Power Transition in China: 1.5/2°C Scenario, Pathways and Challenges
Scenarios
Global carbon budget for 1.5/2°C scenario

- Global power/energy sector must decarbonize under the frame of carbon emission cap in 1.5/2 °C scenario.

Global carbon emissions in various scenarios

Annual fossil fuel and industrial process CO₂ emissions

Source: IPCC; Gambhir (2019)
Carbon budget for 1.5/2°C scenario in China

✓ Power sector accounts for 50% of total CO2 emissions in China.
✓ 1.5/2°C scenario necessitates the zero-emissions and even negative-emissions for power sector by 2050.

Source: 1.5°C report - NCEPU
Hypothesis for 1.5/2°C scenario in China

✓ Total population in China will peak around **1420 million** by 2030.
✓ Per capita electricity consumption is expected to be **6200-7200 kWh/p** in 2030 and **7000-10000 kWh/p**.
✓ It is a must for China to rely on ultra-high energy efficiency to effectively curb the growth of electricity consumption.

### Population outlook in China

- **2018**: 1395 million
- **2030**: 1420 million
- **2050**: 1380 million

### Per capita electricity consumption

Source: 1.5°C report - NCEPU
Hypothesis for 1.5/2°C scenario in China

1.5DS
- 1.5DS asks for very high electrification ratio (>70%).

High electrification
- The high electrification pushes up power demand and even exceeds resource carrying capacity.

Resource carrying capacity
Determines that China cannot follow a way that industrialized nations like the USA or Canada have pursued.

Analysis
We assume that ultra-high energy efficiency can reconcile 1.5DS demands with economy-energy-environment (3E) system.
Thus, we hypothesize the per capita electricity consumption in 2050 is 7000kWh/p and 10000kWh/p in the 2°C and 1.5°C scenario, respectively.

Source: 1.5°C report - NCEPU
Hypothesis for 1.5/2°C scenario in China

✓ Low-carbon transition requires a package of options.
✓ High-share renewable energy is **crucial**, but not enough to achieve negative emissions in the 1.5°C scenario.

### 2°C scenario
- High efficiency
- Low-level of per capita electricity consumption (7000 kWh/per in 2050)
- No more newly-built coal-fired plants
- Non-fossil power capacity approaching resource cap

### 1.5°C scenario
- High-level of per capita electricity consumption (10000 kWh/per in 2050)
- Decarbonization of conventional energy
- Non-fossil power approaching resource cap
- Zero-emission in 2040 and negative-emission in 2050

Source: 1.5°C report - NCEPU
The power system for 1.5/2°C scenario in China features carbon-emitting thermal power generating technologies phase-out and high-share renewables.

Carbon emission outlook for power sector in China

<table>
<thead>
<tr>
<th>Year</th>
<th>2010 (GW)</th>
<th>2017 (GW)</th>
<th>2030 (GW)</th>
<th>2050 (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Th</td>
<td>319</td>
<td>1777</td>
<td>3537</td>
<td>5768</td>
</tr>
<tr>
<td>Nu</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>RE</td>
<td>73%</td>
<td>62%</td>
<td>34%</td>
<td>13%</td>
</tr>
</tbody>
</table>

Power sector: zero emissions in 2040 and Negative in 2050

Source: 1.5°C report - NCEPU
Renewables will become the dominate power guaranteeing the main power supply through the flexibility of various power plants.

Electricity consumption outlook in China

<table>
<thead>
<tr>
<th>Year</th>
<th>TWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>1313TWh</td>
</tr>
<tr>
<td>2010</td>
<td>4228TWh</td>
</tr>
<tr>
<td>2018</td>
<td>6994TWh</td>
</tr>
<tr>
<td>2030</td>
<td>10583TWh</td>
</tr>
<tr>
<td>2050</td>
<td>14073TWh</td>
</tr>
</tbody>
</table>

Note: Th-Thermal; Nu-Nuclear; RE-Renewable energy

Source: 1.5°C report - NCEPU
Pathways
Pathway 1: mass deployment of renewables

- Grid parity will be achieved in the near & short term.
- A sun-set mechanism in FiT and then integration with the market are the solution for large-scale development of renewables.

Wind power resource districts and its tariff in China

Solar power resource districts and its tariff in China

Source: NDRC
The large-scale deployment of wind & solar power is the pillar of energy supply revolution, replacing coal power.

Wind & Solar capacity outlook in 1.5/2°C scenario, China

Source: 1.5°C report - NCEPU
Pathway 2: coal power phase-out

✓ Both scenarios will require the coal capacity stabilizing around **1000GW** during 2020-2030 and then quick phase out afterwards.

✓ The pressure of phase-out in the 1.5 DS is smaller than that in 2DS, due to more CCS deployment.

✓ BUT, Coal power phase-out is not on track with China’s existing policy

Coal power phase-out pathways in line with 2/1.5DS in China

- Source: 1.5°C report - NCEPU
Pathway 3: massive biomass deployment

- Large-scale development of coal coupled biomass is essential for negative-emissions of power sector.

**Dedicated biomass**
- Capacity: 1-50MW
- Efficiency: ≤30%
- Initial investment: High
- Economics: Poor (limited by biomass resource)

**Coal + biomass**
- Capacity: 100-1000MW
- Efficiency: ≥40%
- Initial investment: Only retrofit cost
- Economics: High

**Characteristic**
- + CCS

**Tip**
The expansion of biomass power is decided by the unconventional biomass resources.

Source: 1.5°C report - NCEPU
Pathway 4: nuclear power development

- Nuclear capacity under construction in China ranks the first place in the world.
- There is still a fraction of gap between reality and target of nuclear power during 13th FYP.
- For the long-term transition, the capacity gap is even large in China.

Nuclear power development scenarios in China

<table>
<thead>
<tr>
<th>Year</th>
<th>1.5DS</th>
<th>2DS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>44.6</td>
<td></td>
</tr>
<tr>
<td>2020BAU</td>
<td>58</td>
<td>53</td>
</tr>
<tr>
<td>2030</td>
<td>150</td>
<td>140</td>
</tr>
<tr>
<td>2040</td>
<td>210</td>
<td>190</td>
</tr>
<tr>
<td>2050</td>
<td>300</td>
<td>230</td>
</tr>
</tbody>
</table>

Source: 1.5°C report - NCEPU
Pathway 5: energy storage deployment

- China's energy storage development are seriously inadequate.
- Proper pumped storage resources are rather limited.
- To be on track, new energy storage must develop quickly in China.

The share of ES in total generation capacity, 2017

- Pumped storage: 98.7% (2017: 28.9 GW, 1.3%)
- Electrochemical energy storage: 1.6%

Energy storage development in China

- 2017: 28.9 GW
- 2030: 250 GW (60%)
- 2050: 800 GW (63%)

Source: 1.5°C report - NCEPU
Pathway 6: CCS deployment

- CCS technology is essential to global carbon emissions abatement.
- China has the largest fleet of coal units that should be considered attractive for CCS retrofit.
- The below 2°C target necessitates 182 GW coal power with CCS retrofit, while 2030-2035 is the best deployment time for China.

**Existing CCS project map in China**

**CCS retrofit outlook in China**

<table>
<thead>
<tr>
<th>Year</th>
<th>Retrofit Potential</th>
<th>Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>2030</td>
<td>430 GW</td>
<td>$54.3 billion</td>
</tr>
<tr>
<td>2035</td>
<td>140 GW</td>
<td>$38.46 billion</td>
</tr>
<tr>
<td>2040</td>
<td>3 GW</td>
<td>$13.39 billion</td>
</tr>
</tbody>
</table>

Source: IEA; Yang (2019) - CCUS map
### LCOE outlook for decarbonization power technology in China

<table>
<thead>
<tr>
<th>Category (CNY/kWh)</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>USC</td>
<td>0.39</td>
<td>0.37</td>
<td>0.36</td>
<td>0.35</td>
</tr>
<tr>
<td>USC+CCS</td>
<td>0.68</td>
<td>0.66</td>
<td>0.65</td>
<td>0.64</td>
</tr>
<tr>
<td>CFBC</td>
<td>0.48</td>
<td>0.46</td>
<td>0.45</td>
<td>0.44</td>
</tr>
<tr>
<td>CFBC+CCS</td>
<td>0.86</td>
<td>0.83</td>
<td>0.82</td>
<td>0.80</td>
</tr>
<tr>
<td>IGCC+CCS</td>
<td>0.74</td>
<td>0.70</td>
<td>0.67</td>
<td>0.65</td>
</tr>
<tr>
<td>NGCC</td>
<td>0.72</td>
<td>0.66</td>
<td>0.6</td>
<td>0.53</td>
</tr>
<tr>
<td>NGCC+CCS</td>
<td>0.8</td>
<td>0.74</td>
<td>0.67</td>
<td>0.6</td>
</tr>
<tr>
<td>Distributed gas power</td>
<td>0.7</td>
<td>0.64</td>
<td>0.58</td>
<td>0.5</td>
</tr>
</tbody>
</table>

### Total investment for 1.5/2°C transition in China

<table>
<thead>
<tr>
<th>Time Period</th>
<th>2°C</th>
<th>1.5°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015-2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020-2030</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030-2040</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2040-2050</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Renewable investment will peak during 2030-2040.**
- **The additional transition investment from 2DS to 1.5DS will be ¥8960 billion during 2015-2050, including decarbonization cost of traditional power, renewables grid-integration cost and new energy storage cost, etc.**

*Source: 1.5°C report - NCEPU*
Transition costs in 1.5°C scenario, China

✓ However, if the stranded assets value of earlier coal phase-out/low efficiency operation are taken into consideration, the transition costs will double!

Stranded asset estimation of existing and new coal power beginning in 2016, China

<table>
<thead>
<tr>
<th>Stranded year</th>
<th>Existing</th>
<th>Newly-built</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2021 (5 years)</td>
<td>[A] ¥2703 ($393)</td>
<td>[B] ¥4498 ($654)</td>
<td>[A+B] ¥7201 ($1047)</td>
</tr>
<tr>
<td>2026 (10 years)</td>
<td>[C] ¥2051 ($298)</td>
<td>[D] ¥3746 ($545)</td>
<td>[C+D] ¥5797 ($843)</td>
</tr>
<tr>
<td>2031 (15 years)</td>
<td>[E] ¥1426 ($207)</td>
<td>[F] ¥2994 ($435)</td>
<td>[E+F] ¥4420 ($643)</td>
</tr>
<tr>
<td>2036 (20 years)</td>
<td>[G] ¥843 ($123)</td>
<td>[H] ¥2243 ($326)</td>
<td>[G+H] ¥3086 ($449)</td>
</tr>
</tbody>
</table>

Source: Stranded assets and thermal coal in China- B. Caldecott, et al.- University of OXFORD
Challenges
Transition challenges in China

- 1.5DS asks for very high electrification ratio (>70%) and pushes up demand
- Unconventional biomass resource (LUBE) and its LCA carbon footprint
- Technology breakthrough of CCS/CCUS and its massive deployment
- Technology innovation and prompt commercialization of GIII and GIV nuclear
- The planning and operation of high-share renewables-based power system
- The integration of multi-energy systems and energy internet
- Commercialization and mass application of Energy storage in power systems
Challenge 1: provision of flexibility

- Large-scale commercial energy storage, traditional flexible power (pumped storage, gas and CSP) and new flexible resources (EVs and DR) ensure the reliable operation of renewable power system.

Flexible resources demand in 1.5°C scenario, China

Source: 1.5°C report - NCEPU
Planning process of power transition in China

- Four steps of transition planning are defined as: **generation expansion planning** (20-40 years), **geo-spatial planning** (5-20 years), **dispatch simulation** (weeks to a year) and **technical network studies** (current and near-time).

- From long-term through short-term planning steps, clear and internally consistent **feedback loops** within techno-economic assessments can avoid near-term inefficiencies due to a poorly specified long-term transition plan.

- The five main properties of VRE generators are: **weather-dependent nature**, **uncertainty in forecasts**, **location constrained**, **non-synchronous** and feature as **distributed generation**, which influences certain functional properties of the power system (**firm capacity, flexibility, transmission capacity, voltage control, and frequency and voltage response***).

Key links between variable renewable energy, power system properties and planning

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**VRE PROPERTIES**
- Non-Synchronous
- Location-constrained and distributed
- Uncertainty
- Variability

**SYSTEM PROPERTIES**
- Frequency and Voltage response
- Voltage control
- Transmission capacity
- Flexibility
- Firm capacity

**PLANNING STAGES**
- Technical network studies
- Geo-spatial planning and technical network studies
- Dispatch simulation
- Generation expansion planning

Tools and analyses for energy system planning with feedback

**Long-term energy planning models**
(time resolution: hours - seasons)

**Geo-spatial planning models**
(time resolution: hours - seasons)

**Production cost models**
(time resolution: minutes - hours)

**Static grid models**
(time resolution: single point)

**Dynamic grid models**
(time resolution: milliseconds - minutes)

Source: Planning for the renewable future - IRENA
For reasons specific to Jilin province, wind power curtailment is more pervasive owing to an inflexible power generation system dominated by conventional heating fleet.

The production simulation case hypothesizes that the minimum technical output of condensing and CHP units could reach 30% and 40% of rated capacity, respectively.

### Power structure in Jilin province

- **Coal**: 58%
- **Hydro**: 19%
- **Wind**: 16%
- **Solar**: 5%
- **Others**: 2%

### Parameters for production simulation in Jilin, 2030

<table>
<thead>
<tr>
<th>Parameters</th>
<th>BAU scenario</th>
<th>Low-carbon scenario</th>
<th>Extreme scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum load</td>
<td></td>
<td>18.75GW</td>
<td></td>
</tr>
<tr>
<td>Minimum output of condensing unit</td>
<td></td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>Minimum output of CHP in summer</td>
<td></td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>Minimum output of CHP in winter</td>
<td></td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>Coal power capacity</td>
<td>22.75GW</td>
<td>12GW</td>
<td>6GW</td>
</tr>
<tr>
<td>REs</td>
<td>22.5GW</td>
<td>29.7GW</td>
<td>34.7GW</td>
</tr>
<tr>
<td>Pumped storage</td>
<td></td>
<td>4.1GW</td>
<td></td>
</tr>
<tr>
<td>Gas power</td>
<td></td>
<td>1GW</td>
<td></td>
</tr>
<tr>
<td>Nuclear</td>
<td></td>
<td>2.5GW</td>
<td></td>
</tr>
<tr>
<td>Net export</td>
<td>3.34GW in summer</td>
<td>2.56GW in winter</td>
<td></td>
</tr>
</tbody>
</table>

*Source: NDRC, NCEPU*
✓ De-capacity for coal power would not weaken the reliability of power system.
✓ The loss of load probability is still within reliable range in the low-carbon and extreme scenarios.

### Scenario indicators of production simulation, 2030

<table>
<thead>
<tr>
<th>Loss of load probability (LOLP, %)</th>
<th>BAU Summer</th>
<th>BAU Winter</th>
<th>Low-carbon Summer</th>
<th>Low-carbon Winter</th>
<th>1.5DS Summer</th>
<th>1.5DS Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seasonal utilization hours</td>
<td>4.95E-22</td>
<td>1.54E-11</td>
<td>1.01E-06</td>
<td>9.61E-06</td>
<td>6.48E-06</td>
<td>5.01E-05</td>
</tr>
<tr>
<td>Annual utilization hours</td>
<td>1027</td>
<td>0</td>
<td>1031</td>
<td>0</td>
<td>1033</td>
<td>0</td>
</tr>
<tr>
<td>Coal power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seasonal utilization hours</td>
<td>2053</td>
<td>2063</td>
<td>2066</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual utilization hours</td>
<td>522</td>
<td>738</td>
<td>4589</td>
<td>1557</td>
<td>3098</td>
<td>5700</td>
</tr>
<tr>
<td>Wind power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seasonal utilization hours</td>
<td>3049</td>
<td>499</td>
<td>598</td>
<td>498</td>
<td>2203</td>
<td>2188</td>
</tr>
<tr>
<td>Annual utilization hours</td>
<td>504</td>
<td>597</td>
<td>499</td>
<td>598</td>
<td>2203</td>
<td>2188</td>
</tr>
<tr>
<td>Solar power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seasonal utilization hours</td>
<td>308</td>
<td>310</td>
<td>310</td>
<td>311</td>
<td>302</td>
<td>312</td>
</tr>
<tr>
<td>Annual utilization hours</td>
<td>1236</td>
<td>1242</td>
<td>1242</td>
<td>1242</td>
<td>1236</td>
<td>1227</td>
</tr>
<tr>
<td>Wind curtailment rate (%)</td>
<td>0.46</td>
<td>0.22</td>
<td>1.21</td>
<td>0.35</td>
<td>1.46</td>
<td>0.59</td>
</tr>
<tr>
<td>Solar curtailment rate (%)</td>
<td>0.41</td>
<td>0.31</td>
<td>0.86</td>
<td>0.22</td>
<td>2.92</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Source: NDRC, NCEPU
Production simulation case in Jilin province

✓ The flexibility of coal power and adding gas capacity is crucial to grid-integration of wind & solar power.

Source: NDRC, NCEPU
Challenge 2: massive stranded coal assets

✓ With an average plant age of 14 years, retirement plan could lead to high stranding value.
✓ For the coal fleet built in 2016, if stranding 200GW in 1.5DS and 700GW in 2DS, the stranded assets could be ¥150 and 520 billion (with 2020 as stranding year).

Operating coal power plant capacity by year built

Stranded asset estimation beginning in 2016, China

Source: 1.5°C report - NCEPU
Challenge 3: inadequate unconventional biomass resources

✓ The inadequate unconventional biomass resources intrinsically challenge the feasibility of negative emissions in the 1.5°C scenario.
✓ Even having enough resources, the LCA footprint of unconventional biomass is a matter of issue.

Biomass resource supply in China, 2050

<table>
<thead>
<tr>
<th></th>
<th>Conventional supply</th>
<th>Unconventional supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mtce</td>
<td>1.5DS</td>
<td>2DS</td>
</tr>
<tr>
<td>2018</td>
<td>200</td>
<td>460</td>
</tr>
</tbody>
</table>

Source: 1.5°C report - NCEPU
Nuclear power will remain an indispensable base-load power source competitive with coal power.

The technology innovation of third-generation nuclear (GⅢ) and commercialization process under coming power markets are barriers for expanding nuclear capacity.

Source: 1.5°C report - NCEPU
Challenge 5: Energy storage commercialization

Challenges

1. Economics
2. Position definition
3. Commercial model
4. Battery recycling

Energy storage

Resource | Generation | Transmission | Distribution | Consumption

Source: 1.5°C report - NCEPU
**Challenge 6: Energy efficiency and DR**

- The potential energy conservation share by EE should be 30-40% of total consumption.
- However, deploying EE in such a large scale is a tremendous challenge to China.

### Electricity saving by EE in China, 2020-2050

<table>
<thead>
<tr>
<th>Demand side resources</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric vehicle</td>
<td>3.6</td>
<td>40</td>
<td>100</td>
<td>270</td>
</tr>
<tr>
<td>Efficient lightbulb</td>
<td>187.5</td>
<td>375</td>
<td>450</td>
<td>500</td>
</tr>
<tr>
<td>Efficient motor</td>
<td>28</td>
<td>60</td>
<td>100</td>
<td>140</td>
</tr>
<tr>
<td>Efficient transformer</td>
<td>28</td>
<td>480</td>
<td>640</td>
<td>800</td>
</tr>
<tr>
<td>Variable frequency speed governor</td>
<td>17.5</td>
<td>300</td>
<td>400</td>
<td>500</td>
</tr>
<tr>
<td>Ice Thermal Storage</td>
<td>1.6</td>
<td>4</td>
<td>80</td>
<td>9.6</td>
</tr>
<tr>
<td>High efficiency household appliances</td>
<td>16</td>
<td>40</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Demand response (DR)</td>
<td>2</td>
<td>3.5</td>
<td>50</td>
<td>580</td>
</tr>
<tr>
<td>Energy efficiency of building</td>
<td>0</td>
<td>100</td>
<td>1000</td>
<td>1500</td>
</tr>
<tr>
<td>Others</td>
<td>0</td>
<td>48</td>
<td>315</td>
<td>156</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>284</td>
<td>1450</td>
<td>3255</td>
<td>4140</td>
</tr>
</tbody>
</table>

**Source:** 1.5°C report - NCEPU
Challenge 7: CO2 Peak to zero in two decades---impossible mission?

✓ It is possible for China to achieve zero emissions by 2050 after peaking in 2030?

Carbon emissions in peaked nations, 1965-2017

- Germany: 1973
- France: 1973
- Britain: 1973
- Denmark: 1996
- Finland: 2003
- Italy: 2005
- US: 2007
- Japan: 2012
Wrapping up

Transition to 1.5/2DS power system is possible but with tremendous challenges.

We can hypothesize the abatement scenarios, but the pathways remain highly uncertainty.

Coal power represents the largest barrier to 1.5DS transition: no new build and stranded assets.

No one-size-fits-all solution: high share of RE is not enough for 1.5DS transition!

We suggest to implement more ambitious 2050 Energy Revolution Strategy and roadmap, meanwhile reform the energy system in a retrospective way, making sure that medium and short term targets consistent with long-term vision.

Time matters! Today’s policy and planning, will determine the road towards 2030 and 2050.
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Questions & Comments

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