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国网能源研究院有限公司
STATE GRID ENERGY RESEARCH INSTITUTE CO., LTD.

Research on Carbon Emission Reduction Pathways in China's Power Industry

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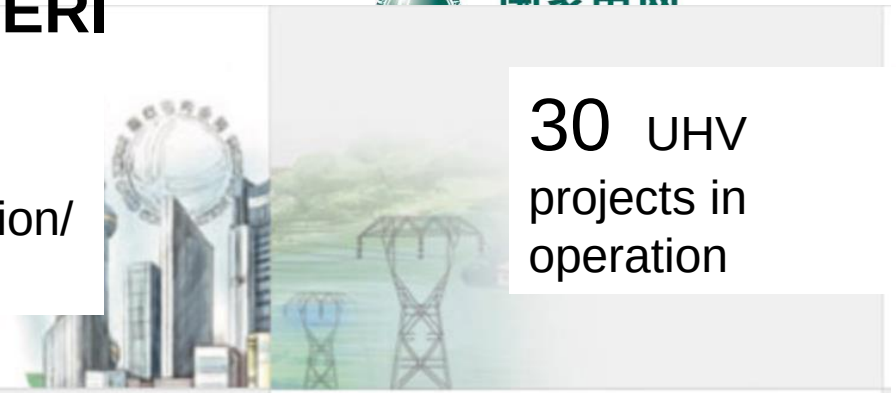
Introduction of SGCC and SGERI

State Grid Corporation of China

- Investment, construction, and operation of power grids
- Propose “Carbon Peak and Carbon Neutrality Action Plan of SGCC” in 2021 and 2022

State Grid Energy Research Institute

- Think tank of SGCC
- Carrying out national level researches on energy transition
- 11 research areas:



26 Province/ Autonomous Region/ Municipality

30 UHV projects in operation

Service area accounts for 88% of China’ land area

3rd place on Fortune Global 500

Providing energy service for over 1.1 billion people

1st Place on China's most valuable brand for 8 consecutive years

Carbon peaking and neutrality; new-type power system; Energy strategy and planning; Power system planning; Power Market; Digitalization of power sector; Enterprise strategic planning; Enterprise operation and finance; Enterprise operations; Corporate governance and risk control; Brand Culture and Social Responsibility

Backgrounds

- China proposed carbon peaking and carbon neutrality goals at the 75th United Nations General Assembly in 2020
- From an overall perspective, it requires combined efforts from different sectors to achieve the transition to a carbon-neutral society.
- Power sector – 40% of carbon emission; 90% of renewable energy are utilized by generation.
- Electrification transfers carbon emission from other sectors to power sector.
- Carbon peaking and reduction paths in power/industry/transportation/buildings… sectors should be coordinated and optimized at a national level considering 'remaining carbon budget', to **achieve overall carbon peaking and carbon neutral more economically.**

Considering different amount of carbon cap, three power sector development paths through 2020 to 2060 are simulated using power system planning model and several key issues are discussed.

- **Scenarios:** generation portfolio, power exchange, carbon emission and reduction, transition cost
- **Key issues:** future of coal-fired generation, renewable energy development and utilization, future power grid，…

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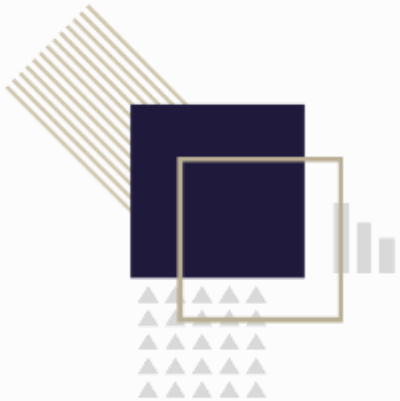


(1) Scenario Design

Ultra low emission scenario (ULE)

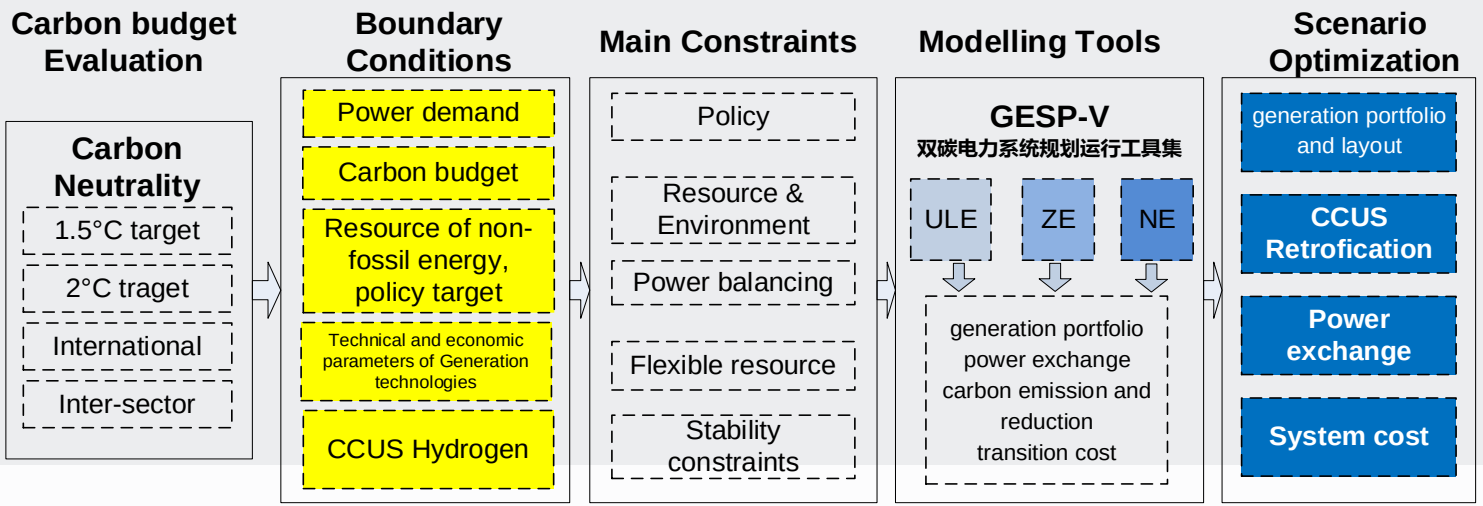
- 0.8 billion tons of carbon dioxide emissions cap in 2060
- 130 billion tons of cumulative carbon dioxide emissions cap from 2020-2060

Zero emission scenario (ZE) - mainly discussed in this presentation

- 0 of carbon dioxide emissions cap in 2060
- 100 billion tons of cumulative carbon dioxide emissions cap from 2020-2060

Negative emission scenario (NE)

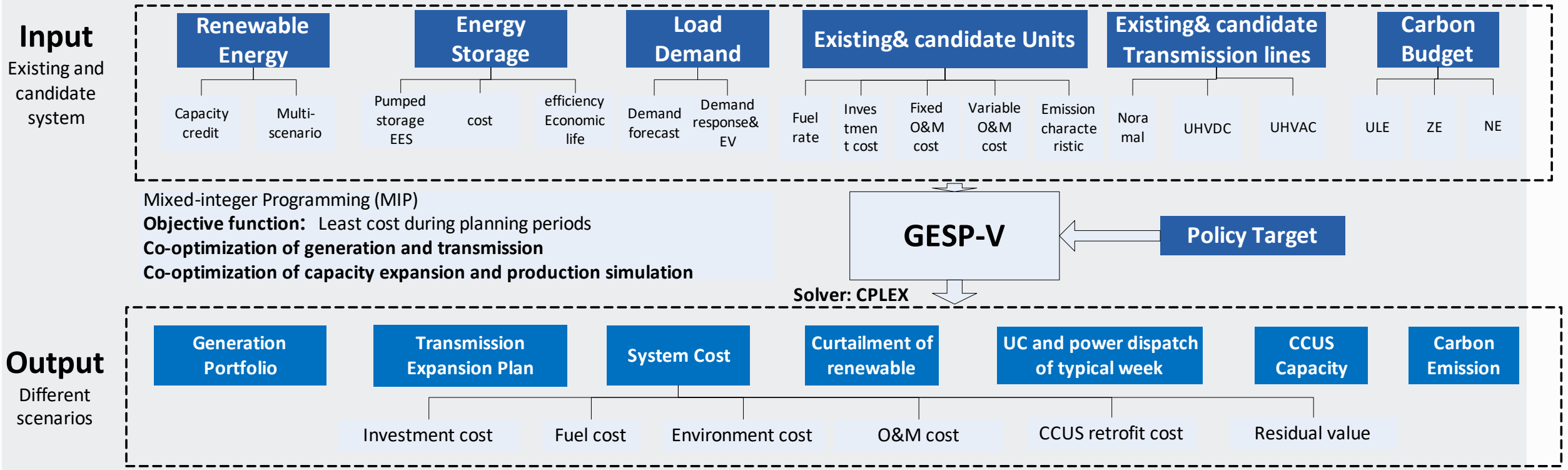
- -0.6 billion tons of carbon dioxide emissions cap in 2060
- 78 billion tons of cumulative carbon dioxide emissions cap from 2020-2060



(2) Modeling Tools

GESP – least cost capacity expansion model developed by SGERI

- provide system planners with an optimal solution for generation and transmission expansion and related detailed technical and economic information of the power system



(3) Model Assumptions

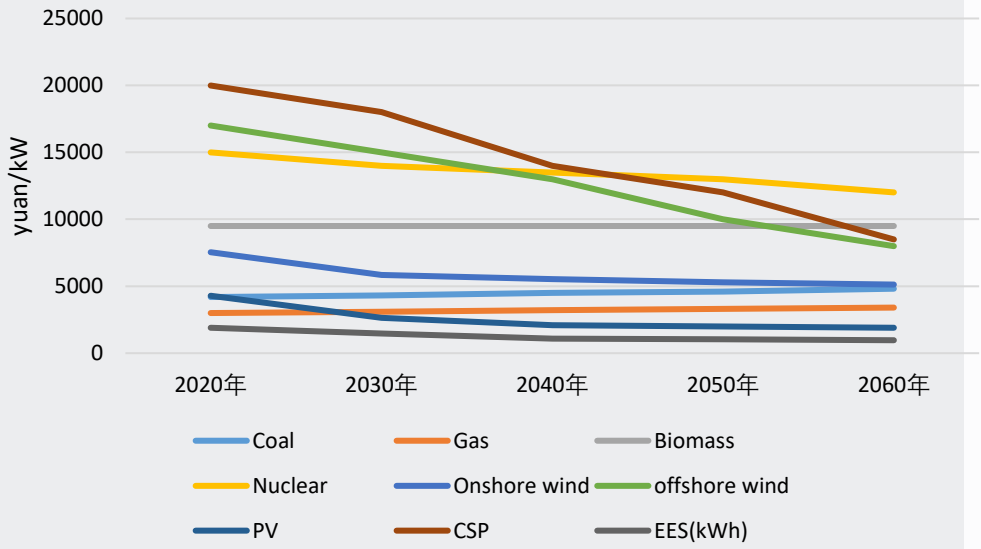
- **Spatial resolution:** 7 balancing areas
- **Investment period:** 5-year investment period from 2020-2060
- **Time Slice:** Weekly UC for each month of each typical year; hourly time resolution
- **Transmission:** transmission between balancing areas
- **Generation technology:** onshore/offshore wind power, PV, CSP, nuclear*, hydro*, coal-fired, gas-fired, pumped storage*, EES, CCS

*** Predetermined**

- **Electricity demand:** 12.3 trillion kWh in 2030

  15.7 trillion kWh in 2060

Balancing areas

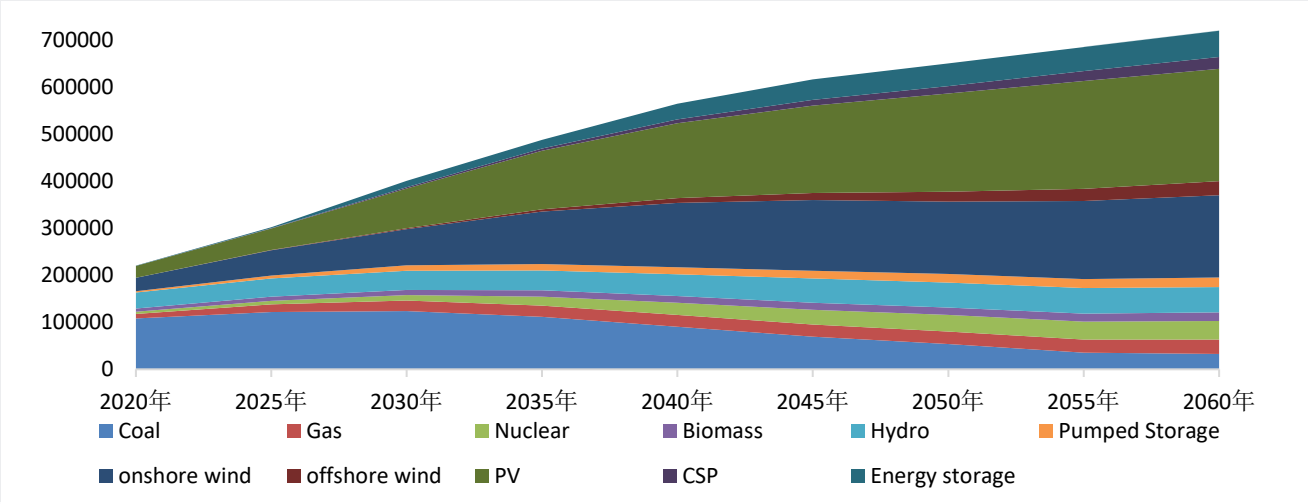


Investment cost assumptions

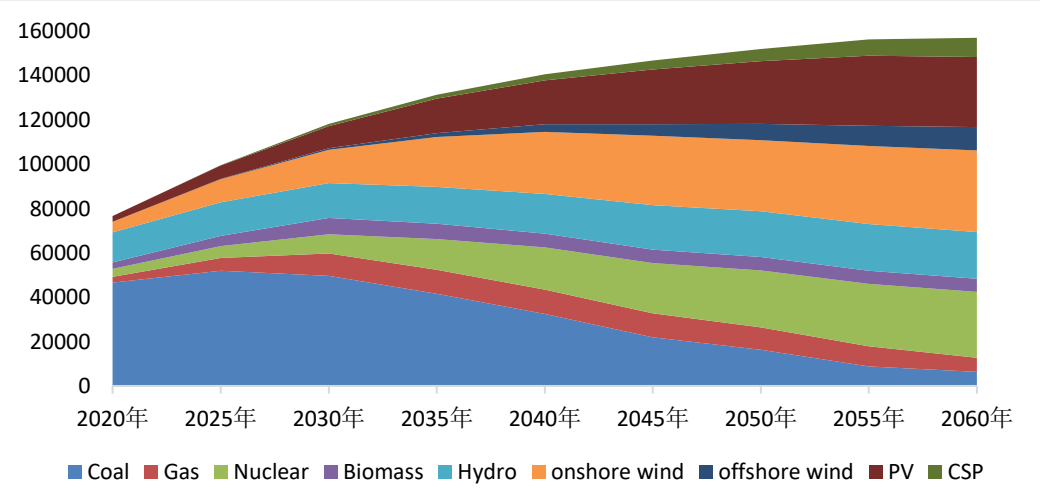
(4) Scenario Analysis

Zero emission scenario (ZE)

- **Total installed capacity –** 4060GW in 2030, 7190GW in 2060
- **Share of non-hydro renewable generation (wind/solar/biomass)**
  - **Capacity -** 45% in 2030, 69% in 2060 (27% in 2020) 65%(ULE) 74%(NE)
  - **Generation –** 28% in 2030, 60% in 2060 (12% in 2020) 53%(ULE) 65%(NE)
- **Share of coal-fired generation**
  - **Capacity -** 31% in 2030, 5% in 2060 (49% in 2020)
  - **Generation –** 42% in 2030, 4% in 2060 (61% in 2020)



Generation capacity portfolio through 2020 - 2060

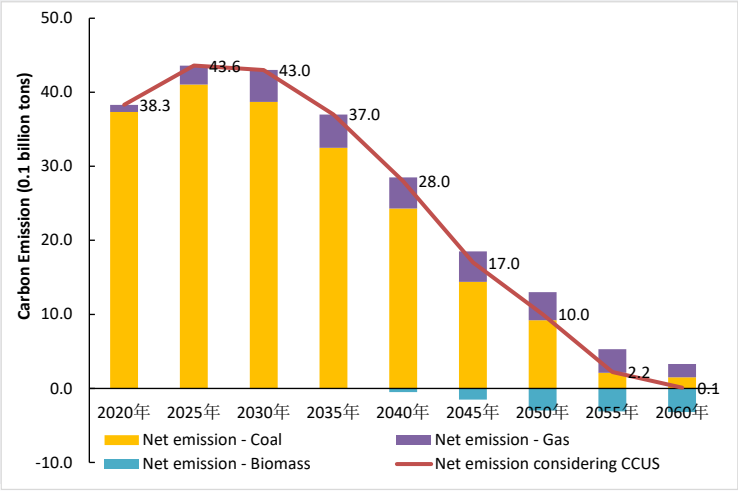


Generation portfolio through 2020 - 2060

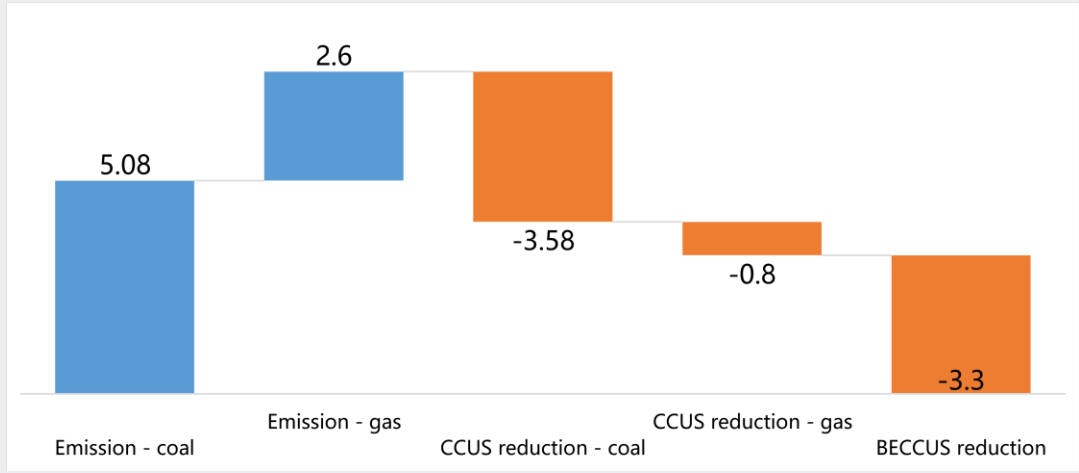
(4) Scenario Analysis

Three phase of power sector decarbonization :

- **Carbon peaking phase：** power sector emission peaks around 2030, later than other sectors. Peak CO2 emissions – 4.7 billion tons, accounting for 49% of energy combustion emissions.
- **Ultra-low emission phase ：** platform period after emission peaking(2030-2035), and fall to less than 1 billion tons/yr in 2050,showing slow and then fast decreases.
- **Zero emission phase：** Emissions falls to 0 in 2060. The net carbon emissions of coal-fired, gas-fired and biomass generation are 0.15, 0.18 and -0.33 billion tons.



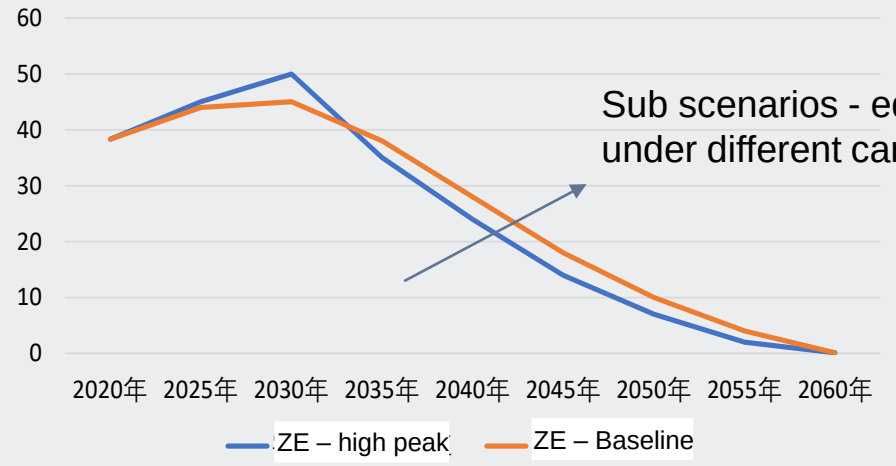
Carbon emission of power sector from 2020- 2060 (ZE)



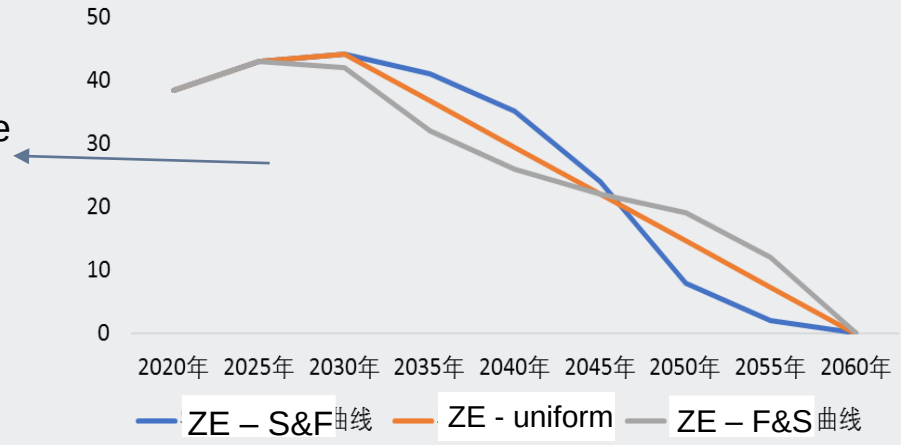
Carbon emission and capture of power sector in 2060 (ZE)

(4) Scenario Analysis

- **With the same carbon budget, ‘slow and then fast decrease’ trend is more economical and technically feasible than ‘fast then slow decrease’ and ‘uniform decrease trend’.**
  - Under sub-scenarios with different decrease trend, the accelerated renewable generation and early large-scale application of CCS would increase system cost by 5% - 9%.



Carbon emission of power sector with higher and lower peak



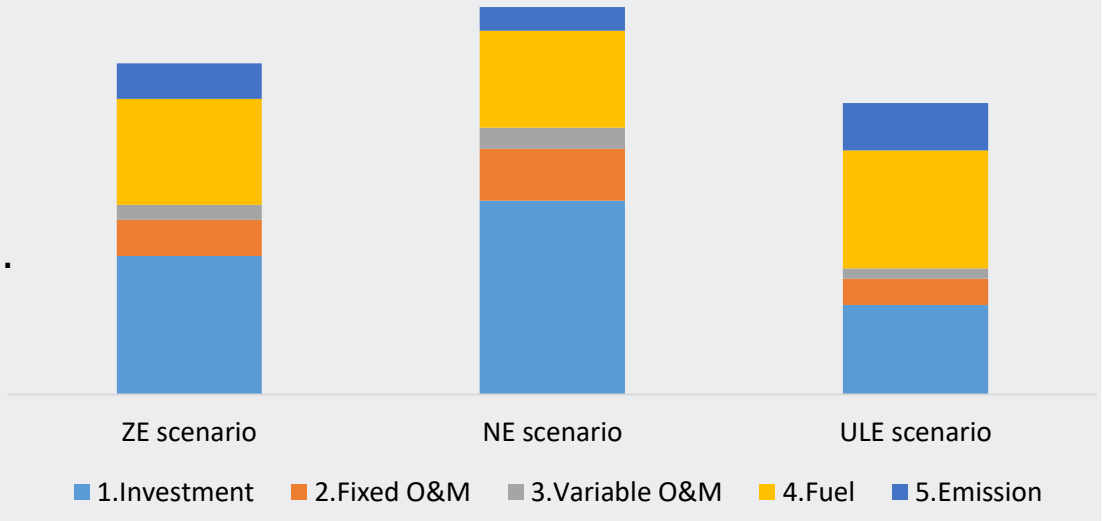
Carbon emissions of power sector with different decrease trends

(4) Scenario Analysis

- **Transformation cost varies under different scenarios**
  - Different carbon reduction paths put forward different demands on the development of low-carbon technology and non-fossil energy.
  - Higher level of decarbonization means higher transformation cost.
  - The development paths of power sector should coordinate with other sectors and achieve carbon-neutrality in a most economical and socially-beneficial way.

- **ZE –** Total system cost of the planning periods (2020-2060) is 57.3 trillion yuan*.
- **NE** – Higher renewable penetration and more BECCS brins more investment in flexible resource, transmission, and de-carbon technology, cost increase by 17% than ZE.
- **ULE** – Lowest system cost, cost decrease by 12% than ZE.

*present value with 4% discount rate, gird cost inside balancing area not considered



System cost under different scenarios

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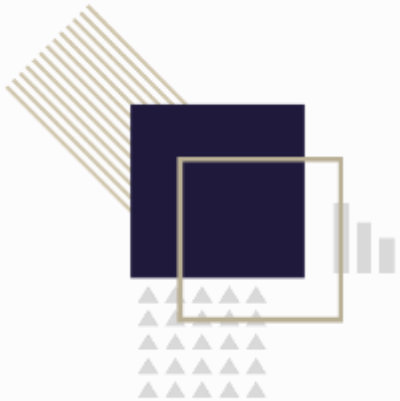
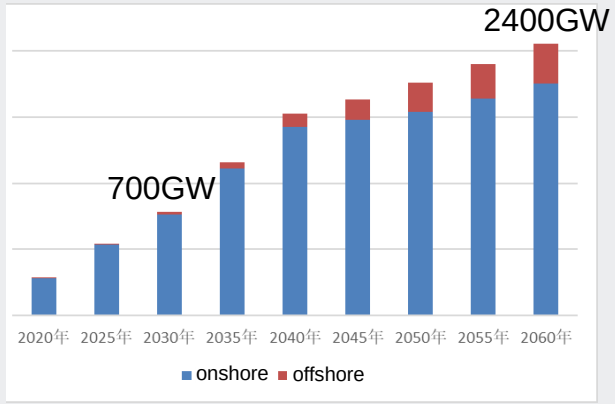
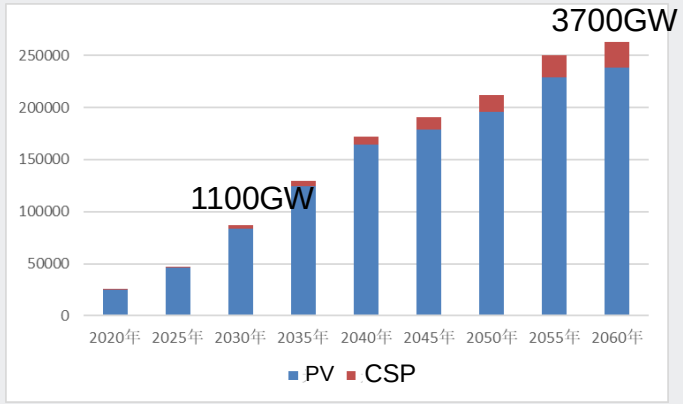


(1) Development and utilization of Renewable energy

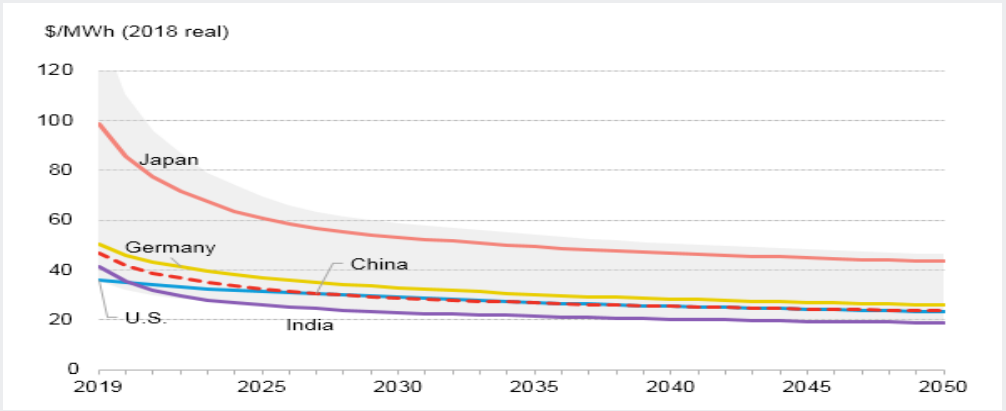
- **Carbon peak and neutrality calls for stronger resolution in renewable energy**
  - **Rich resource potential –** hydro, nuclear and biomass are limited by site selection and resources, the **technical potential of wind and solar generation are more than 3500GW and 5000GW in China.**
  - **Rapid cost decrease -** The costs for solar photovoltaics, wind, and battery storage have dropped markedly since 2010, and are expecting more decrease in the next decades.
  - **Complete industrial chain and abundant production capacity –** China's PV module and wind turbine production capacity have reached 150GW and 60GW per year.
  - **The long industrial chain can drive the vigorous development of economy**, new technologies and new businesses modes such as energy storage and integrated energy.



Wind generation capacity from 2020-2060



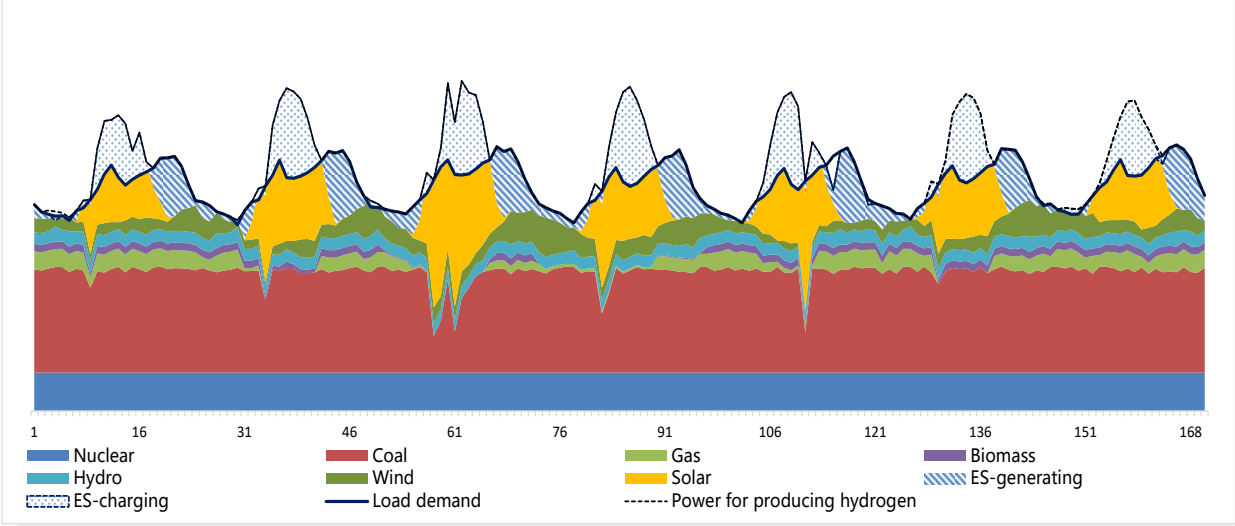
Solar generation capacity from 2020-2060



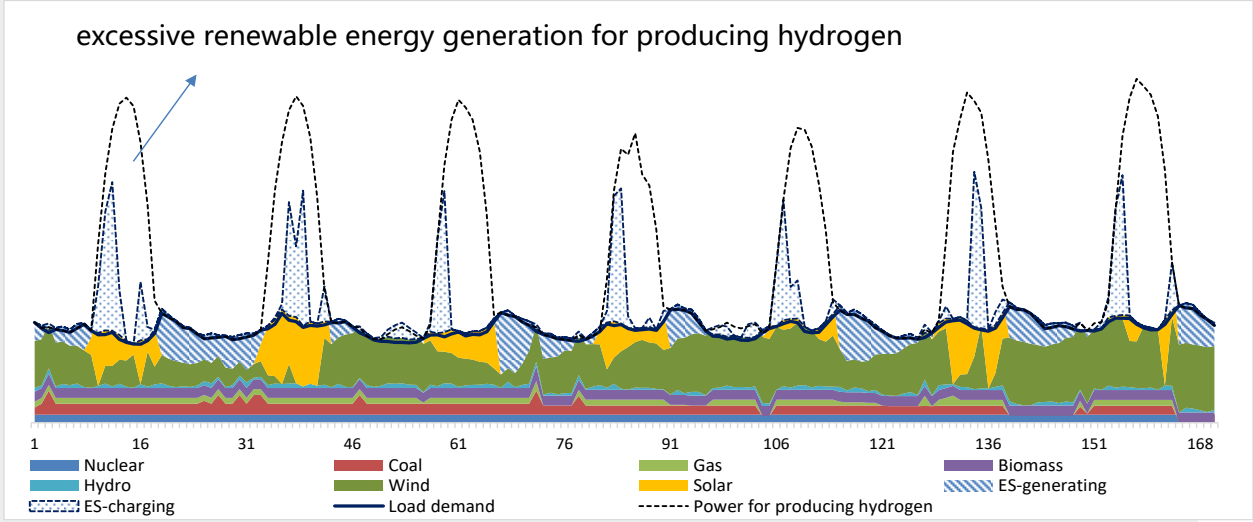
LCOE projection of wind/solar generation

(1) Development and utilization of Renewable energy (wind/solar)

- **High renewable penetration system requires more flexible resources**
  - Thermal generation flexible retrofit, energy storage, demand response, power transmission….
  - Reasonable curtailment can significantly reduce system cost.
- **With ultra-high penetration, it is difficult to make full use of renewable energy relying solely on power system, hydrogen production from renewable energy is a feasible way for the diversified utilization of new energy**
  - renewable energy generation for producing hydrogen is expected to reach 2 trillion kWh.



Power system production simulation in 2030

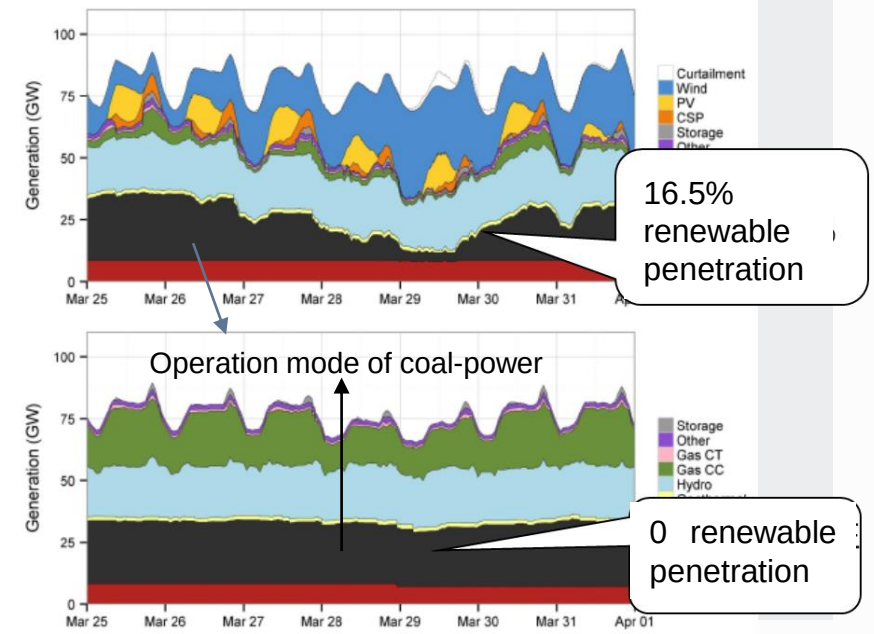


Power system production simulation in 2060

(2) Future of coal-fired generation in China

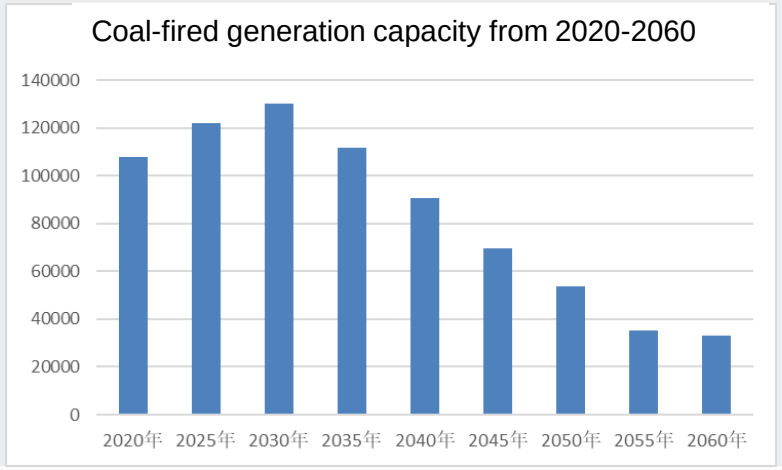
Redefine the role of coal-fired generation is a most crucial issue to China's carbon peaking and neutrality.

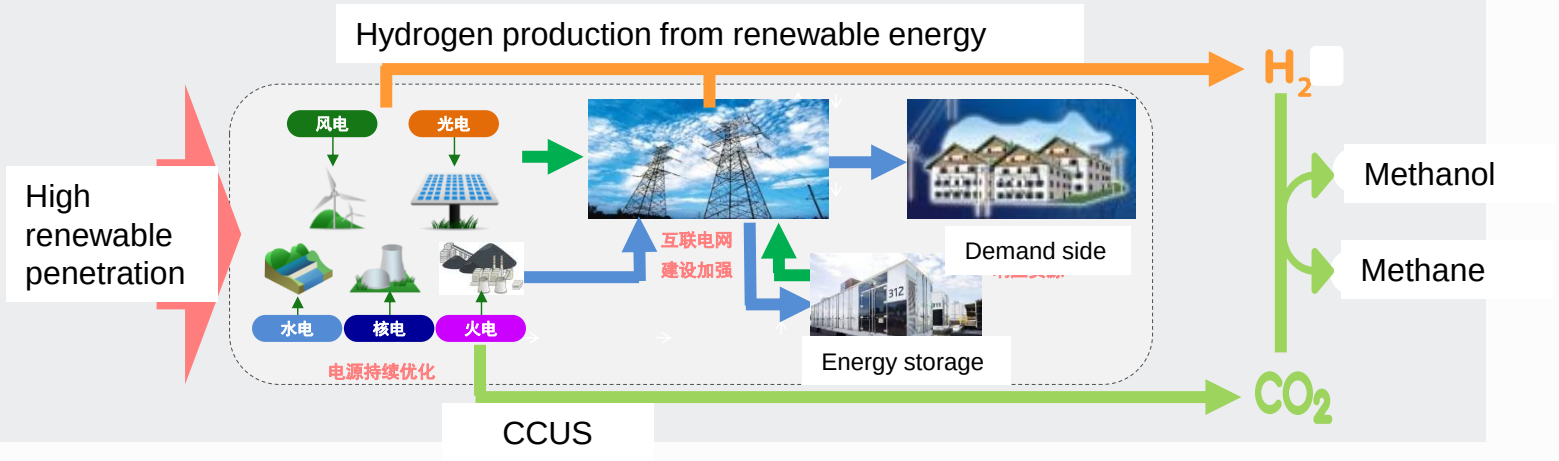
- Coal-fired generation accounts for 58% of China's power supply in 2022 and is the single biggest emission source. **Gradually quit and transformation of coal-fired generation.**
- Meanwhile, with fast-growing power demand, **radical coal-fired generation retirement plan may bring power supply security problems**.
- Coal-fired generation and renewable energy are not simply a substitute for each other.
  - From the perspective of capacity, coal power decreases and renewable increases.
  - From the perspective of role in the system, **coal power is transforming to flexible resource. In short-term,** with flexible retrofit, it can facilitate integration of renewable energy, while providing reserve and secure power supply. **In the long term,** with CCUS retrofit, the system can still hold certain amount of coal-fired generation.



(2) Future of coal-fired generation

- **Installed capacity of coal-fired generation gradually increase to 13GW-14GW by 2030.**
- **Coal generation peaks earlier and falls more rapidly than installed capacity.**
  - Capacity would decrease after 2030 and fall to 400-800GW by 2060.
  - Generation peaks in 2030 to 6 trillion kWh and fall to 0.4-0.9 trillion kWh in 2060, account for about 4% of total generation.
  - Capacity factor decrease to 0.24 (with CCUS) and 0.15 (without CCUS) by 2060.
- **The scale of CCUS continues to expand rapidly after 2030, which helps coal-fired generation become a part of 'carbon cycle economy'.**





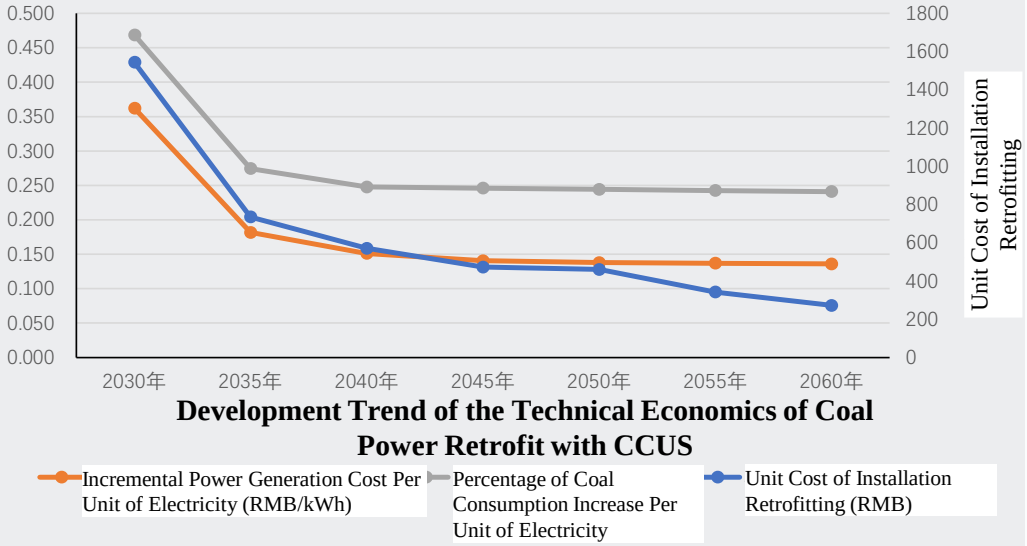
(3) Key Generation and Power Sector Technologies

- **Energy storage, especially long-term energy storage, will be key to the green and low-carbon transition of the power system**
  - Pumped storage: 160 GW in 2030, 400GW in 2060
  - Other energy storage: 150 GW in 2030, 800GW in 2060.

- **Hydrogen energy is an important technology for deep decarbonization in the terminal sectors**
  - new hot spot of competition in the energy industry.
  - Currently, China’s accounts for 1/3 of global hydrogen consumption.
  - Proportion of green hydrogen will reach 1.5-2% in 2030, 15% in 2060.

(3) Key Generation and Power Sector Technologies

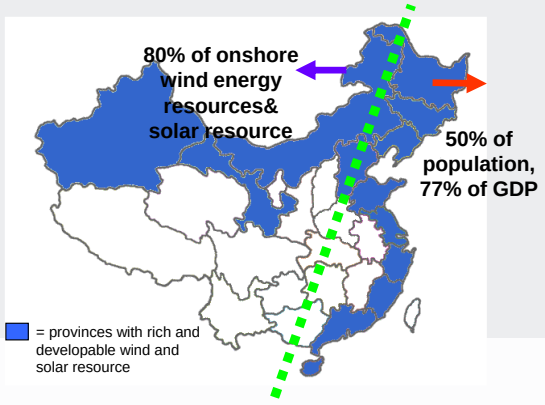
- **CCUS technologies will profoundly influence the way of coal phase-out and coal power transformation**
  - More than 500GW of fossil energy generation requires to deploy CCUS in 2060
  - 500GW - 1300GW installed capacity of wind/solar generation and more than 1000GW energy storage will be required if CCUS cannot achieve technical breakthroughs

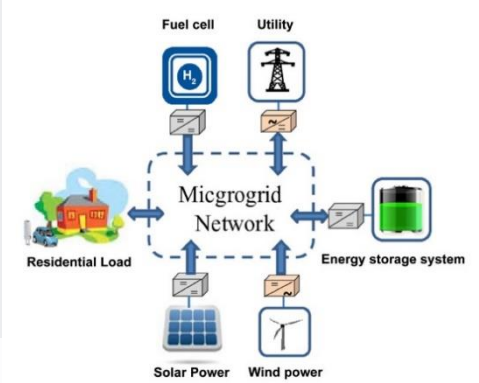


- **Role of hydro and nuclear power**
  - Southwest region: future development of hydropower in China. 420GW in 2030, 500GW in 2060.
  - Nuclear energy is a stable and a clean energy source with the lowest carbon emissions in the life cycle
  - Coastal Nuclear Power Station Site is limited. 110GW in 2030, 200GW in 2060

(4) Power grid transformation

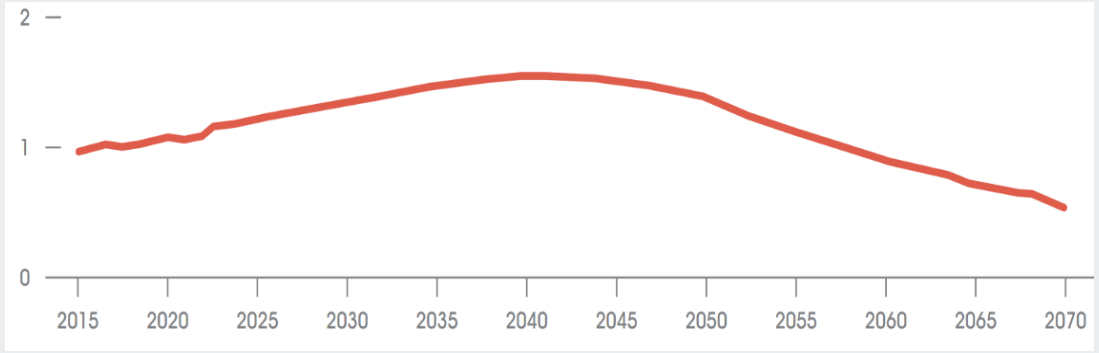
- **Power grid will transform to a new form of integrated development of large-scale cross region power delivering and micro power grids.**
  - More self-balanced microgrids would occur to better utilize distributed renewable energy.
  - Due to the mismatch between resource and demand, reallocating clean energy from national and regional scope is still a crucial role for power grid under carbon neutrality pledge.
  - Cross-region transmission capacity will exceed 350GW in 2030.
- **Upgrade to digital and intelligent power grid.**
  - The integration of digital technology and the power system is deeper and deeper.
  - The integration of new digital infrastructure and power infrastructure would bring a innovative and diverse developing pattern for power grid.



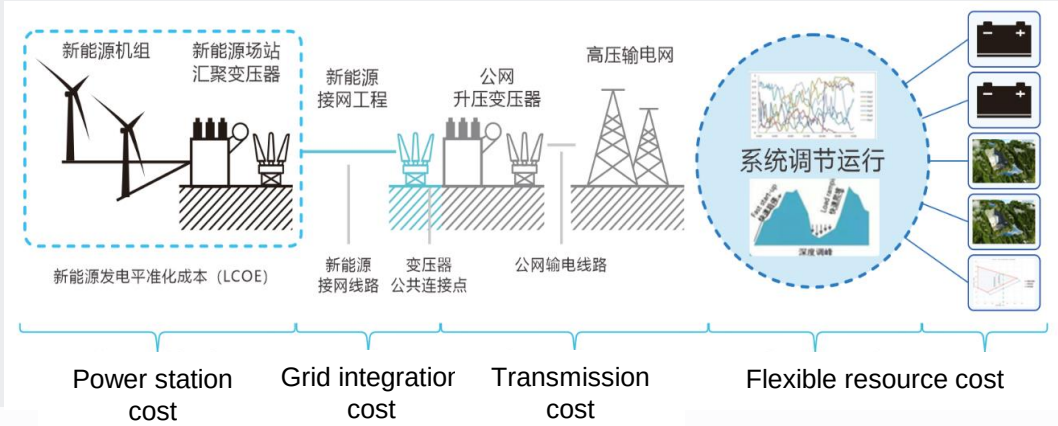


(5) Power Supply Cost

- **Power supply cost may increase rapidly in the next few years**
  - When renewable generation penetration exceeds 15%, the integration cost (excluding the cost of the power station) would increase drastically. **It is estimated that in 2025 and 2030, integration cost would reach 0.2 yuan and 0.35 yuan per kWh.**
  - The German electricity price rose from 19 Euro cents/kWh in 2006 to 30 Euro cents/kWh in 2019, with an average annual increase of 3.6%. The renewable energy surcharge increased from 0.88 Euro cents/kWh to 6.4 Euro cents/kWh, with an average annual increase over 16.5%.
- **Power supply cost would decrease in the long run**



China's power supply cost projection (the cost in 2020 is set to 1)



System cost of renewable energy

- Coping with climate change is an international consensus that calls for all parties to work together.
- The long-term energy sector transformation in China is a highly complex issue that needs to integrate multidisciplinary, multi-sectoral and multi-territorial efforts under industry-university-research institute collaboration.
- SGERI is willing to strengthen communication and cooperation with all parties to make contributions.

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Thanks!

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