



Energy Technologies Area

Lawrence Berkeley National Laboratory

Challenges and Strategies for Electricity Market Transition in China

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- Background
- Research Questions
- Methods and Scenarios
- Results
- Conclusions

- China is currently undergoing power sector reform
 - Change from planning to markets for both electricity pricing and dispatch
- Guangdong power market reform
 - Focusing on electricity wholesale market and promoting demand side management
 - Among the first batch of pilots to launch real-time wholesale market in 2018
- Market reforms in China have started to run into political economy obstacles
 - Current discussion in China lacks a more quantitative sense of what the impacts on different stakeholders might be, and how these could be overcome

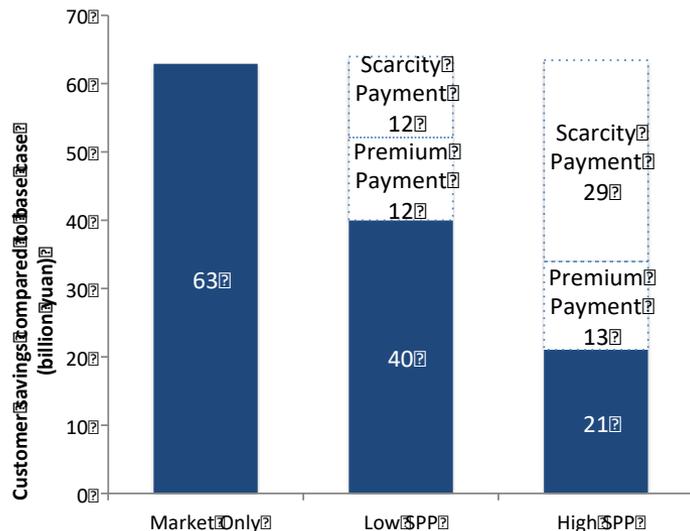
- History of generator tariffs/cost recovery and investment in China (1985-Present)

| Generation Pricing Approach | | Years | Description |
|-----------------------------|--------|--------------|--|
| Cost-plus tariff | 还本付息电价 | 1985-1998 | Paid generators on a levelized energy cost (yuan/kWh) basis using actual annual costs, calculated individually for each plant and, in some cases, each unit; tariffs were initially high, reflecting depreciation costs, and then dropped significantly once the plant or unit was fully depreciated |
| Operating life tariff | 经营期电价 | 1998-2002 | Paid generators on a levelized energy cost (yuan/kWh) basis, calculated individually for each plant using average cost across the expected lifetime of the plant; addressed the “tariff shock” problem with the cost-plus tariff |
| Benchmark tariff | 标杆上网电价 | 2004-present | Pays generators on a fixed benchmark energy cost (yuan/kWh) basis, with a nearly uniform tariff for all coal generators and using a benchmark based on the estimated levelized cost of an advanced coal unit |
| Market pricing | 市场定价 | 2015-present | Generation prices are negotiated bilaterally between generators and buyers or cleared through a monthly auction; initially generation prices were based on reductions from the benchmark tariff |

- Generator economics in a market environment
 - Shift from administratively-determined fixed price to market price

Previous Study and Research Question

- Significant potential gains (21 to 63 billion yuan, 9%-27% reduction in total costs in a base case) from implementing electricity markets in Guangdong (and China)
 - The extent of these gains depends on how much in savings must be paid out as premiums to clean generation and paid to generators in the form of scarcity payments
 - Even with these payments, significant savings are likely to remain



- Research Question

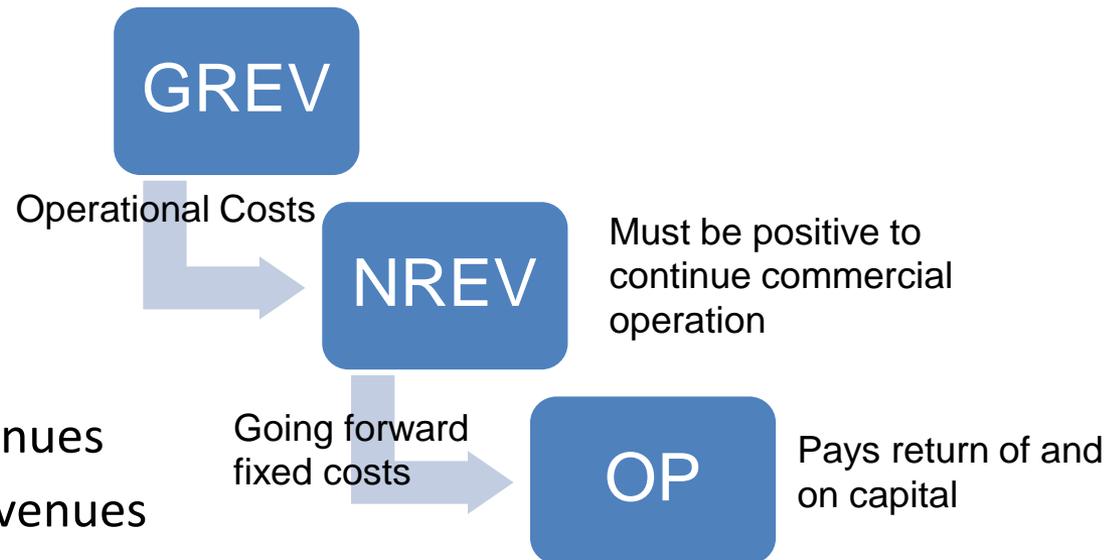
- What are the impacts of electricity market on different coal power plants and companies?

- Calculate financial situations of each generator and company under different market price scenarios

- $NREV = GREV - C_{oper}$

- $OP = NREV - C_{fixed}$

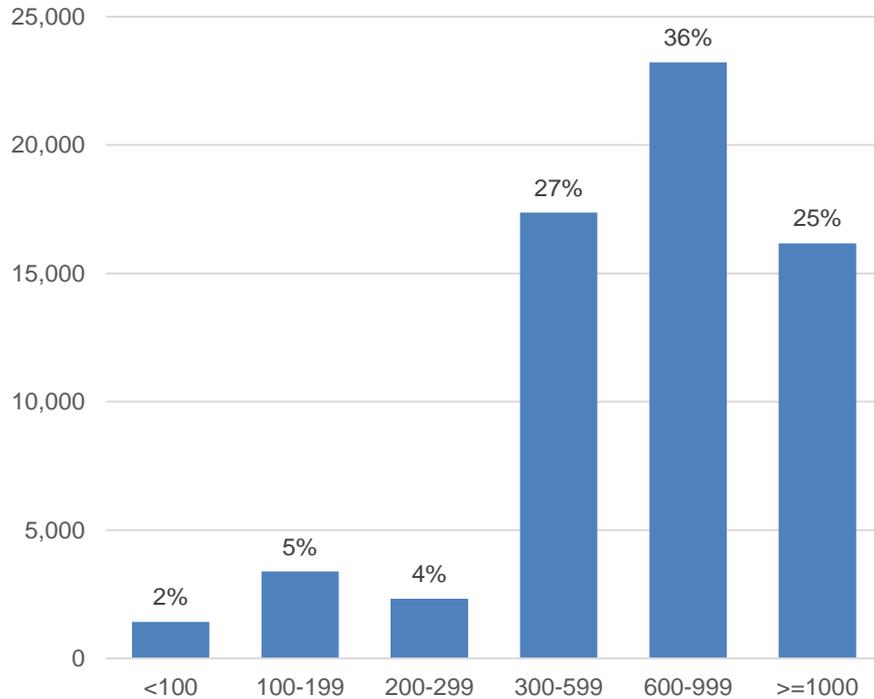
- NREV: Net revenues
- GREV: Gross revenues
- C_{oper} : Operational costs
- OP: Operating profits
- C_{fixed} : Fixed costs/going forward fixed costs, which is the sum of insurance, labor costs, fixed O&M costs, and taxes



- **Benchmark Scenario:** Inherent the “reference scenario” of the previous study
 - planned operating hours
 - Demand: Total electricity consumption in Guangdong was 561 TWh (2016); 28% import
 - Supply: Installed capacity and annual operating hours for each type of generators
- **Low Market Price Scenario:** Inherent the “market-only scenario” of the previous study
 - least marginal cost dispatch
 - Coal price = 800 yuan/tce
 - Hydro operating hours = 2016 levels (3,550 hours)
- **High Market Price Scenario:** Inherent the “market-only scenario” of the previous study, but increase coal price and decrease hydro availability
 - Coal price = 1000 yuan/tce
 - Hydro operating hours = 2015 levels (2,096 hours)

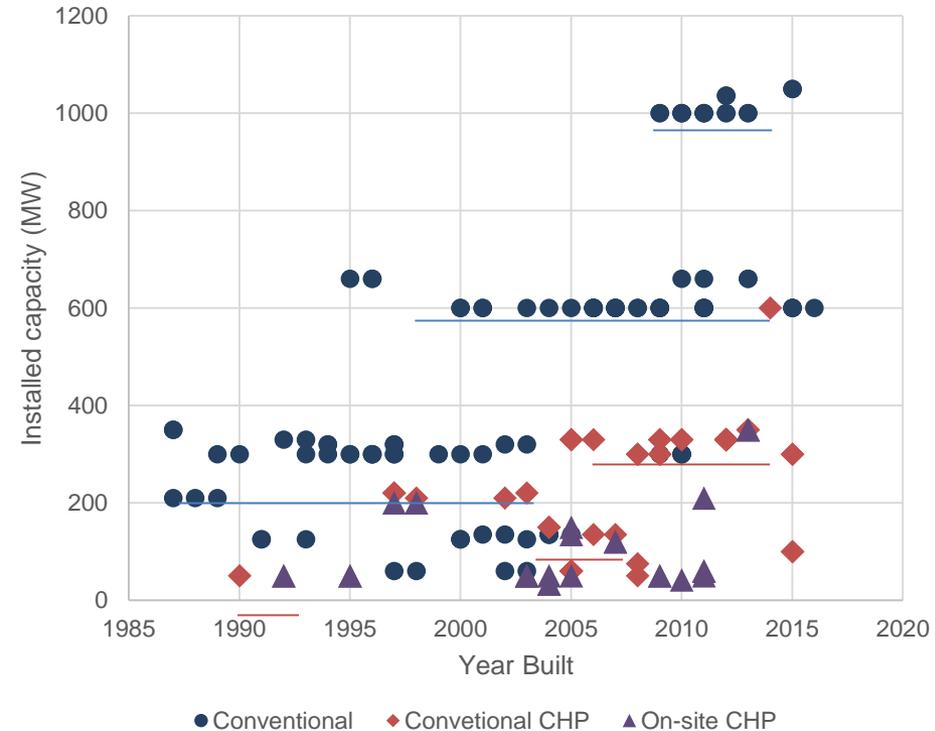
Structure of Guangdong coal fleet

Installed Capacity by Plant Size



- Large (≥ 600 MW) units make up just over 60% of Guangdong's coal generation fleet
- Mid-size (300-350 MW) units account for most of the remainder.

Installed Capacity by Year Built and by Type

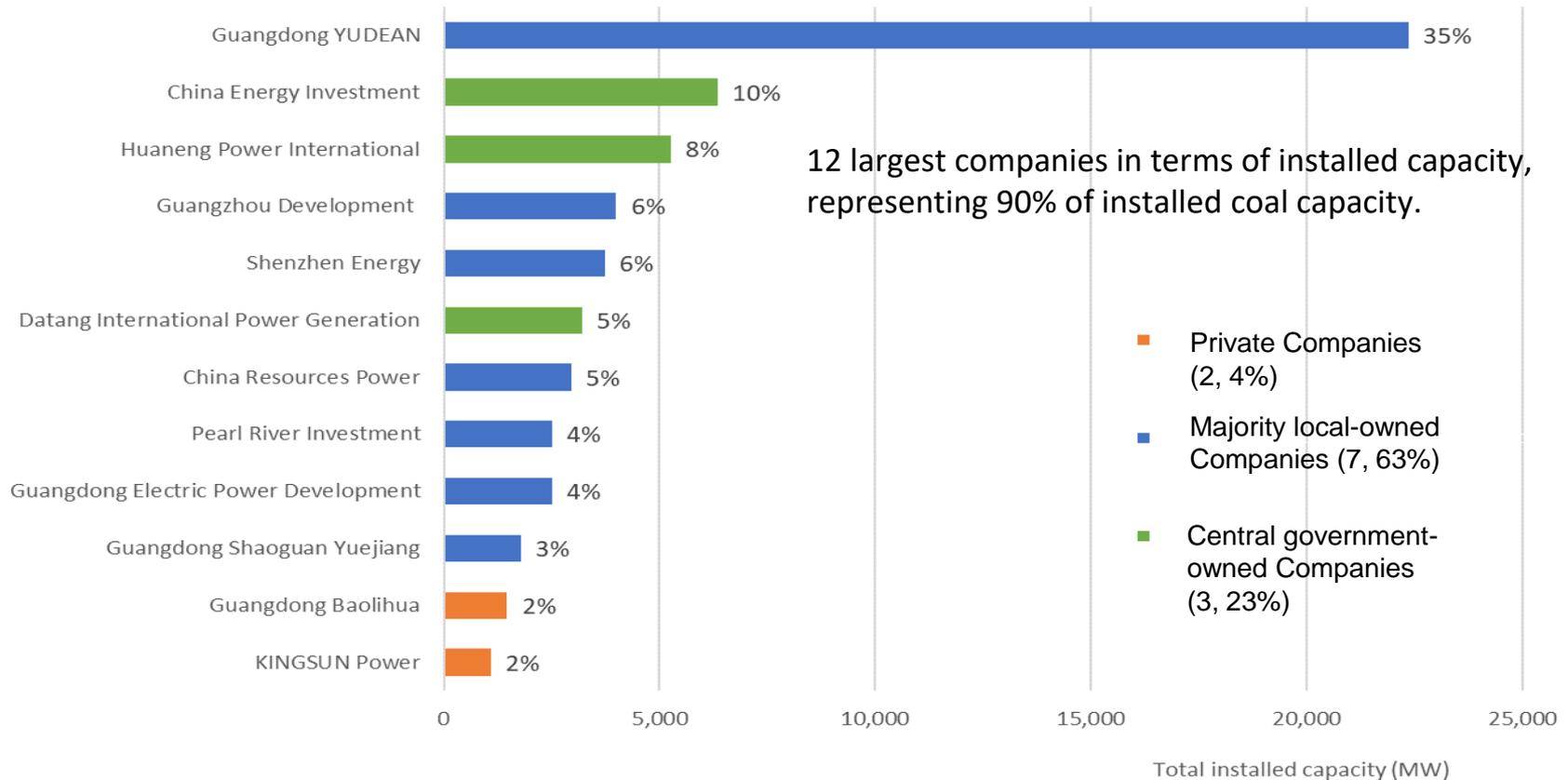


- Nearly 70% of Guangdong's coal generation capacity was built after 2005
- About half of Guangdong's small- to mid-size coal generation capacity (≤ 350 MW) are CHP units.
- Many smaller (< 200 MW) units are on-site CHP.

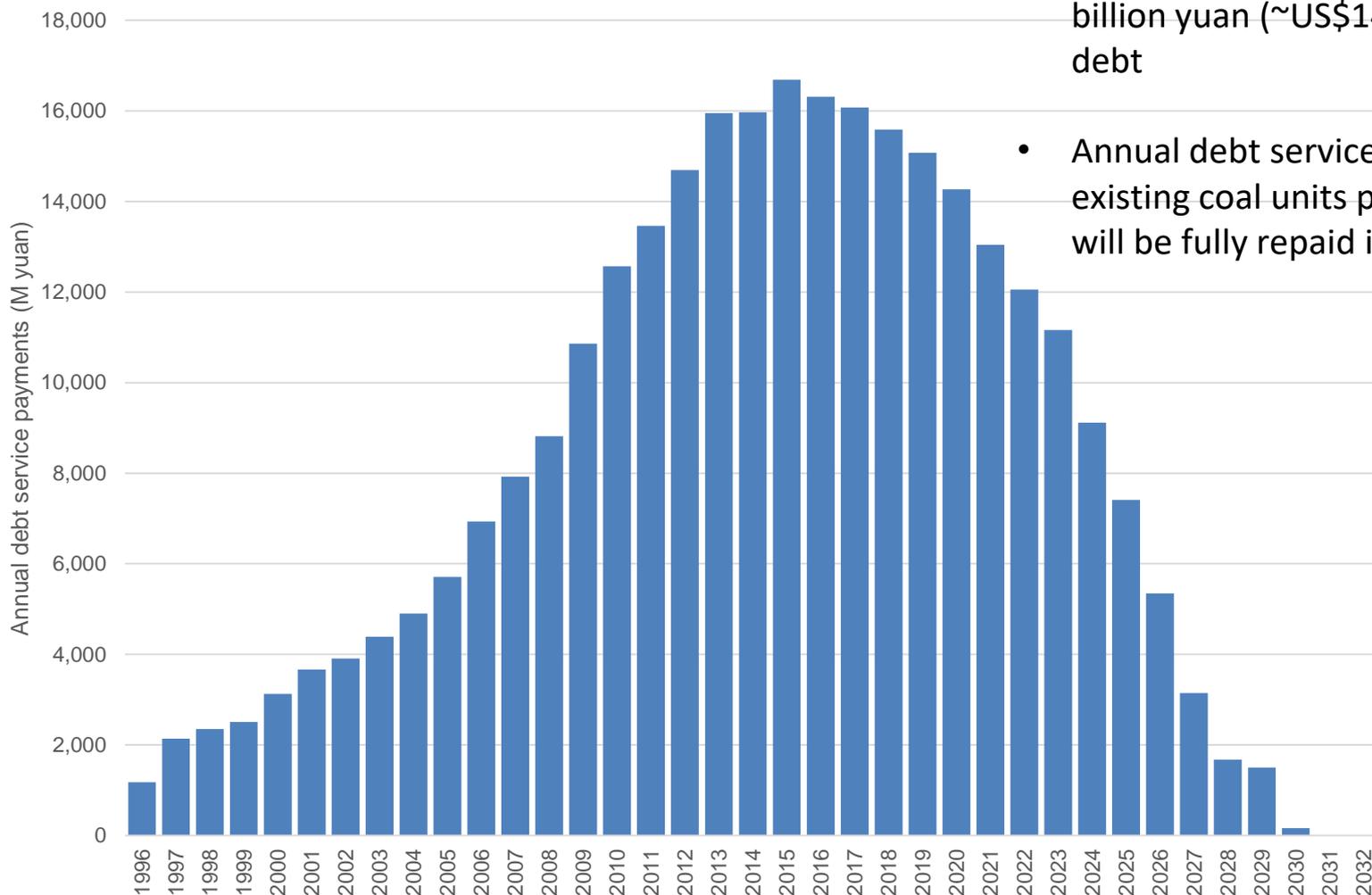
Coal generation ownership in Guangdong is relatively concentrated

Guangdong's coal generation fleet is owned by 30 companies

- 92% of total capacity owned by 17 state-owned companies and most of this state-owned capacity majority-owned by local companies
- 7.6% of total capacity owned by 12 privately owned companies
- Remaining owned by 1 international company



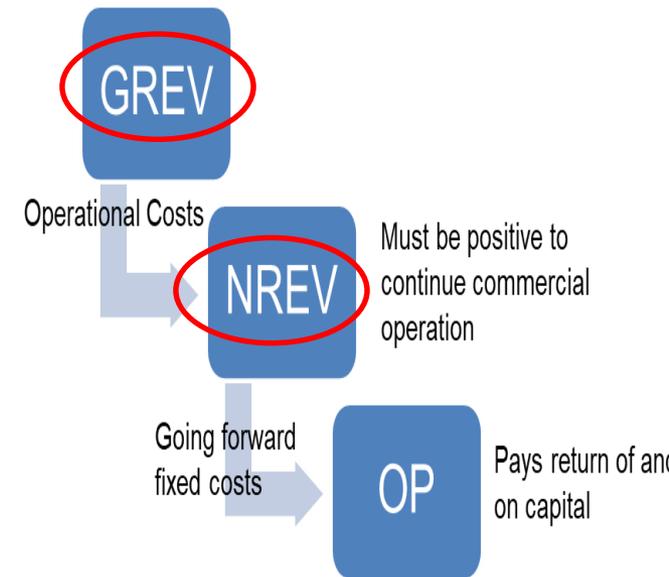
Guangdong's coal units have a significant amount of outstanding debt



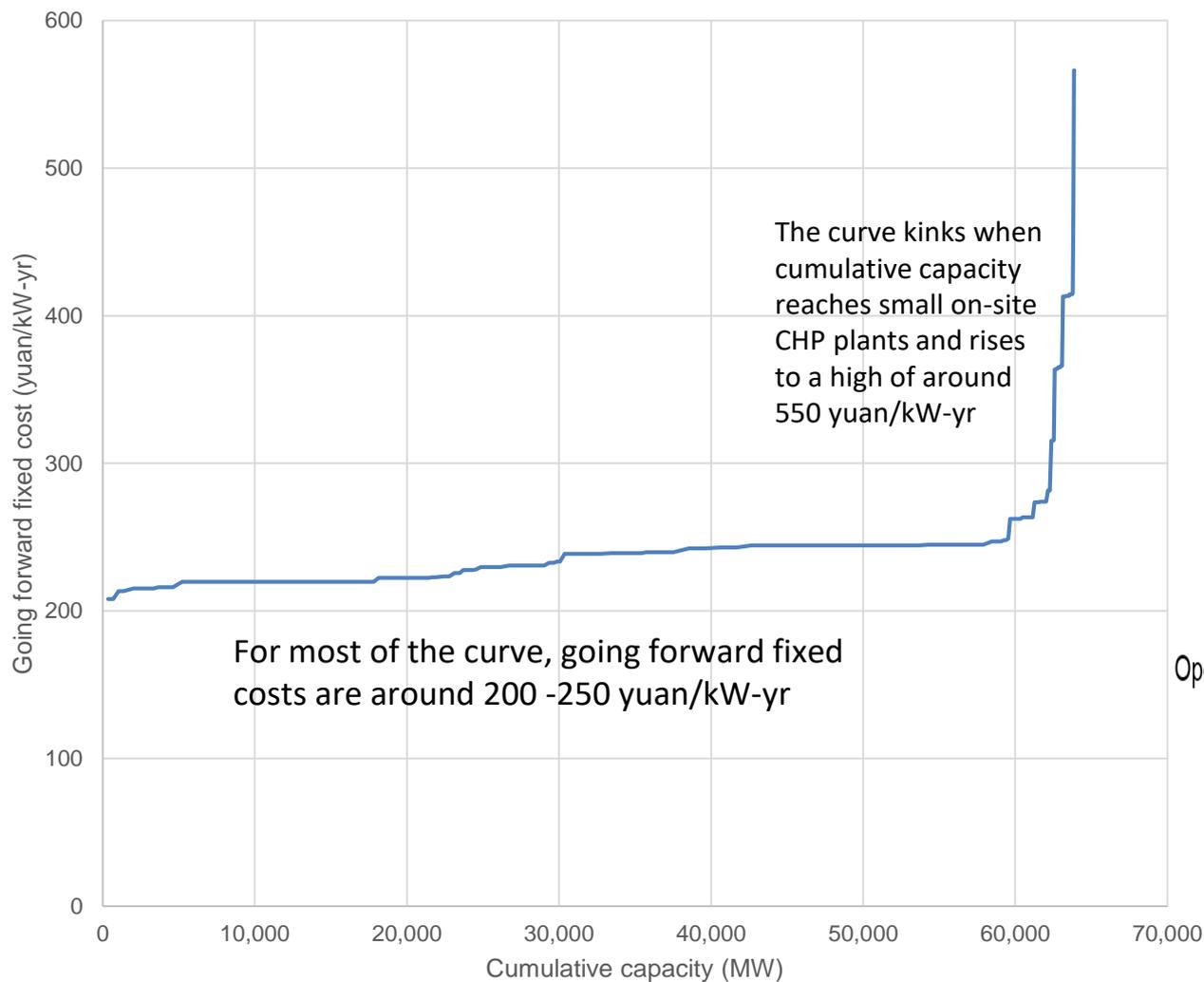
- Guangdong's coal units owe nearly 94 billion yuan (~US\$14 billion) in total debt
- Annual debt service payments for existing coal units peaked in 2015 and will be fully repaid in 2032,

Net Revenues

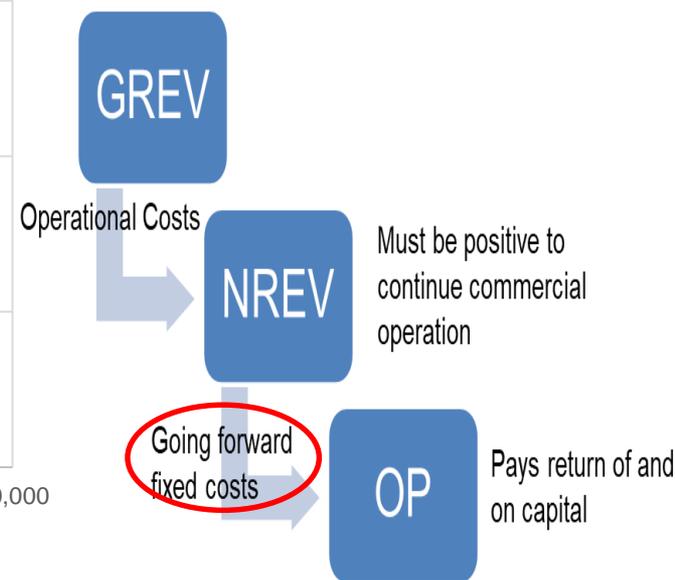
| Category | Base Case | | Low Price Scenario | | High Price Scenario | |
|----------|-----------------------------|---------------------------|-----------------------------|---------------------------|-----------------------------|---------------------------|
| | Gross revenues (yuan/kW-yr) | Net Revenues (yuan/kW-yr) | Gross revenues (yuan/kW-yr) | Net Revenues (yuan/kW-yr) | Gross revenues (yuan/kW-yr) | Net Revenues (yuan/kW-yr) |
| Coal 1 | 1771 | 771 | 2060 | 293 | 2544 | 380 |
| Coal 2 | 1771 | 707 | 2053 | 196 | 2593 | 258 |
| Coal 3 | 1771 | 664 | 1558 | 122 | 2071 | 162 |
| Coal 4 | 1771 | 630 | 1001 | 99 | 1383 | 128 |
| Coal 5 | 1771 | 592 | 554 | 68 | 839 | 84 |
| Coal 6 | 1771 | 553 | 288 | 62 | 524 | 70 |



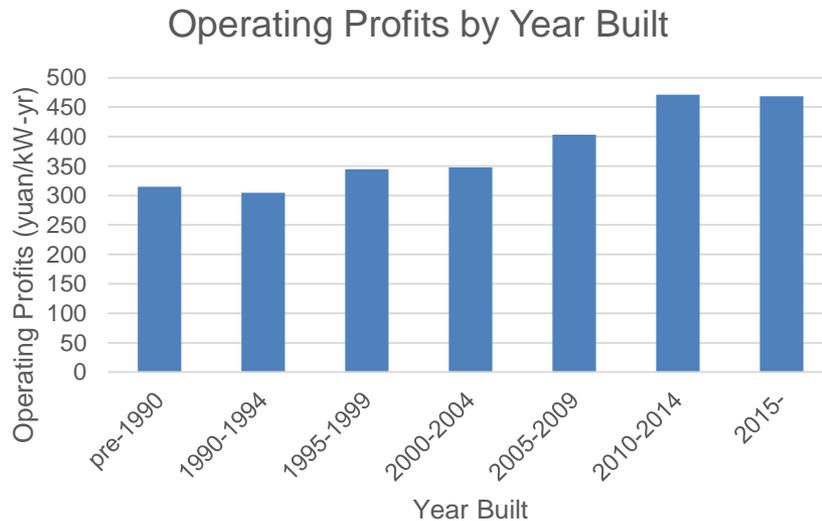
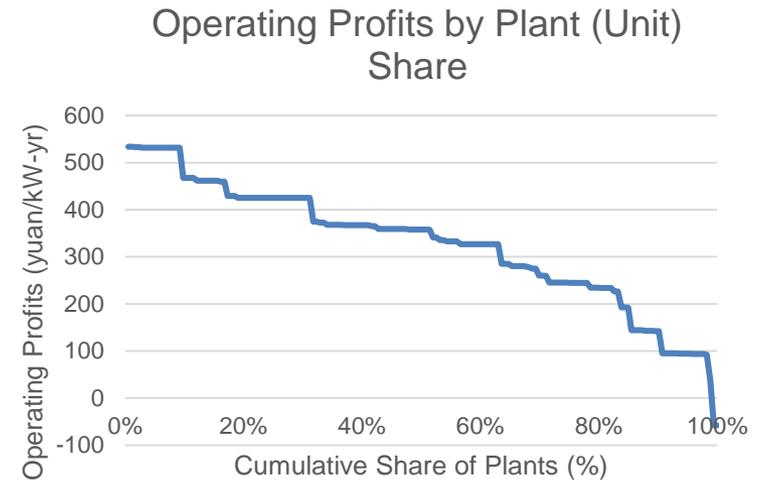
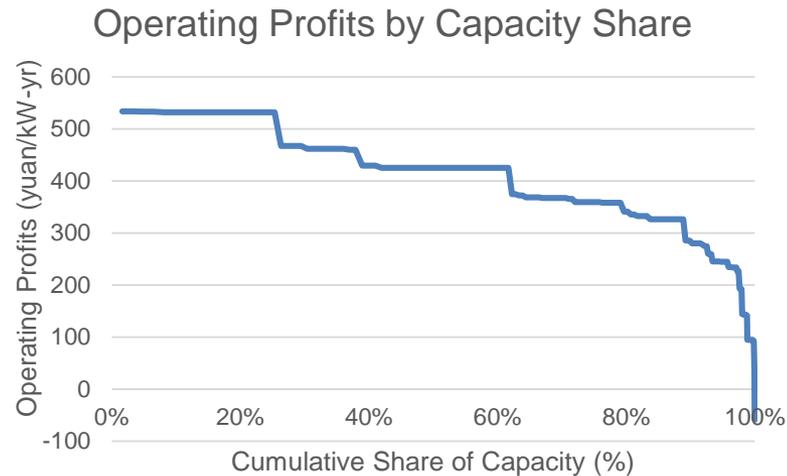
The going forward fixed cost curve for the province's coal units is relatively flat



Going forward fixed cost
= labor + insurance +fixed
O&M + tax

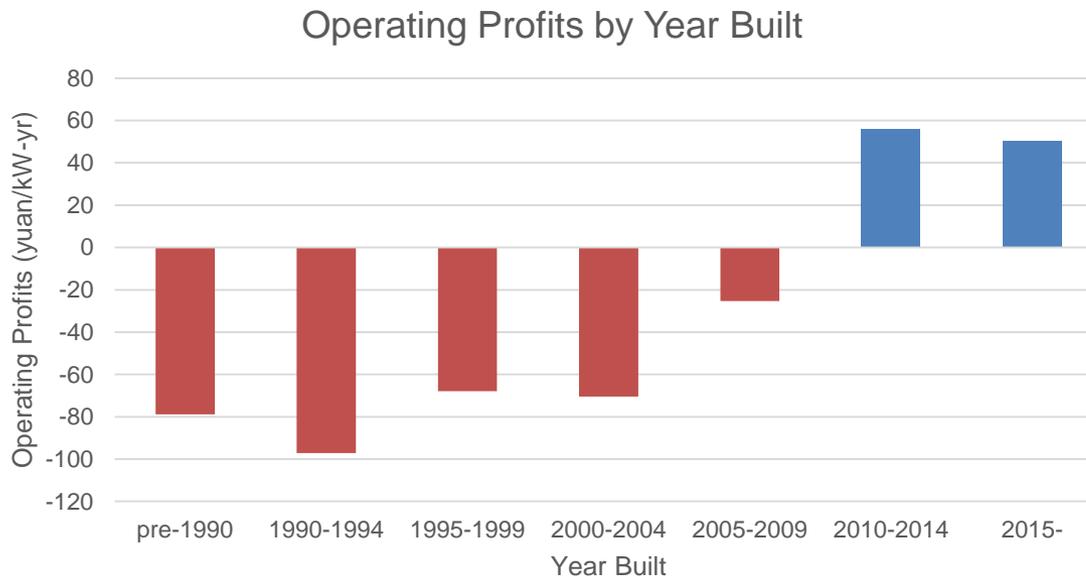
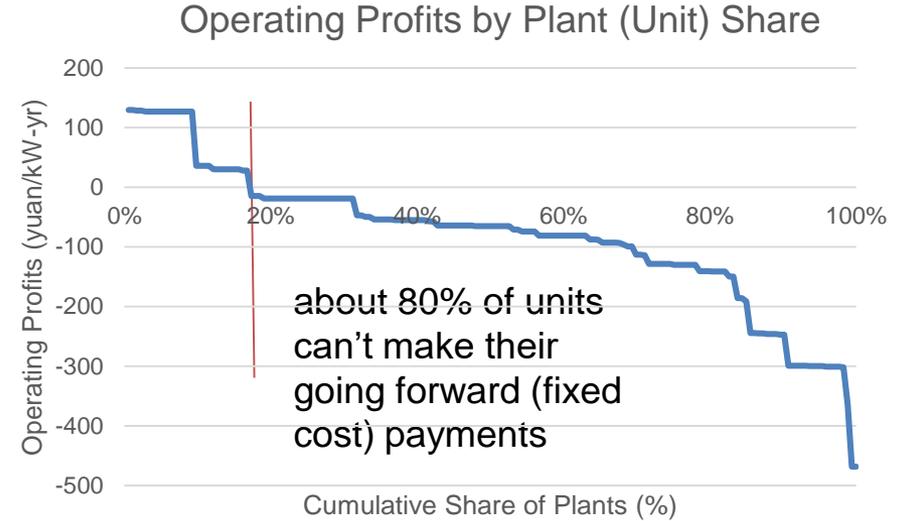
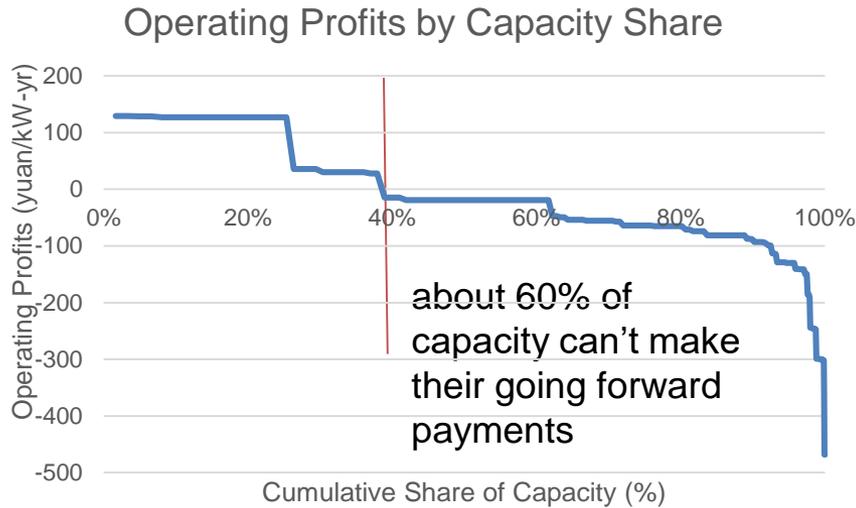


Operating Profits under the Benchmark Scenario (2016 actual condition)



- In the Benchmark scenario, all but two small on-site CHP plants have positive operating profits — net revenues minus going forward fixed costs.
- Newer and larger plants have higher operating profits

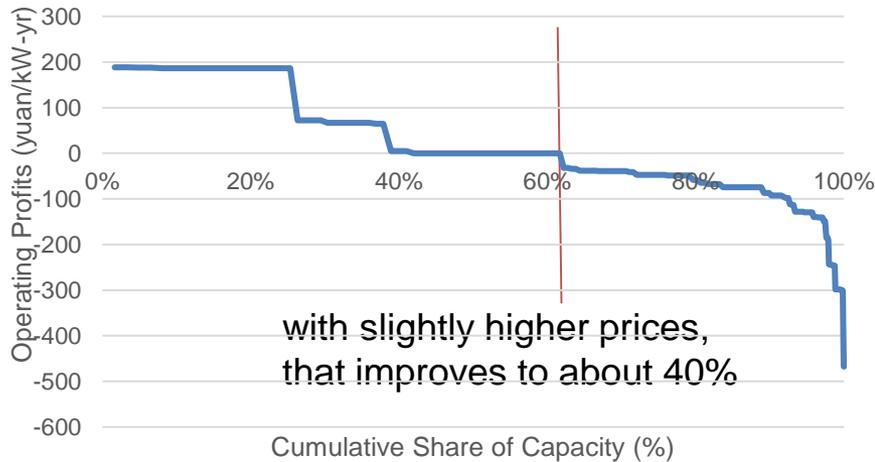
Operating Profits under the Low Market Price Scenario (2016 condition with electricity market)



In the Low Market Price scenario, only units larger than 1,000 MW and built after 2010 have positive operating profits

Operating Profits under the High Price Scenario (lower hydro availability and higher coal price)

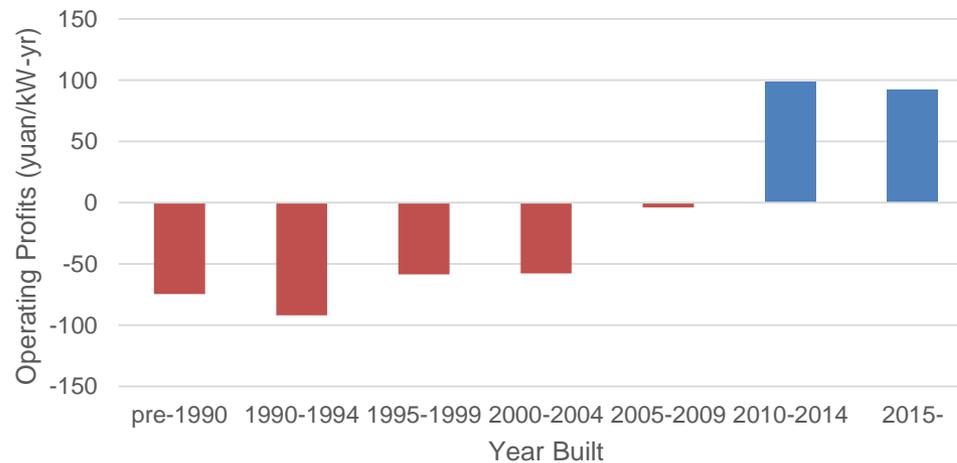
Operating Profits by Capacity Share



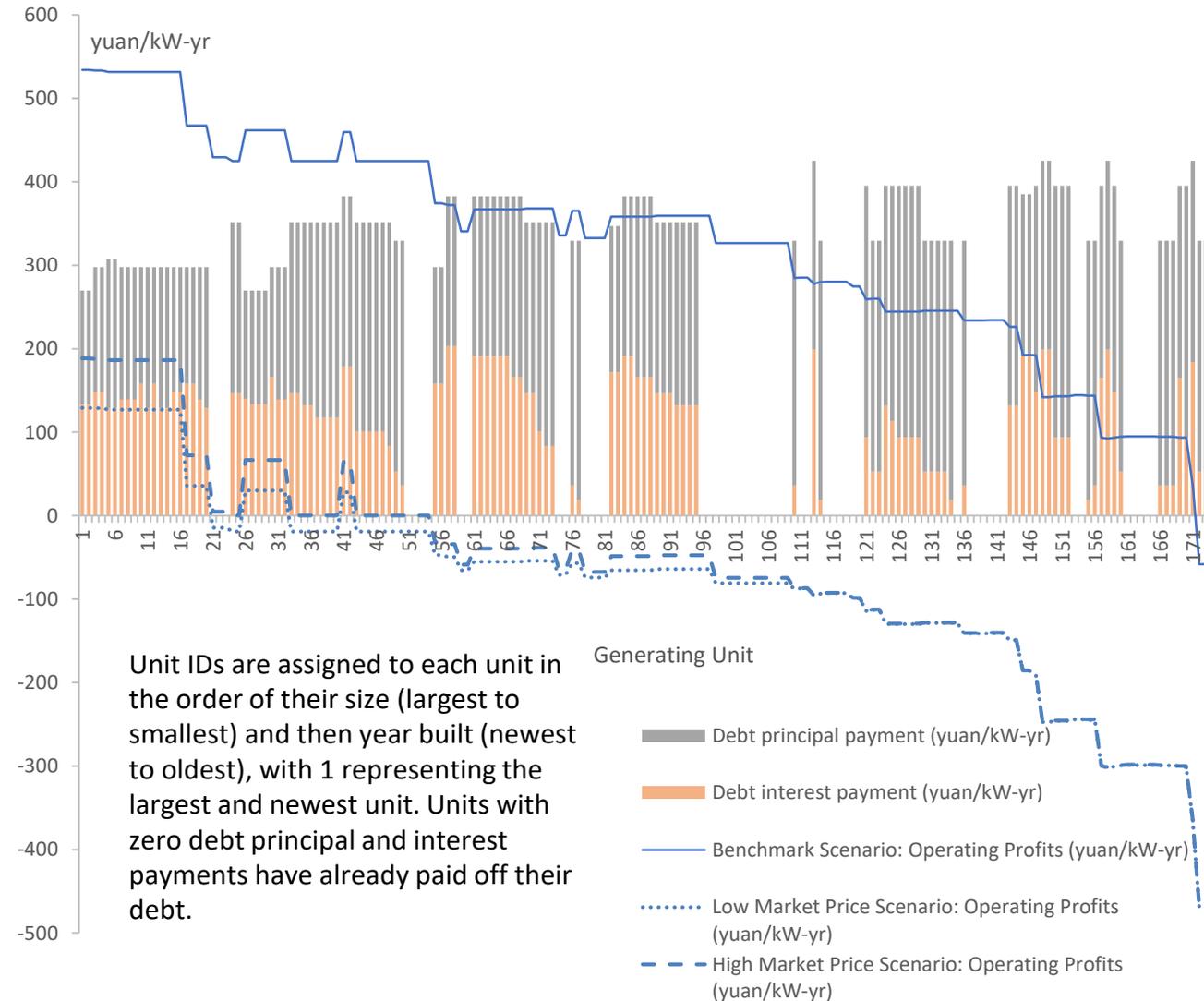
Operating Profits by Plant (Unit) Share



Operating Profits by Year Built

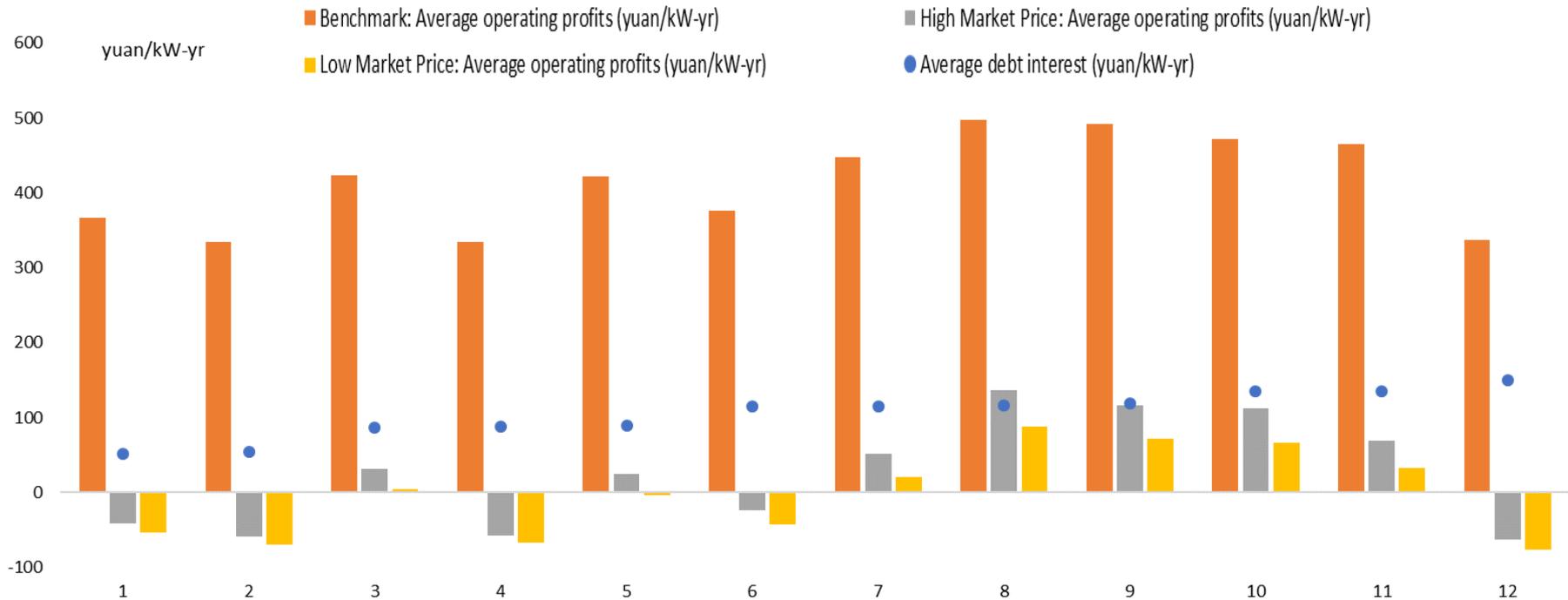


Operating Profit, Debt Interest, and Principal Payment by Unit



- In the Benchmark scenario, all but 10 units have high enough operating profit to pay annual debt interest and two-thirds of units can pay their full annual debt principal
- In the High Market Price scenario, 13% of units can pay their full annual debt interest and 4% of units can pay full annual debt principal.
- In the Low Market Price scenario, no units can pay their full annual debt interest.

Operating Profit and Debt Interest Payment by Company



- In the Benchmark scenario, the top 12 companies by installed capacity have relatively high operating profits.
- Under the Low Market Price and High Market Price scenarios, their operating profits drop significantly, with 40% of these companies having negative operating profits (their net market revenues are less than their going forward fixed costs)

- Average market prices are likely to be low (variable cost of a mid-merit coal unit) in Guangdong
 - efficient coal generation fleet
 - reasonably large share of low marginal cost resources (hydro, nuclear, wind, solar)
 - low-cost imports
 - gas units would be priced out in a market environment
- In a lower-price (high hydro, low coal price) year, only 20% of coal units (40% of capacity) are able pay their going forward fixed costs
- In a slightly higher-price (low hydro, higher coal price) year, only two generating companies are able to pay their full annual debt interest.

- Nearly 20% of Guangdong's coal capacity is CHP, which tend to be smaller and more expensive.
 - the impact of electricity market pricing on CHP units is uncertain because a large fraction of their value may come from providing heat rather than electricity.
 - The integration of CHP units into electricity markets in Guangdong, and in China more broadly, will have a significant impact on market outcomes because these units may be less sensitive to the operational and reliability needs of the electricity system.

- Coal generators in Guangdong have an estimated 94 billion yuan in total outstanding debt, with total estimated debt service payments of around 16 billion per year in 2016.
 - The inability to service this debt would have significant implications for China's electricity sector, given both its size and the sector's heavy reliance on debt financing.
 - It raises questions about the compatibility of competitive electricity markets and state-owned generation companies that rely on state-owned banks for as much as 80% of their capital

- Two issues associated with the challenge of how to deal with market impacts on coal generators in Guangdong and China
 - Transition: Guangdong has too much baseload coal capacity relative to what might be expected in a competitive electricity market.
 - Long-term resource adequacy: existing coal generators that cannot pay their going forward fixed costs would be forced to mothball or retire.
- Potential Solutions
 - Make transition payments to existing coal generators
 - Develop mechanisms for long-term resource adequacy

Thank You!



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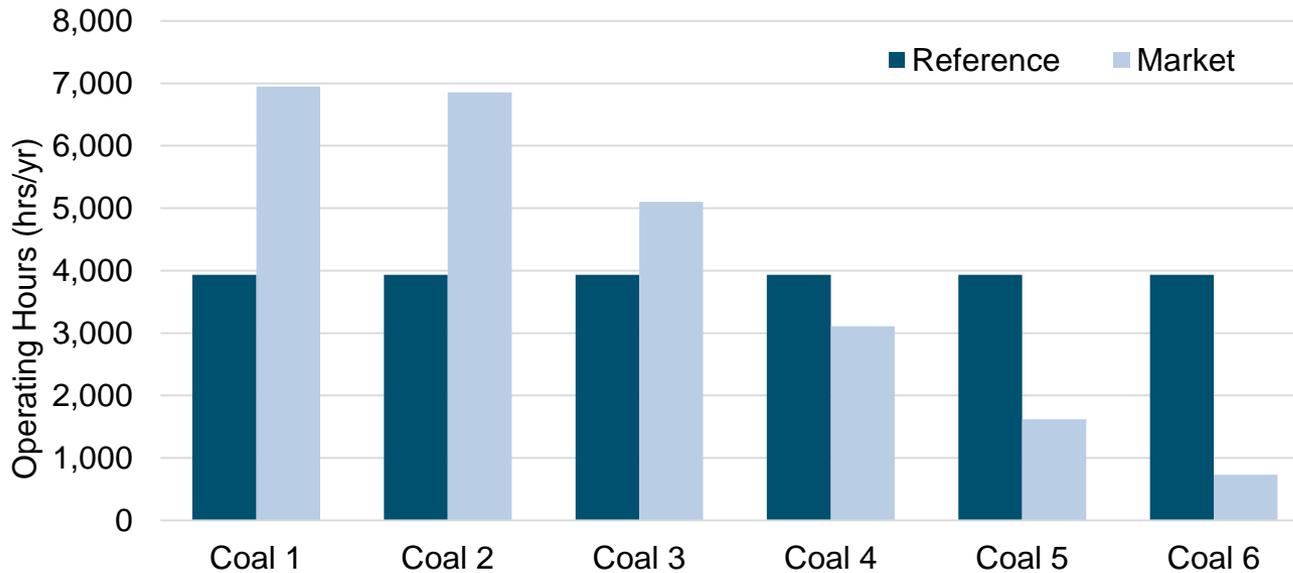
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<http://china.lbl.gov>

<http://btjrc.lbl.gov>

Backup slides

Coal fleet category bins and operating hours



| Category | Size (Capacity) | Vintage | Installed Capacity (MW) | Average Net Heat Rate (gce/kWh) |
|--------------------|-----------------|-----------|-------------------------|---------------------------------|
| Coal 1 | > 1,000 MW | All | 16,172 | 281 (44%) |
| Coal 2 | 600-1000 MW | 2010-2017 | 8040 | 301 (41%) |
| Coal 3 | | 1980-2009 | 15,180 | 315 (39%) |
| Coal 4 | 300-600 MW | 2000-2017 | 11,130 | 325 (38%) |
| Coal 5 | | 1980-1999 | 6,240 | 337 (36%) |
| Coal 6 | < 300 MW | All | 7,128 | 350 (35%) |
| Coal Totals | | | 63,890 | 313 (39%) |

Key Assumptions for Financial Calculation

-Debt Principal and Interest Payments

- Annual debt principal and interest payments (D)
 - From the year built, 15 years of annual loan
 - Annual loan payment = $PMT(\text{debt interest rate, loan term, total loan amount})$
- Debt interest (I)
 - Annual debt interest = debt interest% * remaining principal amount
 - For the first year (at the year built), remaining principal amount = total loan amount
- Debt principal
 - Annual principal payments = $D - I$
 - Remaining principal amount = remaining principal amount for previous year - principal payment
 - For the first year (at the year built), remaining principal amount for previous year = total loan amount

Key Assumptions for Financial Calculation

| | 1980-1994 | 1995-1999 | 2000-2004 | 2005-2009 | 2010-2014 | 2015-2019 |
|------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Depreciation (years) | 15 | 15 | 15 | 15 | 15 | 15 |
| Debt share (% of investment) | 80% | 80% | 80% | 80% | 80% | 80% |
| Debt interest (%) | 11% | 12% | 6% | 7% | 7% | 5% |
| Loan term (years) | 15 | 15 | 15 | 15 | 15 | 15 |

| Technology | Capacity (MW) | Investment (yuan/kW) (number of plants, total capacity in MW) | | | | | |
|--------------------|---------------|--|-------------------|--------------------|--------------------|--------------------|------------------|
| | | 1980-1994 | 1995-1999 | 2000-2004 | 2005-2009 | 2010-2014 | 2015-2019 |
| Subcritical | [0, 300] | 3800 (9,1155) | 3800 (9, 1270) | 4000 (22, 2426) | 4500 (17,1655) | 5000 (5, 422) | 5000 (2,200) |
| Subcritical | [300, 660] | 4500 (10,3200) | 4500 (13,5020) | 4000 (10,4840) | 4000 (16, 6420) | 4500 (17, 6040) | 4500 (2,600) |
| Supercritical | [330, 350] | 4000 (/) | 4000 (/) | 4000 (/) | 4000 (1,330) | 3500 (2,700) | 3500 (/) |
| Supercritical | [600, 660] | 4000 (/) | 4000 (/) | 4000 (/) | 4000 (11, 6600) | 3500 (5,3120) | 3500 (/) |
| Ultrasupercritical | [600, 1050] | 3500 (/) | 3500 (/) | 3500 (/) | 3500 (2,2000) | 3500 (14,13392) | 3500 (6,4500) |

Key Assumptions for Financial Calculation

– Fixed Cost

| Installed Capacity (MW) | Labor Costs | | Insurance rate (%) | Fixed O&M | | |
|-------------------------|-----------------|------------------------|--------------------|--|---|--|
| | Labor (persons) | Wages (yuan/person-yr) | | Maintenance materials costs (yuan/kW-yr) | Normal maintenance costs (yuan/unit-yr) | Large maintenance costs (yuan/unit-yr) |
| [1000, 2000) | 150 | 137,500 | 0.28% | 6.05 | 14,430,000 | 16,500,000 |
| [600, 1000) | 120 | 137,500 | 0.26% | 7.48 | 12,210,000 | 13,200,000 |
| [300, 600) | 110 | 130,000 | 0.25% | 9.35 | 8,880,000 | 9,900,000 |
| [200, 300) | 100 | 125,000 | 0.24% | 13.75 | 7,100,000 | 6,050,000 |
| [100, 200) | 100 | 120,000 | 0.24% | 14.3 | 5,330,000 | 3,850,000 |
| [0, 100) | 60 | 120,000 | 0.24% | 14.3 | 5,330,000 | 3,850,000 |

| Tax | |
|-----------------|----------------------------|
| Operating tax | 3% (% of gross revenues) |
| Other taxes | 0.3% (% of gross revenues) |
| Value added tax | 17% (% of value added) |

Fixed cost: labor + insurance + fixed O&M + tax