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:
   - 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

26 Province/Autonomous Region/Municipality
30 UHV projects in operation
Service area accounts for 88% of China’s land area
Providing energy service for over 1.1 billion people
3rd place on Fortune Global 500
1st Place on China’s most valuable brand for 8 consecutive years
**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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01. Power Sector Transition Scenarios

02. Several Key issues
(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.

Input
Existing and candidate system

Output
Different scenarios

Policy Target

GESPV-V

Mixed-integer Programming (MIP)

Objective function: Least cost during planning periods
Co-optimization of generation and transmission
Co-optimization of capacity expansion and production simulation

Solver: CPLEX
(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
(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)
(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.
(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%.
(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
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01. Power Sector Transition Scenarios
02. Several Key Issues
(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.
(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.

16.5% renewable penetration

0 renewable penetration

Operation mode of coal-power
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)](image)
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.
Thanks!

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