THE PATH TOWARDS A FUTURE OF HIGH RENEWABLE ENERGY IN JIANGSU, CHINA

White paper on power system optimisation

Jiangsu province in China has been at the forefront of the energy transition in recent years. Jiangsu's energy authority issued "Guidelines for Jiangsu Province to Improve the Regulation Capacity of the Power System", which proposes taking comprehensive measures to improve flexibility and adaptability in order to achieve safe, efficient, clean and low-carbon development of the power system.

Based on bilateral energy cooperation between China and Finland, Wärtsilä and the Energy Power Planning & Engineering Institute (EPPEI) jointly launched the study project "Enhancing Power System Flexibility: Finnish Experience and Application in Jiangsu". This study aims to identify the optimal path towards more renewable energy sources (RES) for Jiangsu by improving its power system flexibility. It considers three scenarios – baseline, moderate RES and high RES – and shows how the optimal path to more renewables can help lower system costs while maintaining system reliability.

CONTENTS

In order to achieve this, flexible gas-based capacity is needed to integrate renewables and provide peak regulation. This capacity includes multiple power solutions such as efficient and flexible gas-based internal combustion engine (ICE) power plants as well as battery energy storage.

Jiangsu has been at the forefront of the energy transition in recent years.

In particular, the fast ramp-up and ramp-down rates of high-efficiency ICE power plants allow the system to meet the need for short-term rapid response when integrating renewables.

II. MARKET BACKGROUND

Jiangsu province, located on the east coast of mainland China, has a total area of 107,000 square kilometres and a population of 80.5 million. Located in the Yangtze river economic belt, the province has one of the highest levels of economic development in China. In 2018, Jiangsu's gross domestic product (GDP) was 9.26 trillion CNY with an average annual growth rate of 6.7%.

Installed capacity

By the end of 2018, the total installed capacity of Jiangsu province was 126.6 GW, divided as follows:

- Coal-fired 78.8 GW, accounting for 62.3% of the total installed capacity of the province
- Gas power 15.1 GW, pumped hydro 2.6 GW and nuclear power 4.4 GW
- Wind power 8.6 GW (including 3.0 GW offshore wind power, ranking number one in China), accounting for 6.8% of the total installed capacity of the province
- Solar power 13.3 GW, accounting for 10.5% of the total installed capacity of the province
- Biomass 0.5 GW, waste power 1.0 GW
- Power-grid-side energy storage 0.1 GW
- Others (exhaust, residual heat, pressure, etc.) 2.1 GW

Figure 1. Total installed capacity 2018

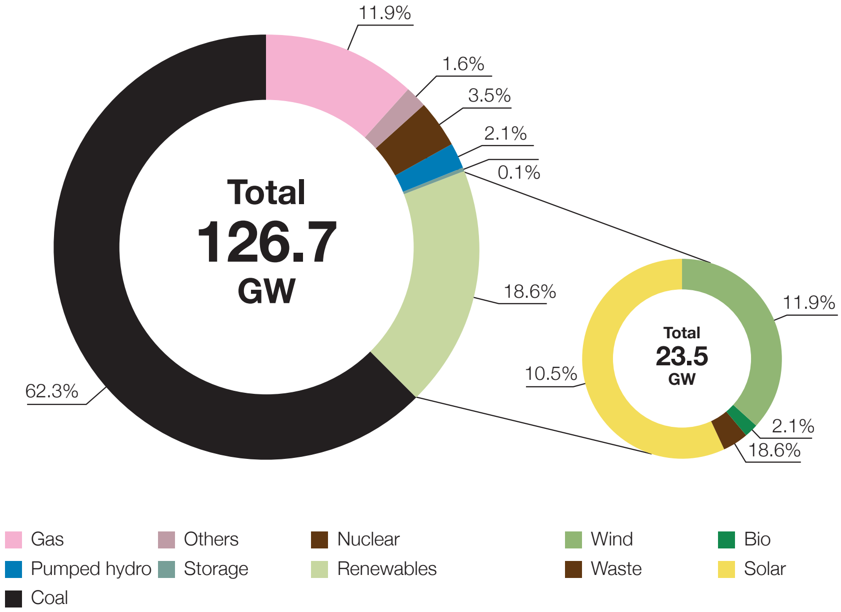
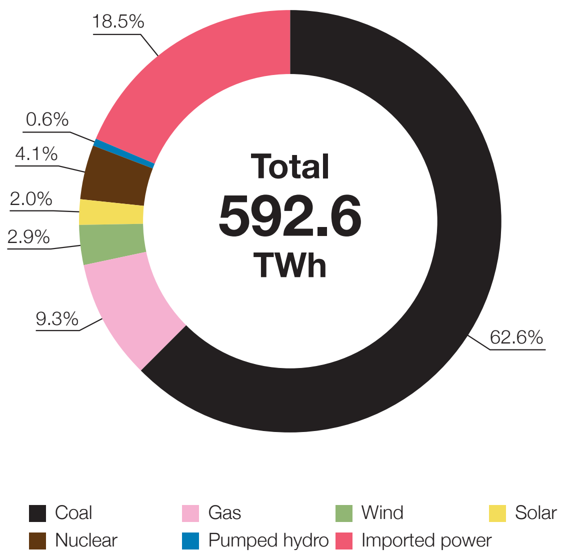
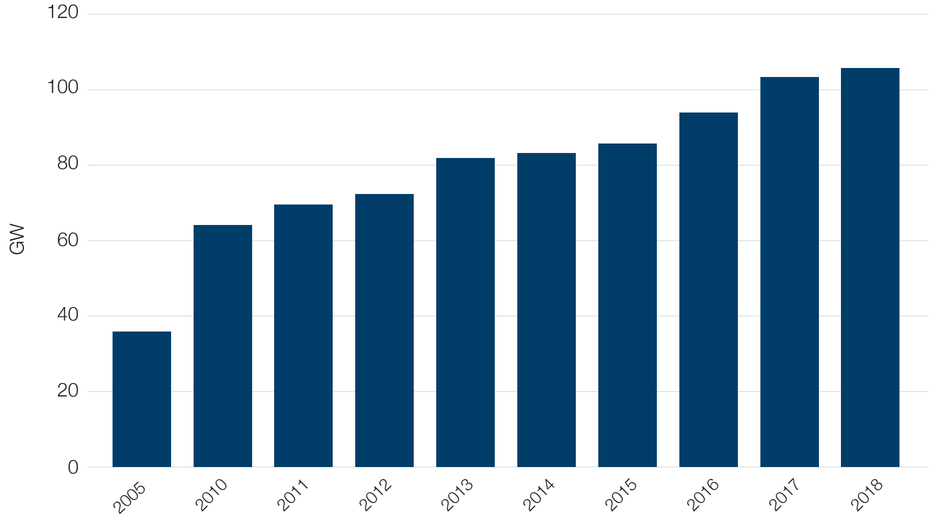


Figure 2. Annual power generation 2018



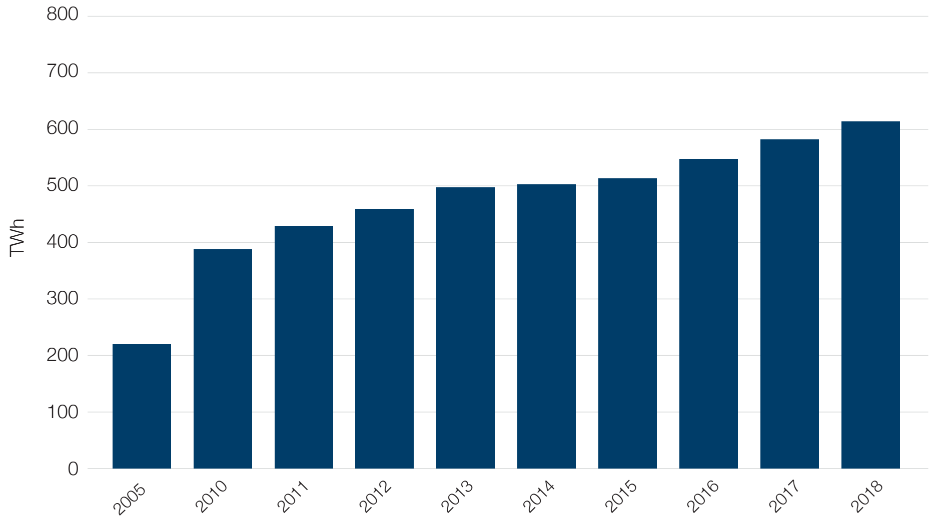
From 2005 to 2018, the peak load of Jiangsu increased from 35.8 GW to 105.7 GW, nearly tripling, with an average annual growth rate of 8.7%. In 2017, the peak load of Jiangsu exceeded 100 GW for the first time, making it the first provincial power grid in China to achieve this figure.

Figure 3. Peak load 2005–2018



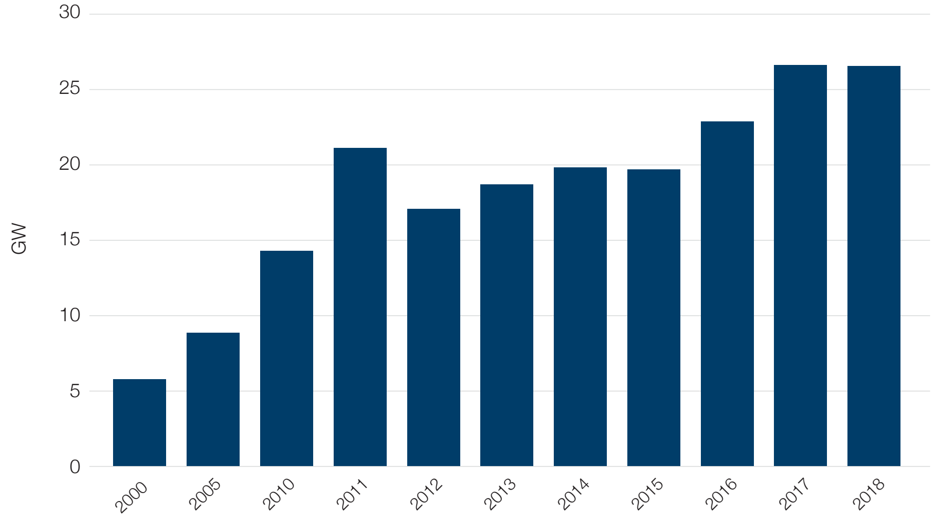
In 2016 and 2017, due to the macroeconomic recovery and the extremely high summer temperatures, the total electricity consumption in Jiangsu reached 545.9 TWh and 580.8 TWh respectively, which for both years represents an increase of over 6% compared to the previous year. In 2018, the total electricity consumption was 612.8 TWh, a 5.5% increase over 2019.

Figure 4. Total electricity consumption 2005–2018



Jiangsu lies in a transitional area between warm temperate and subtropical zones, having four distinct seasons with hot summers and cold winters. In summer, air conditioner use by residents and industry significantly increases the load, resulting in the largest daily peak-valley differences in July and August. As the load level increases year by year, the annual maximum peak-valley difference shows an upward trend.

Figure 5. Maximum and daily peak-valley difference rates



KEY CHALLENGES

Because Jiangsu is one of China's leading provinces in terms of economic development, its power demand will continue to grow in the future, presenting the power supply sector with several challenges:

- Firstly, the development of coal-fired power is restricted according to the principle of "coal reduction/equal coal", which means new coal-fired power plants cannot be built unless the equivalent capacity of existing coal-fired power plants is shut down. In the future, coal-fired power units that have low efficiency or which exceed their planned operational lifespan will also be shut down, meaning Jiangsu will gradually become even more dependent on imported power.
- Secondly, according to a power market capacity analysis with a 12% reserve for the province, the power demand gap of Jiangsu province will reach 27 GW in 2026. In order to address this shortfall, the province will need to increase the amount of power it imports from other provinces. However, Jiangsu's imported power will be unable to achieve this planned capacity due to the national coal power capacity reduction policy and limits on the supply end.
- Thirdly, the peak hours of electricity consumption and gas consumption overlap in the winter. The high demand for electricity puts more pressure on the system in terms of balancing and peaking. At the same time, the utilisation of gas turbine units is restricted due to factors such as high winter gas prices and the limited capacity of west-east gas transmission.

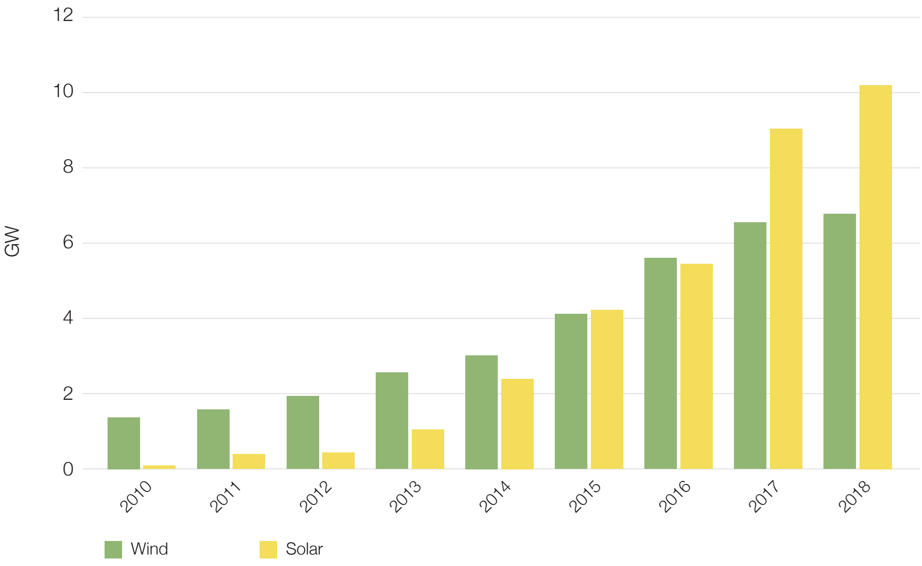


Figure 6. Wind and solar installation capacity

These factors mean that there will be a growing pressure on power supply in Jiangsu during peak times in summer and winter. In order to meet the demand, Jiangsu will mainly develop power sources including gas power, energy storage, nuclear power, pumped hydro storage and variable renewable energy sources. With the acceleration of the transition to low-carbon power generation, a large amount of RES is being connected to Jiangsu's power grid, which not only puts further pressure on power supply, but also poses a threat to the operational stability of the province's power system.

It is expected that the installed capacity of wind and solar power will further accelerate in the future

OUTLOOK FOR RENEWABLES

In recent years, the installed capacity of renewable energy in Jiangsu has been developing rapidly. From 2010 to 2018, the installed capacity of wind power has increased by 4.8 times, while the installed capacity of solar has increased from a very low base to over 10 GW. It is expected that the installed capacity of wind and solar power will further accelerate in the future.

In 2018, the installed capacity of solar and wind power in Jiangsu reached 10.2 GW and 6.8 GW respectively, meaning the total installed capacity had surpassed the 18 GW target in the 13th Five-Year Plan. It is estimated that in 2020 installed solar and wind power capacity will both reach 15 GW, surpassing the installation capacity target by 88% and 50% respectively. It is also expected that in 2025, the installed capacity of solar will reach 28.0 GW and the installed capacity of wind 22.0 GW.

According to research carried out by the Energy Research Institute of the National Development and Reform Commission (ERI), the theoretical maximum capacity for wind and solar power in Jiangsu is 95 GW for wind (including 20 GW of offshore wind power) and 90 GW for solar.

III. MODELLING THE OPTIMAL PATH TO SUSTAINABLE POWER SYSTEMS

ABOUT PLEXOS ENERGY SIMULATION SOFTWARE

PLEXOS by Energy Exemplar is a proven energy simulation software used by system operators, regulators and planners as well as utilities, traders, consultants and manufacturers. Wärtsilä uses PLEXOS globally for power system modelling, in both long-term capacity development optimisation and short-term dispatch optimisation. PLEXOS is designed to find the cost-optimal solution for each scenario based on the applied constraints.

OBJECTIVES FOR THE ANALYSIS

Power supply planning using modern modelling methods can help prepare for an optimal capacity mix with the lowest total system cost and optimal system dispatch and operation. In this study, a full-scale chronological dispatch model is used to obtain system dispatch curves under different scenarios in order to analyse the performance of different power sources.

SCENARIOS CONSIDERED

- **Scenario 1**: Baseline (low RES). Based on the existing development plan, adding 30 GW wind capacity and 30 GW solar capacity by 2030.
- **Scenario 2:** Moderate RES. Adding 50 GW wind capacity and 60 GW solar capacity by 2030 to meet the national emission target and non-fossil-fuel energy consumption target. The Energy Production and Consumption Revolution Strategy (2016–2030) proposes that by 2030, non-fossil energy power generation should account for approximately 50% of total power generation, while carbon dioxide emissions will peak around 2030 with efforts being made to reach the peak sooner.
- **Scenario 3:** High RES. Adding 85 GW wind capacity and 80 GW solar capacity by 2030, which, according to a study carried out by the Energy Research Institute, is considered to be the maximum renewable energy potential in Jiangsu province.

INPUTS FOR THE MODELLING

Power demand forecast

Driven by economic and social development, power demand in Jiangsu will continue to grow steadily. This study uses the prediction results of the State Grid Corporation of Jiangsu Economic Research Institute:

By 2025

- Jiangsu’s electricity consumption will reach 84 TWh, with an average annual growth of 4.4% from 2019 to 2025.
- The peak load will reach 159 GW, with an average annual growth of 6% from 2019 to 2025.

By 2030

- Jiangsu’s electricity consumption will reach 90.5 TWh, with an average annual growth of 1.5% from 2025 to 2030.
- The peak load will reach 175 GW, with an average annual growth of 2% from 2025 to 2030.

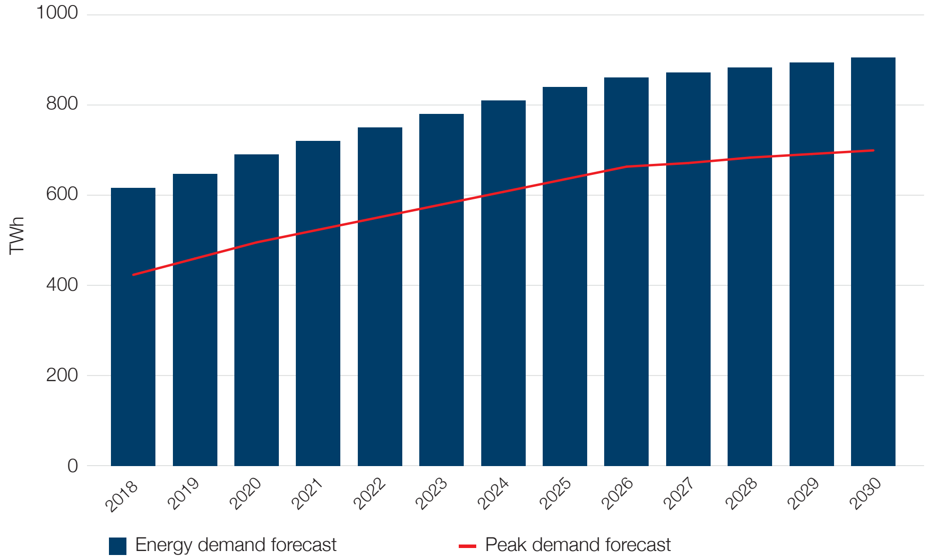


Figure 7. Power demand and peak demand forecasts

Annual load curve

In this study, an annual hourly load curve from 2019 to 2030 was generated and verified based on the 2018 load curve of Jiangsu power grid. The annual maximum load, load characteristics in different seasons, and daily peak-valley differences are all shown.

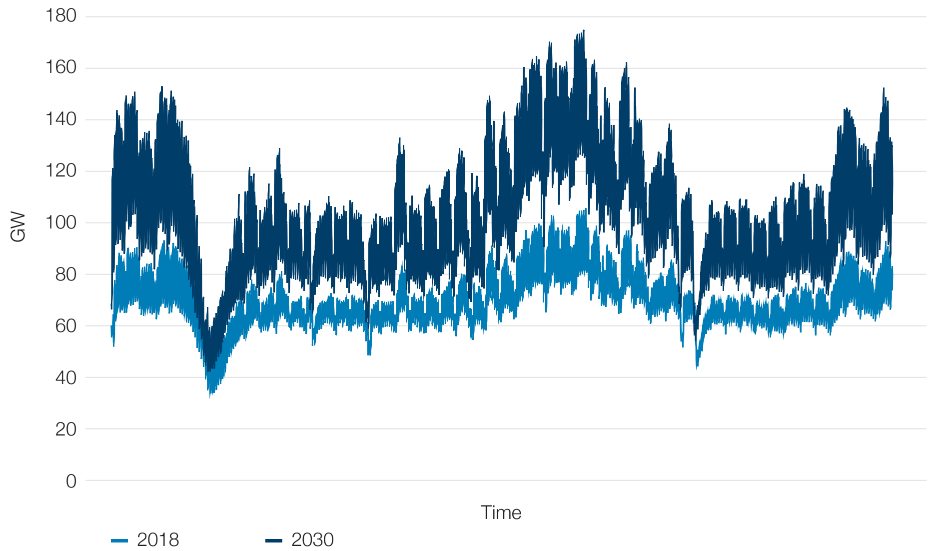


Figure 8. Annual load curve forecast (min interval: 1 hour)

Typical solar and wind profile

Typical annual wind and solar generation profiles for Jiangsu in China were used in the modelling.

Existing power plant parameters

Based on the conditions of the existing power units in Jiangsu, the main parameters of the thermal power units used in this study are shown in table 1 below.

Table 1. Existing power plant parameters (source: Jiangsu grid)

Parameter	Unit	Coal					Gas	
		1,000 MW	600 MW	300 MW	Yangcheng	Independent	Peaking	CHP
Max. capacity	MW	26,000	23,620	25,973	2,800	6,000	5,486	9,503
Min. stable factor	%	40	40	60	70	80	0	70
Heat rate 1	G/MWh	9.0	9.3	10.0	9.3	10.6	10.4	10.4
Heat rate 2	G/MWh	8.2	8.5	9.1	8.5	9.7	9.4	9.4
Ramp-up charge	CNY/MW	132						
Ramp-down charge	CNY/MW	132						
FO&M charge	CNY/kW/year	265						
VO&M charge	CNY/MWh	66						
Maintenance rate	%	13						
Forced outage rate	%	13						
Mean time to repair	h	336						

Comparison of candidate technologies

The study compared different candidate technologies that can provide power system flexibility. Some of the main parameters are shown in table 2 below.

Table 2. Comparison of different candidate technologies

Parameter	Unit	Existing coal	Convert coal	CCGT	OCGT	ICE
Efficiency	%	36.6	37	55	33	46
Start-up cost	CNY/MW/start	927	861	397	265	0
Start-up time	min	180	60	45	10	2
Investment cost	CNY/kW	0	397	2979	3310	3641
Lifetime	years	20				

Learning curve of RES and batteries

According to Bloomberg New Energy Finance (BNEF) research, the cost of renewables and battery storage solutions will continue to drop both in China and around the world, making RES more competitive and increasing demand for flexibility.

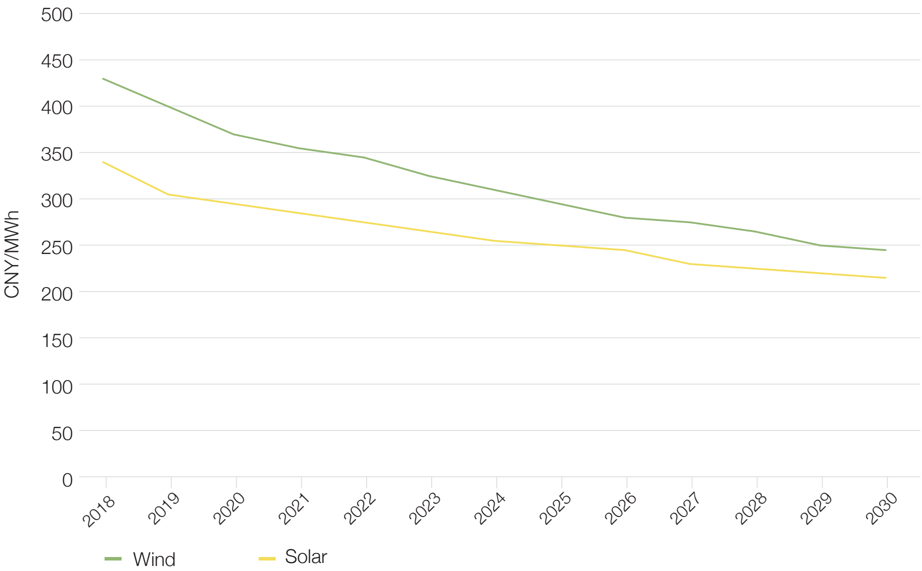


Figure 10.1. RES pricing forecast (source: BNEF 2019)

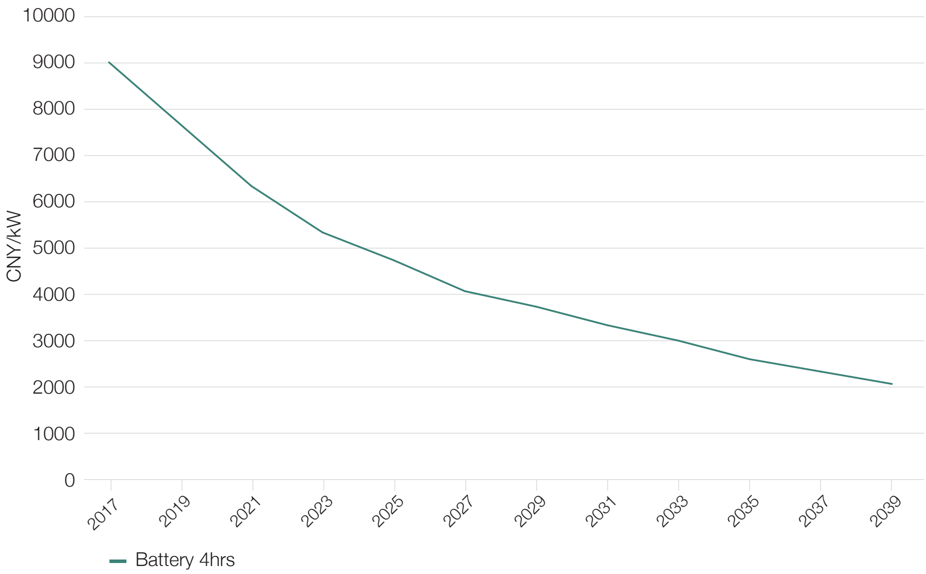
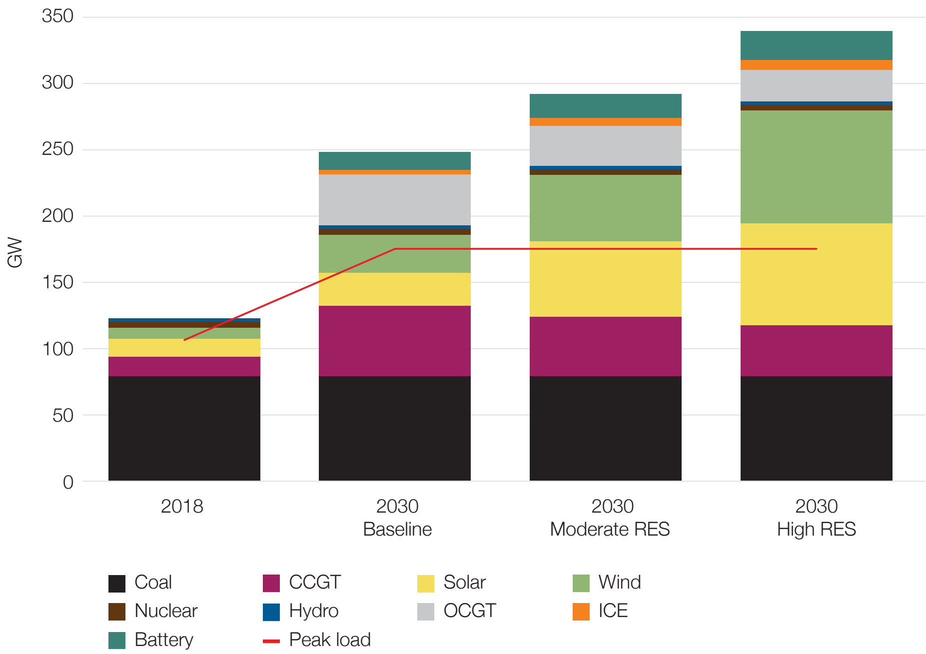


Figure 10.2. Batteries pricing forecast (source: BNEF 2019)

IV. POWER SYSTEM MODELLING RESULTS

Figure 11. Power system modelling results



BASELINE (LOW RES):

Total installed capacity will reach 248 GW in 2030.

Share of renewables

Wind plus solar is 54 GW, accounting for 21.8% of the total installed capacity.

MODERATE RES

Total installed capacity will reach 292 GW in 2030.

Share of renewables

Wind plus solar is 102.3 GW, accounting for 35% of the total installed capacity.

HIGH RES

Total installed capacity will reach 340 GW in 2030.

Share of renewables

Wind plus solar is 162.4 GW, accounting for 47.8% of the total installed capacity.

COMPARISON OF THE THREE SCENARIOS

The figure below presents a comparison of the total installed capacity and structure of different types of power systems in Jiangsu in 2030 under the different scenarios.

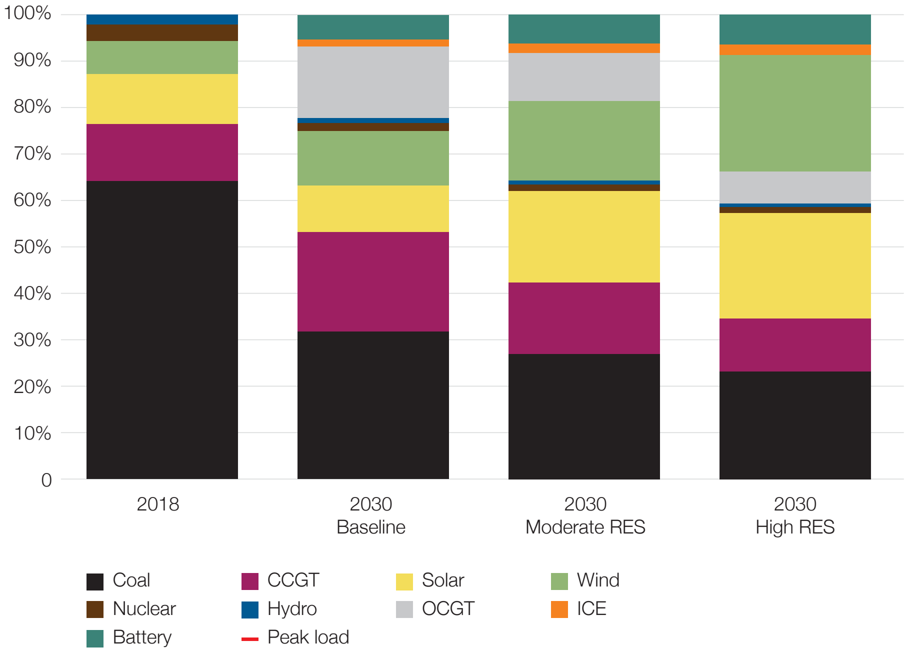


Figure 12. Comparison of total installed capacity and structure of different types of power systems

In terms of fossil energy, as installed coal-fired power capacity remains unchanged, the proportion will continue to decline from more than 60% in 2018 to about 20–30% in 2030. The proportion of installed natural gas (including non-peaking gas turbines, peaking gas turbines and flexible ICE power plants) varies greatly between the scenarios. In terms of non-fossil energy, nuclear power and pumped hydro storage capacity will not change, while wind and solar installed capacity will increase significantly according to the modelling scenarios. The proportion of installed non-fossil power capacity reaches 30% in the baseline scenario, 45% in the moderate RES scenario and 56% in the high RES scenario compared to 23.6% in 2018.

V. RECOMMENDATIONS AND BENEFITS

RECOMMENDATIONS

In the context of large-scale integration of renewable energy, the future demand for electricity and the need for reliable system operation can be met by:

- Building and integrating large-scale renewable energy capacity into the power system to enable a lower system cost and more sustainable energy generation
- Maintaining, and increasing the flexibility of, remaining coal-fired plants in line with the reduction/equal-coal policy
- Adding flexible power generation solutions for renewables integration and balancing, including efficient gas-fired ICE power plants and battery energy storage
- Adding required peaking capacity, including gas-fired ICE power plants, gas turbines and battery energy storage

Power generation from non-fossil fuels by type, 2019–2030

By 2030 the installed capacity of flexible power sources including peaking gas turbines, pumped hydro storage power stations and ICE power plants will reach 58 GW in the baseline scenario, 56.9 GW in the moderate RES scenario and 55.7 GW in the high RES scenario, accounting for 23, 19 and 16% of the total installed capacity respectively.

Share of renewables in the future system

According to the results of the load forecast, Jiangsu's electricity consumption will reach 905 TWh in 2030. The proportion of imported electricity will remain at around 26%, and nuclear power generation will account for about 3%. The proportion of wind and solar power generation will increase from 4% in 2018 to 11%, 20% and 30% in 2030 under the baseline, moderate and high RES scenarios respectively. The proportion of fossil fuel power generation will decline from 72% in 2018 to 60% in the baseline scenario, 51% in the moderate RES scenario and 41% in the high RES scenario by 2030. Figures 13.1–13.3 below show the power generation structure for each scenario for the period 2018–2030.

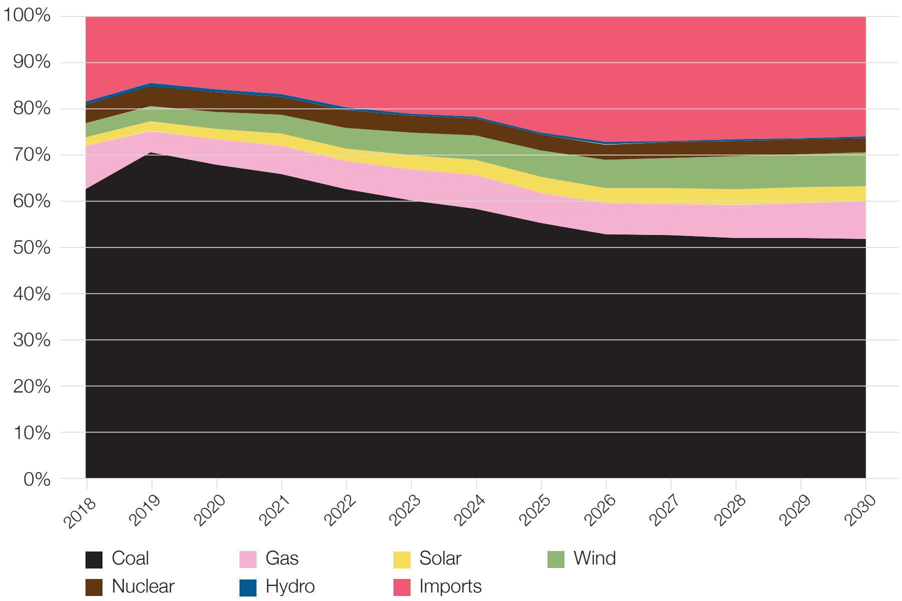


Figure 13.1. Power generation structure for baseline scenario, 2018–2030

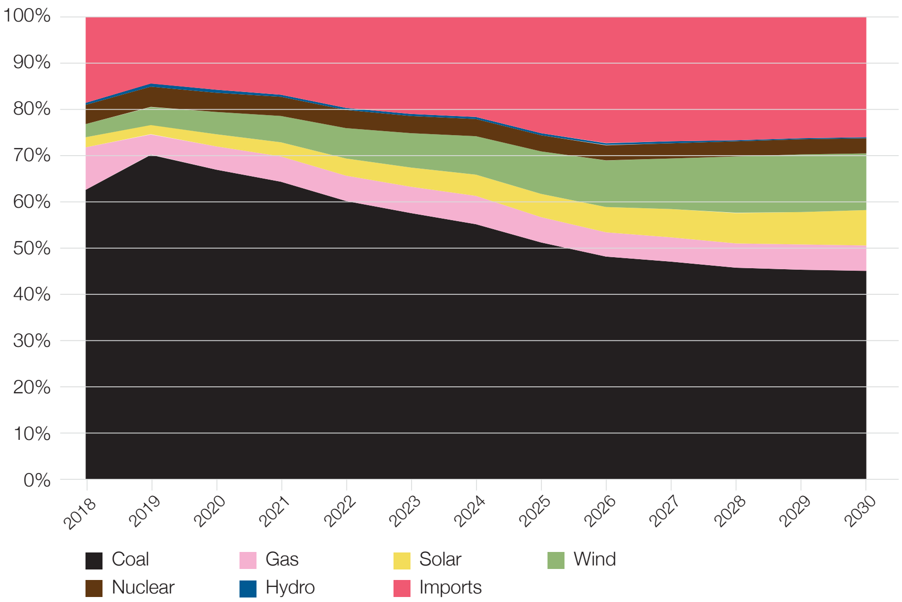
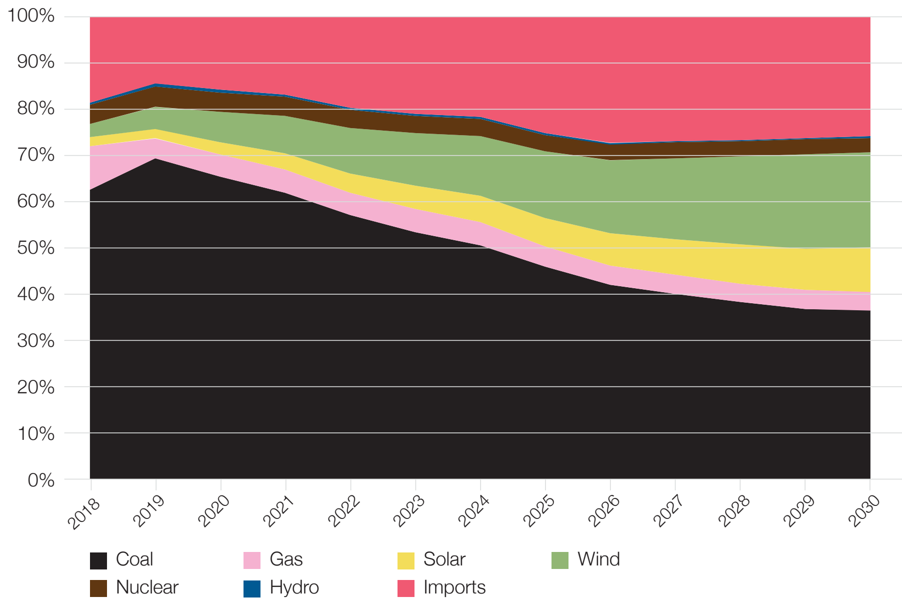


Figure 13.2. Power generation structure for moderate RES scenario, 2018–2030

Figure 13.2. Power generation structure for high RES scenario, 2018–2030



Electric Power Planning & Engineering Institute (EPPEI)

Established in 1954 as a national consultation institution, EPPEI mainly provides services to the Chinese government, financial institutions, the power industry and relevant enterprises. EPPEI is qualified by the National Development and Reform Commission (NDRC) to conduct the evaluation of electric power projects across China.

EPPEI has issued the following policy suggestions:

- Undertake flexibility retrofits of existing coal-fired power units and take advantage of peak regulation potential with minimal marginal cost.
- Explore the construction of various types of natural gas power station for peak regulation including introducing flexible ICE power plants to supplement traditional gas turbine power stations.
- Strengthen inter-provincial and inter-regional power interconnection to increase clean energy transmission. Optimise the power transmission curve with improved short-term RES prediction to strengthen peak adaptability.
- Unlock the potential of demand-side response resources to mitigate the challenge presented by large-scale integration of RES in the power system.
- Accelerate spot market construction to ensure the priority of renewable energy in a competitive market to generate power and unleash the potential of system flexibility through floating electricity prices.
- Improve the auxiliary services market mechanism and fully mobilise power generation enterprises to participate in providing flexibility with reasonable payback.

BENEFITS

Significant economic benefits can be achieved through the comprehensive application of peaking power supplies and large-scale renewable energy. The average power cost based on the power generation system is shown in figure 14 below.

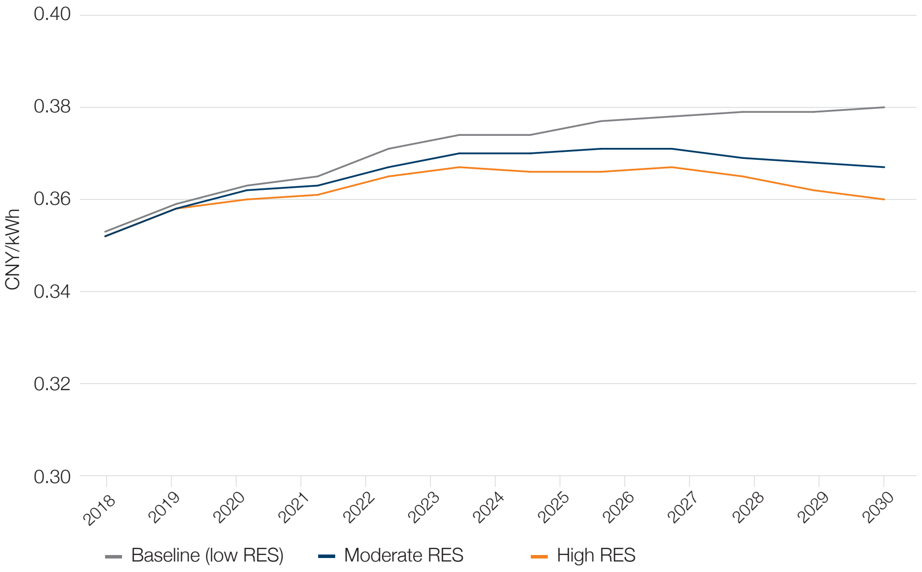


Figure 14. Average power cost based on the power generation system (CNY/kWh)

By 2030, because of the large-scale use of cheap renewable energy, the high RES scenario shows an average power cost that is 2% lower than in the baseline (low RES) scenario. If the comparison is made year on year, the accumulated cost of the high RES scenario is CNY 64 billion lower than in the baseline scenario.

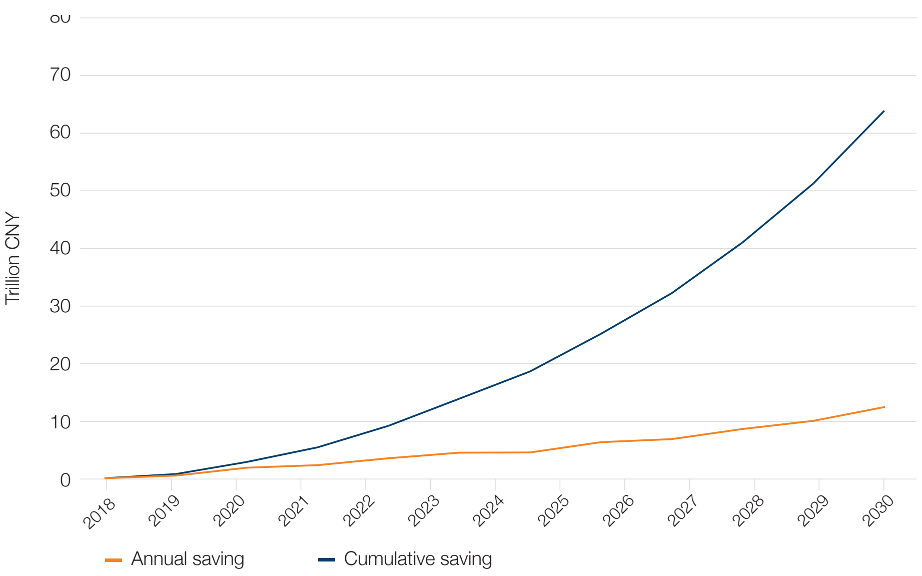
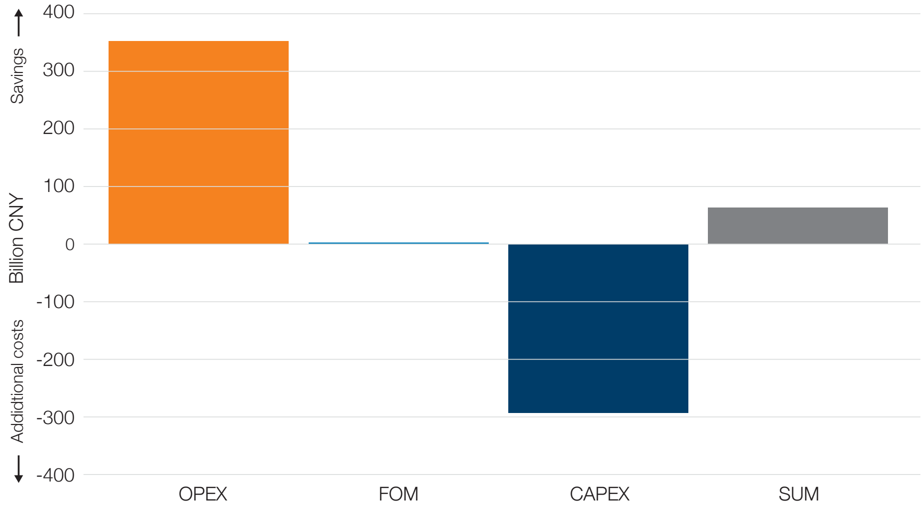


Figure 15. Annual and cumulative savings based on the high RES scenario

Reduced levelised cost of electricity (LCOE)

To further analyse the cost difference between the high RES and baseline (low RES) scenarios, the following cost savings are achieved. These costs are divided into operational costs (OPEX, consisting mainly of fuel costs and variable costs) fixed operations and maintenance costs (FOM), and capital costs (CAPEX).

Figure 16. Savings based on the high RES scenario (billion CNY)



Investment expenditures increase significantly with the deployment of large-scale renewable energy. However, due to the lower marginal cost of renewable energy and the need for much less fossil fuel, the operational expenses decrease, and the flexibility of power supply improves the system's ability to adjust, resulting in lower operating costs. This means that between 2020 and 2030 the total cost of the power generation system can be reduced by nearly CNY 64 billion, bringing considerable economic benefit.

Reduced emissions and fossil fuel power generation

The graphs below show the year-on-year comparison of total carbon emissions and carbon emission intensity under the three different scenarios.

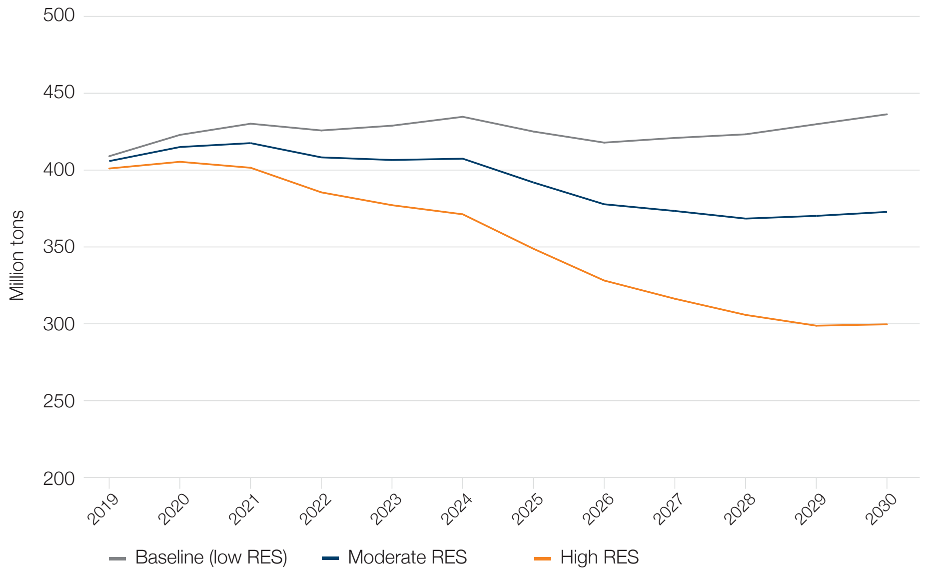


Figure 17.1. Year-on-year comparison of total carbon emissions (million tons) for the three scenarios

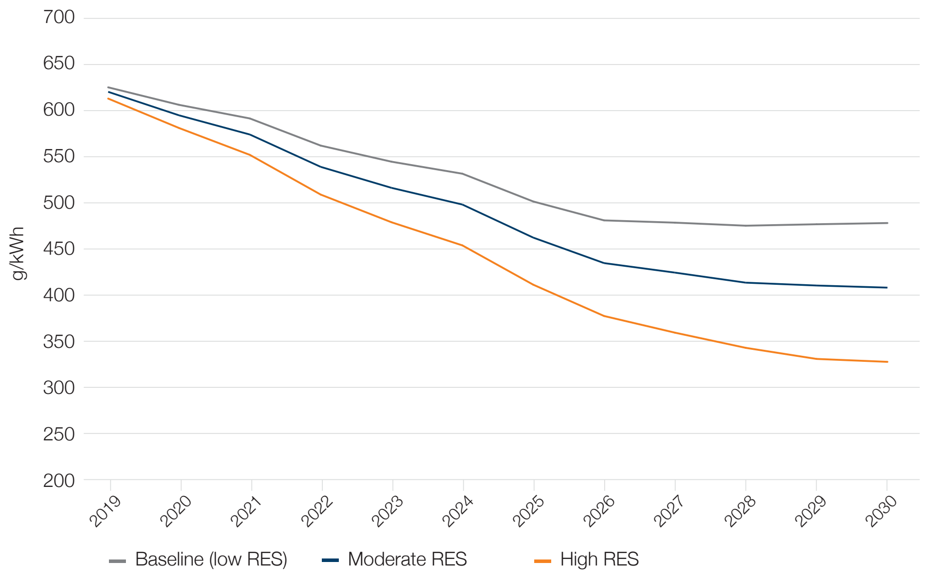


Figure 17.2. Year-on-year comparison of carbon emission intensity (g/kWh) for the three scenarios

Compared with the baseline (low RES) scenario, total carbon emissions are reduced by more than 25% and carbon emission intensity is reduced by more than 45% under the high RES scenario.

In general, by 2030, with the increase in the proportion of renewable energy, the amount of power generated by fossil energy will decrease accordingly. Figures 18.1 and 18.2 below are a schematic diagrams of the change in installed power generation capacity of fossil fuels.

Figure 18.1. Changes in fossil energy power generation, gas (TWh)

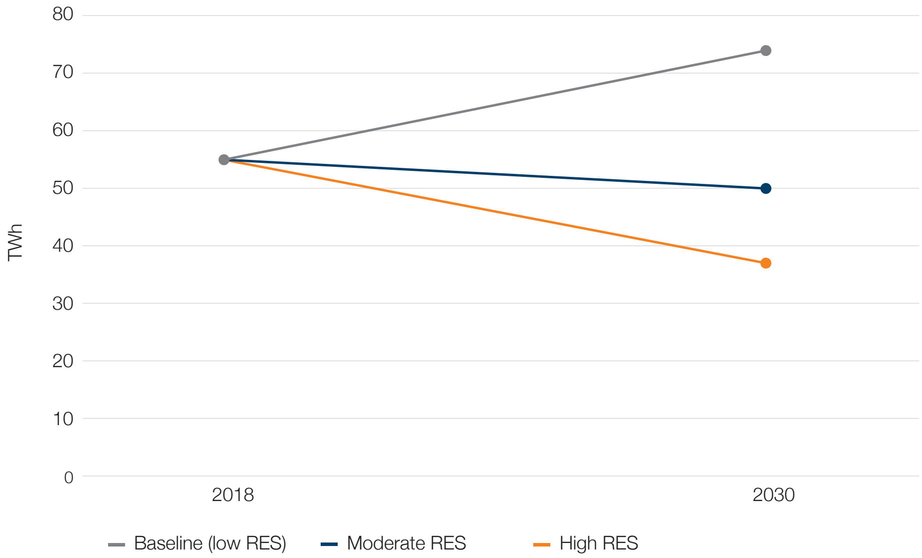
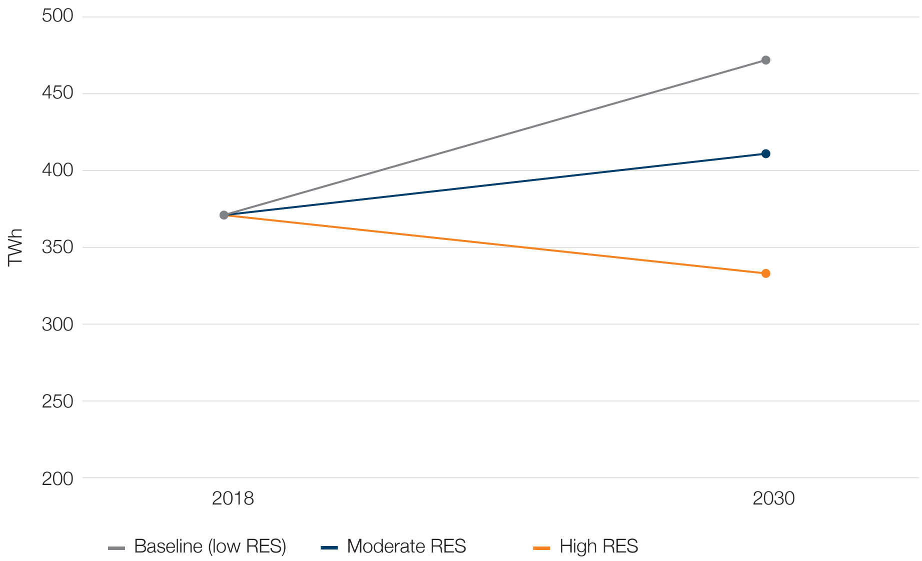


Figure 18.2. Changes in fossil energy power generation, coal (TWh)



Under the three scenarios, coal power will remain the main component of the power generation structure and continue to play a key role in guaranteeing base load. When the proportion of renewable energy increases, natural gas power will play a larger role in peaking, so the utilisation hours of gas power will be reduced as they move from baseload and mid-merit towards more peaking applications.

By 2030, the annual utilisation hours of coal-fired generation units will be 4,224 hours in the high RES scenario, 5,215 hours in the moderate RES scenario and 5,995 hours in the baseline (low RES) scenario. The utilisation hours of the gas generation units will be 641 hours, 817 hours and 1,085 hours respectively.

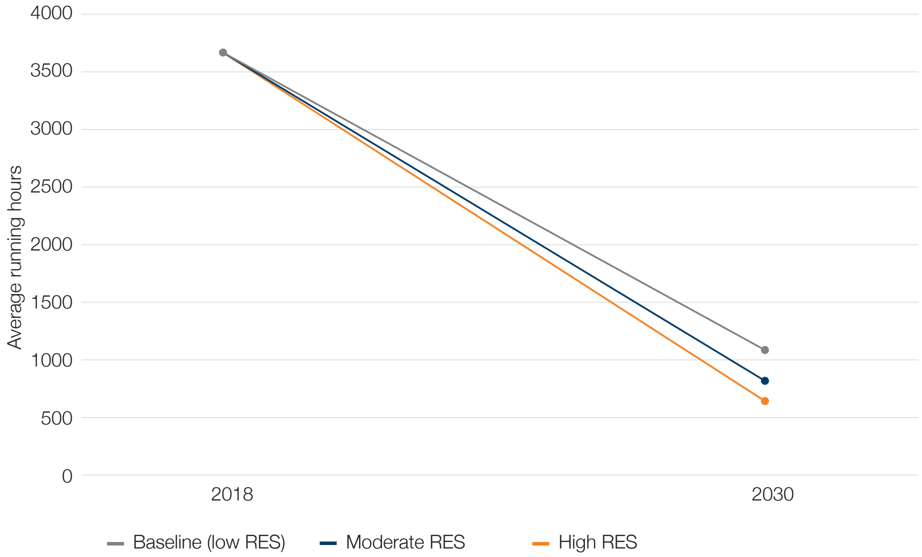


Figure 19.1. Change in annual utilisation hours, gas

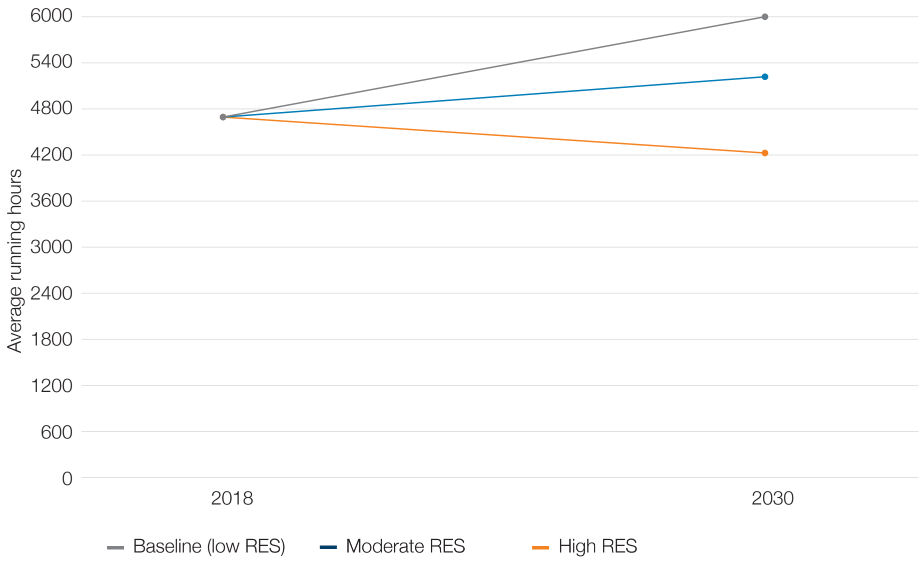


Figure 19.2. Change in annual utilisation hours, coal

VI. CONCLUSION

Power demand in Jiangsu province can be effectively satisfied and system reliability achieved by:

- scaling up renewable energy ambitions
- building and integrating large-scale renewable energy capacity into the power system
- maintaining the existing coal power capacity with optional flexibility retrofits
- integrating multiple flexible power solutions such as gas internal combustion engines, and battery energy storage

With the increase of renewable energy, the amount of fossil power generation decreases accordingly. Coal power will be used for baseload while gas power will mainly provide peak regulation, meaning the utilisation hours of gas power will be reduced as they move from baseload and mid-merit towards more peaking applications.

Although coal-fired plants, combined cycle gas turbines and ICE power plants can provide flexibility in varying degrees, the fast response of ICE plants (within 2 minutes) offer superior balancing and short-term rapid response for variable wind and solar.

Increasing renewable energy integration will contribute to significantly lower system costs. In the high RES scenario non-fossil generation will reach nearly 50%, carbon emissions will peak before 2030 and carbon intensity will drop by about 45%.

BENEFITS OF THE HIGH RES SCENARIO IN 2030 WITH FULL UTILISATION OF RENEWABLES

CNY 64 BILLION ACCUMULATED SAVINGS

45% REDUCTION IN CARBON EMISSIONS INTENSITY

1,771 HOUR REDUCTION IN UTILISATION HOURS OF COAL FIRED GENERATING UNITS

04/2021 / Tenfour

WÄRTSILÄ ENERGY IN BRIEF

Wärtsilä Energy leads the transition towards a 100% renewable energy future. We help our customers unlock the value of the energy transition by optimising their energy systems and future-proofing their assets. Our offering comprises flexible power plants, energy management systems, and storage, as well as lifecycle services that ensure increased efficiency and guaranteed performance. Wärtsilä has delivered 72 GW of power plant capacity in 180 countries around the world.