Economic and carbon emissions benefits of transitioning to electricity market in China: provincial vs regional grid optimization

中国电力市场改革的经济和减排效益：省内和区域电网优化

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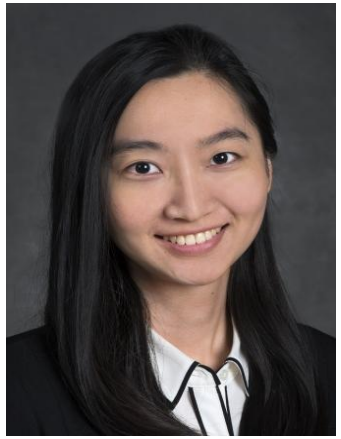

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Outline 大纲

- Background and Context 背景
- Overview of the Southern Grid System 南网概况
- Methods and Data 方法和数据
- Scenarios 情景分析
- Results 结果
- Sensitivity Analysis 敏感性分析
- Conclusion and Policy Implications 结论和政策意义

Background 背景

- China is currently undergoing power sector reform 中国电力市场改革正在进行
  - Change from planning to markets for both electricity pricing and dispatch 计划电价和发电转向经济定价和发电
- Electricity market transition in China has the potential to further the country's environmental and economic aspirations, and accelerate the transition to a clean power system 中国的电力市场转向可以帮助解决环境和经济问题，并加速电力系统清洁化
  - Stop excess investment in coal power 解决煤电过度投资问题
  - Reduce curtailment of solar/wind/hydro 减少弃风弃光弃水
  - Meet air quality and GHG targets 实现空气质量和温室气体排放目标
  - Increase efficiency of power system operation 提高电力系统运行效率
- Previous 2 studies on Guangdong power market reform 之前的针对广东电力市场改革的两项研究发现
  - Significant potential gains (21 to 63 billion yuan, 9%-27% reduction in total costs in a base case) from implementing electricity markets in Guangdong 市场带来巨大收益，210-630亿人民币
  - Significant financial risks for coal generators under market scenarios 市场给煤电厂带来较大财务风险
- Southern Grid power market reform 南网区域电力市场改革试点
  - Real-time wholesale market starts in Guangdong and expand to regional market 广东起步实施现货市场并推广到区域市场

Research questions 研究问题

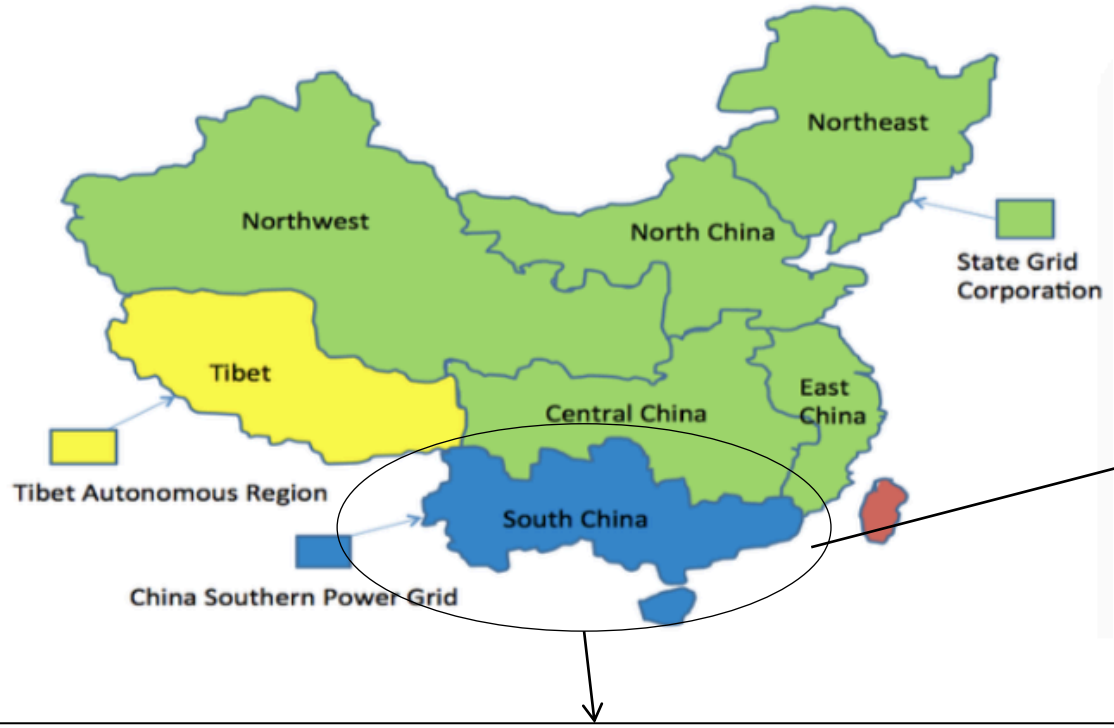
Overarching 总领性问题

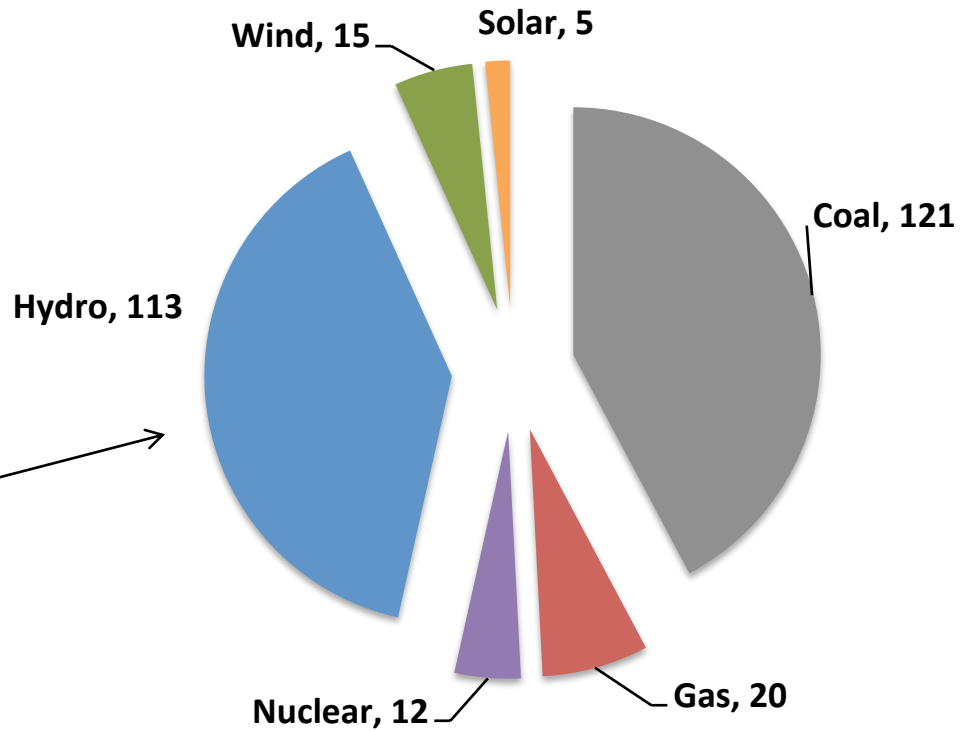
- How can the Southern Grid best navigate the ***political economy*** of a transition to electricity markets? 南方电网区域如何最好的把握电力市场改革的政治经济问题
- How can regulation and market design support the transition to a cleaner electricity system? 规章制度和市场设计如何支持电力系统清洁化

Specific 具体问题

- How significant would the cost savings be from market transition in each province (economic dispatch and electricity pricing)? 南方电网各省可以从电力市场改革获得多大成本节约？
- How would a regional market affect different provinces? 区域市场对各省有何影响？
- How would these benefits distribute among different provinces? 收益在各省如何分配？
- How might transmission capacity expansion influence the impacts? 扩大省间电力传输能力能带来多大影响？

Overview of the Southern Grid System 南网概况





Peak Load (2016) 最高负荷 = 155 GW
Annual Energy (2016) 每年全社会用电量 = 1010 TWh
(~20% of national) 占全国20%

Installed generation capacity by fuel (2016)
装机容量
Total installed capacity = 285GW

Image source: Menezes et al (2015)

Method and Data 数据和模型

- We simulate the current quota based planned dispatch and market based dispatch in the Southern Grid system using PLEXOS

在PLEXOS中建立南方电网区域模型

  - Hourly simulation for the whole year 全年每小时模拟
  - Reduced form network model (1-node per province) 每省作为一个单位

- We chose year 2016 – the most recent year for which we had access to the hourly load and dispatch data

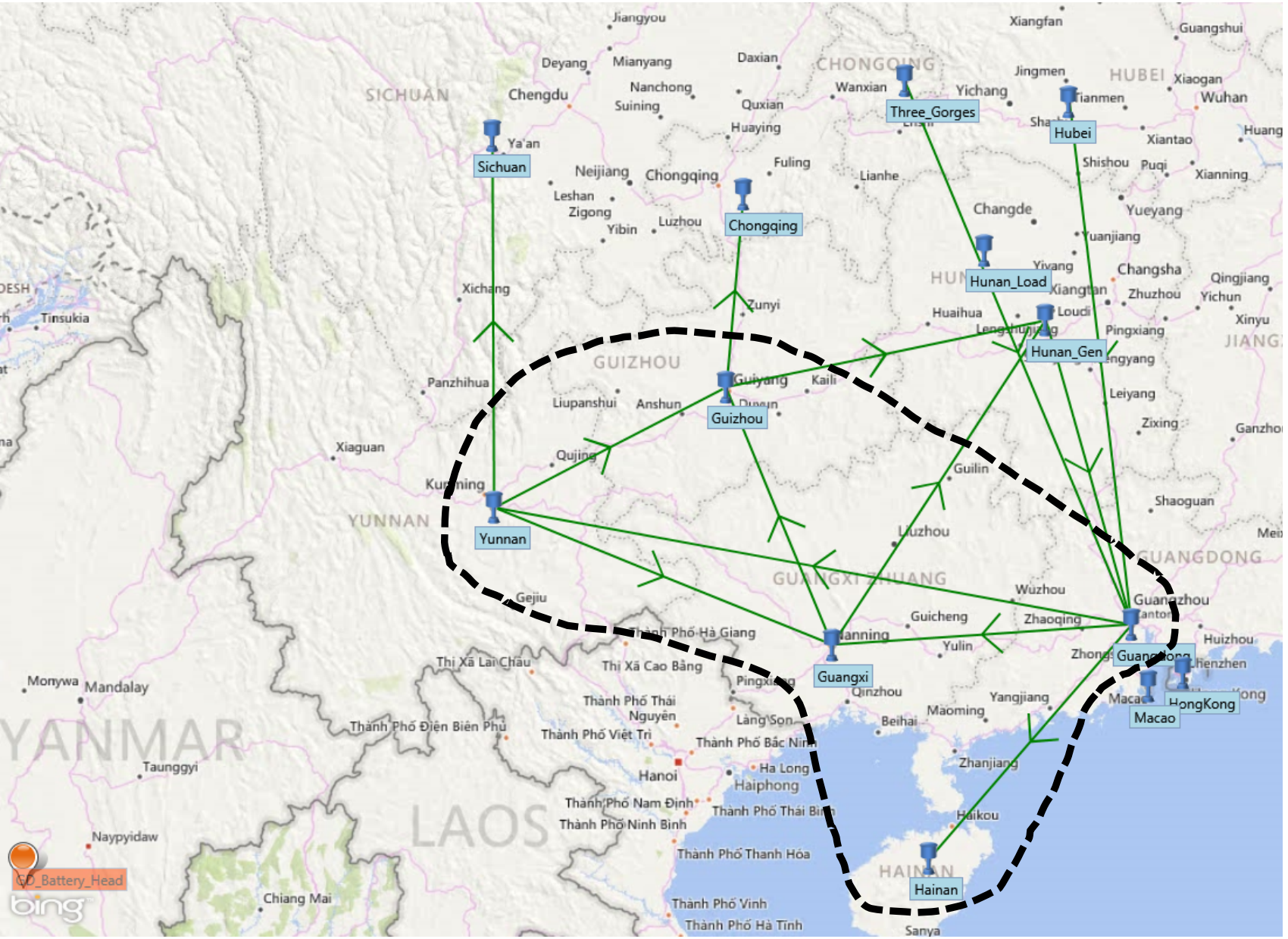
选择可获得电力负荷和调度数据的最近年份-2016年为研究年

- Results for the baseline case (quota based dispatch) were calibrated for the 2016 actual numbers

模型模拟数据和2016年实际数据做校对

- We conduct sensitivity analysis around key uncertainties such as flexibility in hydro dispatch, available transmission capacity etc.检验增加省间传输能力和提高水电灵活性的影响

Southern Grid network 南网区域模拟



Southern Grid network is represented in a reduced form (1 node per province). 简化模型：每个省作为一个节点

Imports / Exports from the neighboring grids are also modeled. 对其他电网与南网间的传输也纳入了模型

Scenarios 情景设置

1. **Simulated Actual 2016 (Baseline) 2016年实际模拟情景（基准情景）**

At the provincial level, fleet level annual energy generation is calibrated (~95-99% accuracy) with the actuals in 2016. Within each thermal fleet uniform dispatch rule was implemented to assess the total costs. Current transmission line limits apply to inter-regional flows. 依据2016年实际情况进行模拟，年发电量准确度95-99%，对不同效率火电机组分配相同的发电小时数

2. **Provincial Market (Provincial Market) 省内市场情景**

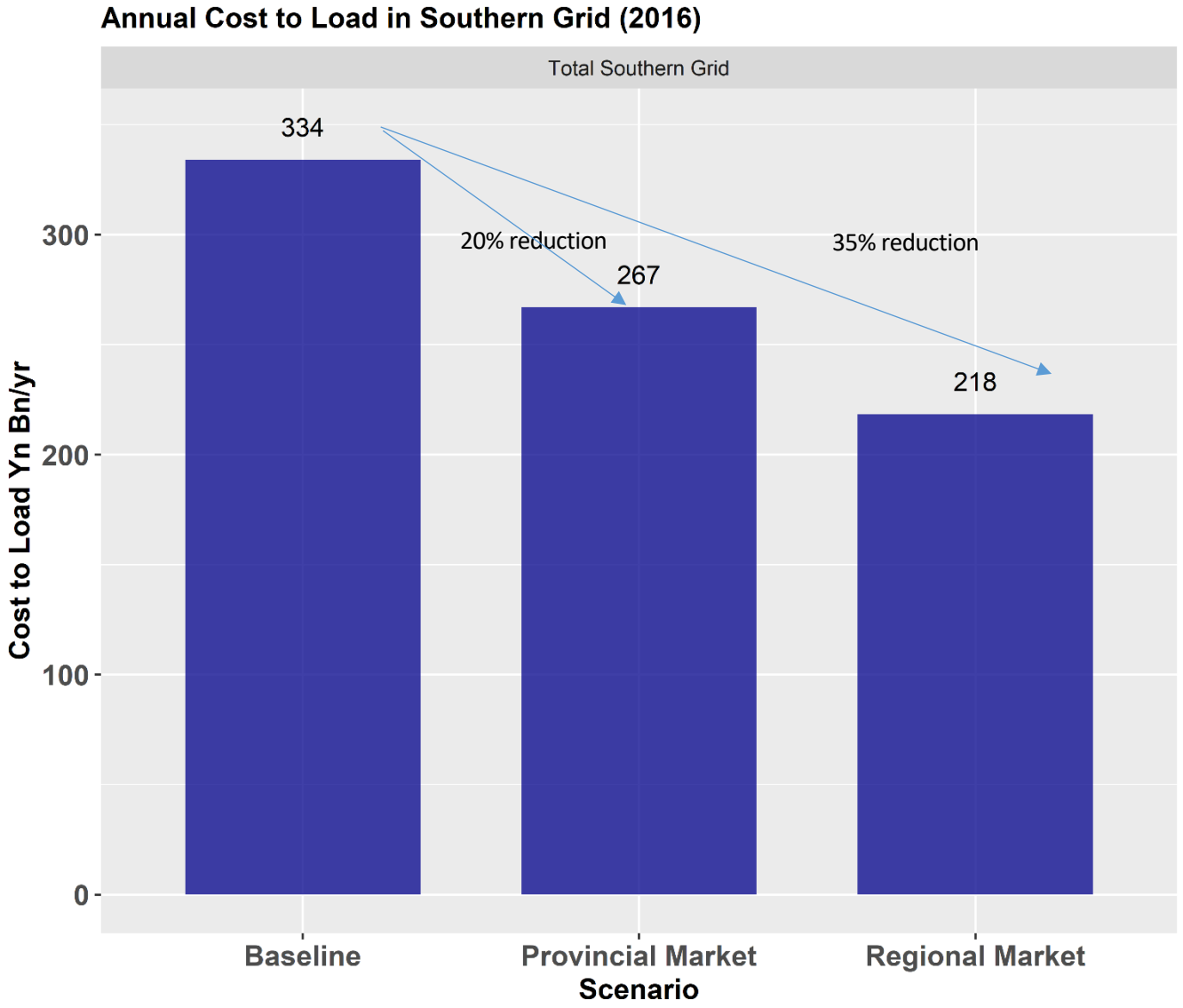
At the provincial level, imports and exports are calibrated with the 2016 actual (~95-99% accuracy). But within each province, the power dispatch is optimized for least cost. Current transmission line limits apply to inter-provincial flows. 南网五省建立省内电力市场，按照成本最小原则进行调度，但省间交易情况按照2016年实际情况模拟，准确度95%-99%

3**. Southern Grid Market (Regional Market)南网区域市场情景**

Entire southern grid system dispatch is optimized for least cost. Current transmission line limits apply to inter-regional flows. 在建立省内电力市场的基础上，建立南网区域市场，整个电网按照成本最小原则调度

Results 结果

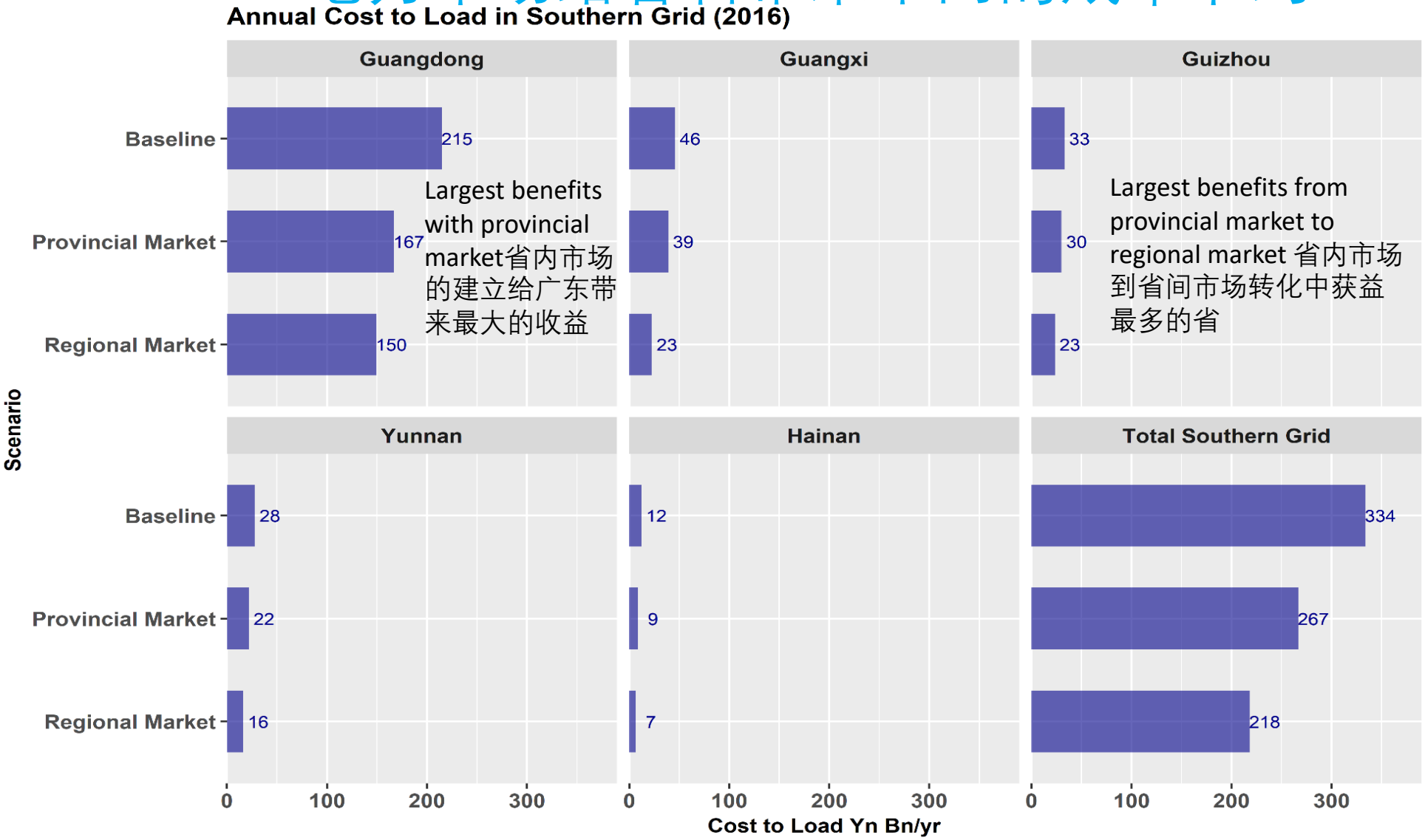
Substantial savings from provincial and regional markets (Over 100 B/year)
省间和区域市场带来巨大收益（每年超过1000亿人民币）



Southern Grid gains substantial economic benefits from provincial electricity market and inter-provincial transactions (Over 100 Billion RMB/year) 南网区域因省内电力市场（经济调度和市场定价）和省间交易获得巨大经济收益，每年超过1000亿人民币

Provincial market and southern grid markets are pareto optimal. 对整个南网区域来说，建立省间和区域市场是帕累托最优情景

Provincial Differences in Potential Cost Savings from Electricity Market 电力市场给各省带来不同的成本节约

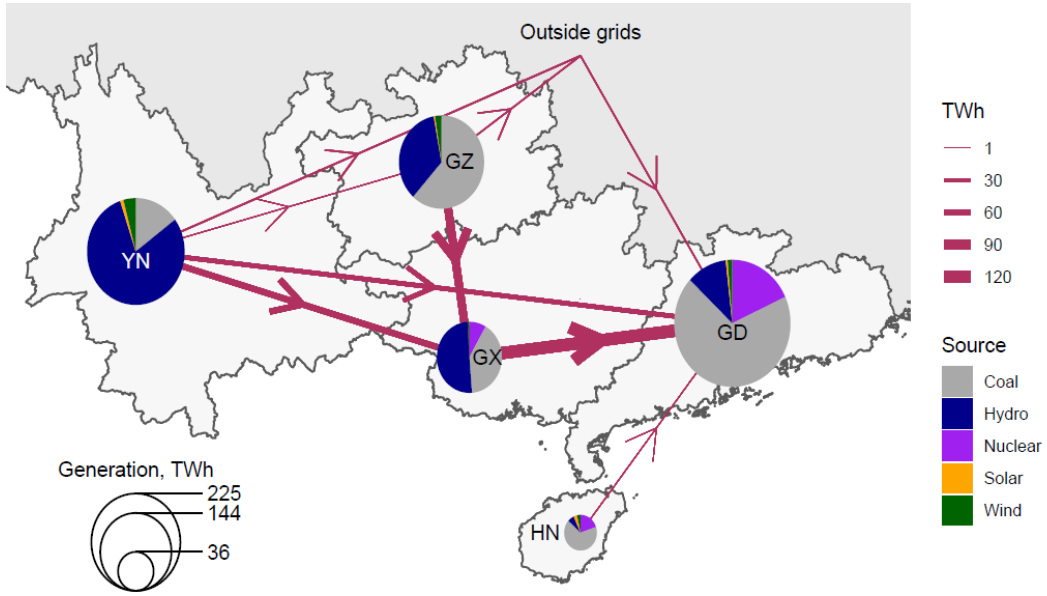


Provincial market and southern grid markets are pareto optimal for all provinces under all scenarios.

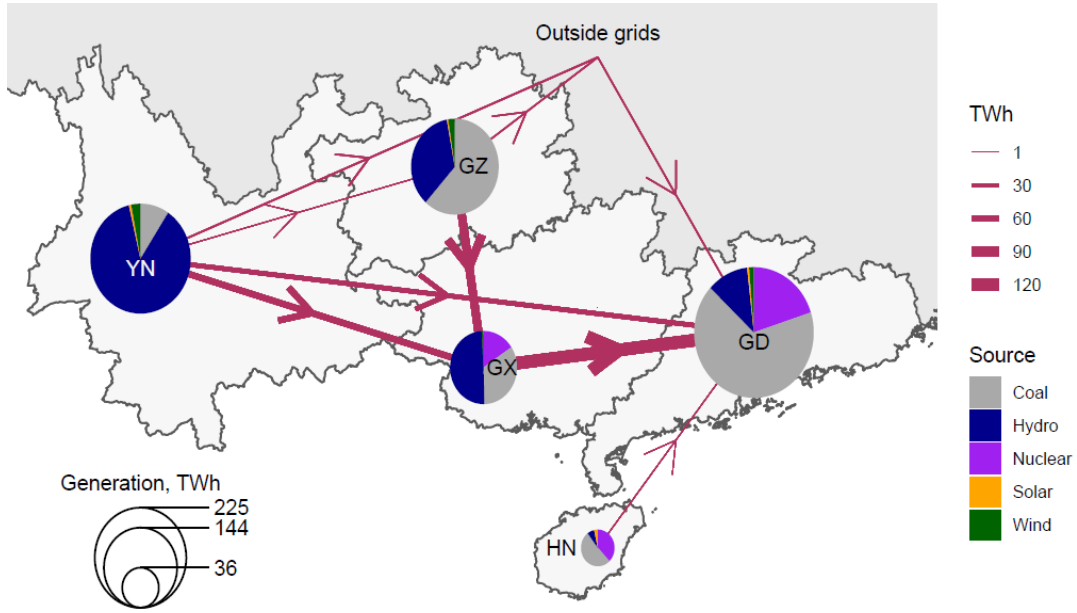
省内市场和省间市场对各省来说都是帕累托最优。

Power flow under different scenarios 不同情景下的电力输送情况

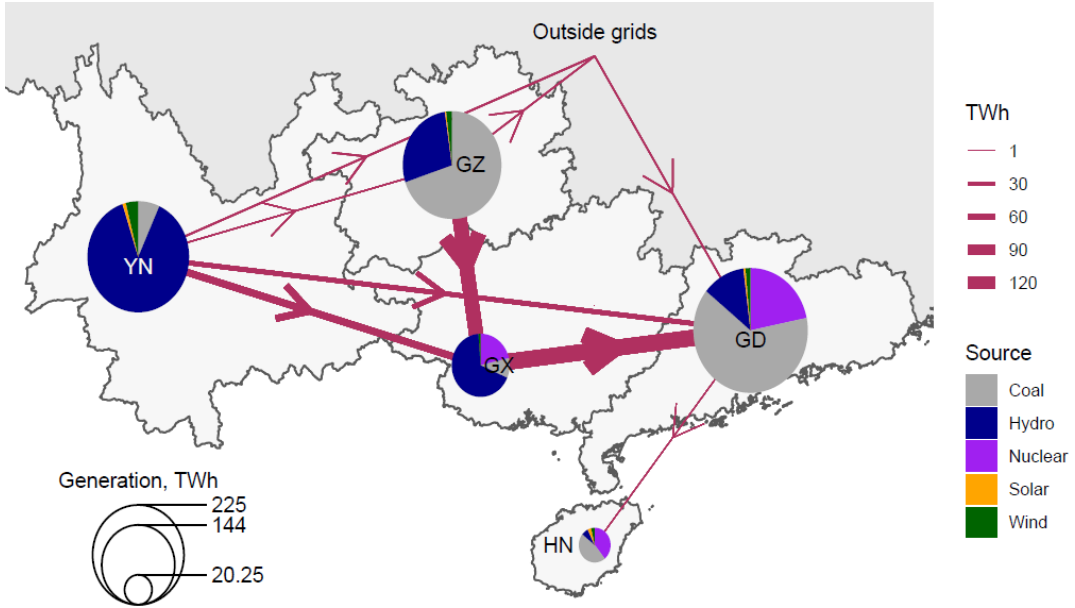
Baseline 2016实际模拟情景



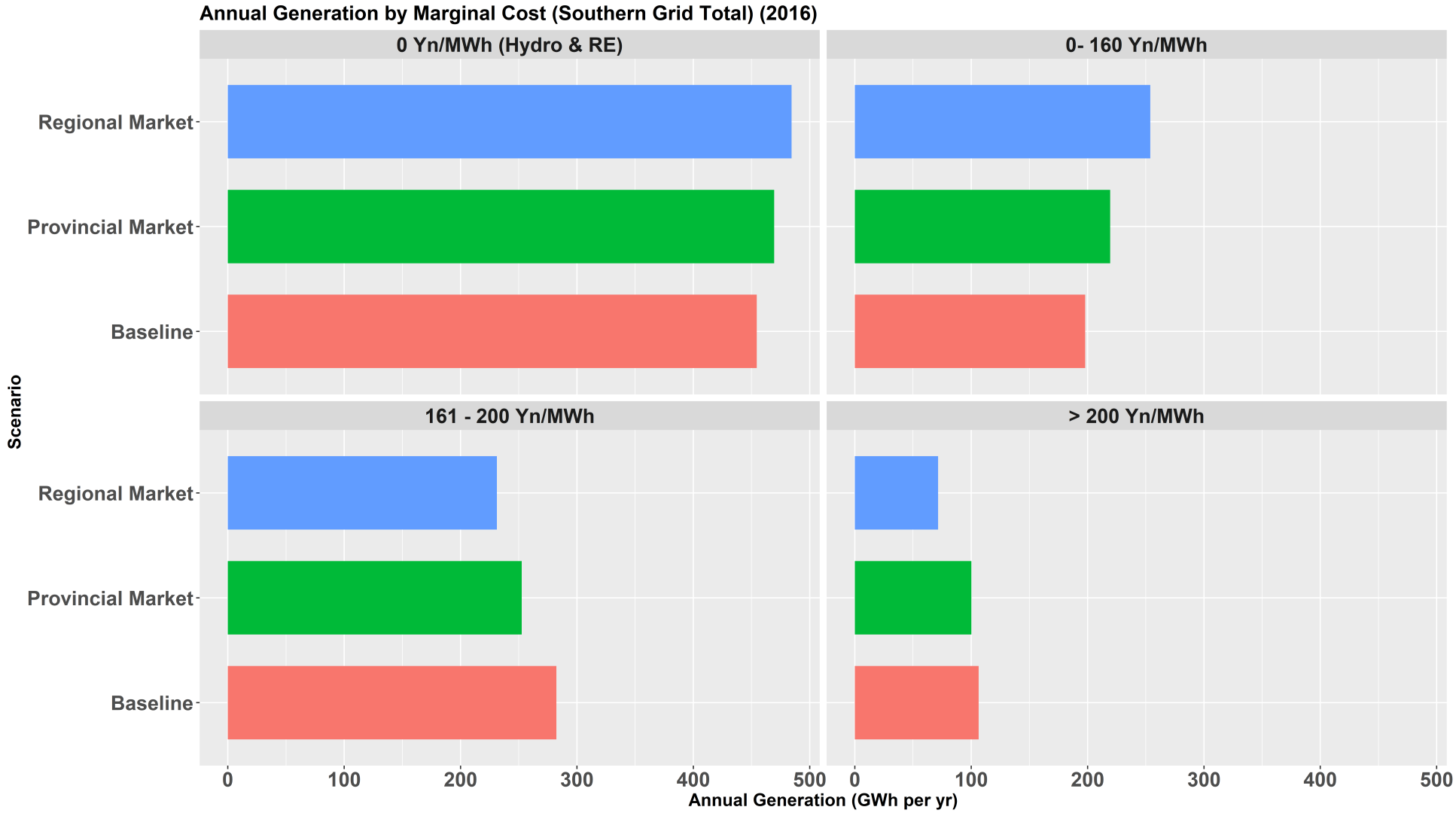
Provincial Market 省内市场情景



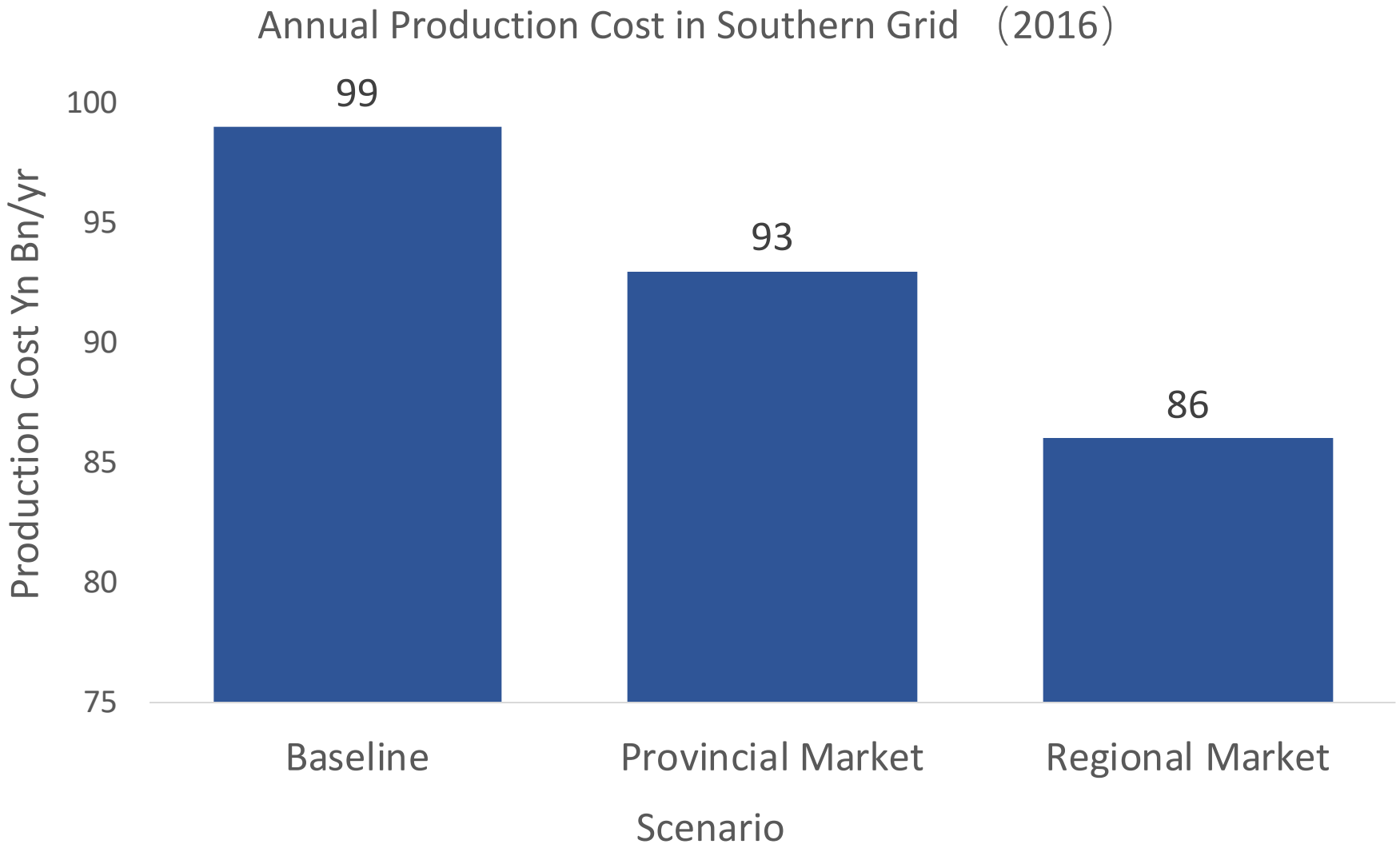
Regional Market 南网区域市场情景



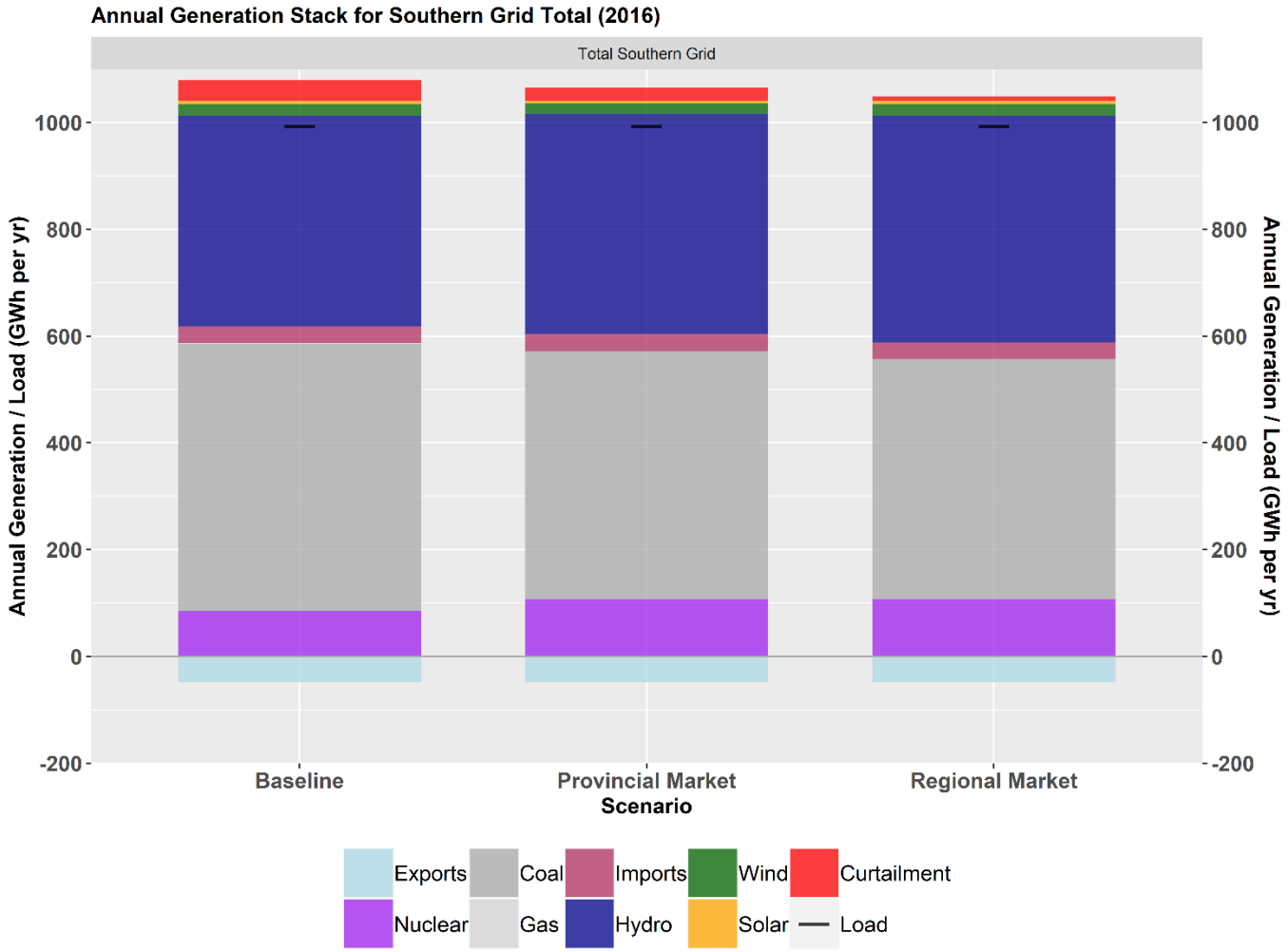
Market allows plants with lower marginal costs to generate more electricity
市场优化电源效率，低边际成本电源获更多发电小时数



Economic dispatch alone can reduce the production cost by ~13%
经济调度减少约13%的发电成本

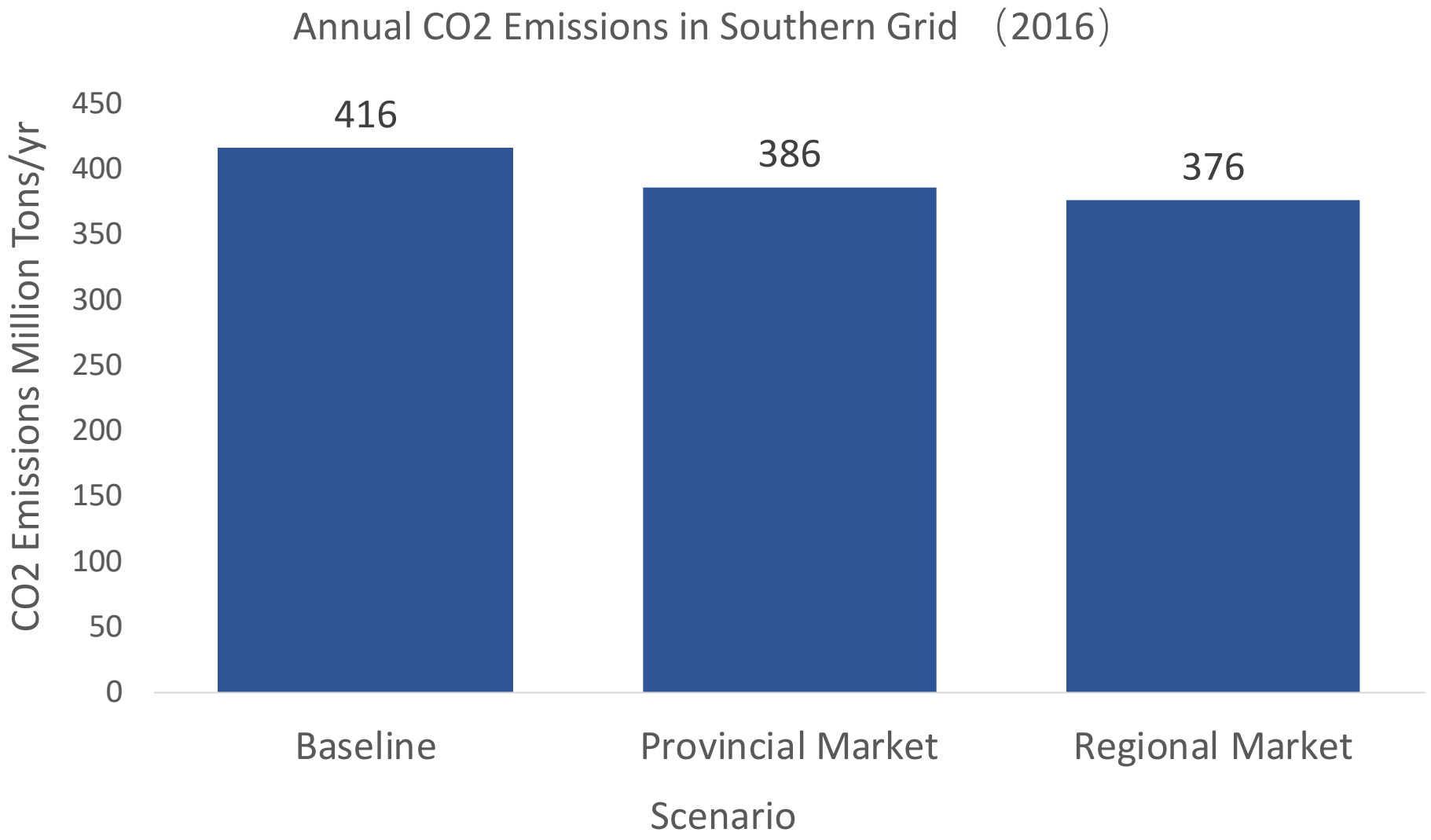


Regional markets reduce coal generation by over 10% and avoids hydro and renewable curtailment区域市场降低煤电10%，减少弃风弃光弃水

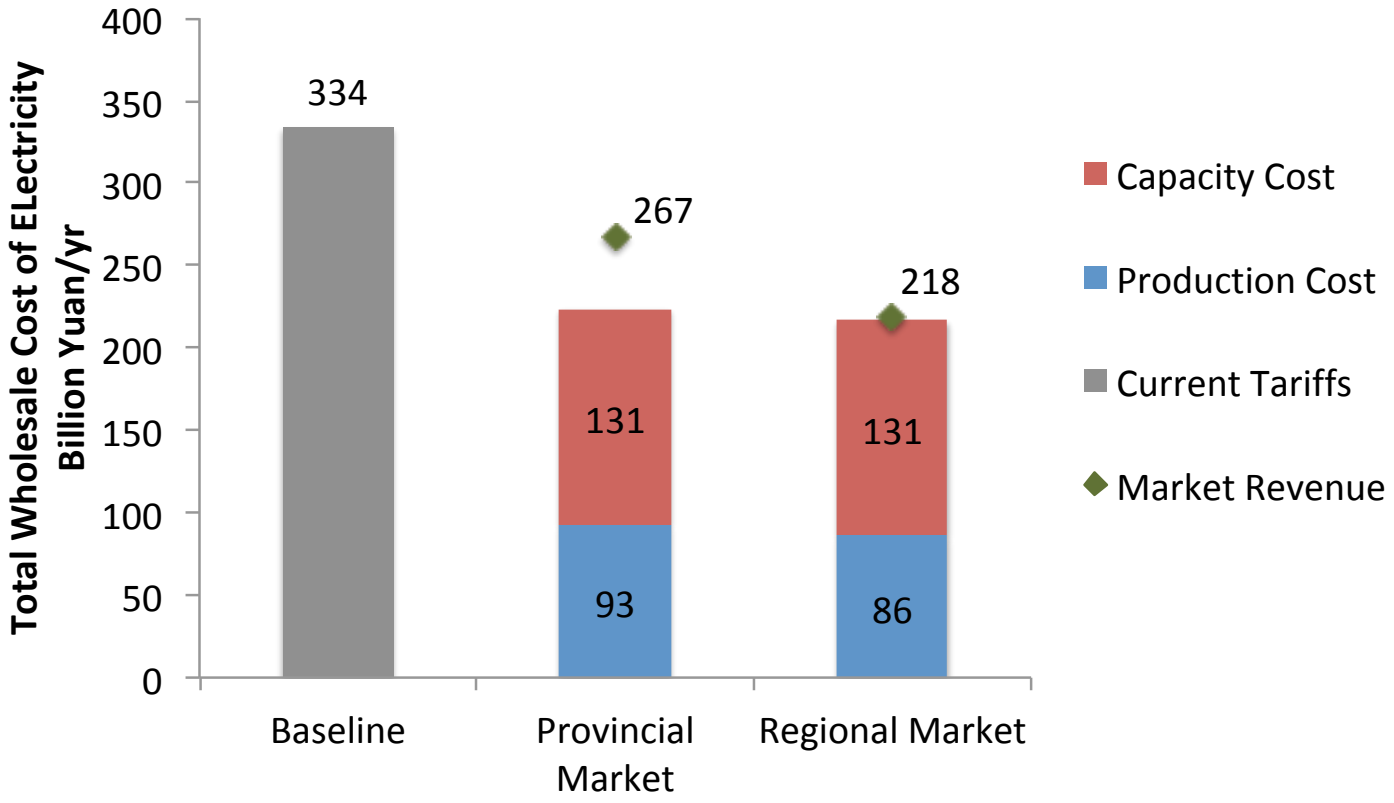


Note: Curtailment includes RE as well as Hydro curtailment

Economic dispatch can reduce the power sector carbon emissions by ~ 10%
经济调度减少电力系统碳排放10%



How to address the missing money problem？如何解决容量成本问题？



- Market revenue is enough to cover the production cost and capacity costs
- 市场总收入超出生产成本和容量成本

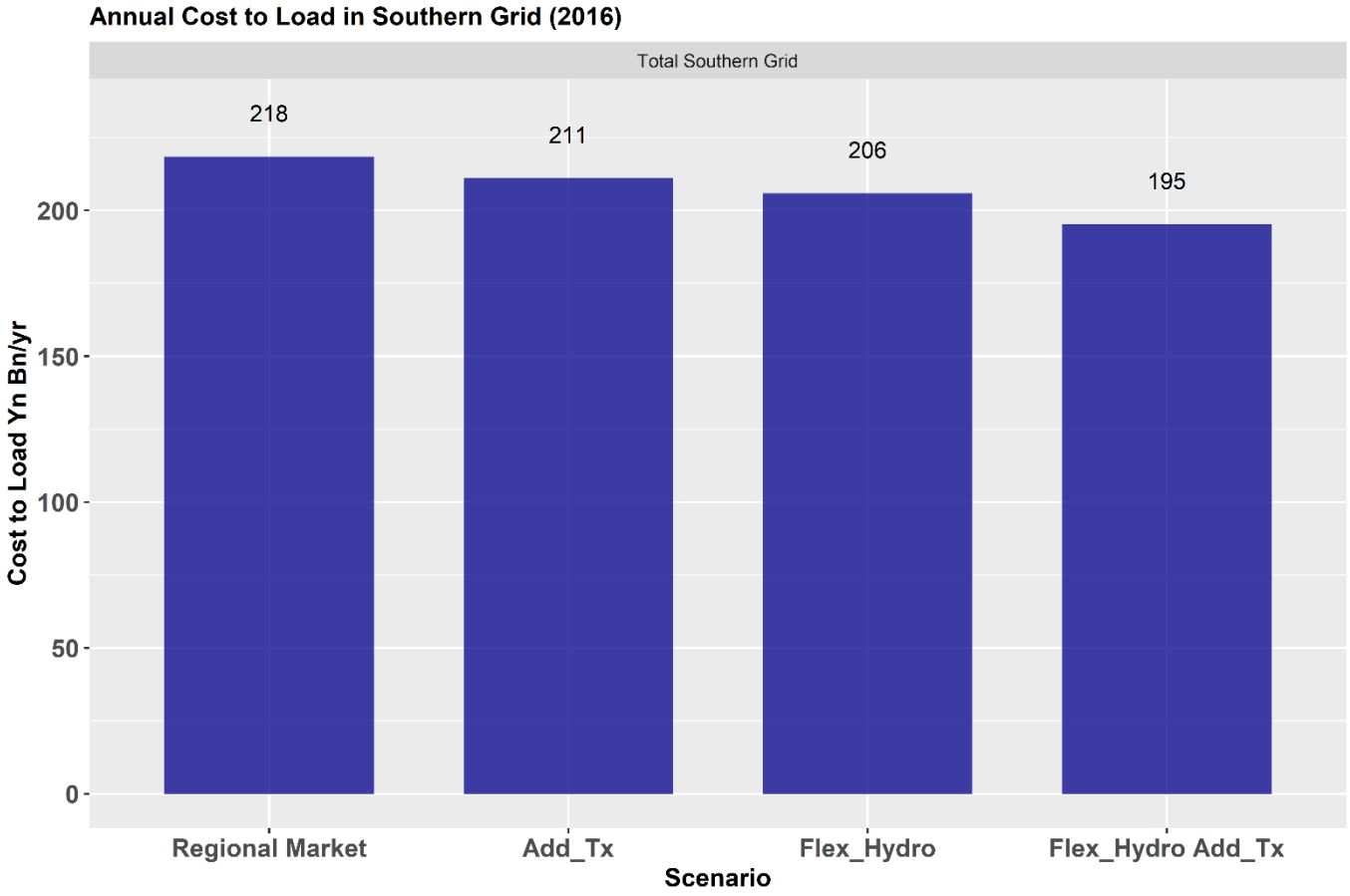
Sensitivity Analysis
敏感性分析

1. **Additional Transmission Investments (Add_Tx)增加额外传输能力**
We assume new investments are made in the inter-provincial transmission capacity and the available transfer capacity increases by 50% of the existing capacity.
假设省间电力传输能力增加50%

2. **Flexible Hydro Dispatch (Flex_Hydro)灵活水电**
We make the hydro dispatch in all provinces somewhat flexible – hydro power plants can deviate by 25% from the fixed hydro dispatch. They still have to follow the monthly energy budget constraints.各省水电分配更加灵活，在各月总水电不变的情况下，根据实际负荷情况增加水电灵活性25%

These sensitivity cases are run for the Regional Market scenario.在南网区域市场情景的基础上进行敏感性分析

Sensitivity Analysis 敏感性分析



- By increasing the transmission capacity by 50%, the wholesale cost would reduce further by ~3% relative to the regional market scenario.省间传输能力增加50%，总成本相对于南网区域市场情景减少3.5%
- By making the hydro dispatch somewhat flexible (25% flexibility relative to the baseline dispatch while following the same monthly energy budgets), wholesale cost reduces by ~6% relative to the regional market scenario.增加水电灵活性25%，总成本相对于南网区域市场情景减少6%
- Flexible hydro also makes coal dispatch flatter 灵活水电使煤电调度更平缓
- With flexible hydro as well as additional transmission investments both - cost to load reduces by ~10%.增加省间传输能力50%以及水电灵活性25%可整体减少总成本约10%（相对于南网区域市场情景）

Conclusions结论

- Transitioning from the uniform power plant dispatch to market based dispatch would lead to significant economic benefits to the southern grid system (20%-35%)计划调度到市场调度给南网区域带来巨大经济效益（20%-35%的成本节约）
- Market operations lead to significant reduction in the curtailment of renewable energy and hydro resources (from 33 TWh/yr to almost 0) – leading to an overall reduction in the coal based generation电力市场大幅消除弃风弃光弃水现象（33TWh到几乎完全消除）
- As a result, power sector CO_2 emissions reduce by ~10%电力市场减少二氧化碳排放约10%
- Market revenue seems enough to address the missing money problem of generators – provided critical financial mechanisms are put in place市场经济收益可以弥补电厂的容量成本
- Given the current load and generation capacity, enhancing the inter-provincial transmission capacity leads to minor reduction in the electricity costs; flexible hydro generation seems far more valuable现有情况下，省间传输线能力的扩大的成本节约效果不显著。增加水电灵活性带来的成本节约略高于省间传输能力增加带来的成本节约

Policy Implications 政策意义

- With increasing penetration of RE resources, making the power system more flexible becomes crucial 随着可再生能源在电力系统比重不断提高，保证电力系统灵活性至关重要
  - System operations and markets are found to be some of the cheapest sources of flexibility 系统运行和市场化可以以较低成本提供灵活性
  - Value of a market based flexible system is only going to increase with increasing RE penetration and / or uncertain loads such as EVs 可再生能源或其他不确定负荷（如电动汽车）越多，市场提供灵活性的价值就更大
- Markets can create enough financial headroom in the system to restructure some of the existing stranded assets or avoid creating new ones市场可以帮助解决潜在搁浅资产问题
  - Overinvestment in thermal assets now is only going to make their retirement and thus climate mitigation more difficult 如果现在对火电进一步过度投资，将导致其退出更加困难
- Regional market crucial to accelerate the transition to a carbon neutral power system区域市场对加速低碳化电力系统转型有重要意义

Thank You!

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