route of this project is shown in figure 5-1 as follows:

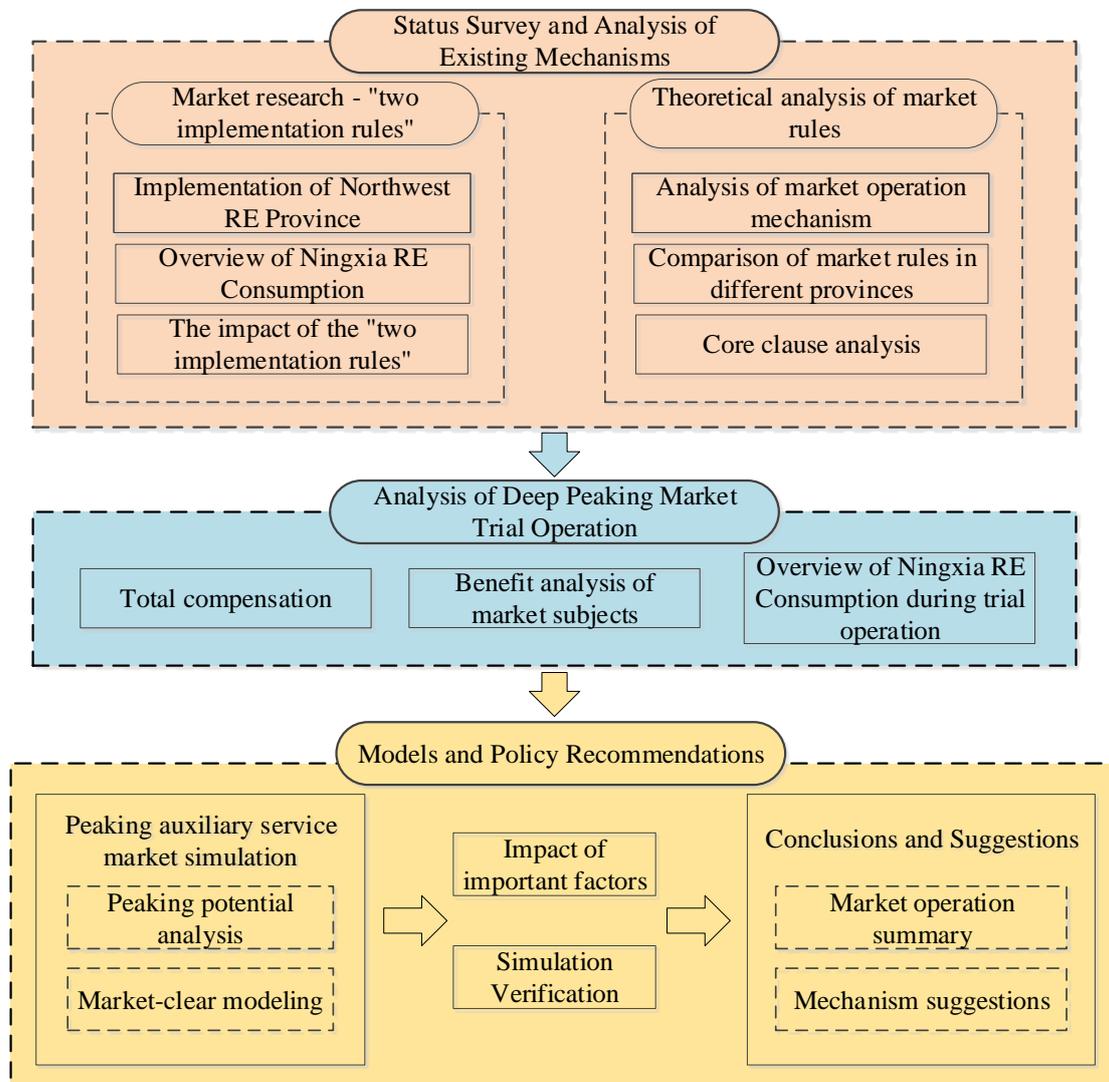


Figure 5-1 Technical route of Task 4

The practice of improving the mechanism and optimizing the allocation of resources

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is the important means to achieve efficient RE consumption. The project aims to propose a market mechanism for peaking auxiliary services that adapts to high proportion of RE and promote the sustainable development of RE. Specifically speaking, the research methods are given as follows:

- (1) To analyze the implementation of the “Two Implementation Rules”: Since the implementation, the “Two Implementation Rules” have played a positive role in ensuring the safety, high quality and economic operation of the Northwest Power System, improving the operational management level of grid-connected generating units in the Northwest, and mobilizing power generation enterprises to participate in the ancillary services. It is necessary to do rule analysis of “Two Implementation Rules ” and explore the possibility of hydropower and pumped storage power stations participating in peaking auxiliary services. Additionally, it is valuable to survey the implementation progress in Xinjiang, Gansu and Ningxia which have rich renewable energy and RE consumption in Ningxia specifically in 2015-2017. The next step is to analyze the impact of the two rules on RE consumption based on implementation effects.
- (2) To analyze pilot ancillary service market rules in Ningxia theoretically: In order to understand market rules deeply, it is necessary to analyze basic guiding ideology and operational mechanism of the Ningxia peaking market rules. The project conduct research on transaction pricing, market participants, market operation processes, and operational problem prediction. Additionally, it explores the idea of users participating in the allocation of auxiliary services. What’s more, it analyzes the advantages and disadvantages of the Ningxia rules by analyzing the terms of Ningxia's auxiliary service market rules and comparing with other province rules.
- (3) To analyze the impact of pilot ancillary service market on RE integration: According to the relevant requirements of the “Ningxia Power Auxiliary Service Market Operation Rules (Trial)”, after the start of the trial operation in early May, Ningxia Power Dispatching Control Center actively carried out deep peak-shaving transactions. The project tracks the implementation of the pilot ancillary service market in Ningxia during May-December, and quantitate impacts of the operation of this market on RE consumption. Furthermore, it summarizes the highlights and areas for improvement of this market during the trial operation phase.
- (4) To simulate operation of pilot ancillary service market in Ningxia: It is obvious that Ningxia Electric Power Dispatching Center actively organized the deep peaking trading of thermal units, continuously improved the technical support system, expanded the consumption space of RE, and made outstanding contributions to promoting the optimal allocation of RE. However, there are some inevitable problems in the rules. Since the trial operation time is still short, it is necessary to simulate the operation of the Ningxia peaking auxiliary service market according to the operational rules, and deeply analyze its advantages and disadvantages. Therefore, the project analyzes the potential of the ancillary service market, conduct quotation and market clearing simulation, and analyze the market simulation operation. This market clearing model takes the social welfare maximization as the objective function and comprehensively considers thermal power plant quotation, RE subsidies and other factors.
- (5) To propose conclusions and suggestions: Combining the above research, the project

sums up the experience of Ningxia peaking auxiliary service market operation, put forward the opinions for the introduction of peaking auxiliary service market in the northwest region, and promote the effective consumption of RE.

## 5.2 Analysis of market mechanism of peaking auxiliary service

This project investigates and analyzes market mechanism of peaking auxiliary service in Ningxia aiming to promote RE consumption. The conclusions are given in the following:

### 5.2.1 The pressure on the auxiliary service is increasing, so it is necessary to develop the auxiliary service market.

Since the issuance of the "Two Implementation Rules", Ningxia Power Grid has actively carried out assessment and compensation work. In 2016-2017, the assessment of the monthly compensation for Ningxia is shown in figure 5-2. It suggests that the punishment scores in Ningxia remained stable and even slightly decreased, the compensation scores generally showed an upward trend, indicating that the operation of the grid-connected power plants in Ningxia was relatively stable, and the paid auxiliary services participating in the power plants gradually increased.

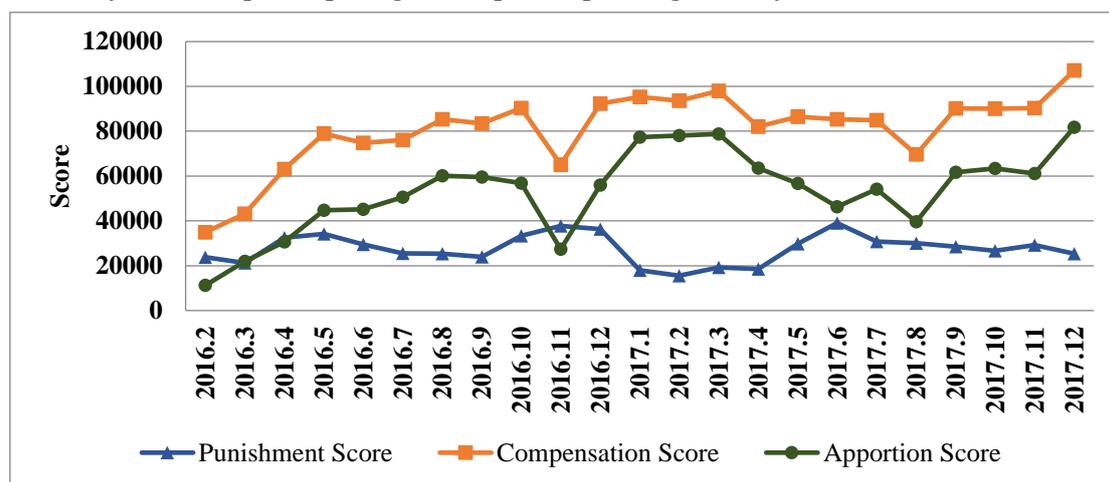


Figure 5-2 monthly assessment compensation points in Ningxia

Ningxia is located in the hinterland of the northwest. The abundant wind energy and solar energy resources make RE scale expand continuously, and the grid capacity increases rapidly. As shown in table 5-1, the grid-connected capacity of wind power has increased by 7%, 12.5% and 7.32% year by year, and the PV grid-connected capacity has increased by 73.5%, 17.5% and 29.6% year by year. It can be seen that in recent years, the level of RE consumption in Ningxia has been increasing, and the rate of abandoned wind and solar has been decreasing year by year. However, the consumption situation of solar and wind power is still severe, and the amount of discarded electricity is as high as 1.2 billion kWh in 2017.

Table 5-1 Overview of Ningxia's RE consumption in 2015-2018

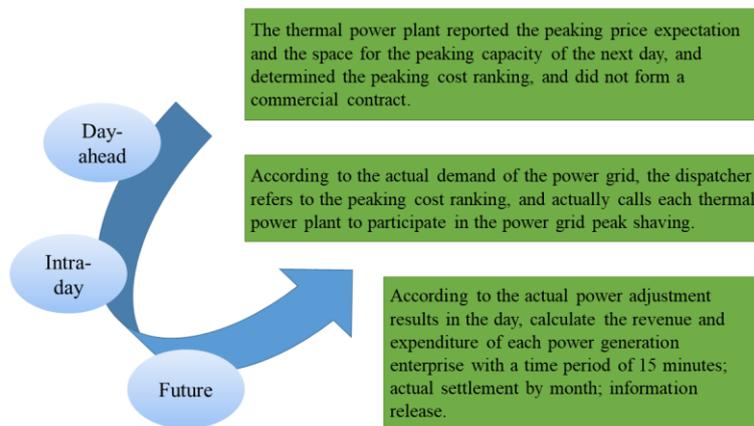
Year	Capacity access to grid (ten thousand kWh)	Cumulative power generation (one hundred million kWh)	Cumulative curtailment (one hundred million kWh)	Abandoned wind/solar rate
2015				
2016				
2017				
2018				

	Wind	Solar	Wind	Solar	Wind	Solar	Wind	Solar
<b>2015</b>	782.3	288.4	84.2	31.3	12.7	2.9	15.10%	9.30%
<b>2016</b>	837.1	500.4	128.69	52.38	19.32	4.03	13.05%	7.15%
<b>2017</b>	942	588	153.05	70.35	7.7	4.8	4.80%	6.40%
<b>2018</b>	1011	762	184.39	89.74	4.36	4.14	2.31%	4.41%

Since the formal implementation of the “Two Implementation Rules”, the total cost of grid-connected operation assessment has dropped significantly, and the mechanical role of promoting the safety, stability, quality, and economic operation of the power system and ensuring reliable supply of electricity has been exerted. However, with the expansion of the installed capacity of RE, the pressure on the auxiliary service sector is increasing, and the construction of an auxiliary service market is imminent.

**5.2.2 Ningxia Power Auxiliary Service Market Rules are designed to promote the absorption of RE. The overall market mechanism is well designed, but there are still shortcomings.**

The trial operation phase of Ningxia Power Auxiliary Service Market includes four types of transactions: deep peak trading, mediation standby trading, adjustable load trading and electric energy storage trading. The trial operation started in May, according to the current calculations, after the implementation of this market, Ningxia's entire network will be able to release about 140 ten thousand kWh of peak-shaving space, effectively solving the problems of peaking and RE consumption in power operation. The operation process and price mechanism are shown in the figure 5-3 and table 5-2.



**Figure 5-3 The operation process of peaking auxiliary service market in Ningxia**

**Table 5-2 "Stepped" quotation method and price mechanism**

Price level	Thermal plant load rate	Lowest (yuan/kWh)	Highest (yuan / kWh)
Level 1	40% < load rate < 50%	0	0.38
Level 2	Load rate ≤ 40%	0.38	0.95

The deep peak-shaving transaction is settled according to the compensated peak power of each level and the corresponding market clearing price. The market clearing price in the level refers to the quote of the last peaking unit actually called in the same level within the unit statistical period. Therefore, the compensation fee obtained by the called thermal unit is the sum of the product of the compensated peak power of each level and the clearing price of each level. The purchasers of the deep peak-shaving transaction are wind, solar, and thermal units that have not reduced their output to compensated peaking. When calculating the fee of apportion, the power generation of thermal power that have not been reduced to the compensated peaking, wind farms and solar plants is adjusted according to certain rules. The proportion of the corrected power generation is multiplied by the total compensation amount, which is expenditure of each power generation enterprise.

However, the actual peak operation of Ningxia currently involves transactions between power plants. The allocation and compensation of auxiliary service costs are carried out between power plants, but users are not considered. For example, some high-pollution and high-impact users have a large impact on peak shaving and should therefore be included in the auxiliary service allocation.

### 5.2.3 Under the current circumstances, thermal plants have a high enthusiasm for participating in the real-time deep peaking market in Ningxia.

After the start-up meeting of the trial operation in early May, Ningxia Electric Power Dispatching Center actively carried out deep peak-shaving transactions. The compensation from May to December in 2018 is as shown in the figure 5-4. It is obvious that in July, compared with May and June, the compensation for electricity and compensation fees increased sharply. In August-November, the average price of compensation increased rapidly and remained stable.

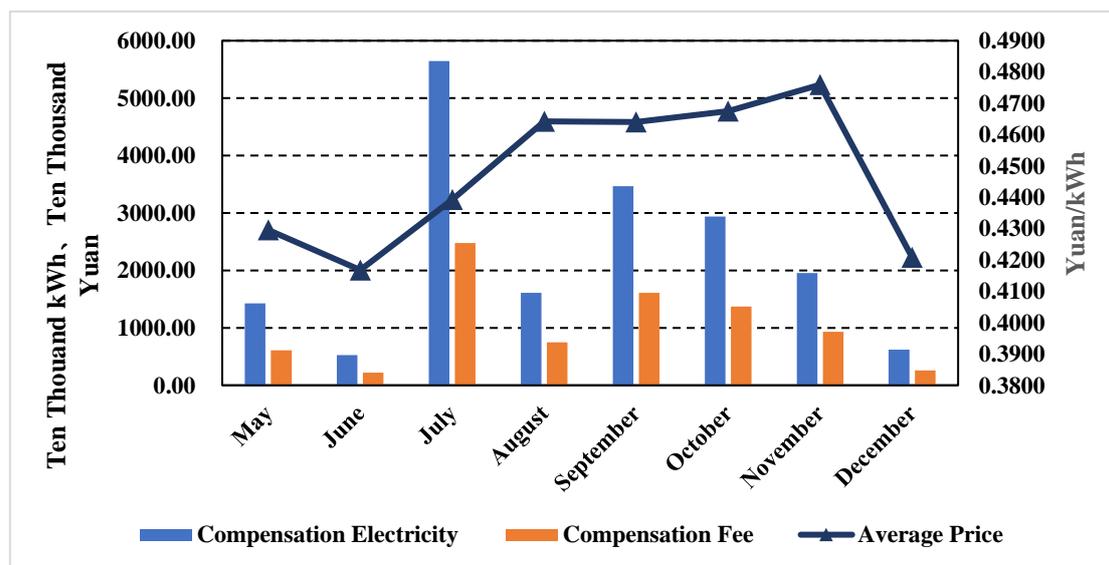


Figure 5-4 deep peaking trading situation in 2018

**Table 5-3 Average price of power compensation for each grade from May to December**

Month	Level 1 compensation average price (yuan/kWh)	Level 2 compensation average price (yuan/kWh)
May	0.38000	0.95000
June	0.38000	0.95000
July	0.38000	0.95000
August	0.37996	0.94979
September	0.37996	0.94980
October	0.37998	0.94992
November	0.38000	0.95000
December	0.38000	0.95000

By dividing the compensation cost by the compensation power, we can get the compensation average price of each peak shift in each month, as shown in table 5-3. It can be seen that the average compensation price for the peak-shaving transactions in May-July and November-December is at the upper limit of the quotation, Level 1 is 0.38 yuan/kWh, level 2 is 0.95 yuan/kWh. In August-October, Level 1 and 2 is also very close to the limit. This shows that the enthusiasm of the thermal unit to participate in the real-time deep peaking market is relatively high, which lays a good foundation for further promoting the peaking auxiliary service market.

#### **5.2.4 The operation of the peaking auxiliary service market has greatly promoted the effective consumption of RE.**

Under the deep peak shaving compensation rules, both thermal power and RE can actively participate in transactions, promote RE consumption, and reduce the rate of abandoned wind and solar. From May to December, the abandoned rate before and after peak peaking is shown in table 5-4, figure 5-5 and figure 5-6.

**Table 5-4 Abandonment of wind and solar rate from May to December**

Month	Actual abandoned wind rate	Caused by peaking	Before peaking	Actual Abandoned solar rate	Caused by peaking	Before peaking
May	1.09%	0.41%	1.50%	2.84%	0.66%	3.50%
June	0.06%	0.30%	0.36%	0.04%	0.23%	0.27%
July	0.73%	2.16%	2.89%	0.54%	1.94%	2.48%
August	0.15%	0.89%	1.04%	0.09%	0.69%	0.78%
September	3.30%	1.16%	4.46%	7.33%	2.37%	9.70%
October	6.17%	0.94%	7.11%	10.24%	1.66%	11.90%
November	3.41%	0.91%	4.32%	3.45%	0.90%	4.35%
December	4.62%	0.27%	4.89%	5.75%	0.27%	6.02%

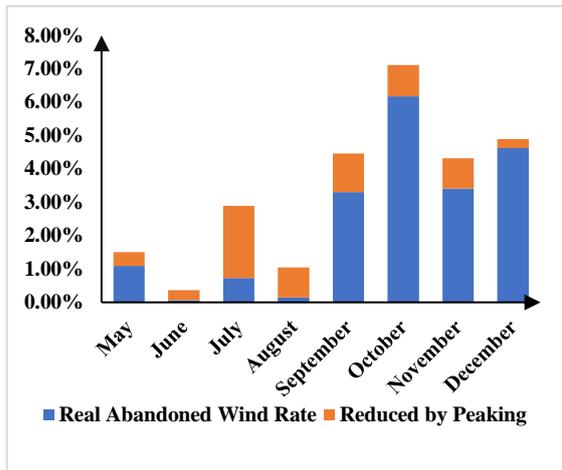


Figure 5-5 Abandonment of wind rate

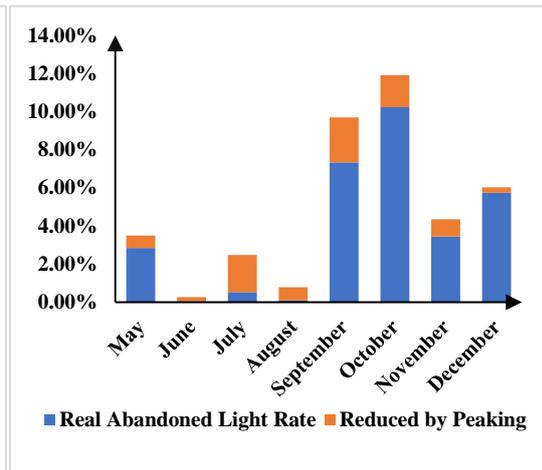


Figure 5-6 Abandonment of solar rate

It can be seen that after the deep peak trading, the abandoned wind and solar rate indicators have been greatly decreased. In July, for example, the wind-removal rate was 0.73%, which was 2.16% lower than that before the peaking market was started. The abandoned solar rate was 0.54%, which was 1.94% lower than that before the peaking market started. It shows that deep peak-shaving trading plays a good role in promoting RE consumption and has high practical value.

**5.2.5 The overall design of the Ningxia peaking market rules is better, basically achieving the balance of interests of all parties in the market.**

**1) Benefit analysis of market mains participating in peaking market**

The net benefit that a thermal plant can obtain is the compensation income minus peaking cost. Calculate the thermal power efficiency from May to December is shown in the figure 5-7. It can be seen that the more electricity that participates in deep peak-shaving transactions, the greater the benefits that thermal plants can achieve. The reason for this phenomenon is that the average price of compensation for thermal power plants is higher than the average cost, so the greater the compensation, the greater the benefits.

In addition to the cost of selling electricity, the benefits of RE also include subsidies from the state. Since state subsidies are distributed to power plants in a few years, the calculation of subsidy benefits should be multiplied by the discount rate. In addition, each RE power plant must participate in the apportionment, and then the benefits of RE from May to December are shown in the figure 5-8. It can be seen that in the absence of state subsidies, RE, as the main cost-sharing bearer, their gains are negative due to the higher cost of peaking auxiliary services. Positive returns can only be obtained through state subsidies.

**2) Benefit analysis of environment**

By promoting RE consumption, the state can reduce the cost of governance for carbon emissions. The cost of national savings is the amount of electricity that is used to generate RE instead of thermal, that is, the peaking compensation power, and then multiplied by the corresponding unit governance cost, to obtain the benefits of CO<sub>2</sub> treatment from May to December, as shown in figure 5-9. It can be seen that the more electricity that thermal units transferred, the more benefits it can get from carbon

dioxide treatment.

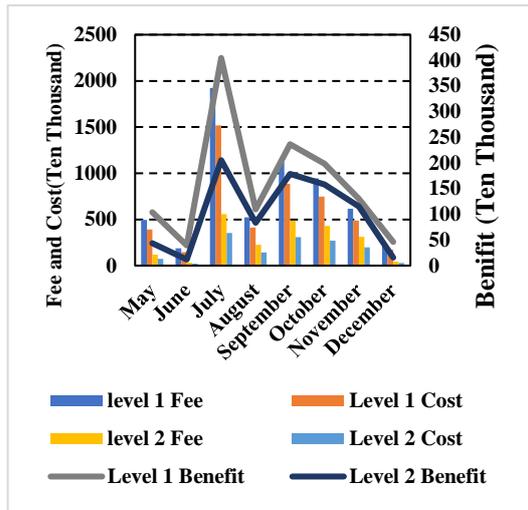


Figure 5-7 thermal benefits

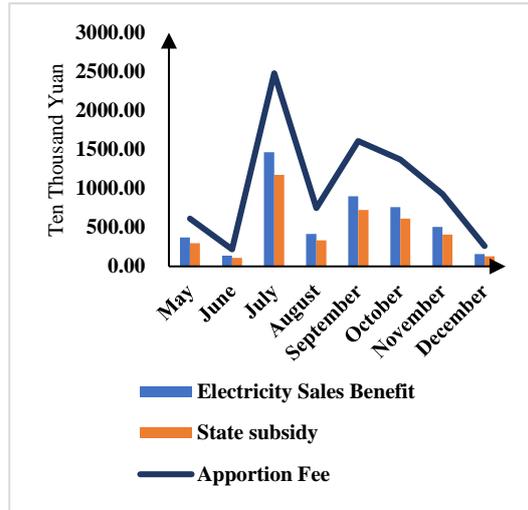


Figure 5-8 RE benefit

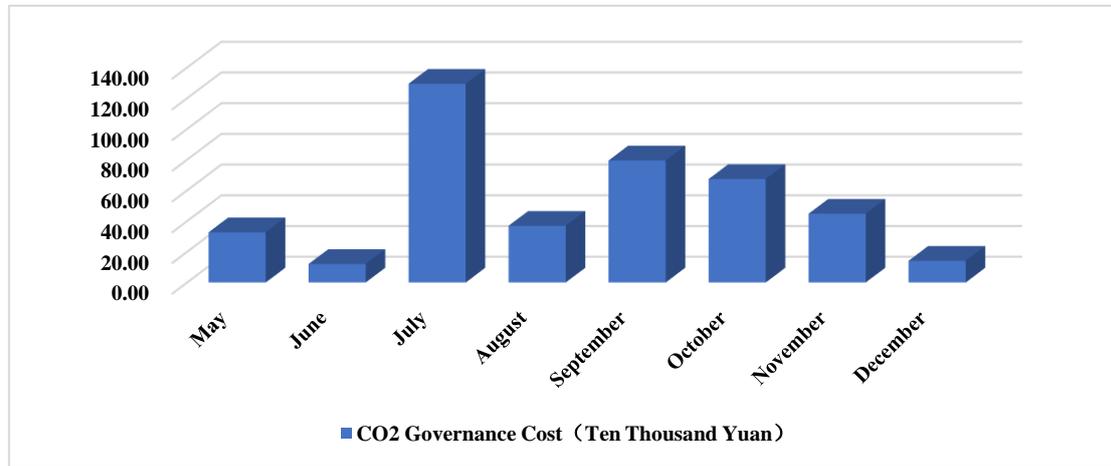


Figure 5-9 environmental benefits

In summary, by participating in deep peak-shaving transactions, thermal plants and RE plants can all achieve considerable benefits, and through this market, social benefits can also be achieved by reducing carbon emissions.

**5.2.6 Through the peaking auxiliary service market simulation, it is found that there are still some points for improvement in the market mechanism.**

Since the trial operation time is still short, it is necessary to simulate the operation of the Ningxia peaking auxiliary service market according to the operational rules, and deeply analyze its advantages and disadvantages. The deep peaking trading is established on the basis of the day-ahead simulation calculation. The simulation output of the thermal plants, wind and solar and the initial curtailment of the system can be obtained by day-ahead calculation. Then, we take the social welfare maximization as the objective function, consider the market peaking constraints, operational constraints, etc. to construct the clearing model of this market, and correct the clearing results according to the rules. Using this model for market simulation, we can get the impact of important factors on the peaking market.

**(1) Unilateral quotes and bilateral quotes**

In a mature market environment, wind and solar plants purchase power generation space at a certain price. That is bilateral quotes, which we suggest to use. We can simulate bilateral and unilateral quotes and measure the income of market mains. The results are shown in the figure 5-10. Under the bilateral quotation mode, the benefits of each market entity are positive, and under the unilateral quotation, the PV has a loss. According to the rules, RE plants must participate in the allocation regardless of whether they receive the power of the thermal units. Some RE units still need to participate in the allocation without the power of the thermal plants. The original design of the rules is to promote RE to participate in the peaking market, but still has certain planning characteristics. It is recommended that RE plants should also participate in the quotation of the peaking market, reflect the role of entity in this market, and ensure the balance of interests.

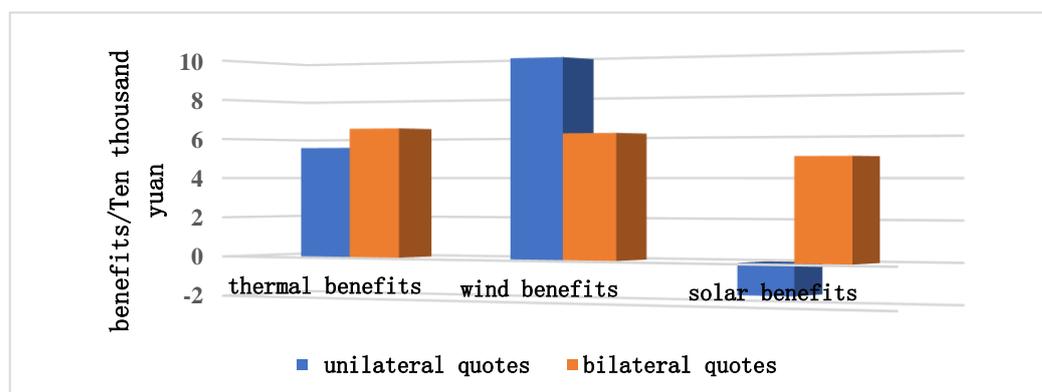


Figure 5-10 Income of thermal plants and RE plants on July 19th

## (2) The subsidies of RE

The reason why the peaking auxiliary service market can operate smoothly will inevitably bring certain benefits to the RE plants. This part of the income includes the revenue from the sale of electricity generated by the thermal power obligation, and also includes the benefits of the state's subsidies for RE access. The calculation compares the benefits of the RE plants without/with the subsidies, as shown in the figure 5-11. As can be seen from the figure, under the current price mechanism, the benefits of RE are closely related to state subsidies. The higher the price of thermal power to sell power generation space, the higher the cost of RE, although the RE has more power generation space, and then the curtailment decreased while the RE plants' own interests are damaged. Therefore, if the "zero subsidy" is used in the future, under the current price mechanism, the willingness of RE to participate in the deep peaking market will be greatly reduced, and the peaking market will lose its effect.

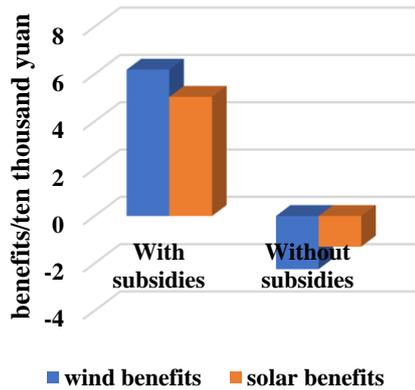


Figure 5-11 Whether to take into account the subsidies of RE income

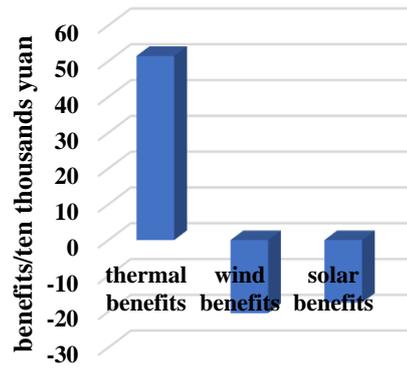


Figure 5-12 Thermal power and RE income on January 15th

### (3) Mandatory rate requirement

Taking the data of January 15, 2018 in Ningxia as an example, the market simulation calculation of the heating season was carried out. Measuring the benefits of various stakeholders as shown in figure 5-12. It can be seen that compared with July 19th, the interests of market mains in January 15th were damaged. This is because the initial curtailment in the system increased greatly in January, and some units could not provide the duty peaking power due to the heating demand. Therefore, RE must purchase the paid peaking auxiliary service of the thermal units at a higher price to meet the “Double Drop” target. That is to say, RE will pay an economic price, affecting the enthusiasm of RE to participate in the peak-shaving market to a certain extent, and even the market may not operate normally.

## 5.3 Supervision Suggestions for Market Mechanism of Peaking

### Auxiliary Service

Conducting peaking service market transactions is an important way to optimize resource allocation and an important way to promote RE consumption in the northwest region. In order to further develop the peaking auxiliary service market, based on the above research basis, this project proposes the following suggestions for the construction of market mechanisms:

#### (1) Bilateral quotation mode

In the existing mechanism of Ningxia, the RE plants passively distribute the peaking compensation costs, which damages the interests of RE plants to a certain extent, and does not conform to the market-oriented development law. It is recommended to allow RE plants to voluntarily quote, self-financing, and use the market's own control measures to promote the healthy development of peaking auxiliary services.

#### (2) Research on the upper limit of thermal units

In response to the arrival of the “zero subsidy” era, the quotation of thermal plants in the auxiliary market operation rules should also keep pace with the times. Based on the mutual checks and balances between the interests of thermal plants and RE sources, in order to ensure the smooth operation of the peaking market, it is recommended to

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conduct research on the upper limit of thermal plants compensation quotation. The new upper limit should meet the profit demand of thermal power and resource energy, urging the peaking market to develop in an orderly manner

**(3) Distinguish the upper limit of the quotation of thermal units between heating and non-heating periods**

The increase in RE curtailment in winter and the limited peaking capacity of thermal units due to heat supply have increased the cost of purchasing thermal generation space. It is possible that RE revenues are not high or even negative. Therefore, it is suggested that the upper limit of the quotation of thermal units should be differentiated between the heating period and the non-heating period. Specifically, the quotation of the heating period is higher than the quotation for the non-heating period, which promotes the “win-win” of thermal power and RE in the whole year.

**(4) Two-part quotation**

From the international experience, in order to ensure long-term supply security, mature markets such as the United Kingdom and PJM have established a matching capacity market mechanism. Based on this, it is recommended to increase the long-term capacity guarantee mechanism in the Ningxia peaking auxiliary service market, that is, to introduce the “two-part quotation”. Specifically, peaking capacity trading should be considered in the peaking auxiliary service market. The quotation should be divided into two-part, which is divided into “electricity quotation” and “capacity quotation” to encourage more units to participate in flexible transformation and fully tap the peaking potential of thermal units.

**(5) Provide a variety of market trading varieties and add more peak trading entities**

In the future development of the power grid, we should continue to conduct mediation and standby transactions, adjustable load transactions, and electric energy storage transactions to provide diversified market choices for NE consumption and system peaking, and optimize resource allocation. It is recommended to add more peaking trading entities, such as energy storage, hydropower, pumped storage power stations, etc., and encourage more power users to participate in peaking transactions through demand side management mechanisms.

**(6) Users participate in auxiliary service market cost sharing**

The rules currently involve transactions between power plants such as wind, solar and thermal plants. The allocation and compensation of auxiliary service costs are carried out between power plants, but users are not considered. It is recommended that some auxiliary service market operating costs be transmitted to the user side, that is, some users (such as high-pollution and high-impact users) participate in the auxiliary service sharing and sharing mechanism, and break through the auxiliary service market cost sharing limitation on the power supply side.

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## 6. Conclusions

The tasks of this project has been successfully completed. After the implementation of the project, Northwest China Energy Regulatory Bureau of National Energy Administration of the People's Republic of China fully grasped the operation effect of renewable energy (RE) integration mechanisms abroad and its application in Northwest China, and the status and problems of inter-provincial and inter-regional transactions in Northwest China. Through research, the project has concluded that 'northwest China had some problems on RE integration such as insufficient local demand, underutilized export potential, limited peaking regulation capacity, insufficient accuracy of RE forecasting, and imperfect market and dispatching mechanisms', 'the overall utilization rate of inter-provincial and inter-regional outbound corridors in Northwest China still had considerable potential for improvement', 'large-scale inter-regional transportation of electricity played an important role in RE integration the Northwest China', 'current inter-provincial and inter-regional trading mechanism had initially met the trading needs, but the completeness and flexibility of trading mechanism needed to be further improved' and so on. Meanwhile, this project has investigated the operation of peaking ancillary service market and dispatch methods in Ningxia through the project team, and reached conclusions such as 'thermal plants have a high enthusiasm for participating in the real-time deep peaking market in Ningxia', 'the operation of the peaking auxiliary service market has greatly promoted the effective consumption of RE', 'the current overall design of the Ningxia peaking market rules is better', 'The performance of impartiality dispatch mode is comparatively bad' and so on.

The project put forward some development proposals such as 'the plan-oriented RE generation planning should be transferred to the market-oriented RE generation planning', 'peaking regulation mechanism should be transferred from fully utilizing peaking regulation resources to efficiently utilizing these resources', 'power grid planning development should consider two aspects: improving grid transmission capacity and reasonable pricing of transmission resources', 'market mechanism should expand the transaction type and the integrated transaction type simultaneously', 'inter-provincial and inter-regional trading mechanism should enrich the trading varieties and activate the enthusiasm of thermal units to participate in RE integration'. The proposals provided a theoretical basis for the planning and construction of the future development path of RE integration mechanism in Northwest China.

According to the project, the proposed amendments were propounded as the theoretical basis for the revision of the Ningxia Power Auxiliary Service Market Operation Rules, such as 'allow wind power plants to participate in the quotation', 'distinguish the upper limit of thermal power unit quotation between heating period and non-heating period', 'two-part quotation', 'provide a variety of market trading varieties and add more peak trading entities', 'allow hydropower and pumped storage power stations to participate in the peaking auxiliary service market', 'Users participate in auxiliary service market cost sharing' and so on.

According to the dispatch improvement suggestions proposed by the project, it is

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applied to the operation and dispatch of the power system as the theoretical basis for improving the optimal dispatching mode of the power system in Ningxia Autonomous Region. The dispatch improvement suggestions include ‘adopting the appropriate dispatch mode according to local conditions’, ‘encouraging the captive power plants to participate in system dispatch’, ‘digging the potential peaking capacity of thermal units by combining with the depth peak-regulation ancillary service market’, ‘abolishing the mode of “Determining Power generation by heat” in cogeneration power plants to improve the flexible of dispatch’ and so on.

After the implementation of the project achievements, it effectively promoted the rolling development of RE integration mechanism in Northwest China and the potential mining of inter-provincial and inter-regional power transmission. Moreover, the project will help promote the start-up and trial operation of the Northwest Pilot Auxiliary Service Market (Ningxia). The operation effect is approving and the social benefits are remarkable. It has played an active role in promoting the peaking ability of the power system, the fair and orderly development of the auxiliary service market, the promotion of large-scale RE integration and the promotion of China's power system reform and construction.

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## Appendix

Table 1 Rolling mechanism path arrangement of RE generation planning in northwest regions

Generation side		By 2020	By 2025	By 2030
<b>RE generation planning</b>		Overall idea: transition from plan-oriented to market-oriented and planning decision-making from power generation resources assessment to comprehensive resource assessment + profitability transition.		
	<b>Questions</b>	<ul style="list-style-type: none"> <li>● Channel capacity, system peak regulation, load and flexibility are not suitable for the development of new energy.</li> </ul>	<ul style="list-style-type: none"> <li>● Establish market-oriented online price system.</li> </ul>	<ul style="list-style-type: none"> <li>● Establish a mechanism for the coordinated development of sources, network, load and storage under the market environment.</li> </ul>
	<b>Objectives</b>	<ul style="list-style-type: none"> <li>● The proportion of RE installation reach 33%-36%.</li> <li>● The proportion of RE generation reach 18%-20%.</li> <li>● The curtailment rate of RE is less than 5%.</li> </ul>	<ul style="list-style-type: none"> <li>● The proportion of RE installation reach 40%-45%;</li> <li>● The proportion of RE generation reach 22%-25%;</li> <li>● The curtailment rate of RE is less than 3%。</li> </ul>	<ul style="list-style-type: none"> <li>● The proportion of RE installation reach 50%-55%;</li> <li>● The proportion of RE generation reach 30%-35%;</li> <li>● The curtailment rate of RE is less than 2%。</li> </ul>
	<b>Actions</b>	<ul style="list-style-type: none"> <li>● Power pricing mechanism: competitive electricity price (bidding, bilateral negotiation) for RE power generation projects; power generation rights replacement, cross-provincial and cross-regional transactions, and direct transactions with power selling companies and large consumers;</li> <li>● Planning idea: comprehensive evaluation of resource, network and load based on primary energy resources;</li> <li>● Centralized decision-maker</li> </ul>	<ul style="list-style-type: none"> <li>● Power pricing mechanism: competitive electricity price for new projects and government pricing for existing projects for basic electricity cooperate with spot market; trade in medium and long-term transactions, encourage participation in spot market and auxiliary service market; power generation rights replacement;</li> <li>● Planning idea: considering multiple links of resource, network, storage and environment;</li> <li>● Planning decision-maker: power plants make their own investment decisions.</li> </ul>	<ul style="list-style-type: none"> <li>● Power pricing mechanism: competitive electricity price; integrated variety trading market; reasonable evaluation mechanism for the penalty electricity quantity;</li> <li>● Planning idea: sources, network, load and storage + ecological environment + comprehensive assessment of profitability;</li> <li>● Planning decision maker: All new projects are invested by the power plant itself.</li> </ul>
	<b>Pre-conditions (transitional arrangement)</b>	<ul style="list-style-type: none"> <li>● Same price for photovoltaic and thermal power; significantly reduced cost of wind power;</li> <li>● Load elasticity is increased.</li> </ul>	<ul style="list-style-type: none"> <li>● Wind power access to the grid at fair price;</li> <li>● RE generation projects have subjective willingness to participate in market;</li> <li>● Further Improvement of Load Elasticity.</li> </ul>	

Table 2 peak regulation and rolling mechanism path arrangement of the RE power system

Generation side		By 2020	By 2025	By 2030
<b>peak regulation and rolling mechanism path arrangement</b>		Overall idea: transit from fully utilization to efficient utilization and from solving lack of peak regulation capacity (increasing capacities and expand scopes) to set accurate price for peak regulation resources.		
	<b>Problems</b>	<ul style="list-style-type: none"> <li>● Available peak regulation capacity is not sufficient.</li> </ul>	<ul style="list-style-type: none"> <li>● Market signal represent the value of peak regulation resources.</li> </ul>	<ul style="list-style-type: none"> <li>● Reasonable planning and pricing of peak regulation resources.</li> </ul>
	<b>Objectives</b>	<ul style="list-style-type: none"> <li>● Traditional units: more than 60% peak regulation ability;</li> <li>● Inter-provincial peak regulation ancillary service market;</li> <li>● Reasonable allocation of peak regulation cost.</li> </ul>	<ul style="list-style-type: none"> <li>● Traditional units: more than 65% peak regulation ability;</li> <li>● Inter-provincial and provincial peak regulation ancillary service market;</li> <li>● The preliminary realization of peak regulation resource allocation guided by market signal.</li> </ul>	<ul style="list-style-type: none"> <li>● Traditional units: more than 70% peak regulation ability;</li> <li>● Withdrawal from peak regulation ancillary service market; the marginal value of peak regulation resources can be accurately reflected by market price.</li> </ul>
	<b>Actions</b>	<ul style="list-style-type: none"> <li>● Peak regulation resources: current units' flexibility improvement and higher flexibility demand for newly set-up units; traditional units</li> <li>● Mechanism: improve inter-provincial ancillary service</li> </ul>	<ul style="list-style-type: none"> <li>● Peak regulation resources: increase the capacities on generation, demand and storage side;</li> <li>● Mechanism: set up two-level, two-part peak regulation ancillary service and spot market mechanism.</li> </ul>	<ul style="list-style-type: none"> <li>● Peak regulation resource: increase the capacities on generation, demand and storage side by market mechanism; encourage all parts in market to participate in the activity;</li> <li>● Mechanism: resources allocation given by spot and capacity market.</li> </ul>
	<b>Pre-conditions (transitional arrangements)</b>	<ul style="list-style-type: none"> <li>● Increase participation for traditional units and decrease participation for RE units.</li> </ul>	<ul style="list-style-type: none"> <li>● Elimination of wind and solar curtailment;</li> <li>● Guidance for allocation given by spot and ancillary service market</li> </ul>	

Table 3 rolling path arrangement for power grid planning and transmission cost involving high proportion of RE

Transmission side		By 2020	By 2025	By 2030
<b>Power grid planning and transmission cost involving high proportion of RE</b>		Overall idea: development of enhancement of power grid interconnection and reasonable transmission resources pricing		
	<b>Problems</b>	<ul style="list-style-type: none"> <li>● Lack of transmission capacity.</li> </ul>	<ul style="list-style-type: none"> <li>● Reasonable transmission pricing mechanism.</li> </ul>	<ul style="list-style-type: none"> <li>● Reasonable planning and pricing for transmission resources.</li> </ul>
	<b>Objectives</b>	<ul style="list-style-type: none"> <li>● RE curtailment rate decreased to 2% due to power delivery obstruction</li> <li>● Reasonable cross-provincial delivery channel pricing.</li> </ul>	<ul style="list-style-type: none"> <li>● Development of sources, network, load and storage;</li> <li>● Establishment of market-oriented congestion management mechanism.</li> </ul>	<ul style="list-style-type: none"> <li>● Development of sources, network, load and storage in the market mechanism;</li> <li>● Reasonable transmission pricing and allocation mechanism.</li> </ul>
	<b>Actions</b>	<ul style="list-style-type: none"> <li>● Enhance channel capacity: focus on the channel obstruction; consider the source and load to set up the planning;</li> <li>● Reasonable transmission pricing: improvement of transmission pricing mechanism; establishment of reasonable evaluation system.</li> </ul>	<ul style="list-style-type: none"> <li>● Enhance channel capacity: increase inter-provincial channel capacity and fully utilization of cross-provincial capacity;</li> <li>● Reasonable transmission pricing: capacity and electricity pricing mechanism to develop risk-averse financial markets, and to account for the investment, operation and congestion costs of power grids.</li> </ul>	<ul style="list-style-type: none"> <li>● Enhance channel capacity: improve coordinate development;</li> <li>● Reasonable transmission pricing: improve comprehensive pricing and financial market trading mechanism; fix different prices to each part of the grid, to improve the mode of transmission cost allocation; manage the congestion based on the market mechanism.</li> </ul>
	<b>Pre-conditions (transitional arrangements)</b>	<ul style="list-style-type: none"> <li>● Relief of transmission capacity obstruction.</li> </ul>	<ul style="list-style-type: none"> <li>● Basic elimination of RE curtailment due to obstruction;</li> <li>● Transmission price to allocate cost reasonably and promote power trade.</li> </ul>	

Table 4 rolling path arrangement of demand side management for promoting RE consumption

Consumption side		By 2020	By 2025	By 2030
<b>Demand side management for promoting RE consumption</b>		Overall idea: make the flexibility transferred to accurately follow RE, promote the predictability and controllability of response		
	<b>Problems</b>	<ul style="list-style-type: none"> <li>● Insufficient flexibility on demand side.</li> </ul>	<ul style="list-style-type: none"> <li>● Difficult to predict and control the demand response.</li> </ul>	<ul style="list-style-type: none"> <li>● Make response follow RE by market mechanism.</li> </ul>
	<b>Objectives</b>	<ul style="list-style-type: none"> <li>● Cultivate incentive compatible demand response projects market players</li> </ul>	<ul style="list-style-type: none"> <li>● Peak load reduced by 5%;</li> <li>● Enhance the willingness of demand side to participate actively in market competition;</li> <li>● Promote predictability and controllability</li> </ul>	<ul style="list-style-type: none"> <li>● Peak load reduced by 5%;</li> <li>● Realize the mode of the demand side to follow RE actively in the market.</li> </ul>
	<b>Actions</b>	<ul style="list-style-type: none"> <li>● Figure out flexibility: promote multiple time of use price models on the user side and demand response projects such as interruptible load and adjustable load;</li> <li>● Cultivate flexibility: develop distributed storage, electric vehicle and smart grid technology; cultivate load aggregators and integrated energy service providers;</li> <li>● Flexibility resources : large consumers, EVs, etc.</li> <li>● Market players: large consumers, etc.</li> </ul>	<ul style="list-style-type: none"> <li>● Figure out flexibility: launch demand response projects including time of use price, peak price, interruptible load, changeable load and emergent demand response; set up models of active participation in the market for demand side; establish distributed energy trading mode; launch multi-energy complementary projects;</li> <li>● Cultivate flexibility: develop distributed storage and EVs technology to provide the flexibility of occupants ; improve the interconnection of multi-energy sources on the demand side;</li> <li>● Flexibility resources: distributed generation resources, distributed storage, EVs, terminal occupants and some non-electrical consumers;</li> <li>● Market players: large consumers, load aggregator, integrated energy service provider.</li> </ul>	<ul style="list-style-type: none"> <li>● Figure out and cultivate flexibility: coordinate development of four parts in the power system together with integrated energy system of gas and transportation;</li> <li>● Flexibility resources: energy department users of gas, electrical and transportation;</li> <li>● Market players: users that can participate independently in demand response or through agents in the activities.</li> </ul>
	<b>Pre-conditions (transitional arrangement)</b>	<ul style="list-style-type: none"> <li>● Profits for consumers;</li> <li>● Storage and comprehensive energy system to promote RE consumption.</li> </ul>	<ul style="list-style-type: none"> <li>● Promote RE consumption by participating in demand response or market competition;</li> <li>● More than 20% of load participates in projects with demand response projects.</li> </ul>	

Table 5 rolling path arrangement of market mechanism with high proportion of RE

Macro-mechanism		By 2020	By 2025	By 2030
Market mechanism involving high proportion of RE		Overall idea: develop expanding transaction (managing risk) and integrating transaction simultaneously		
	<b>Problems</b>	<ul style="list-style-type: none"> <li>● Restriction of efficient resource allocation due to imperfect trading mechanism</li> </ul>	<ul style="list-style-type: none"> <li>● Temporary trading measures need to be systematized.</li> <li>● Market risk intensifies.</li> </ul>	<ul style="list-style-type: none"> <li>● Provide various trading modes and comprehensive risk management tools</li> </ul>
	<b>Objectives</b>	<ul style="list-style-type: none"> <li>● The proportion of electricity in market-oriented transactions reaches 50%.</li> </ul>	<ul style="list-style-type: none"> <li>● The proportion of electricity in market-oriented transactions reaches 75%.</li> <li>● Enhance the market competitiveness of RE.</li> </ul>	<ul style="list-style-type: none"> <li>● The proportion of electricity in market-oriented transactions reaches 95%.</li> <li>● Allocate RE cost reasonably and allocate the benefits of RE based on market mechanism of power resources allocation</li> </ul>
	<b>Actions</b>	<ul style="list-style-type: none"> <li>● Main Energy Market: establish a relatively perfect electricity market mechanism, including expanding the medium and long-term trading scale;</li> <li>● Ancillary service: establish inter-provincial market and transmission cost evaluation system;</li> <li>● Balance mechanism: clarify clearing agents to set up balance mechanism;</li> <li>● Market mechanism of RE: transactions of generation rights and bilateral contracts, etc.;</li> <li>● RE policies: benchmarking price, government subsidies and of additional policies to enhance the competitiveness.</li> </ul>	<ul style="list-style-type: none"> <li>● Main Energy Market: integrating trading varieties, improving market mechanism, establishing spot market and capacity market in the region; perfecting distributed generation market; starting derivatives market such as power futures;</li> <li>● Auxiliary services: improve the transmission capacity, electricity price mechanism, carry out financial transmission rights trading, start FM, standby and other ancillary services market;</li> <li>● Balance mechanism: improve balance mechanism</li> <li>● Market mechanism of RE: same for the traditional energy and RE; break barriers of cross-provinces.</li> <li>● RE policies: quota system, green certificate and pollutant emission trading; premium mechanism and differential contract in spot market</li> </ul>	<ul style="list-style-type: none"> <li>● Market mechanism: establish multi-level and coordinated multi-variety national unified power market with multi-market participants, realize diversified transaction of distributed generation, improve power financial derivatives market, and establish a sound balance mechanism;</li> <li>● RE policies: no special policy for RE; perfect pollutant emission market.</li> </ul>
	<b>Pre-conditions</b>	<ul style="list-style-type: none"> <li>● Market mechanism can reasonably allocate RE related to costs and benefits.</li> </ul>	<ul style="list-style-type: none"> <li>● It is more competitive for RE than the traditional energy in the market mechanism.</li> </ul>	

Table 6 rolling path arrangement of dispatching mechanism involving high proportion of RE

Macro-Mechanism		Before 2020	Before 2025	Before 2030
Dispatching mechanism involving high proportion of RE		Overall idea: clarify the process of dispatching and market responsibility and expand the demand side dispatchable resources		
	Problems	<ul style="list-style-type: none"> <li>● There are many restrictions on fairness.</li> </ul>	<ul style="list-style-type: none"> <li>● There are many restrictions on dispatching.</li> </ul>	<ul style="list-style-type: none"> <li>● High-efficient dispatching under the market mechanism.</li> </ul>
	Objectives	<ul style="list-style-type: none"> <li>● The priority objective is to consume RE resources and ensure the safe and economic operation of the system and define the dispatching responsibilities in the process of market-oriented transformation.</li> </ul>	<ul style="list-style-type: none"> <li>● The priority objectives are to implement market trading results, consume RE resources and ensure the safe and economic operation of the system.</li> </ul>	<ul style="list-style-type: none"> <li>● Define the dispatching responsibility to ensure the safe and economic operation of the system under the market mechanism.</li> </ul>
	Actions	<ul style="list-style-type: none"> <li>● Dispatching responsibilities: reduce the power arranged by dispatching and transfer the function of dispatching to check the results of transactions and real-time power balance; focus dispatch mainly on the RE consumption; establish RE-oriented dispatching</li> <li>● Dispatching objects: generation resources</li> </ul>	<ul style="list-style-type: none"> <li>● Dispatching responsibilities: undertake the functions of real-time power balance, safe execution of market transaction results, purchase of ancillary services, etc. treat traditional and RE fairly and economically, establish new energy-oriented dispatching regulations.</li> <li>● Dispatching objects: generation resources, load aggregator and integrated energy service provider.</li> </ul>	<ul style="list-style-type: none"> <li>● Dispatching responsibilities: carried out according to the results of market transactions, and only takes on the functions of real-time power balance (quotation according to market participants) and purchasing ancillary services;</li> <li>● Dispatching objects: integrate all links, including power generation resources, load aggregator, etc.</li> </ul>
	Pre-conditions	<ul style="list-style-type: none"> <li>● In many types of market transactions, dispatching can fully consume RE.</li> </ul>	<ul style="list-style-type: none"> <li>● New energy can be fully consumed through market transactions.</li> </ul>	