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Power System Transition: A Carbon Perspective

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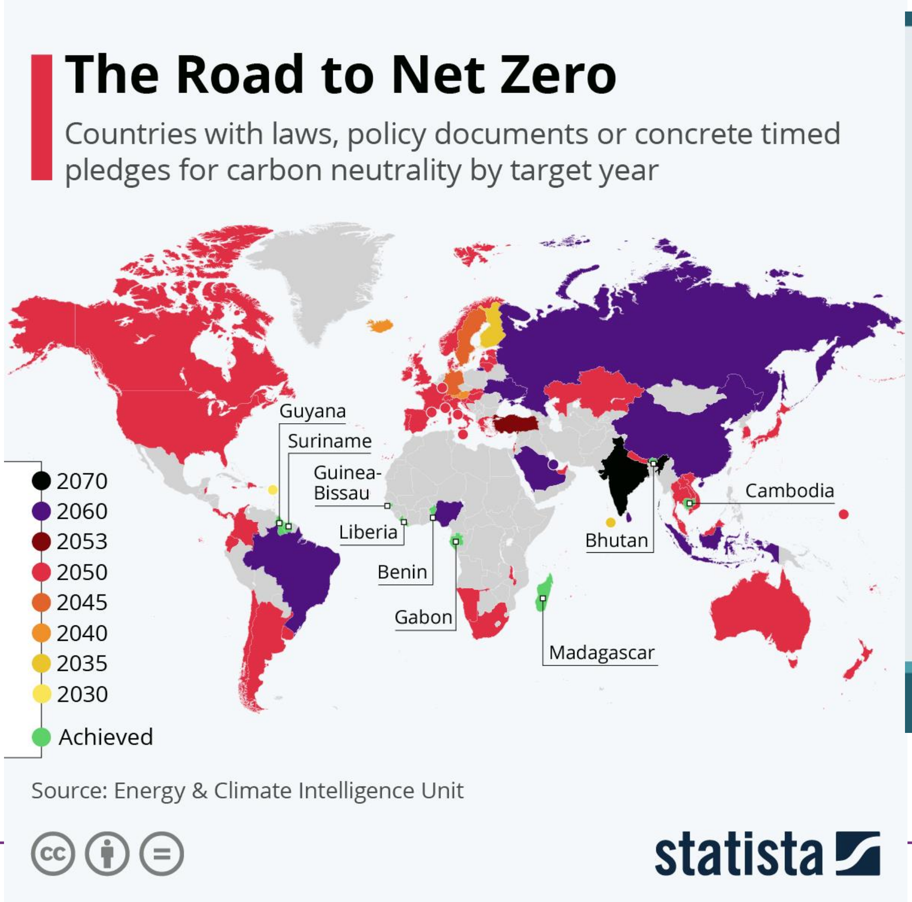
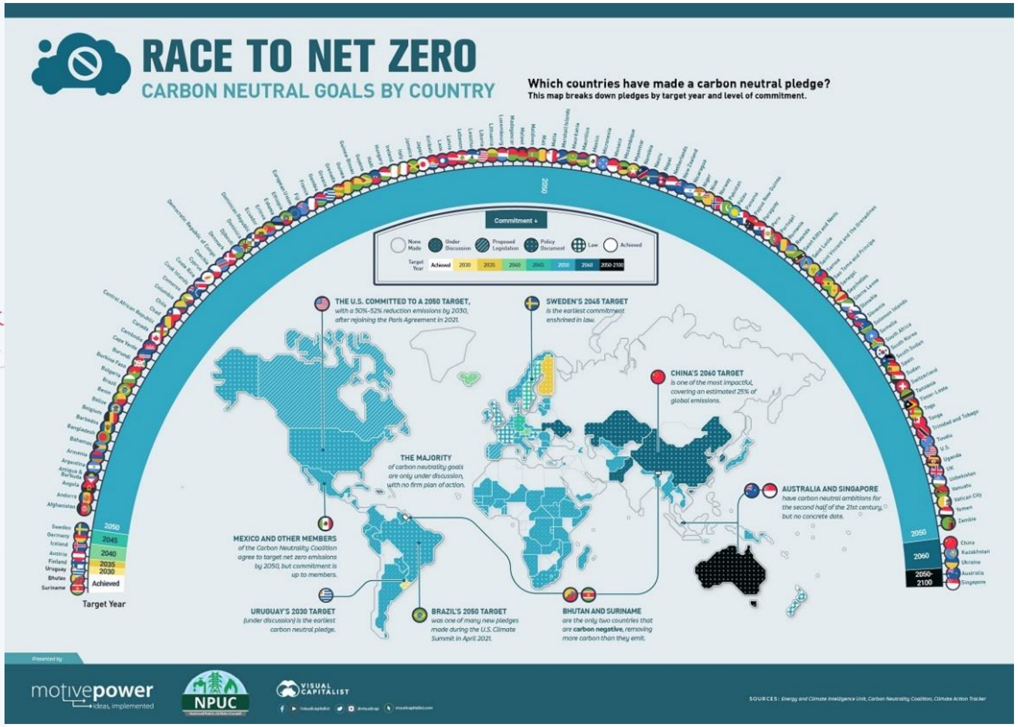
1. Response to Climate Change: Energy Transition

Carbon Neutrality Targets in Different Countries

- Most of the developed countries attempt to achieve carbon neutrality target **in 2050**. A small number of countries set 2060 as their carbon neutrality target year.
- Due to **energy strategies and climate change issues**, achieving decarbonization of the entire energy system is becoming the consensus of countries around the world.





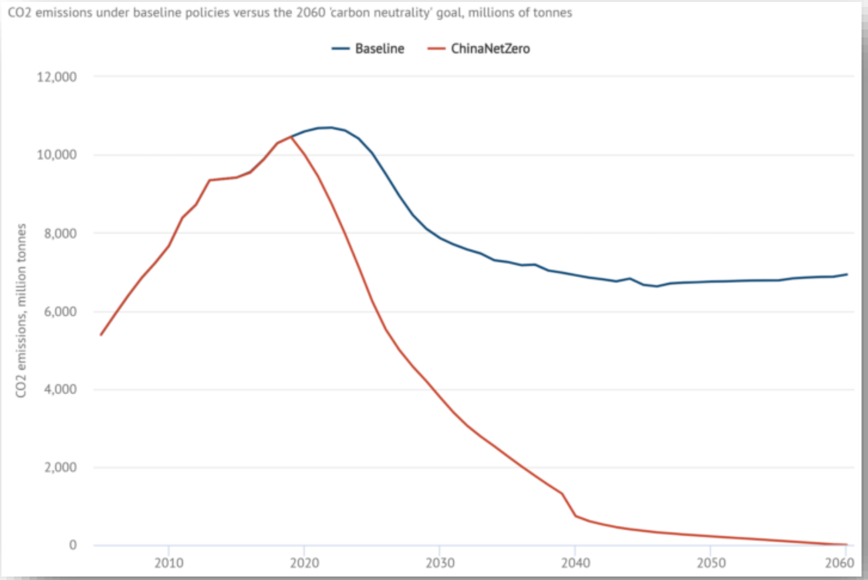
Source: https://www.visualcapitalist.com/race-to-net-zero-carbon-neutral-goals-by-country/

IEEE Ad Hoc Committee to Coordinate IEEE’s Response to Climate Change

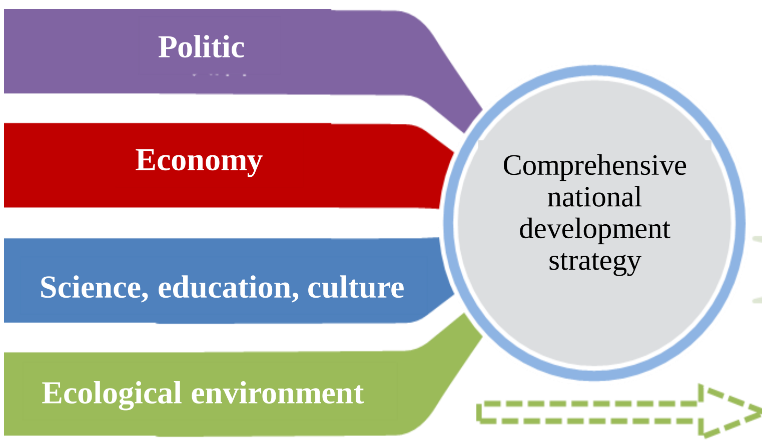
Established on	1 January 2022
Established by	2022 IEEE President Ray Liu
Scope	The 2022 IEEE Ad Hoc Committee to Coordinate IEEE’s Response to Climate Change is chartered to develop a cross-IEEE strategy to synchronize and guide IEEE’s response to changes in the Global Climate. This committee should make specific recommendations on strategic initiatives for IEEE, including but not limited to: ● Identifying ongoing efforts across IEEE ● Recommending new programs and activities for IEEE ● Developing a policy statement on climate change for consideration by the IEEE Board ● Identifying key external partners for cooperative efforts ● Ensuring that our response to climate change is substantial, appropriate, and properly engages IEEE, its members, and the larger technical professions.

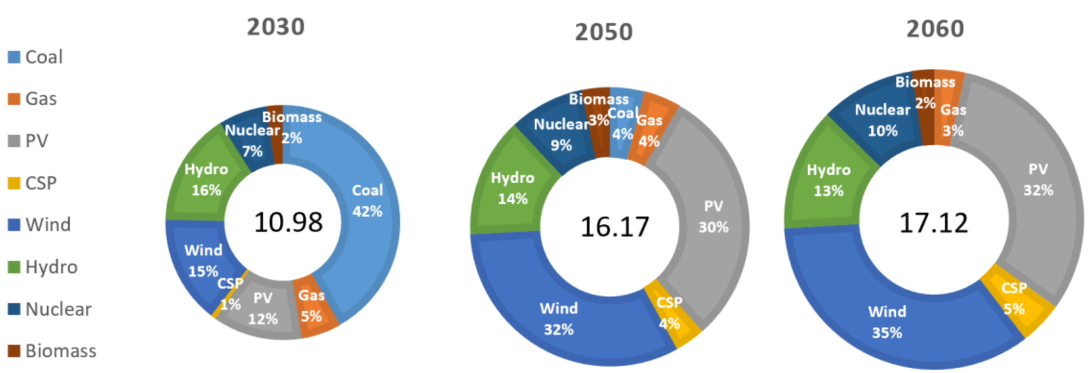
Carbon Neutral Pledge of China

"China will scale up its Nationally Determined Contributions by adopting more vigorous policies and measures. We aim to have CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060." – *President Xi at the 75th UNGA*

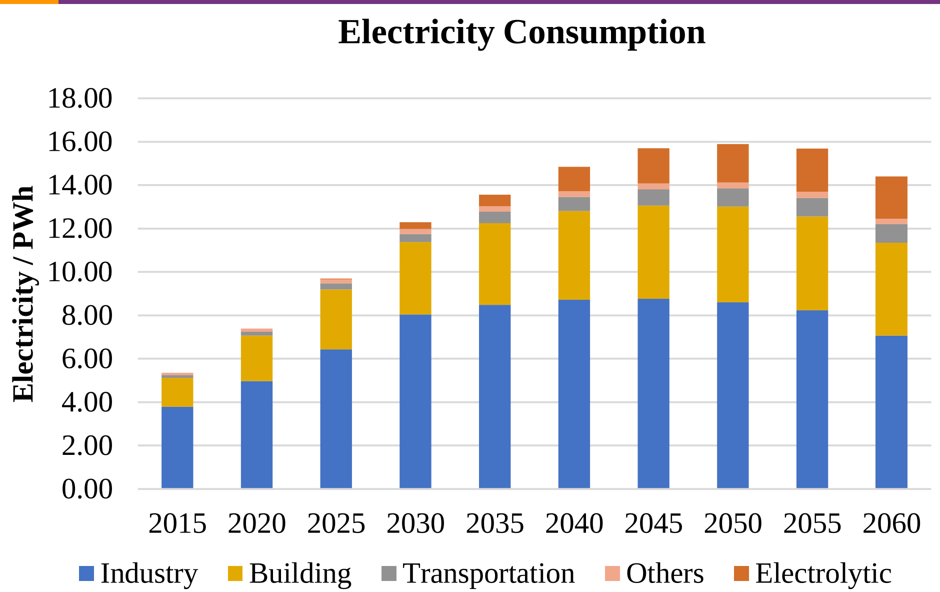


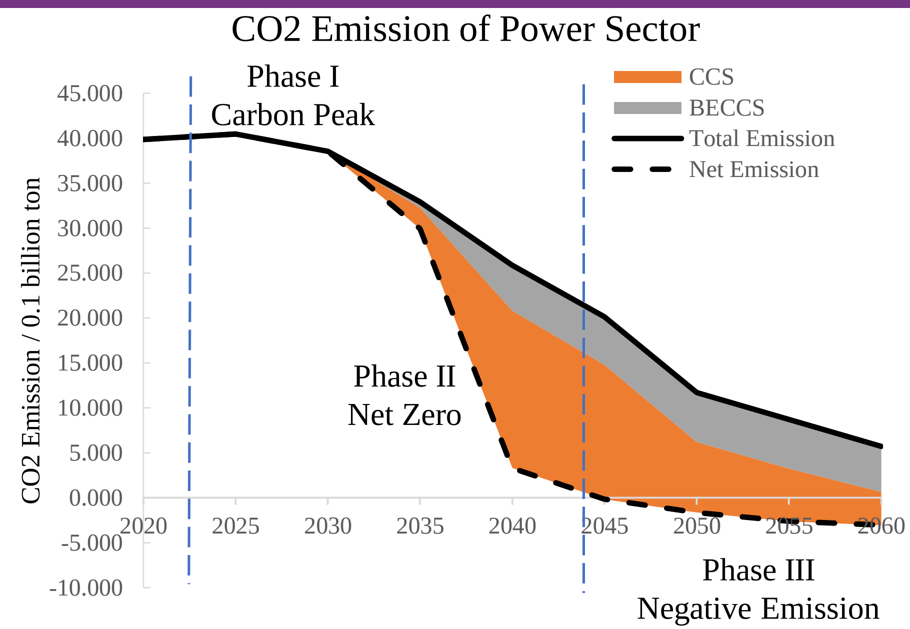
Source: Cambridge Econometrics modelling.





Power system plays a key role

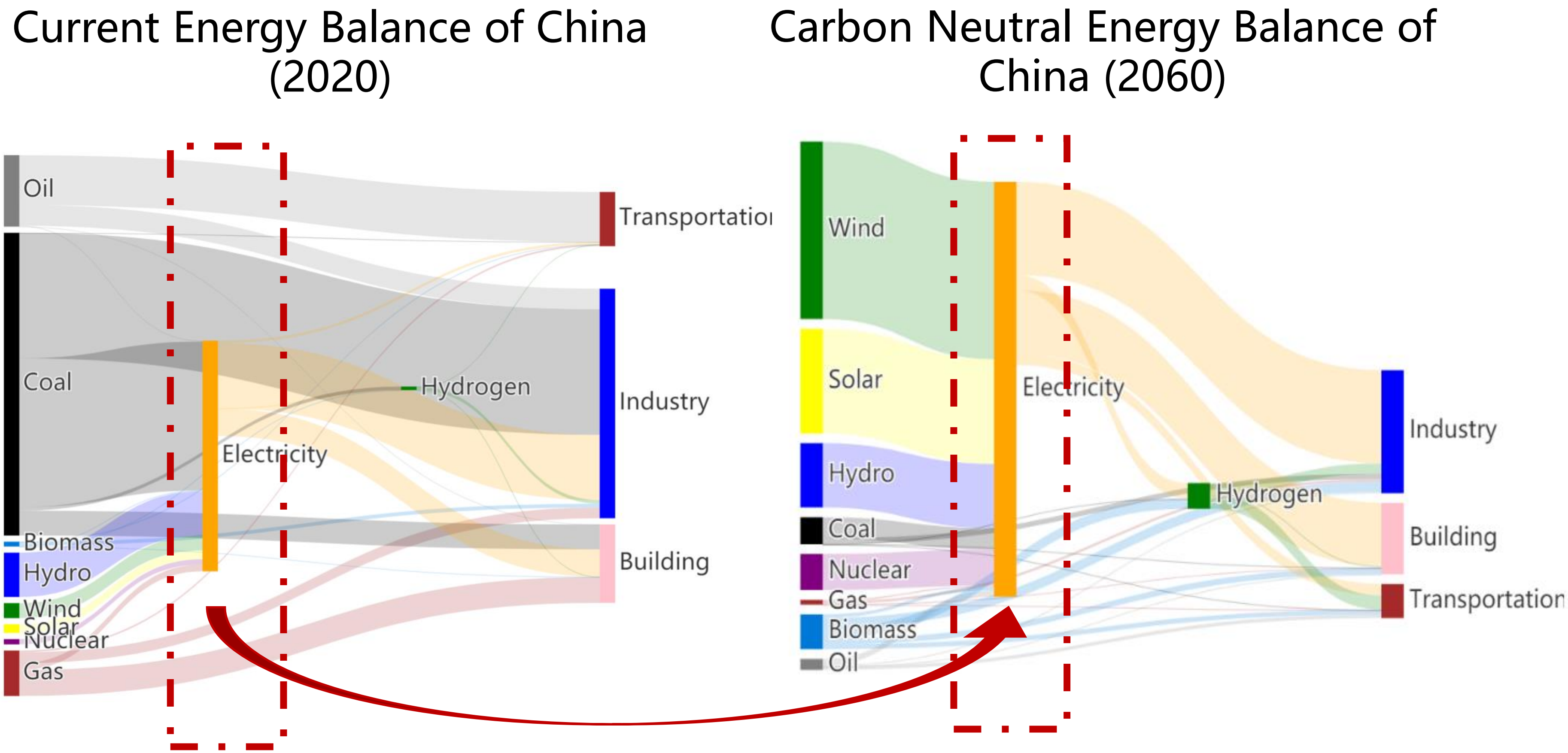




Key Indicators of China Carbon Neutral Pathway

Indicators	2020	2030	2050	2060
Share of Non-fossil Fuel Consumption (%)	15.89	>25	80.77	90.74
Electricity Consumption (trillion kWh)	**7.39**	**12.30**	**15.89**	**14.40**
End-Use Electrification Rate (%)	**26.3**	**37.1**	**66.7**	**76.9**

Transition to a Low-carbon Power System

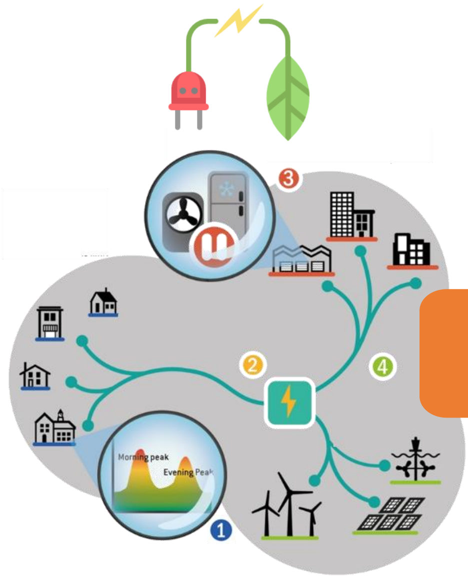


- **The transition to a low-carbon power system becomes a key driver**
- **Carbon neutral path of electricity: Building a High Renewable Penetrated Power System**

2. Power System Transition from the Carbon Perspective

"Electricity perspective" VS "Carbon perspective "

"Electricity perspective" of the power system



Electric-carbon coupling

Electricity measuring

Electricity flow

Electricity optimization

Electricity trading

Electricity planning

Energy security

Energy economy

"Internally driven" development mode

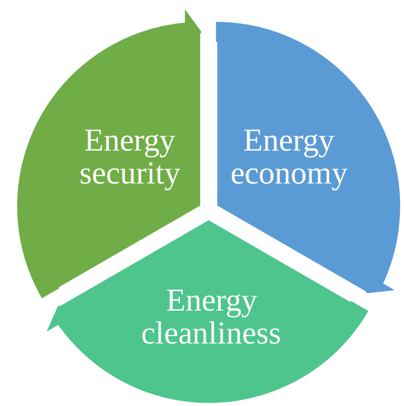
Carbon measuring

Carbon flow

Carbon optimization

Carbon trading

Carbon planning

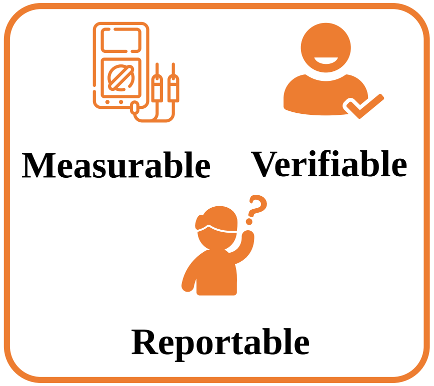


" Carbon perspective" of the power system

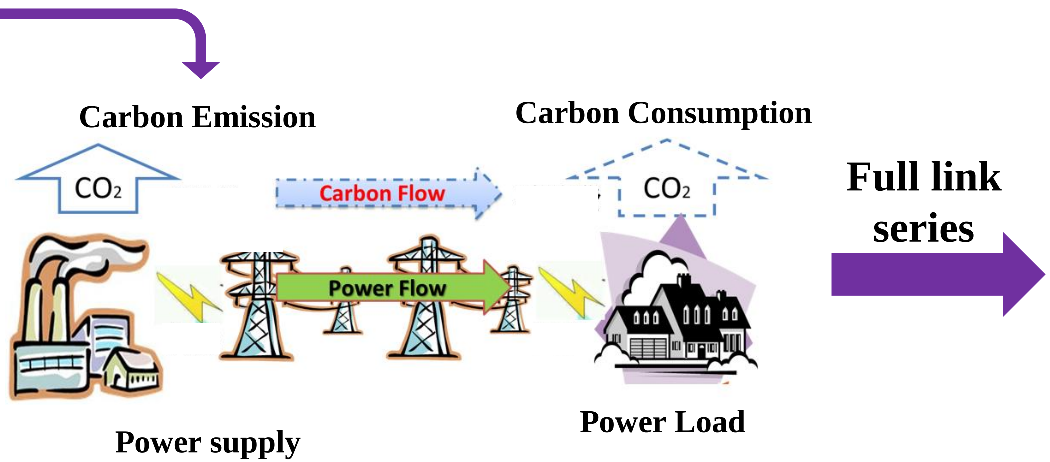
"Zero emission driven" development mode

Starting Point: Carbon Emission Measurement

Current Status: Focusing on the generation side, only a simple fixed electricity carbon emission factor



The principle of MRV(IPCC)



Carbon emission measurement and analysis in the whole process

Key questions

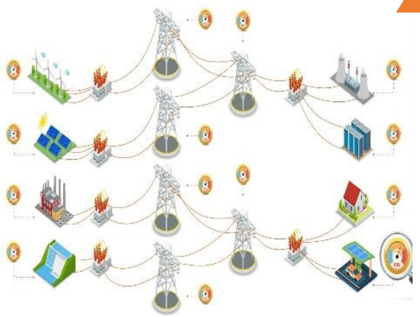
- From generation side, how to measure carbon emissions in a real time manner since the power generated by coal and renewables are variable?
- While talking about the accounting of Carbon Emission Responsibility, how to measure carbon accurately in the whole process from generation to demand side through network?

The framework of research from Carbon Perspective

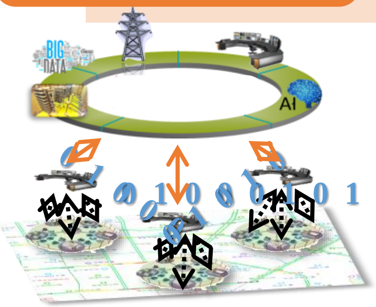
From the "carbon perspective", studying the carbon metering technology and planning, operation and trading methods of power system

The key fundamental problem of "electric-carbon coupling" for low carbonization of power system

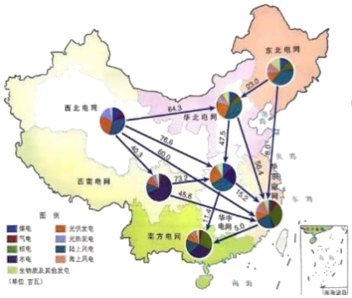
Carbon metering



Operation

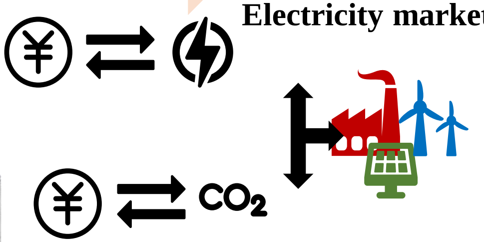


Planning



Trading

Electricity market

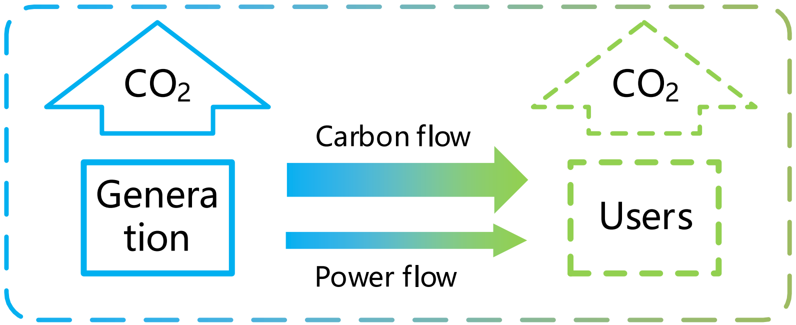


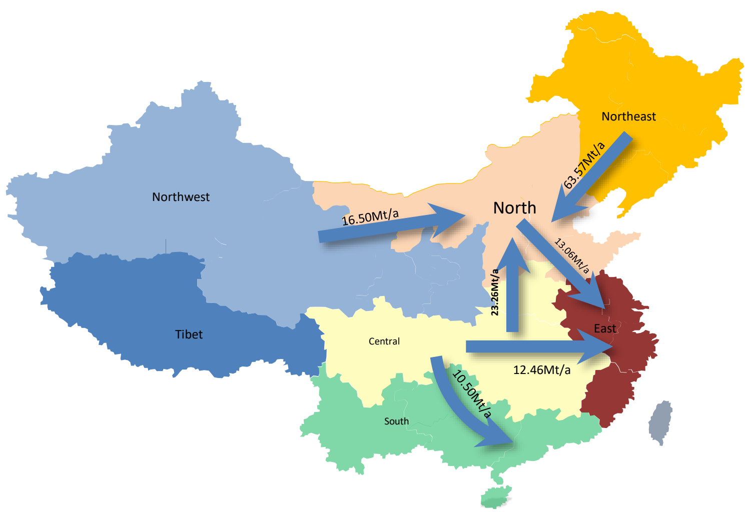
Carbon market

Objective: To provide theoretical basis and model, mechanism and policy of low-carbon in the power industry, and for the research and practice of energy system transformation in power industry.

Carbon Emission Flow in Power System

Carbon Emission Flow (CEF) in Power System: A coupled carbon emission that depends on the existence of the power flow and moves directionally with the active power flow of the system.





KEY INDICATORS

Branch CEF
Branch CEF rate
Branch CEF intensity
Nodal carbon intensity

CACULATION PROCESS

Dispatching results

Generation Data

Power flow data

Carbon emission intensity

Carbon flow analysis

Carbon emission flow data

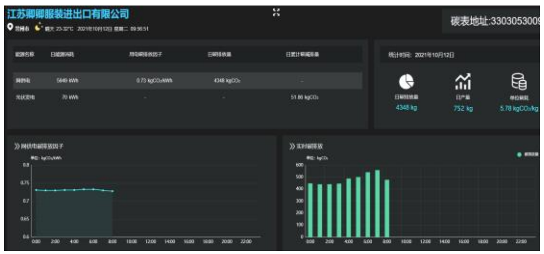
Enable quantifying the carbon emission accompanying the power transmission and consumption.

Carbon Meter and Carbon Metering

Carbon Meters

Generation Carbon Meter

Network Carbon Meter



Consumption Carbon meter

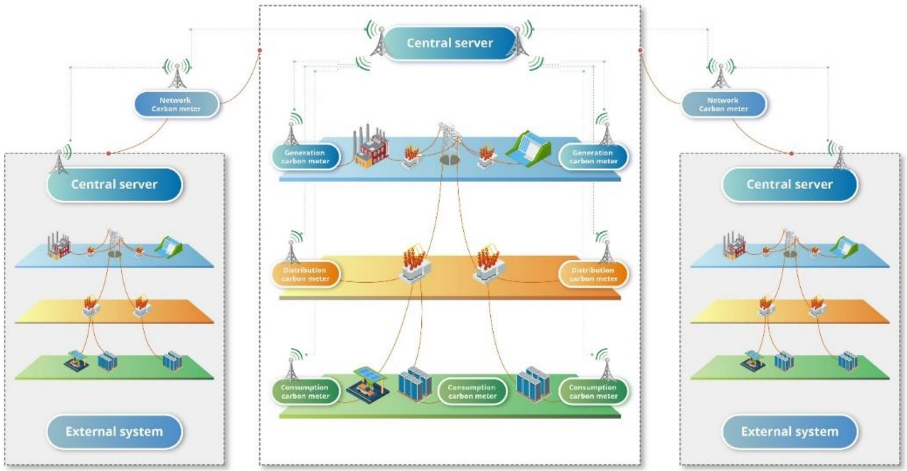
-Generation Carbon Meter (GCM) : Real-time measurement of carbon emissions from power generation;

-Network Carbon Meter (NCM) : Carbon emission measurement of terminal nodes of regional interconnection lines;

-Consumption Carbon meter (CCM) : Instantaneous and accumulated carbon emission information corresponding to consumer`s energy consumption.

Carbon measurement platform

- **Carbon measurement platform based on carbon emission flow analysis theory**
- **Achieving Continuous and accurate real-time tracking and monitoring of carbon emission in the whole power system**



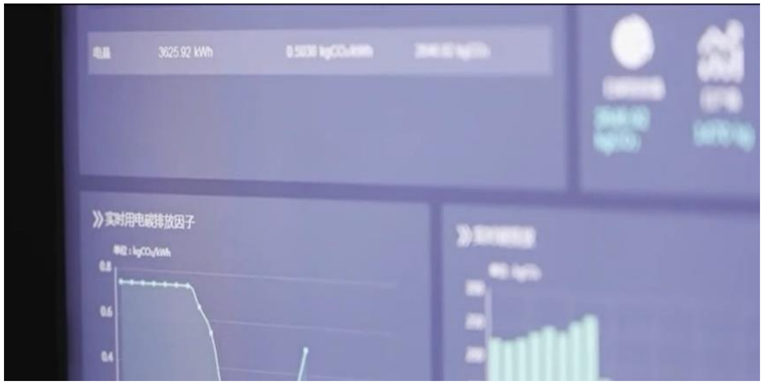
Structure of carbon measurement platform

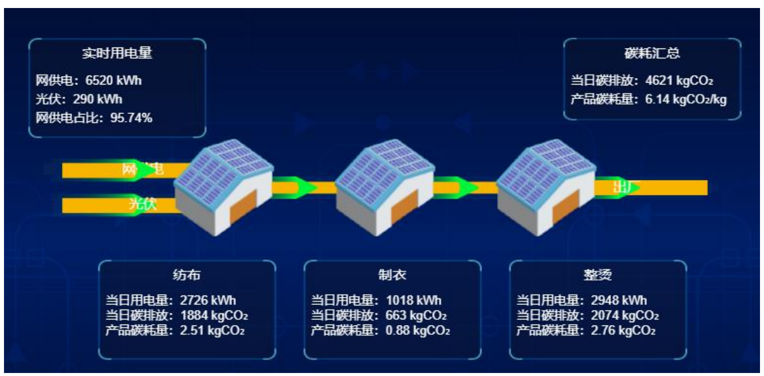
Function of carbon measurement platform

Overview of carbon emission	Gathers energy supply and consumption data, carbon emission data of key industries, and provides a panoramic overview of carbon emissions
Regional carbon measurement	Based on the carbon meter system, it demonstrates the real-time flow of carbon emissions in the power grid and realizes real-time carbon monitoring of the power system
Whole chain carbon response	Brings together responsive resources to realize user-side demand response control and carbon emission reduction measurement and analysis functions
Panoramic carbon footprint	Provide carbon footprint tracking and carbon reduction services for corporate users

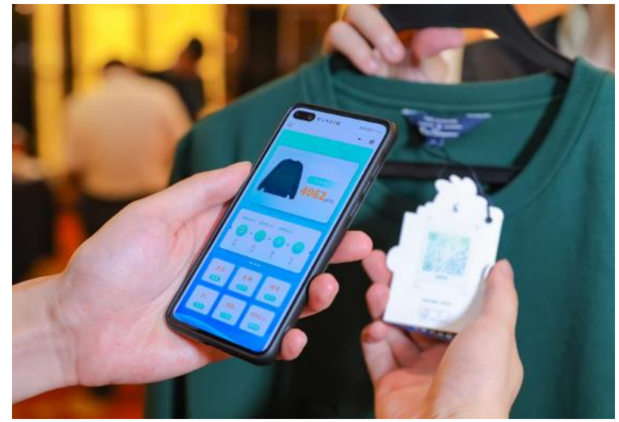
Demonstration Application (Jiangsu Province)

- **Using carbon meter system to monitor carbon emission in the whole production process of enterprises**





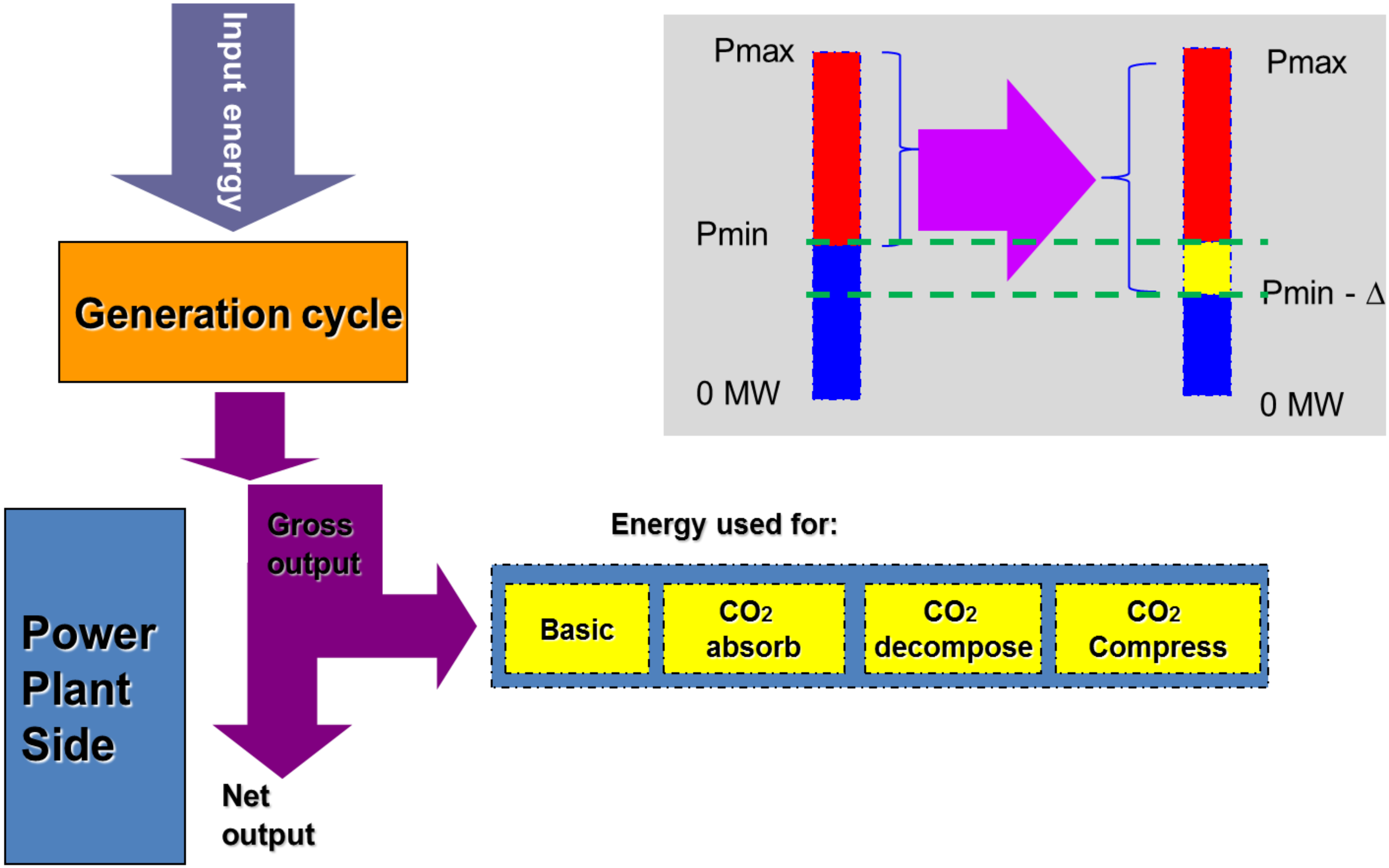
Carbon emission measurement in the production process of spinning, clothing, ironing, etc.



Scan the QR code to know the carbon emission generated during the production process of the product

Guide low-carbon management of enterprises and encourage green consumption of consumers.

The survival of thermal power before carbon neutrality：CCS/CCUS



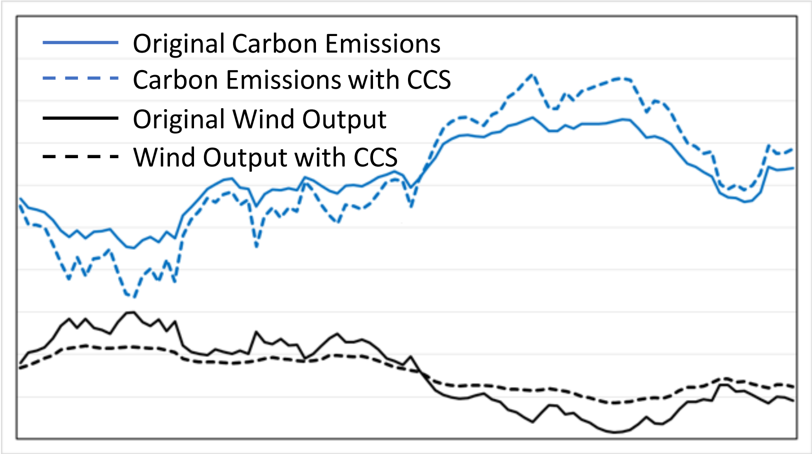
From SCUC/SCED to Low-Carbon Power Dispatch

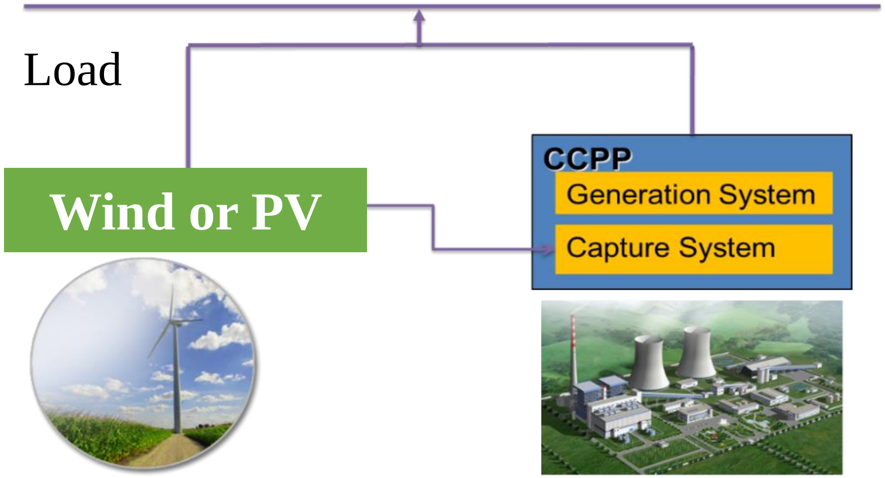
Various types of generators

- ✓ Thermal units + CCS
- ✓ Hydro power plant
- ✓ Nuclear power
- ✓ Variable Renewable Energy

Key issues to be studied

- Power dispatch towards renewable energy integration
- Low-carbon power dispatch model and optimization methods





Simulation considering carbon market and power market synergy

Considering the physical and political constraints of both power markets and carbon market, develop a synergetic simulation technique for transactions in both markets

Profit maximization modeling

Bidding preference constraints

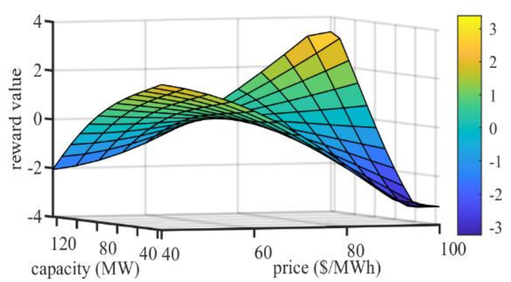
High penetration of renewable energy

Power system operation constraints

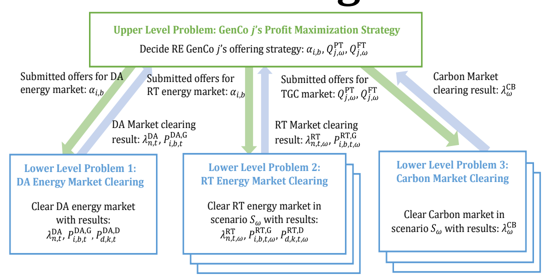
Analytical formula solution

Data-driven power market solution

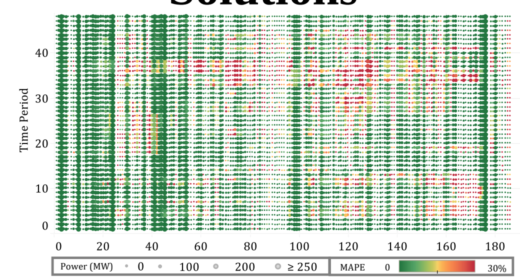
Individual Decision-Making Modeling



Coupled Markets Modeling



Synergetic Clearing Solutions



Individual workflow constraints

Carbon emission constraints

Carbon emission constraints

Carbon transaction constraints

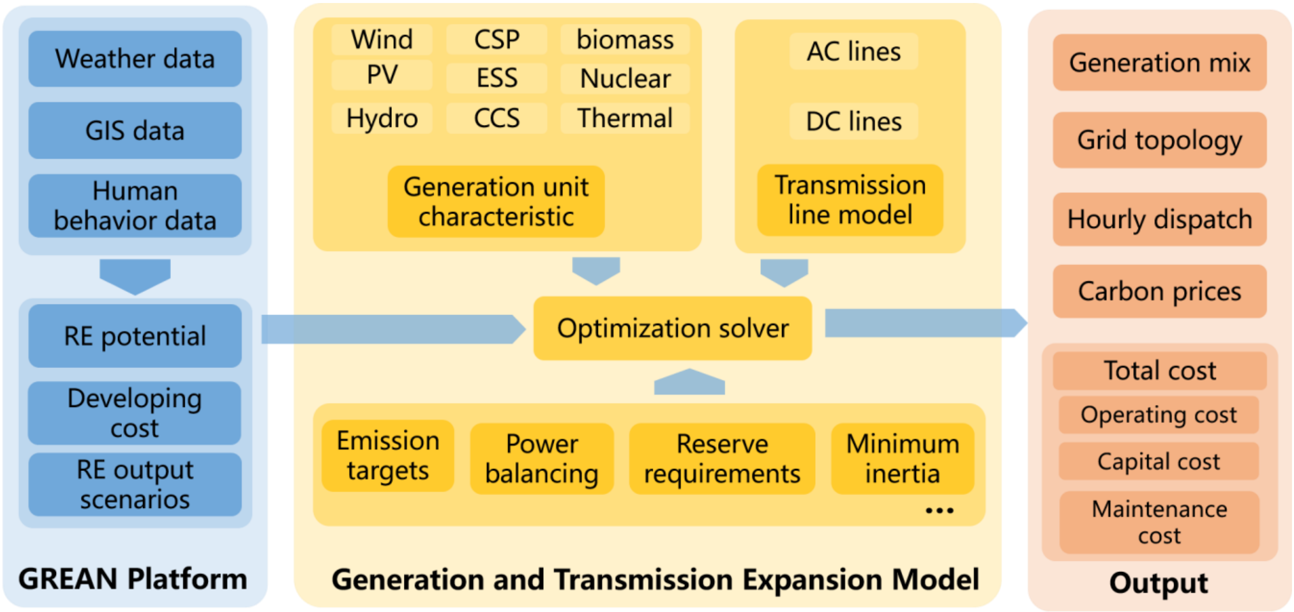
Heuristic carbon market solution

Distributed carbon market solution

3. Power System Transition under 30•60 Goals

Power System Planning for 30·60 Decarbonization Goal

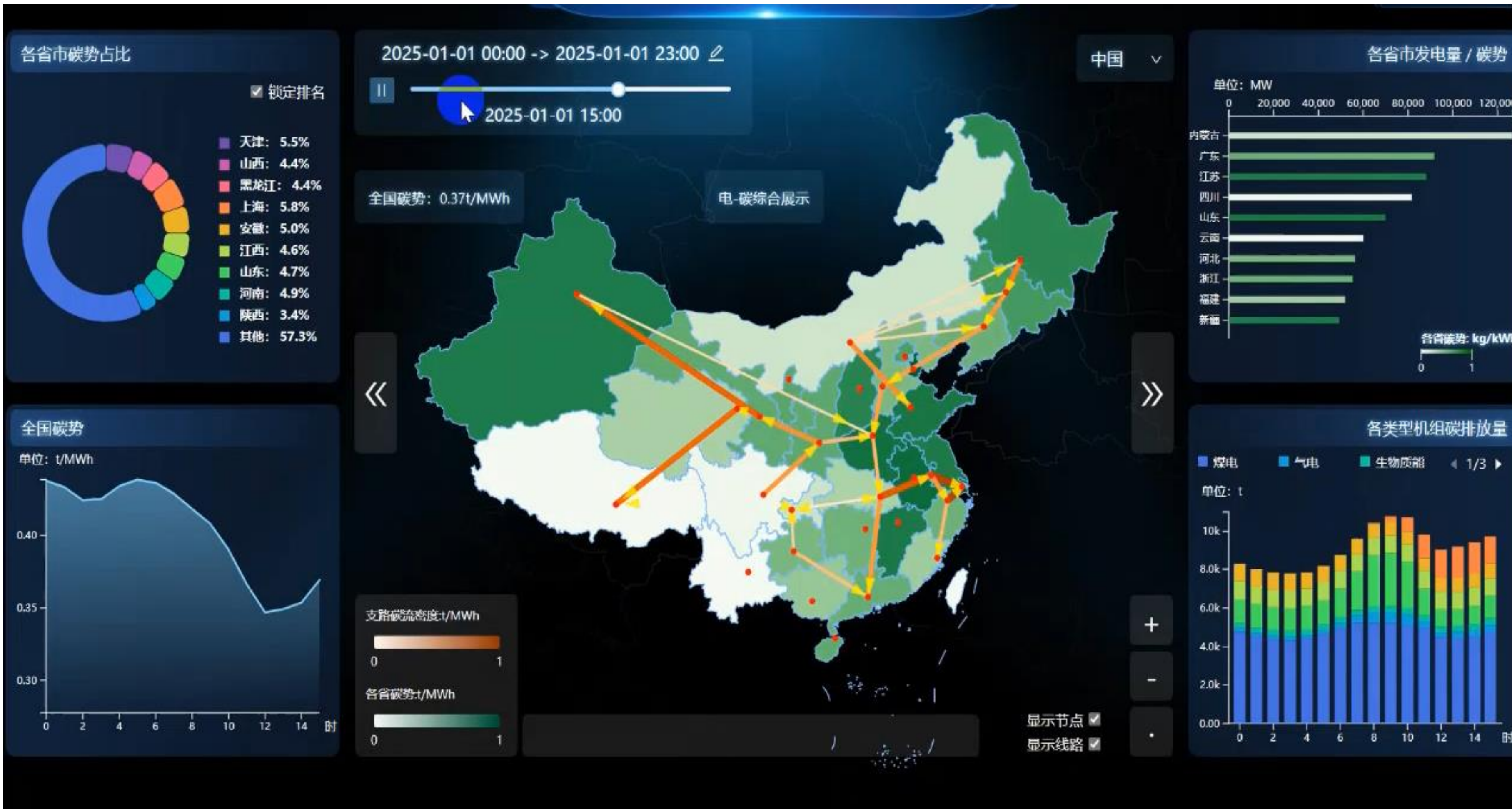
• Coordinated Generation-grid-load-storage Planning Model



- We established a coordinated generation-grid-load-storage optimization planning model for the national power system.
- At the same time, **multiple secure and policy constraints** such as reserve requirements, minimum inertia limits, and carbon emission restrictions are considered.
- Based on **the actual data collection of China's power system**, the provincial RE potential, supply curves, **13 types** of generation units, and all transmission lines are involved in the model.

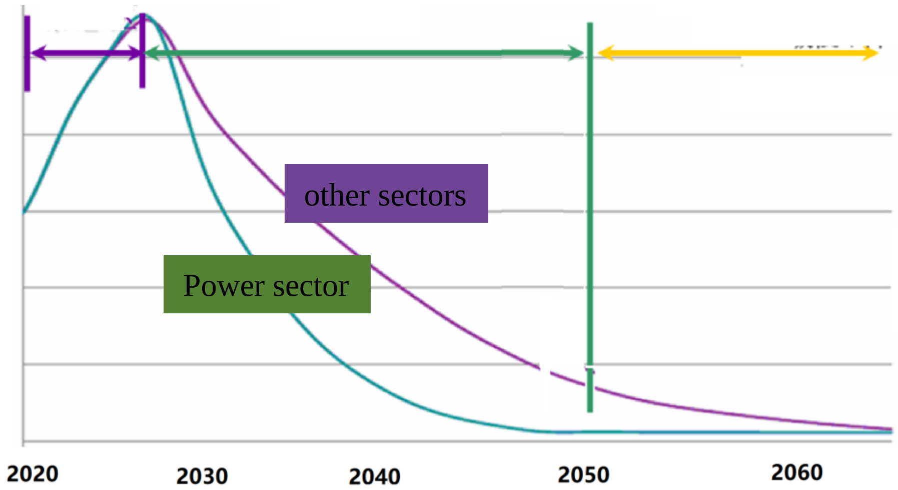
Method and Software Platform towards Low-carbon operation simulations

- A software platform, based on 8760 hours power system operation simulations, is established and is currently serving the power system planning research.



Power system transition towards carbon neutrality

- Carbon neutrality is easier to achieve in the power sector than that in other sectors **due to low-carbon generation and other related technologies**.
- In different studies, it can be seen the carbon neutrality target of power sector will be achieved in 2050. The power system will be stable during the years from 2050 to 2060.



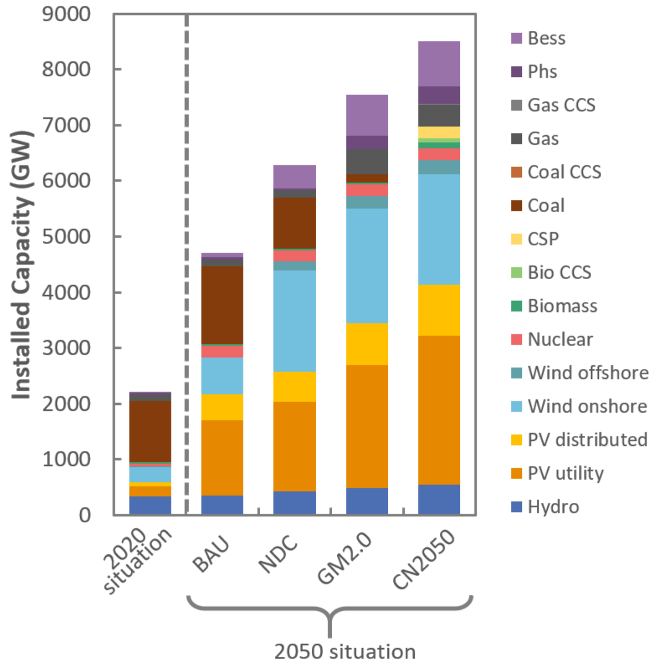
- **Four cases with different carbon mitigation targets** are set for comparison.
- In the CN2050 case, the carbon neutrality target is achieved in 2050.
- Hence, we regard the **CN2050** scenario as **the base case in the following analysis**.

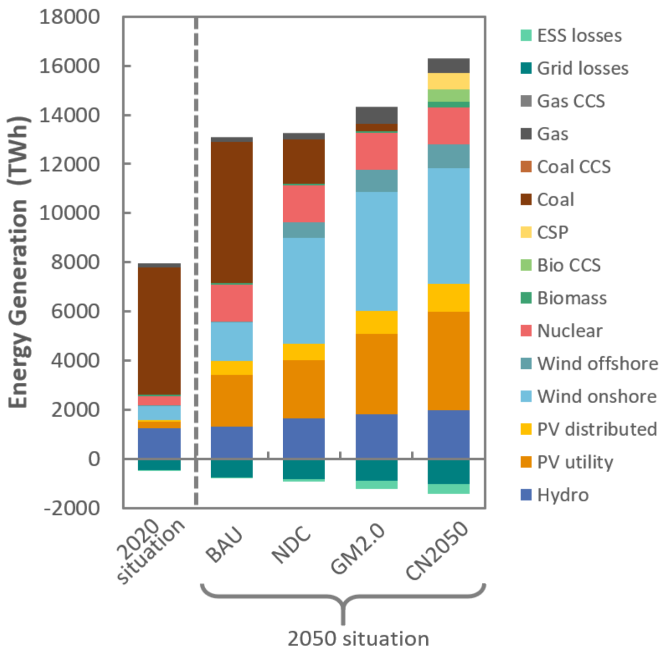
Case settings

	Carbon emission budget during 2020-2050 (billion tonne)	Electricity load demands in 2050 (TWh)
Business-as-usual (BAU)	N/A	12.3
Nationally Determined Contributions (NDC)	104.4	12.3
Global Warming of 2.0 °C (GM2.0)	84.2	13.1
Carbon neutrality (CN2050)	66.2	14.86

Energy mix under carbon neutrality

- **Capacity mix and Generation mix**

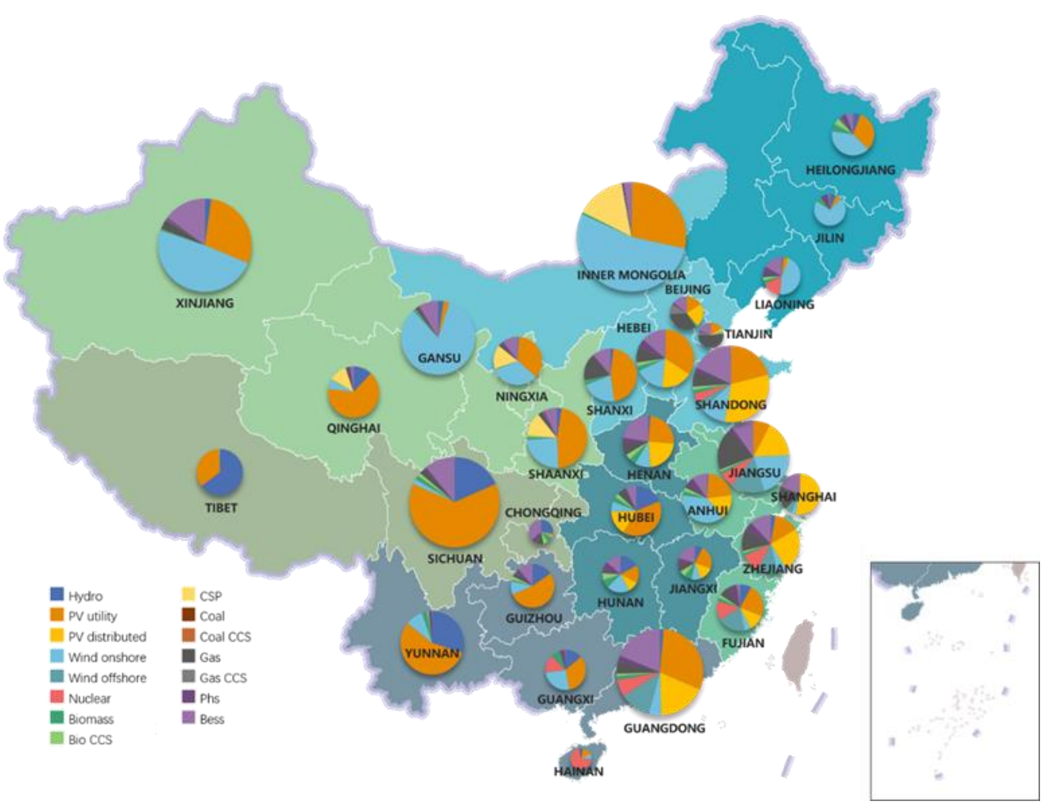




- Coal power begins downscaling significantly on a large scale after 2035.
- Under the carbon neutrality scenario, the variable renewable energy (VRE) penetration reaches **72.8% with 3579.0 GW of PV and 2247.1 GW** of wind.
- Energy storage systems (**ESSs**) and Concentrated solar power (**CSP**) would play **a critical role as a flexible generation source**.

Power system transition towards carbon neutrality

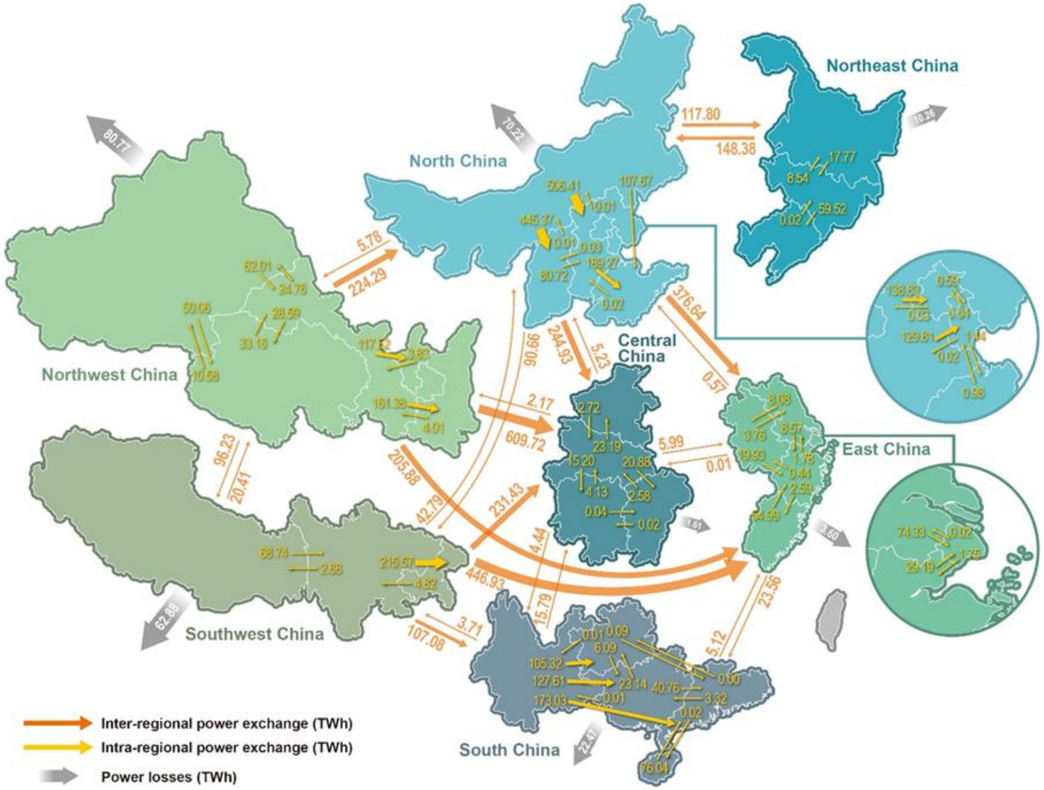
- **Capacity mix in provinces**



- Large-scale onshore wind power units are mainly located in **Northwest, North, and Northeast China**. Offshore wind power is located in the **three coastal load centers**.
- PV units account for a considerable proportion of the generation mix in most provinces in the country, especially in **high-altitude provinces.**
- CSP units are mainly located in **northwest China and Inner Mongolia** where high-quality solar energy resources exist.

Power system transition towards carbon neutrality

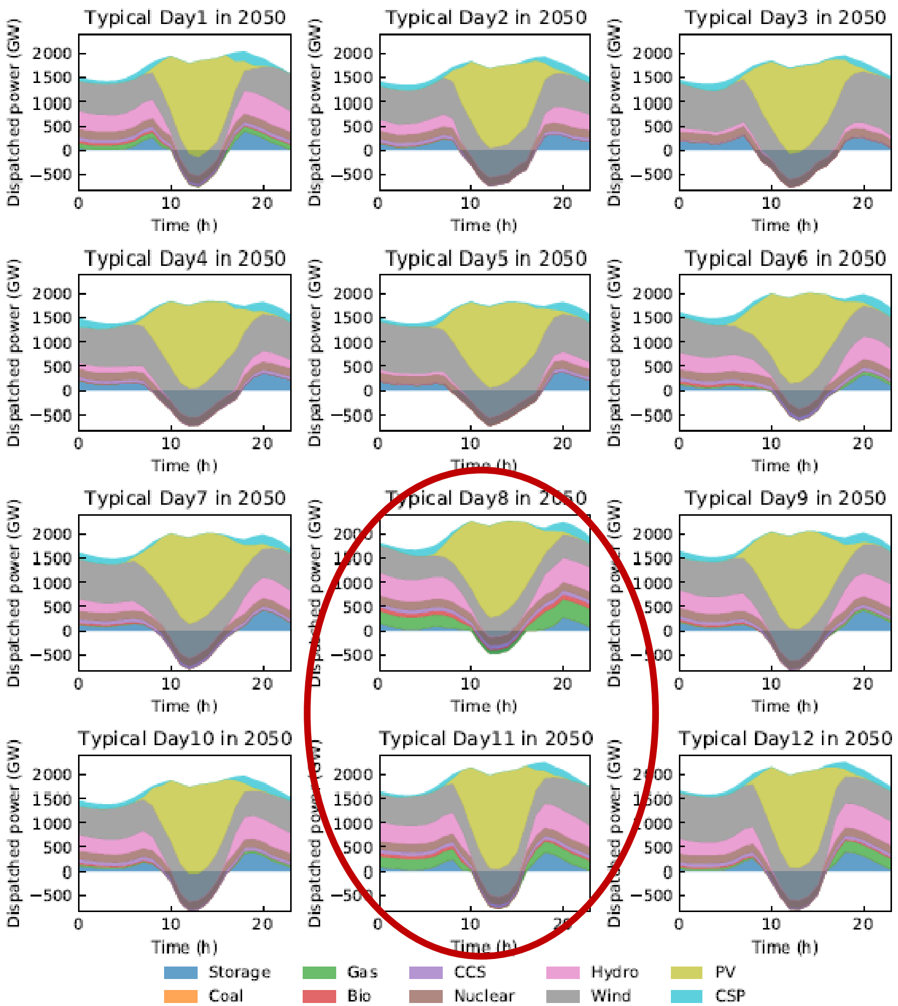
• Power exchange across provinces



- Inter-provincial power delivery reaches **6052.7 TWh per year** under the carbon neutrality scenario, which is 3.8 times the value in 2020.
- The distribution of power flow **continues the current pattern** of "from west to east" and "from north to south".
- The power system gradually transformed from a simple power transmission channel to **a platform supporting bidirectional energy sharing**.

Power system transition towards carbon neutrality

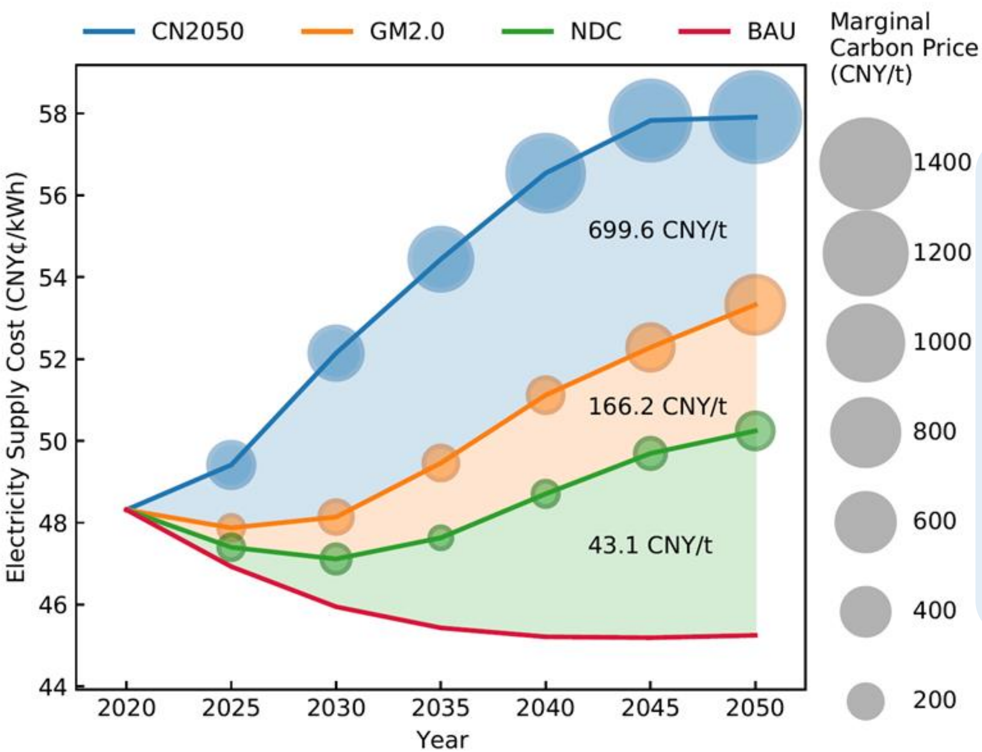
- ## Simulation results in typical days



- The power **during the day** is mainly provided by **PV units**, and the **wind** power output is relatively large **at night**.
- The typical working mode of energy storage **is charging at noon and discharging at night**. The CSP also mainly outputs at night.
- **Gas power and biomass** units play the role of **emergency generation units** when wind and solar output is small as on typical day 8 and typical day 11.
- The time periods when the system needs quantities of peak regulation sources is now the time point of **sunrise and sunset**.

Costs of Carbon Neutrality

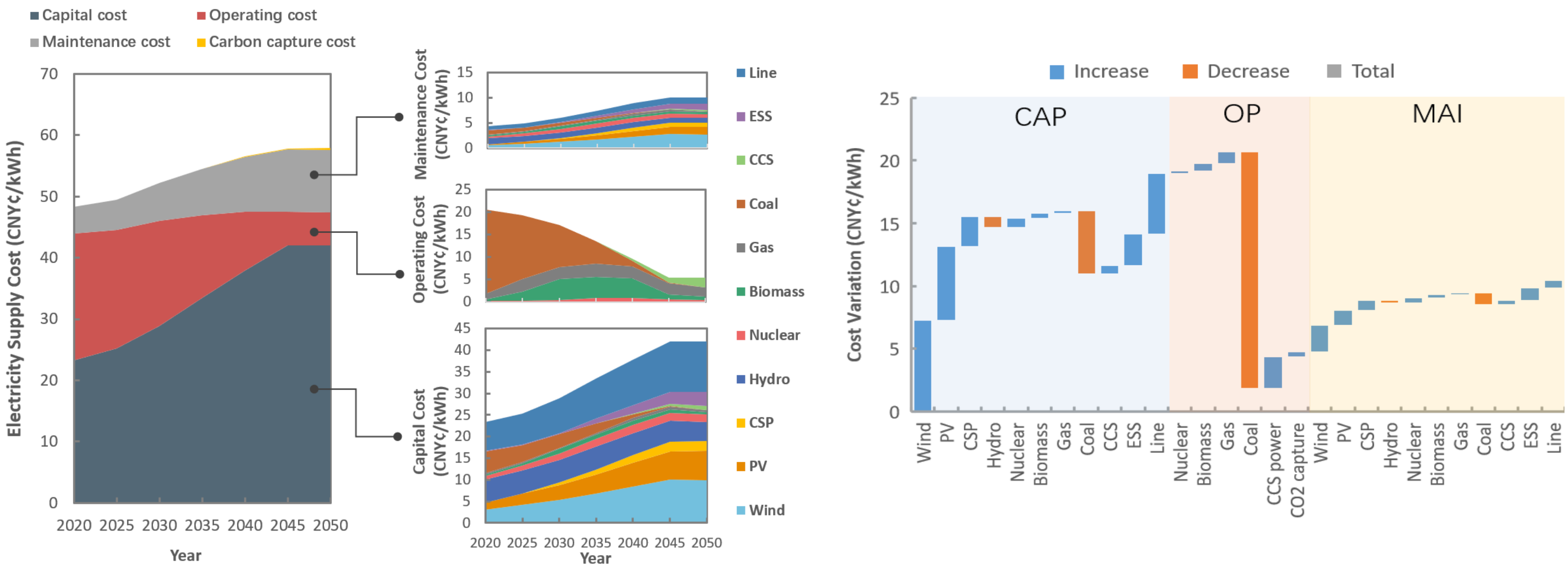
- **Electricity supply cost and marginal carbon price**



- To achieve carbon neutrality, the costs of electricity supply increase by **9.6 CNY ¢ /kWh, or 19.9 %**, over the 30 years to 57.9 CNY ¢ /kWh .
- In the later stage, the marginal carbon price exceeds **1,400 CNY per ton**.

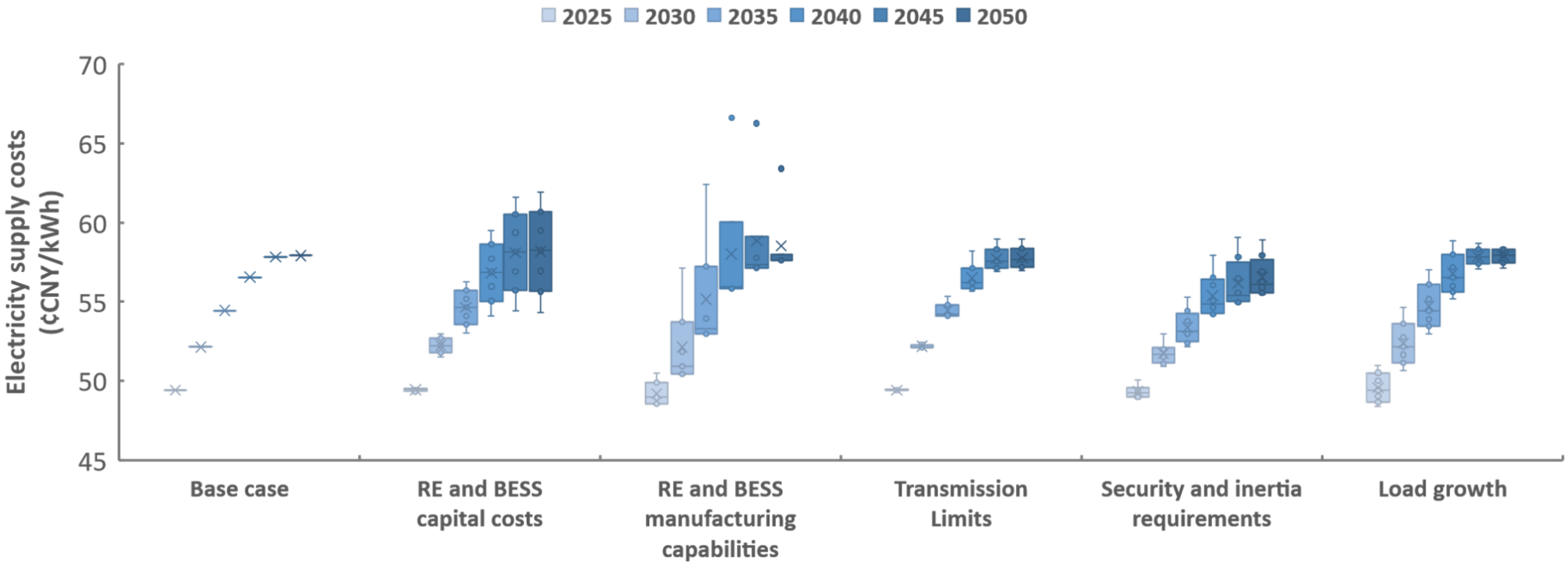
The number between each pair of curves denotes the average carbon mitigation cost per ton between the more stringent scenario and the less stringent one.

Composition changes of electricity supply costs



- The phasing out of coal power naturally causes a decrease in its costs, which accounts for the dominant share at **18.8 CNY ¢ /kWh**.
- The supply cost increments contributed by **VRE are totally 16.4 CNY ¢ /kWh**, although the investment costs per kW decrease by approximately 60%.
- Added gas power, biomass power, ESSs, CSP and transmission expansion result in **additional supply cost increases of 18.4 CNY ¢ /kWh**.

Electricity supply costs under uncertainties



- A sensitivity analysis is conducted on the CN2050 scenario to consider the impact of **the uncertainties of five key factors**: 1） RE and battery energy storage system (BESS) capital costs, 2) the RE and BESS manufacturing capability, 3) transmission capacity limits, 4) security requirements, and the load growth rates.
- Despite the influence of various uncertainties, **increases in the costs are almost inevitable**.
- The uncertainties of RE and BESS capital costs (wind, PV, CSP, and BESS) **result in the largest differences** in the final electricity supply cost at **approximately ±6.5\%.**

Policy implications

- Ensuring **the integrity of the supply chain for wind and PV units** is critical for achieving decarbonization of the power sector.
- **A reasonable market mechanism** is urgently needed to translate the cost change to the electricity price. A capacity market and ancillary service market should be established to **internalize the external costs of high RE penetration.**
- **Policy support remains vital to spur technological innovation and cost reduction**, especially for technologies in the early stages of development, such as BESS and CSP.

More details:

Zhuo, Z., Du, E., Zhang, N. et al. Cost increase in the electricity supply to achieve carbon neutrality in China. Nat Commun 13, 3172 (2022). https://doi.org/10.1038/s41467-022-30747-0

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Cost increase in the electricity supply to achieve carbon neutrality in China

Zhenyu Zhuo, Ershun Du, Ning Zhang, Chris P. Nielsen, Xi Lu, Jinyu Xiao, Jiawei Wu & Chongqing Kang

Nature Communications **13**, Article number: 3172 (2022) | Cite this article

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Concluding Remarks

1

Carbon neutrality is the ultimate targets of energy transition while **the power system will become the backbone** of a carbon-neutral energy system.

2

The transition of the power system needs to be considered **from a carbon perspective**, and the carbon elements are considered in the whole process of **metering, operation, planning, and trading**.

3

Our study indicates that approximately **5.8 TW of wind and solar PV** capacity would be required to achieve carbon neutrality in China's power system by 2050. The electricity supply costs would increase **by 19.9%.**

Thanks for your attention!

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