Documentation for the CPOST Model

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1 Overview

The China POwer System Transition (CPOST) model is an energy system optimization model for China's electric power system transition. It has been co-developed and maintained by Prof. Zhou Wenji's group at the School of Applied Economics, Renmin University of China, and Prof. Ren Hongtao at the School of Business, East China University of Science and Technology.

The model has an hourly temporal resolution (8760 hours in a typical year) and a geospatial resolution that covers 31 provinces belonging to 7 grid regions. CPOST employs a generalized structure that supports multiple nodes and energy carriers. The model's core objective is to minimize total system costs under operational and engineering constraints in the electric power system. Key cost components include capital investments, fixed and variable operational costs, fuel costs, and emission penalties; constraints are set for energy balance, capacity, storage dynamics, and transmission flows; these together offer a detailed representation of power system operations and planning. The model is calibrated to reflect China's generation technologies, storage, regional grids, and extensive transmission infrastructure. It provides a comprehensive and flexible framework for analyzing technical and economic outcomes of various power sector transition pathways.

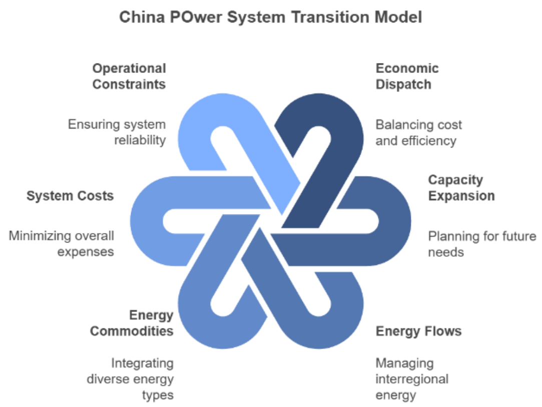

Figure 1-1 A simplified framework of the CPOST model.

2 Mathematical Framework

This section presents the model's optimization framework and the mathematical principles.

2.1 Sets and Indices

The COPST model is mathematically formulated as a mixed integer linear programming problem (MILP). For some cases that need faster computation, the model could also be simplified to regular linear programming by changing configuration settings and ignoring binary variables, as in unit commitment. Table 2-1 below summarizes the core concepts involved in the mathematical programming framework, which are essential for the computational implementation.

Table 2-1 Symbols and their explanations.

Symbol	Explanation
$n, n^{'} \in N$	Nodes
$p \in P$	Processes (e.g., generation technologies)
$u \in U$	Generation units
$t \in T$	Time step (hour)
$c \in C$	Commodities (e.g., electricity, hydrogen, methane,

	CO_2, etc.)
$s \in S$	Storage installations (e.g., batteries for electricity storage, pumped hydro, hydrogen storage tanks, etc.)
$f \in F$	Transmission lines (e.g., high-voltage transmission lines for electricity, hydrogen pipelines for hydrogen, etc.)
$C_{com}, C_{dem}, C_{buy}, C_{sell}, C_{emi} \subset C$	Subsets of commodities, where: • C_{com} : regular commodities, e.g., electricity, hydrogen, and others; • C_{dem} : demand commodities; • C_{buy} , C_{sell} : commodities to buy and sell, incl. imported electricity, gas purchased from the market, electricity, hydrogen sold to the market, etc.; • C_{emi} : emissions, e.g.: CO_2, SO_2, etc.
$(n, p, u) \in NPU$	Combination set, unit u of process p at node n
$NPU^{noren}, NPU^{ren} \subset NPU$	Sub-combination set, non-renewable unit u process p at node n, and renewable unit u process p at node n
$(n, s, c) \in NSC$	Combination set, storage s of commodity c at node n
$(n, n', f, c) \in NNFC$	Combination sets, transmission f of commodity c from node n to node n'

Table 2-2 provides an overview of the key parameters in the model.

Table 2-2 Parameters and their explanations.

Parameter	Explanation
$fixedcost_{n,p,u}$	Fixed cost of unit u of process p at node n

$varcost_{n,p,u}$	Variable cost of unit u of process p at node n
$startcost_{n,p,u}$	Start-up cost of unit u of process p at node n
$ramp^{up}_{n,p,u}$	Ramp-up rate of unit u of process p at node n, in percentage of capacity
$ramp^{down}_{n,p,u}$	Ramp-down rate of unit u of process p at node n, in percentage of capacity
$cap_{n,p,u}$	Capacity of unit u of process p at node n
$capfactor_{n,p,u}$	Capacity factor of unit u of process p at node n
$mincap_{n,p,u}$	Minimum capacity of unit u of process p at node n when it is operating
$rate^{in}_{n,p,u,c}$	Inflow rate coefficient of commodity c to unit u of process p at node n
$rate^{out}_{n,p,u,c}$	Outflow rate coefficient of commodity c from unit u of process p at node n
$storcap^{v}_{n,s,c}$	Volume capacity of storing commodity c in storage s at node n, in the unit of energy (e.g., kWh or MJ)
$storcap^{in}_{n,s,c}$	Inflow (charging) capacity of storing commodity c in storage s at node n, in the unit of power (e.g., kW)
$storcap^{out}_{n,s,c}$	Outflow (discharging) capacity of commodity c flowing out from storage s at node n, in the unit of power (e.g., kW)
$storinit_{n,s,c}$	Initial status of storing commodity c in storage s at node n, percentage
$storvarcost_{n,s,c}$	Variable cost of storing commodity c in storage s at node n
$storeff^{in}_{n,s,c}$	Input (charging) efficiency of commodity c in storage s at node n, percentage
$storeff^{out}_{n,s,c}$	Output (discharging) efficiency of commodity c in storage s at node n, percentage
$selfdischarge_{n,s,c}$	Self-discharging (loss) rate of commodity c flowing out of storage s at node n, percentage
$transcap_{n,n',f,c}$	Transmission capacity of storing commodity c in storage s at node n, in the unit of power (e.g., kW)

$transvarcost_{n,n',f,c}$	Variable cost of transmitting commodity c via transmission line f from node n to node n'
$transeff_{n,n',f,c}$	Efficiency for transmitting commodity c via line f from node n to node n', percentage (100% - line loss)
$intermittent_{n,p,t}$	Conversion factor of intermittent energy process p at time step t at node n
$price_{n,c,t}$	Price of commodity c at time step t at node n
$demand_{n,c,t}$	Demand of commodity c at time step t at node n

Table 2-3 lists the variables in the model that are directly associated with the decision-making process:

Table 2-3 Variables and their explanations.

Variable	**Explanation**
$ACT_{n,p,u,t}$	Activity (generation or output) of unit u of process p at time step t at node n
$ON_{n,p,u,t}$	Binary variable, operating status of unit u of process p at time step t at node n, 1: on; 0: off
$SWITCH_{n,p,u,t}$	Binary variable, action of unit u of process p at time step t at node n, 1: switch on
$STORCOM_{n,s,c,t}$	Stored amount of commodity c in storage s at time step t at node n
$STORIN_{n,s,c,t}$	Inflow (charging) rate of commodity c in storage installation s at time step t at node n
$STOROUT_{n,s,c,t}$	Outflow (discharging) rate of commodity c in storage s at time step t at node n
$TRAACT_{n,n',f,c,t}$	Flow rate of commodity c via transmission f at time step t from node n to node n'

2.2 Production Process

The production process in CPOST captures technologies' input-output conversion relationships. This relationship can represent various technologies, including power generation, transmission, and storage. Each process is treated with predefined parameters governing its inflows and outflows. The process supports the representation of diverse energy carriers beyond electricity and enables modeling sector-coupling (e.g., hydrogen, methane) in a consistent framework.

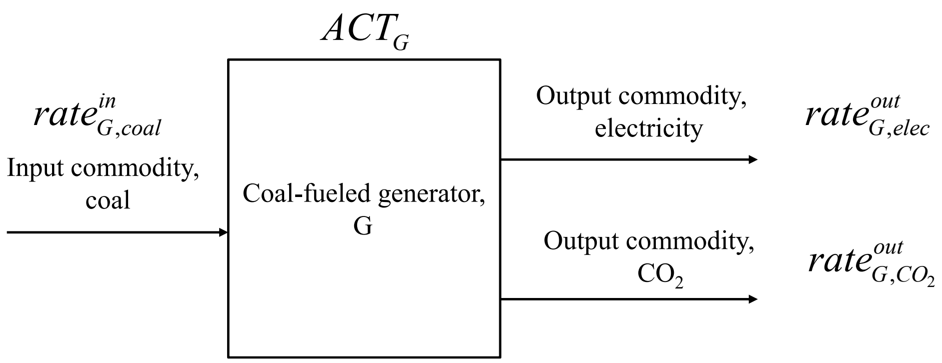

Figure 2-1 Representation of the inflows and outflows of a coal-fired generation unit.

Figure 2-1 illustrates a coal-fueled power plant and the associated input and output flows. The generator *G* has coal as the input fuel and electricity as the primary output product, while it also emits CO_2 as the secondary output commodity. Three parameters need to be defined then: $rate^{in}_{G,coal}$, $rate^{out}_{G,elec}$, and $rate^{out}_{G,CO_2}$, denoting the inflow rate coefficient for coal, the outflow rate coefficients for electricity and CO_2, respectively. Given these three parameters, the model defines only one decision variable, ACT_G, to represent the activity level of generator *G* in a specific circumstance. The electricity output is therefore calculated as $rate^{out}_{G,elec} \times ACT_G$, and similarly, the inflow of coal and the CO_2 emissions are $rate^{in}_{G,coal} \times ACT_G$ and $rate^{out}_{G,CO_2} \times ACT_G$, respectively.

2.3 Objective Function

The objective function is to minimize the total cost of the whole electricity system consisting of a variety of components, including capital investments, fixed & variable costs, storage costs, transmission costs, the purchase cost of fuels, the income from selling the produced commodities (as negative costs in the function), and the penalty from emissions. The overall objective function is expressed as:

$$totalcost = \min(\zeta_{fixed} + \zeta_{\mathrm{var}} + \zeta_{stor} + \zeta_{trans} + \zeta_{buy} + \zeta_{sell} + \zeta_{emi}) \tag{2-1}$$

where the total fixed cost ζ_{fixed} is the sum of all the fixed costs of operating units:

$$\zeta_{fixed} = \sum_{t} \sum_{(n,p,u)\in NPU} fixedcost_{n,p,u} \cdot ON_{n,p,u,t} \tag{2-2}$$

The total variable cost ζ_{var} is the sum of the variable costs for all units. For each unit u, its variable cost is calculated by multiplying the unit variable cost ($/kW) by the generation amount (activities) of each unit (kW) plus the start-up cost if the unit is switched on:

$$\zeta_{\mathrm{var}} = \sum_{t} \sum_{(n,p,u)\in NPU} (varcost_{n,p,u} \cdot ACT_{n,p,u,t} + startcost_{n,p,u} \cdot SWITCH_{n,p,u,t}) \tag{2-3}$$

The total storage cost ζ_{stor} is the sum of the storage costs for all the storage installations. For each installation s, the cost is calculated by multiplying the unit variable storage cost by the inflow rate of commodity c into the installation.

$$\zeta_{stor} = \sum_{t} \sum_{(n,s,c)\in NSC} storvarcost_{n,s,c} \cdot STORIN_{n,s,c,t} \tag{2-4}$$

The total transmission cost ζ_{trans} is the sum of the transmission costs for all the transmission lines. For each line f, the cost is calculated by multiplying the unit variable transmission cost by the flow rate of commodity c via the line.

$$\zeta_{trans}=\sum_{t}\sum_{(n,n',f,c)\in NNFC} transvarcost_{n,s,c}\cdot TRAACT_{n,n',f,c,t} \tag{2-5}$$

The total purchasing cost ζ_{buy} is the sum of the fuel costs for all the commodities flowing into all the units. For each installation *f*, the fuel cost is calculated by multiplying the unit price of commodity *c* with its inflow amounts. Note that the input amounts of commodity *c* flowing into generation unit *u* is the product of its inflow rate coefficient $rate^{in}$ (parameter) and *ACT* of generation unit *u* (decision variable). The same rule applies to outflow calculation.

$$\zeta_{buy}=\sum_{t}\sum_{(n,p,u)\in NPU}\sum_{c\in C_{buy}} price_{n,c,t}\cdot rate^{in}_{n,p,u,v}\cdot ACT_{n,p,u,t} \tag{2-6}$$

The total income ζ_{sell} from selling the product commodity *c* is calculated by multiplying the unit price of this product by its output. Note that this item is negative:

$$\zeta_{sell}=-\sum_{t}\sum_{(n,p,u)\in NPU}\sum_{c\in C_{sell}} price_{n,c,t}\cdot rate^{out}_{n,p,u,c}\cdot ACT_{n,p,u,t} \tag{2-7}$$

Finally, the total emission cost ζ_{emi} for emitting commodity *c* is calculated by multiplying the unit price of this pollutant (e.g., carbon tax or carbon market price) by its emissions:

$$\zeta_{emi}=\sum_{t}\sum_{(n,p,u)\in NPU}\sum_{c\in C_{emi}} price_{n,c,t}\cdot rate^{out}_{n,p,u,c}\cdot ACT_{n,p,u,t} \tag{2-8}$$

2.4 Constraints

The model optimizes the objective function under a set of constraints. These constraints are set for commodity balance (ensures that at each time step *t* within each node *n*, the total supply of each regular commodity *c* equals its total consumption); Unit commitment constraints (ensure that the operating status and the action variable take an appropriate value when units start-up and changes status from the previous time step *t-1*); Capacity constraints (limit the activity for each operating unit within the range between the minimum capacity required for keeping the operating status and the maximum capacity of the unit); Storage constraints (ensure that the charging/discharging speed cannot exceed its charging/discharging capacity (or speed limit)); Transmission constraints (ensures that the transmission flow of commodity *c* could not exceed the capacity of transmission line with the account of the line loss).

2.4.1 Commodity Balance

The commodity balance ensures that at each time step *t* within each node *n*, the total supply of each regular commodity *c* equals its total consumption. The left-hand side of Eq. (9) is the total supply of commodity *c*, containing the outputs of this commodity (outflow) produced from all the generation units, the transmitted amounts from all other nodes to node *n*, and the discharged amounts from all the storage installations. The right-hand side is the total consumption of commodity *c*, including its final demand at node *n*, the amounts consumed for all the generation units, the quantities transmitted from node *n* to all other nodes, and the amounts flowing into all the storage installations. This balance holds for every regular commodity *c* at every time step *t* within every node *n*.

$$\begin{aligned}
&\sum_{(n,p,u)\in NPU} rate^{out}_{n,p,u,c} \cdot ACT_{n,p,u,t} + \sum_{(n',n,f,c)} transeff_{n',n,f,c} \cdot TRAACT_{n',n,f,c,t} \\
&\quad + \sum_{(n,s,c)\in NSC} storeff^{dis}_{n,s,c} \cdot STOROUT_{n,s,c,t} \\
&= demand_{n,c,t} + \sum_{(n,p,u)\in NPU} rate^{in}_{n,p,u,c} \cdot ACT_{n,p,u,t} + \sum_{(n,n',f,c)} TRAACT_{n,n',f,c,t} \\
&\quad + \sum_{(n,s,c)\in NSC} storeff^{ch}_{n,s,c} \cdot STORIN_{n,s,c,t} \\
&\forall n \in N, \forall t \in T, \forall c \in C_{com}
\end{aligned} \tag{2-9}$$

2.4.2 Unit Commitment Constraints

Constraints (10)-(12) ensure that the operating status *ON* and the action variable

SWITCH take an appropriate value (0, 1) when unit *u* starts up and changes status from the previous time step *t-1*.

$$SWITCH_{n,p,u,t} \le ON_{n,p,u,t} \quad \forall t \in T, \forall (n,p,u) \in NPU \tag{2-10}$$

$$SWITCH_{n,p,u,t} \le 1 - ON_{n,p,u,t-1} \quad \forall t \ne 1, \forall (n,p,u) \in NPU \tag{2-11}$$

$$ON_{n,p,u,t} - ON_{n,p,u,t-1} \le SWITCH_{n,p,u,t} \quad \forall t \ne 1, \forall (n,p,u) \in NPU \tag{2-12}$$

Constrain (13) ensures the change rate of activity for unit ***u*** falls within the range of ramp-up and ramp-down speed limits.

$$\begin{aligned} & -ramp^{down}_{n,p,u} \cdot cap_{n,p,u} \le ACT_{n,p,u,t} - ACT_{n,p,u,t-1} \le ramp^{up}_{n,p,u} \cdot cap_{n,p,u} \\ & \forall t \ne 1, \forall (n,p,u) \in NPU \end{aligned} \tag{2-13}$$

2.4.3 Capacity Constraints

Constraint (14) limits the activity for each operating unit *u* within the range between the minimum capacity required to keep the operating status and the unit's maximum capacity.

$$\begin{aligned} & mincap_{n,p,u} \cdot ON_{n,p,u,t} \le ACT_{n,p,u,t} \le cap_{n,p,u} \cdot capfactor_{n,p,u} \cdot ON_{n,p,u,t} \\ & \forall t \in T, \forall (n,p,u) \in NPU^{noren} \end{aligned} \tag{2-14}$$

Constraint (15) ensures that, for non-dispatchable renewable unit *u*, the unit runs at its total capacity if the capacity factor at time step *t* is larger than the minimum capacity requirement. Otherwise, the unit is shut down.

$$\begin{cases} \text{if } cap_{n,p,u} \cdot intermittent_{n,p,t} > mincap_{n,p,u} : \\ ACT_{n,p,u,t} = cap_{n,p,u} \cdot intermittent_{n,p,t} \cdot ON_{n,p,u,t} \\ \text{else:} \\ ACT_{n,p,u,t} = 0 \end{cases} \quad \forall t \in T, \forall (n,p,u) \in NPU^{ren}$$

(2-15)

2.4.4 Storage Constraints

Constraints (16) and (17) ensure that the charging/discharging speed (inflow/outflow rate) of commodity c into/from storage installation s can not exceed its charging/discharging capacity (or speed limit).

$$STORIN_{n,s,c,t} \le storcap^{in}_{n,s,c} \quad \forall t \in T, \forall (n,s,c) \in NSC \tag{2-16}$$

$$STOROUT_{n,s,c,t} \le storcap^{out}_{n,s,c} \quad \forall t \in T, \forall (n,s,c) \in NSC \tag{2-17}$$

Constraint (18) ensures that the stored amount of commodity c in installation s can not exceed the volume capacity of s.

$$STORCOM_{n,s,c,t} \le storcap^{v}_{n,s,c} \quad \forall t \in T, \forall (n,s,c) \in NSC \tag{2-18}$$

Constraint (19) calculates the initial status of commodity c in s when t =1.

$$STORCOM_{n,s,c,t} = storcap^{v}_{n,s,c} \cdot storinit_{n,s,c} \quad \forall t = 1, \forall (n,s,c) \in NSC \tag{2-19}$$

Constraint (20) calculates the energy status change of commodity c in s at time step t from t-1, by taking account of the inflow, the outflow at t, and the natural energy loss during the time interval.

$$\begin{aligned} STORCOM_{n,s,c,t} &= (1 - selfdischarge_{n,s,c}) \cdot STORCOM_{n,s,c,t-1} \\ &\quad + storeff^{in}_{n,s,c} \cdot STORIN_{n,s,c,t} \\ &\quad - storeff^{out}_{n,s,c} \cdot STOROUT_{n,s,c,t} \\ &\forall t \ne 1, \forall (n,s,c) \in NSC \end{aligned} \tag{2-20}$$

2.4.5 Transmission Constraints

Constraint (20) ensures that the transmission flow of commodity $\boldsymbol{c}$ could not exceed the capacity of transmission line *f,* with account the line loss.

$$TRAACT_{n,n',f,c,t} \le transeff_{n,n',f,c} \cdot transcap_{n,n',f,c} \quad \forall t \in T, \forall (n,n',f,c) \in NNFC$$

(2-21)

3 Parameters and Data

The CPOST model features techno-economic details on power generation, transmission, and electricity storage. Parameters and data are calibrated to 2023 based on various sources, including publicly available data, statistical data, commercial databases, and expert consultation.

3.1 Generation

CPOST includes both renewable and non-renewable power generation technologies:

- Coal w/o CCS: ultra-supercritical units (USC), supercritical units (SC), and subcritical units (Sub-C);
- Coal w/ CCS: ultra-supercritical units with CCS, supercritical units with CCS;
- Gas w/o CCS: combined cycle gas turbine (CCGT) and open cycle gas turbine (OCGT);
- Gas w/ CCS: CCGT with CCS and OCGT with CCS;
- Biomass w/ CCS;
- Biomass w/o CCS;
- Solar: centralized/distributed photovoltaic (PV) power station and solar thermal power plant (concentrated solar power, CSP);
- Wind: onshore/offshore wind;
- Nuclear.
- Hydro.

China's electricity demand has grown steadily, reaching 9,224 TWh in 2023—a 6.7% increase from the previous year[1]. This growth is primarily driven by rising industrial consumption, which accounts for 85.3% of total demand. Meanwhile, the supply side is still dominated by thermal power (mainly coal-fired plants), although significant structural shifts highlight progress toward a cleaner power sector. By the end of 2023, China's total installed power generation capacity reached 2,920 GW, a 13.9% increase from 2022. Non-fossil energy sources surpassed half the total capacity for the first time (Figure 3-1).

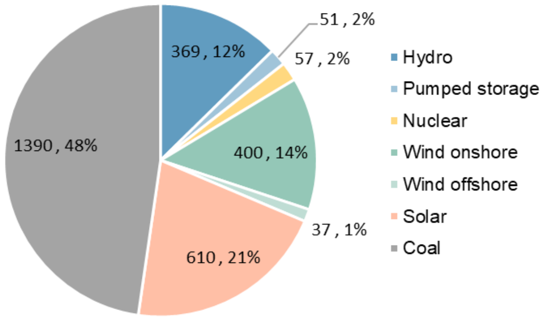

Figure 3-1 Installed capacity mix by technology in 2023 (unit: GW)[1].

Electricity consumption in China's East, Central, West, and Northeast regions grew by 6.9%, 4.3%, 8.1%, and 5.1%, respectively, compared to the previous year. All provinces in China experienced positive growth in total electricity consumption, with six provinces—Hainan, Xizang, Inner Mongolia, Ningxia, Guangxi, and Qinghai—seeing growth rates exceeding 10%[1–3]. These figures are used to calibrate the model's start-year parameters.

Regarding cost trajectory, the default baseline scenario assumes a downward trend in the costs of power generation technologies (Table 3-1). The model allows for adjustments to the cost of each specific generation technology in different scenario designs.

Table 3-1 Assumptions for the declining trend in future capacity costs (unit: US$/kW)[4–18].

technology	2025	2030	2035	2040	2045	2050	2055	2060
Coal w/o CCS	631	606	583	563	546	533	523	514
Coal w/ CCS	1015	932	860	798	753	719	695	668
Gas w/o CCS	325	315	306	298	291	286	282	278
Gas w/ CCS	678	617	564	519	487	463	446	427
Biomass w/o CCS	1290	1231	1191	1150	1113	1080	1053	1032
Biomass w/ CCS	2321	2108	1936	1784	1668	1580	1515	1445
Hydro	2168	2059	1966	1873	1873	1873	1873	1873
Nuclear	2311	2242	2173	2103	2034	1965	1910	1865
Solar: CSP	493	394	296	272	251	232	217	205
Solar: PV	393	336	279	256	235	216	201	189
Solar: thermal	2329	1491	1400	1309	1227	1154	1095	1048
Wind: onshore	600	521	489	457	428	402	378	360
Wind: offshore	1383	1047	808	778	750	726	706	690
Storage: battery	1237	1090	1002	949	917	898	889	884
Storage: pumped-hydro	824	798	773	764	757	750	744	740
UHV	347	329	325	315	306	299	296	295

3.2 Transmission

The CPOST model divides the subnational power systems into seven grid regions: North, Northeast, East, Central, Northwest, South, and Southwest. The provincial coverage of the above grid boundaries is shown as follows (Hong Kong, Macau, and Taiwan are not included for now):

Table 3-2 Regional power grid division.

Region	Provinces
North	Beijing; Tianjin; Hebei; Shanxi; Inner Mongolia; Shandong
Northeast	Liaoning; Jilin; Heilongjiang
East	Shanghai; Jiangsu; Zhejiang; Anhui; Fujian
Central	Jiangxi; Henan; Hubei; Hunan
Northwest	Shaanxi; Gansu; Qinghai; Ningxia; Xinjiang
South	Guangdong; Guangxi; Hainan; Guizhou; Yunnan
Southwest	Chongqing; Sichuan; Xizang

Figure 3-2 Map of regional power grid division.

Inter-regional power transmission in China mainly relies on ultra-high voltage (UHV) lines. These UHV lines are modeled simplistically, where transmission capabilities between regions are uniformly expressed in transmission capacity (GW). By the end of 2023, China's transformer and converter equipment capacity, rated at 220 kV and above, reached approximately 5.42 TW(TVA), a year-on-year increase of 5.7%. Specifically, the capacity of 1000 kV AC transformer equipment was around 213 GVA, while ±800 kV and above DC converter equipment had a capacity of approximately 336 GW[19]. To date, 39 UHV transmission projects have been completed nationwide (among them 18 inter-regional projects), enabling a cross-provincial transmission capacity exceeding 300 GW and a cumulative power transmission exceeding 3 PWh[20,21]. Based on these figures, the model was calibrated to align with the current infrastructure, incorporating the existing list of UHV transmission projects.

Table 3-3 Current status of inter-regional power transmission (source: compiled by the authors based on public information).

Start	End	Investment (billion RMB)	Capacity (GW)
North	Central	5.7	6
North	East	102.9	61
Northwest	East	86.3	55
South	East	45.3	13.6
Northwest	Central	90.7	40
Southwest	East	115.7	24
Southwest	Central	24.4	8

UHV transmission projects' investment costs primarily include infrastructure investment, lines and towers, and in-station equipment. In the CPOST model, the cost of UHV transmission is simplified by calculating the total cost of the transmission project and dividing it by its capacity. Analysis of 18 existing inter-regional UHV transmission projects indicates that the unit capacity cost ranges from $137 to $556 per kW, typically showing a negative correlation with capacity. In addition, the construction cost of UHV lines is significantly affected by location and geographical environment. For instance, the construction cost in the southwest mountainous area can reach approximately 5 times that in the central and eastern plain areas (Figure 3-3). Future expenditure on transmission capacity expansion can be easily calculated by multiplying the capacity by the corresponding average unit capacity cost specific to the grid region involved.

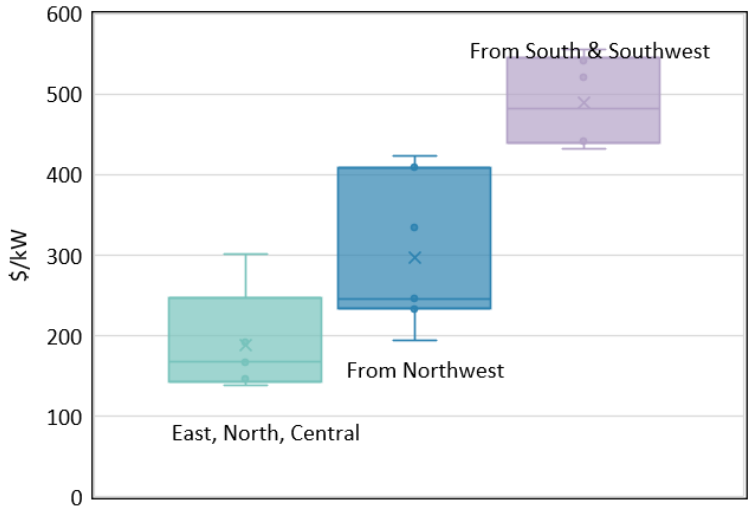

Figure 3-3 Cost distribution of UHV transmission projects (source: compiled by the authors based on public news).

CPOST can also be used to calculate and analyze scenarios for the future development of power transmission. The future power transmission is expected to continue expanding, as the geographic disparity between China's clean energy resources and electricity demand necessitates initiatives like 'West-to-East' and 'North-to-South' power transmission projects to meet the growing demand in central and eastern regions. In CPOST, these changes are calculated with considerations of the announced planning by imposing growth constraints on new transmission capacity in the model. For example, in a baseline scenario (Figure 3-4 and Figure 3-5), it is assumed that by the end of the 14th Five-Year Plan, inter-regional power transmission capacity will increase from 220 GW in 2019 to 360 GW by 2025. This increase includes 127 GW from Northwest China, 94 GW from Southwest China and Yunnan, 93 GW from North China, 15 GW from Northeast China, and 31 GW from other transmission lines. By 2035, total capacity is projected to reach 488 GW; by 2050, it is expected to expand to 631 GW[22].

Figure 3-4 Inter-regional power transmission in 2025.

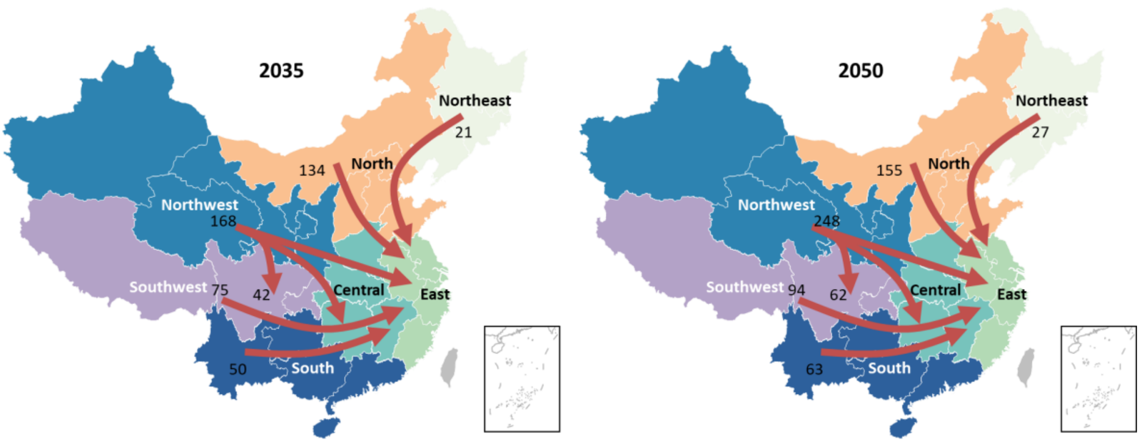

Figure 3-5 Inter-regional power transmission in 2035 and 2050.

3.3 Storage

The storage technologies modeled in CPOST include energy storage power stations and pumped-storage hydroelectricity (PSH). The installations are calibrated based on historical data. The *Global Hydropower Tracker* by Global Energy Monitor provides information on PSH station planning in provinces of China, encompassing announced, planned, and under-construction projects[23]. By 2060, the total installed capacity is projected to increase by 291.4 GW compared to 2030, reaching a cumulative capacity of 437.2 GW. The model is adjusted according to the specific circumstances of each province.

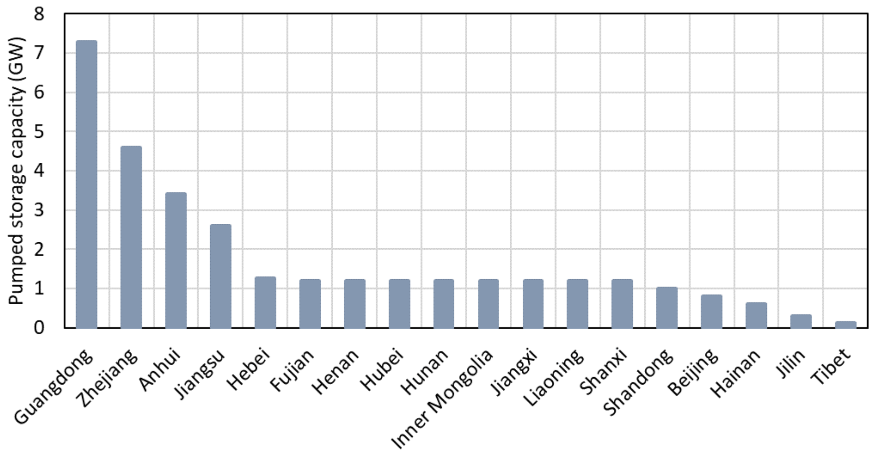

Figure 3-6 Pumped storage capacity in provinces (2020)[23].

Regarding costs, the model refers to the data from the China Electricity Council and calibrated with other sources[11,24,25]. In 2020, the average capital cost of PSH stations (5 hours) was approximately $1422/kW. For chemical energy storage power stations (2 hours), the capital cost is around $950/kW. The possible declining ratios of these costs in the future are taken from NREL and other literature, and then the costs in 2020 are used as a benchmark to derive future costs[26].

4 Demand Estimation

Electricity demand for each province is estimated exogenously to the model, mainly based on projections on driving factors such as GDP, population, industrial structure, etc. China’s total electricity consumption in 2023 reached 9.22 PWh, with a per capita consumption of 6.54 MWh, an increase of 422 kWh per person compared to the previous year[24]. Future pathways are based on the experiences of representative countries, such as the United States, EU countries, and Japan. Analysis of historical data in these countries reveals that total electricity consumption stabilizes after reaching a certain level, with an annual growth rate below 5%[27]. Additionally, per capita electricity consumption tends to rise initially as GDP increases, but eventually peaks and declines.

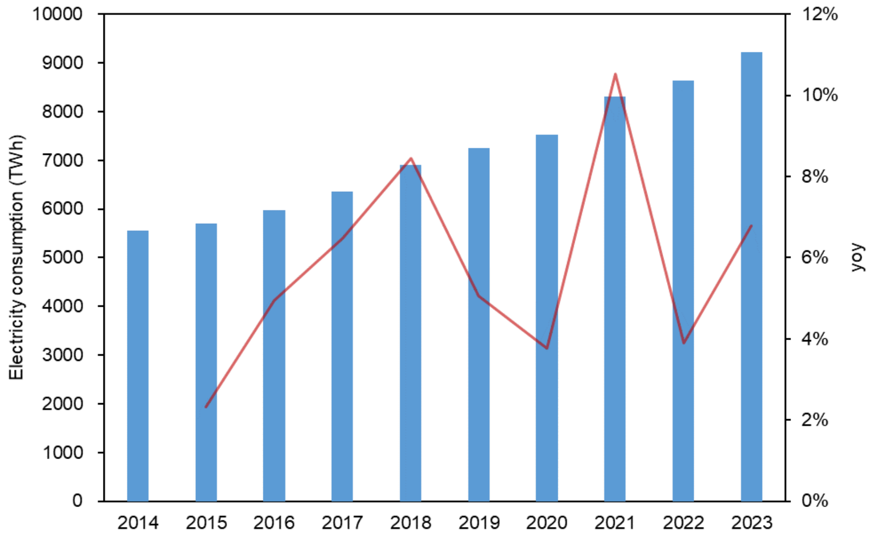

Figure 4-1 Electricity consumption and year-on-year growth rate[25].

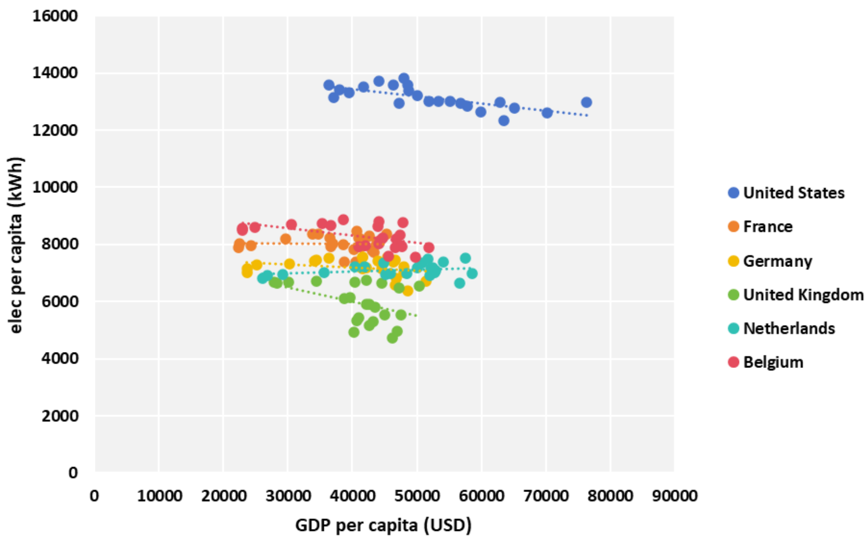

Figure 4-2 Electricity consumption and GDP per capita in representative countries[27].

Considering China still faces rapid electricity demand growth, we assume that future per capita electricity consumption in China will gradually increase from the current level to a saturation level of approximately 12 to 15 MWh. Under the high-demand scenario, the country's total electricity consumption is expected to grow moderately during the 14th FYP (2021–2025), reaching 13.5 PWh by 2030, with an average annual growth rate of about 5.3%; during the 15th FYP (2026–2030), the growth rate is expected to slow to around 2.3% annually, with total electricity consumption reaching 15.1 PWh by 2035. Under the low-demand scenario, electricity consumption is expected to reach 11.9 TWh by 2030 and 13.1 TWh by 2035. These scenarios are exogenously input into the model to generate the total electricity generation required to meet the supply-demand balance.

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