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

Jiang LIN, Nikit Abhyankar, Xu Liu, and Froylan Sifuentes

Lawrence Berkeley National Laboratory

UC Berkeley

劳伦斯伯克利国家实验室

加州大学伯克利分校

Electricity Market International Summit

Beijing, June 1-2, 2019

Outline 大纲

- Background 研究背景
- Research Questions 研究问题
- Methods and Scenarios 方法和情景
- Results 主要结果
- Conclusions 结论和政策建议

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

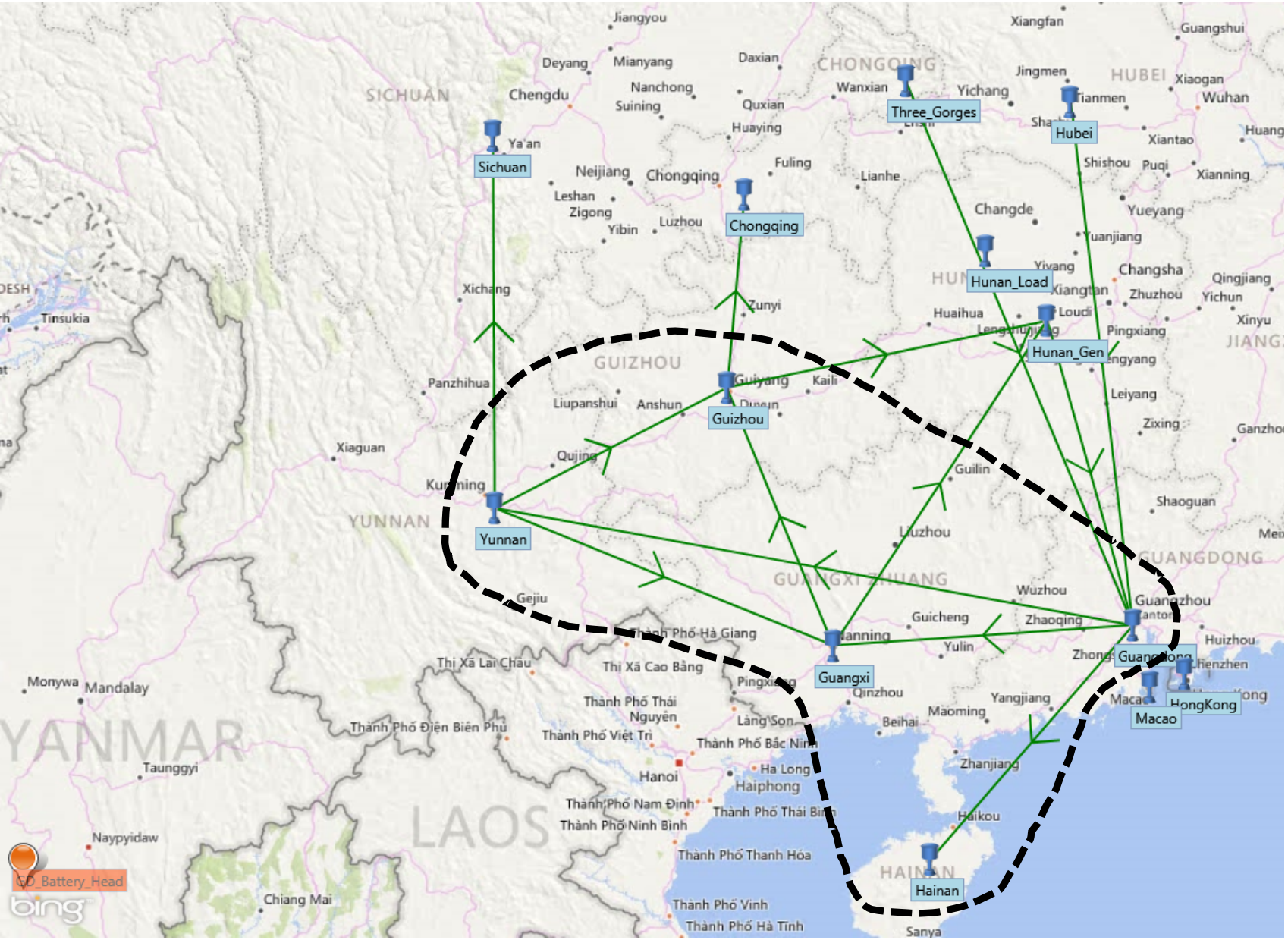
Specific 具体问题

- 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？

Approach 研究方法

- Create model of the Southern Grid territory electricity system in PLEXOS在PLEXOS中建立南方电网区域模型
- Assume convergence to economic (marginal cost-based) dispatch with a single market clearing price for each province, and then for the whole grid各省建立自己的省内电力市场，有各自的出清电价；之后扩展到南方电网区域
- Include transmission and transactions between provinces 考虑到省间传输和交易
- Examine total cost to load and generation impacts relative to a simulated actual scenario, at both the grid level and provincial level分析市场情景下各省和南网整网总成本和发电情况与实际模拟情景的差别
- Sensitivity analysis to consider enhanced inter-provincial transmission and flexible hydro dispatch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



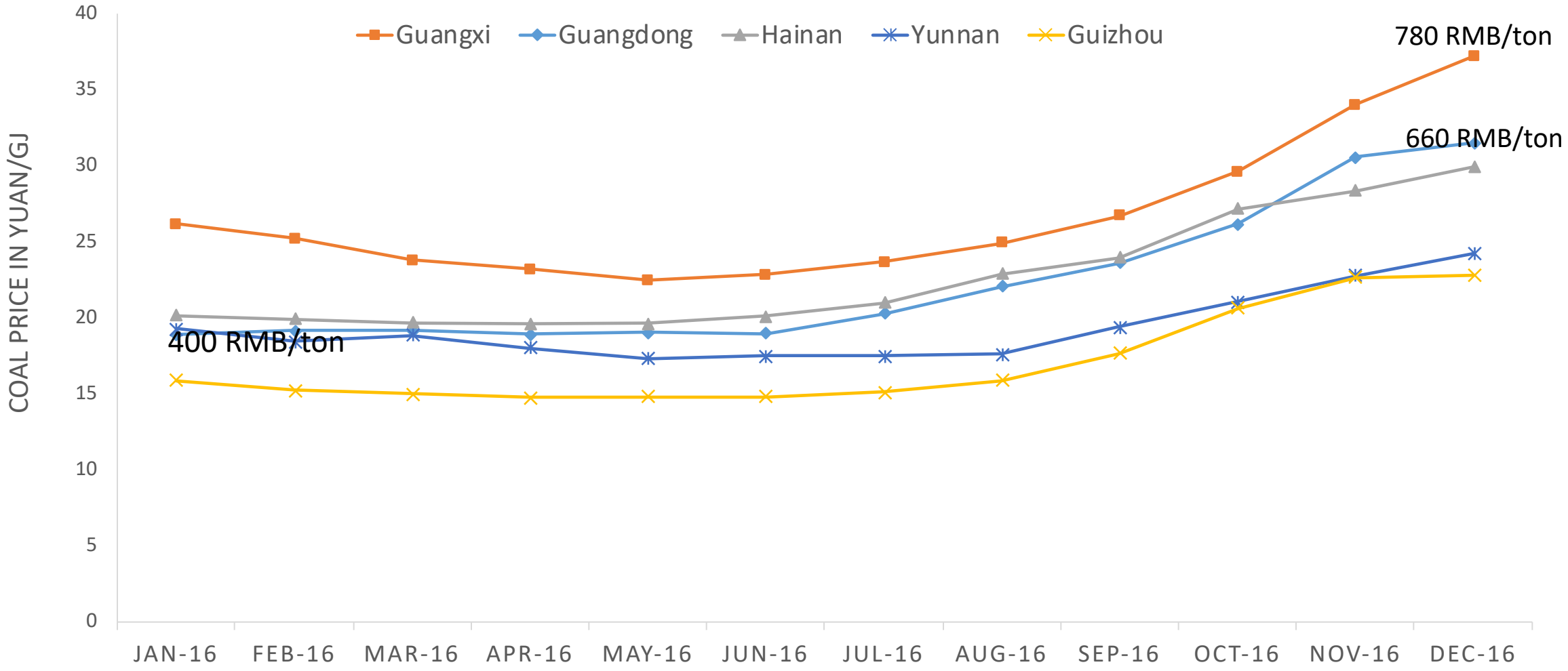
Southern Grid network is represented in a reduced form (1 node per province). 简化模型：每个省作为一个节点

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

Southern Grid System Characteristics 南网系统特征

	Guangdong (GD) 广东		Guangxi (GX) 广西		Guizhou (GZ) 贵州		Yunnan (YN) 云南		Hainan (HN) 海南		Total Southern Grid 南网	
	Installed Capacity 装机容量 MW	Average Marginal Cost 平均边际成本 Yn/MWh	Installed Capacity 装机容量 MW	Average Marginal Cost 平均边际成本 Yn/MWh	Installed Capacity 装机容量 MW	Average Marginal Cost 平均边际成本 Yn/MWh	Installed Capacity 装机容量 MW	Average Marginal Cost 平均边际成本 Yn/MWh	Installed Capacity 装机容量 MW	Average Marginal Cost 平均边际成本Yn/MWh	Installed Capacity 装机容量 MW	Average Marginal Cost 平均边际成本 Yn/MWh
Coal煤炭	59,511	236	16,150	239	29,290	245	12,535	247	3,060	243	120,546	239
Gas天然气	13,438	488	2,406		925	488	1,481	488	1,580	559	19,830	505
Nuclear核电	8,862	55	2,172	55					1,300	55	12,334	55
Hydro水电	14,104		16,630		20,890		60,960		910		113,494	
Wind风电	2,680		670		3,620		7,370		310		14,650	
Solar PV太阳能光伏	1,560		180		460		2,080		340		4,620	
Total总计	100,155	168	38,208	115	55,185	119	84,426	25	7,500	132	285,474	114
Peak Load (MW)峰值负荷	97,929		25,565		21,836		22,456		4,713		155,231	
Demand总电力需求 (TWh/yr)	562		147		124		141		29		1003	

Monthly power coal prices by province in 2016
2016年分月南方电网五省电煤价格



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

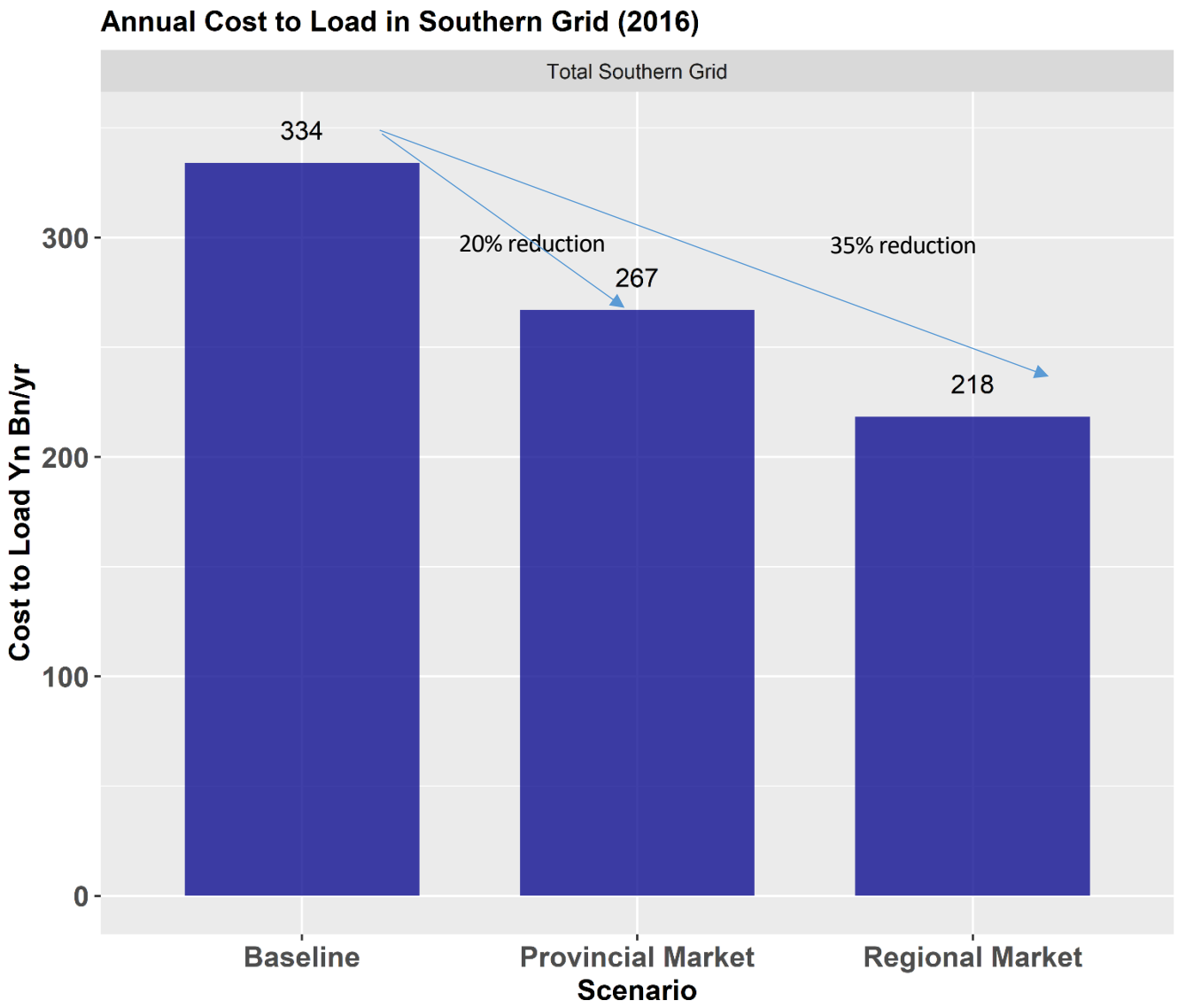
2. **Provincial Market 省内市场情景**

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

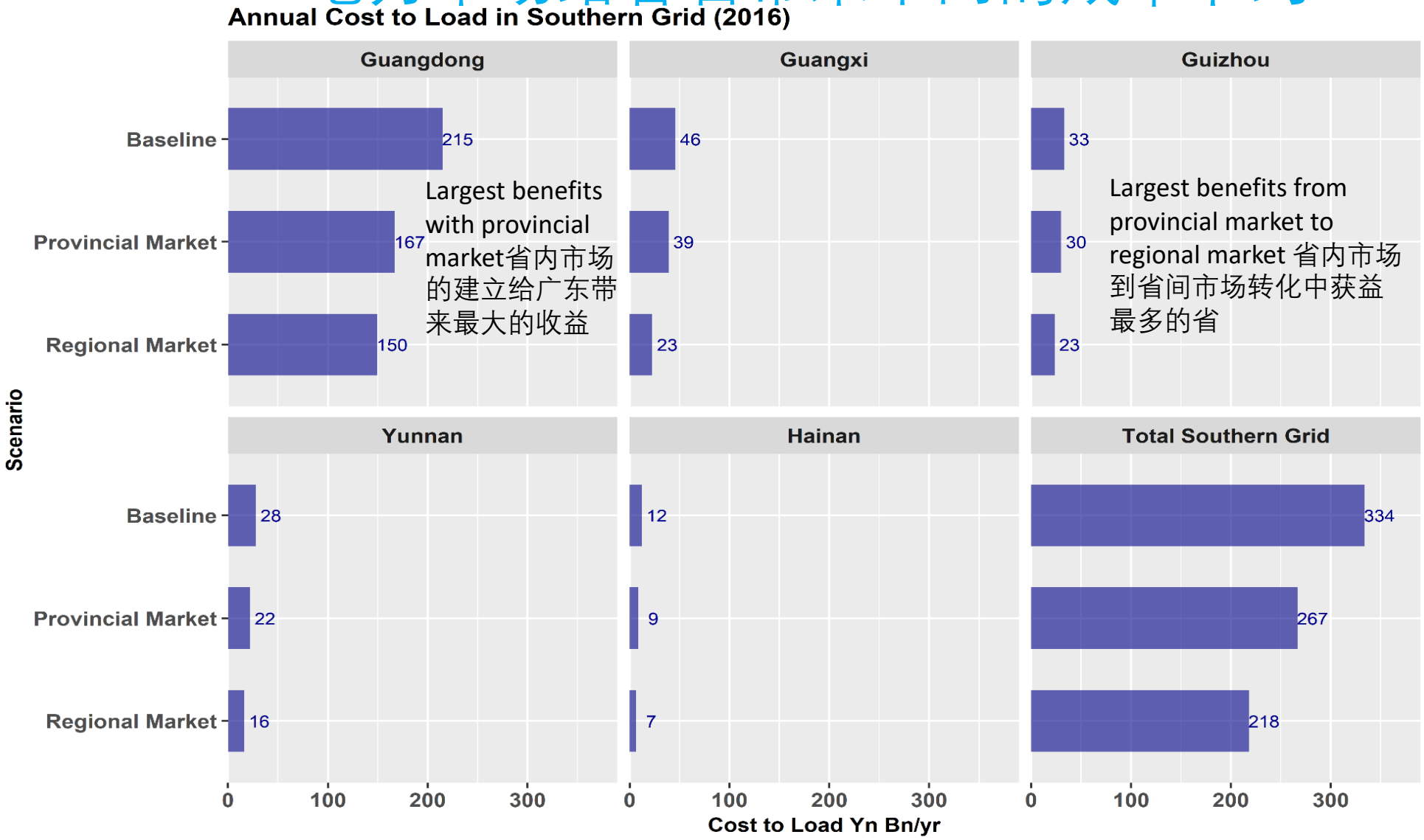
Substantial savings from provincial and regional markets (Over 100 B/year)
省间和区域市场带来巨大收益（每年超过1000亿人民币）



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

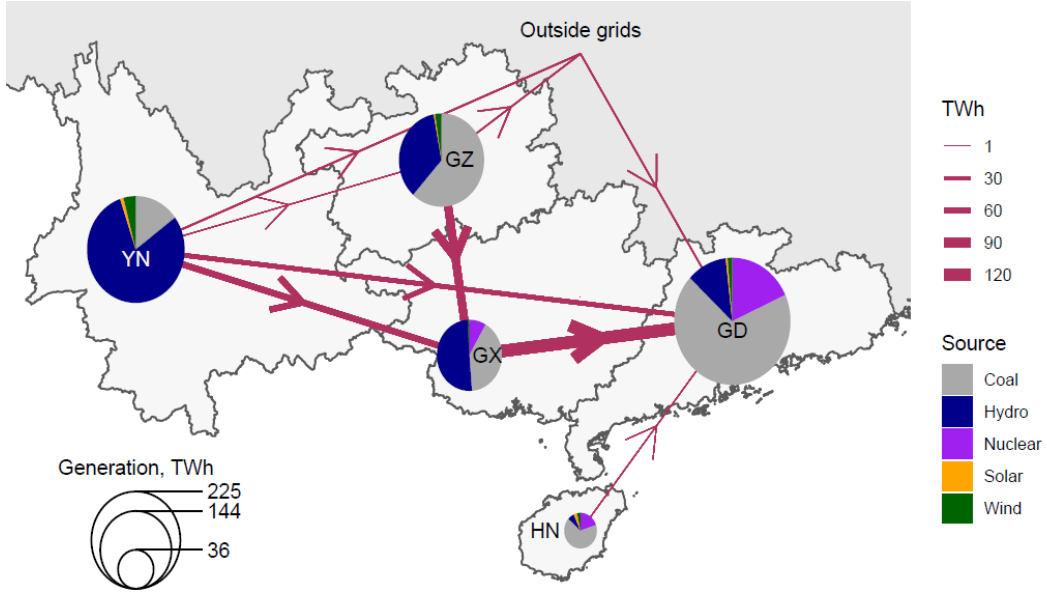


Provincial market and southern grid markets are pareto optimal for all provinces under all scenarios.

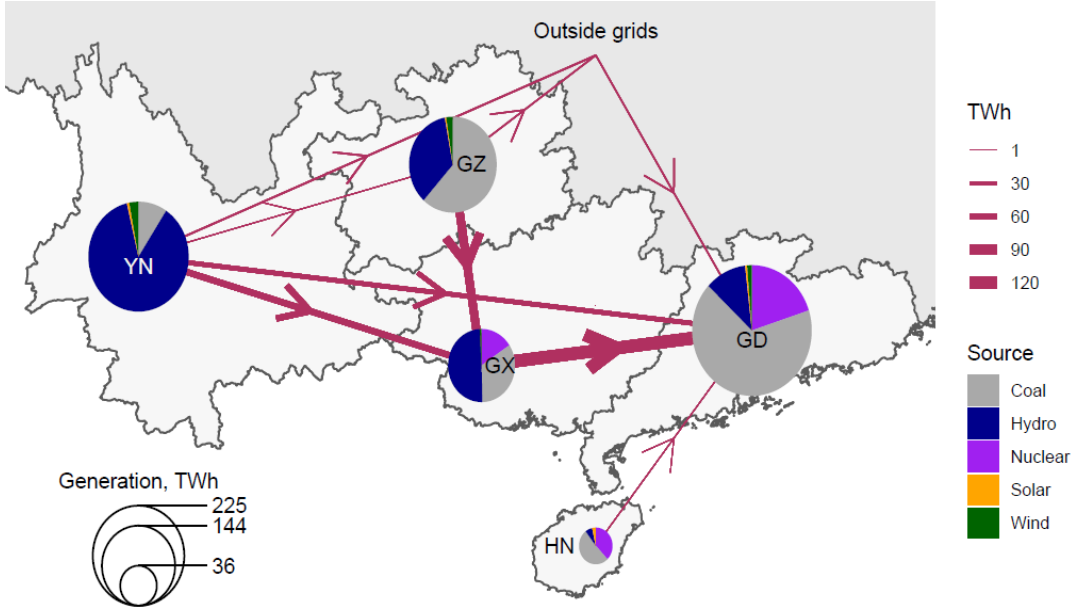
省内市场和省间市场对各省来说都是帕累托最优。

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

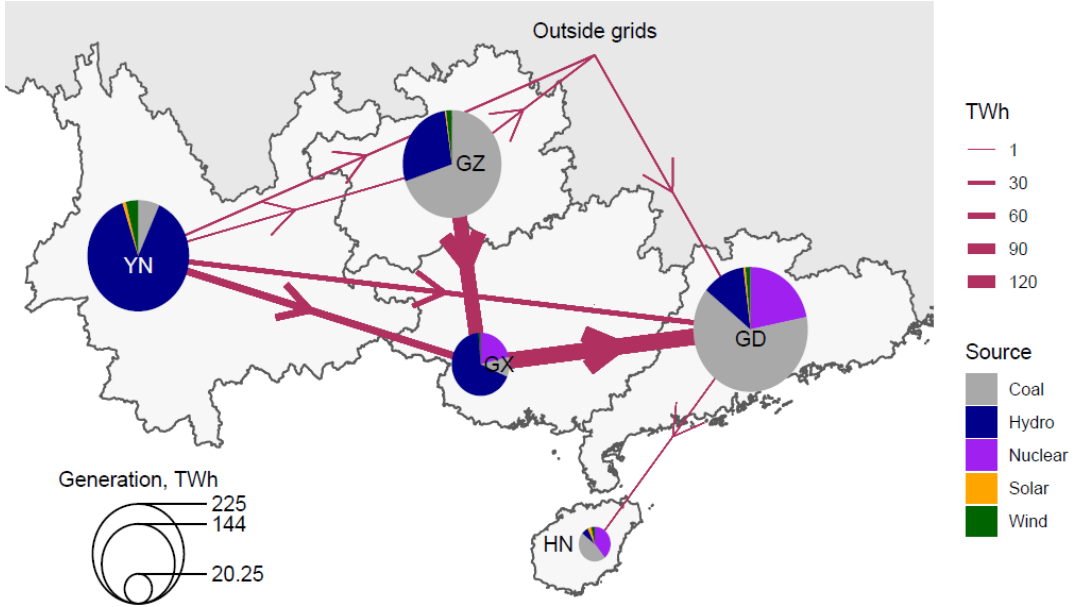
Baseline 2016实际模拟情景

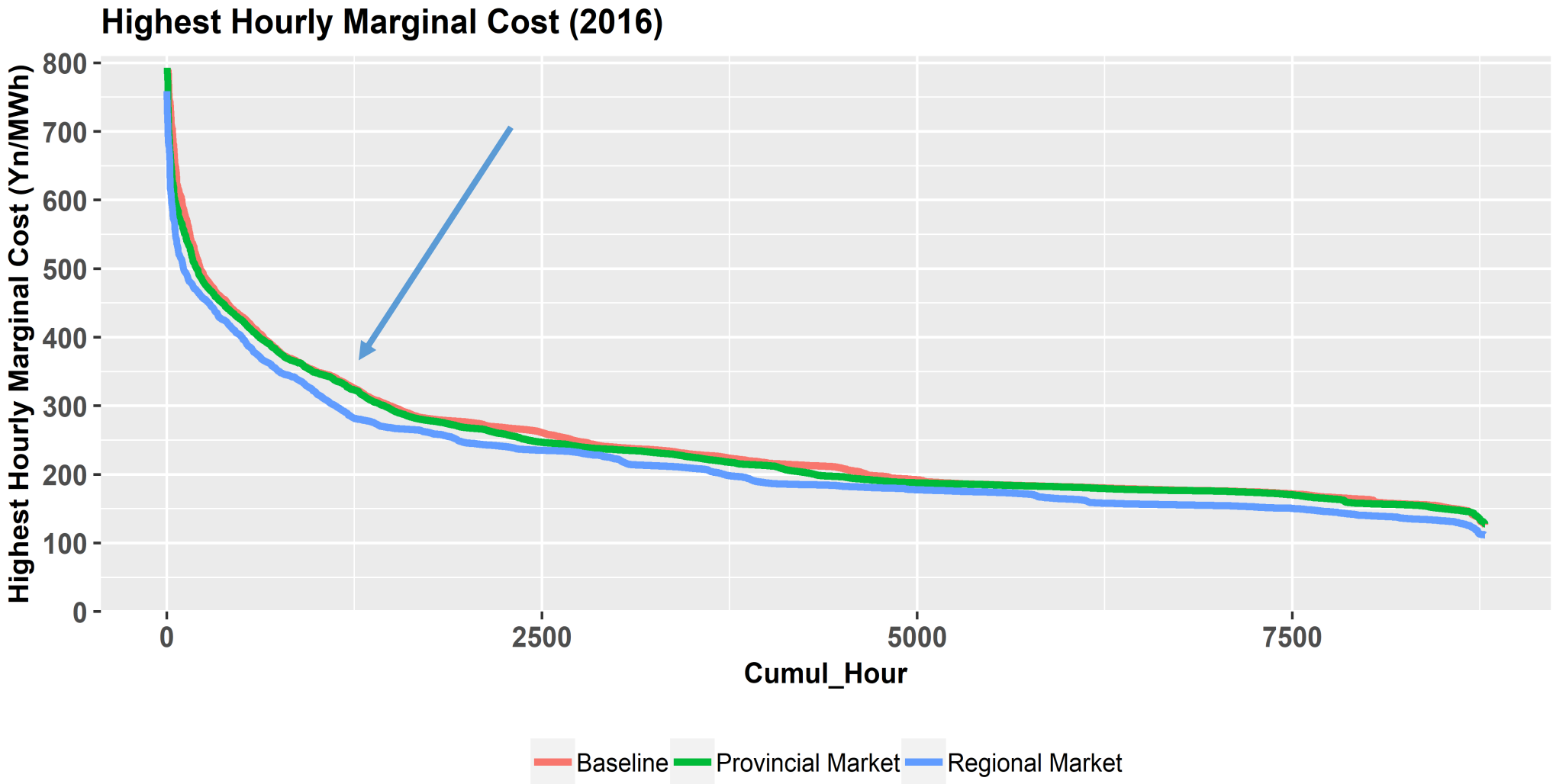


Provincial Market 省内市场情景

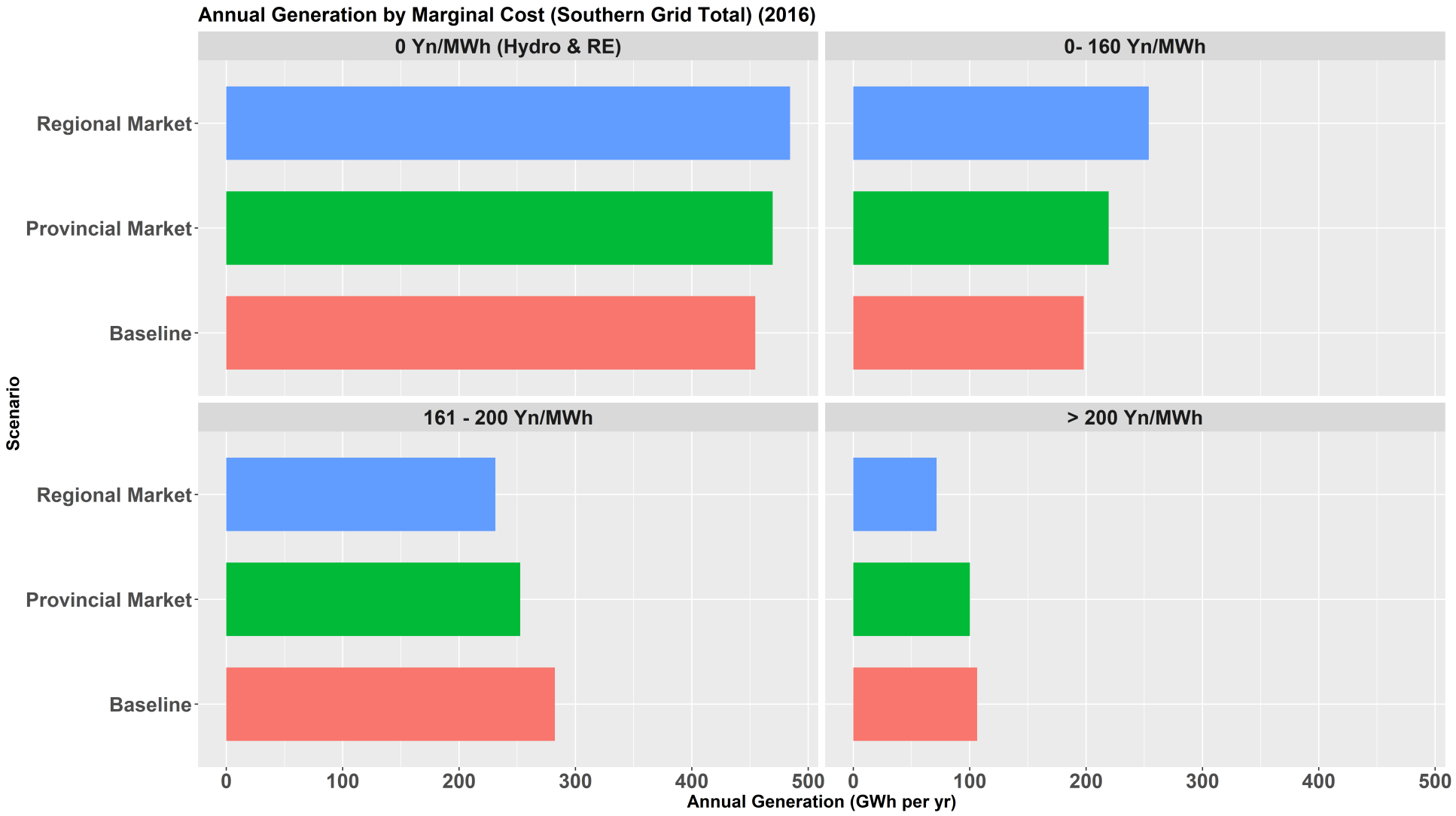


Regional Market 南网区域市场情景

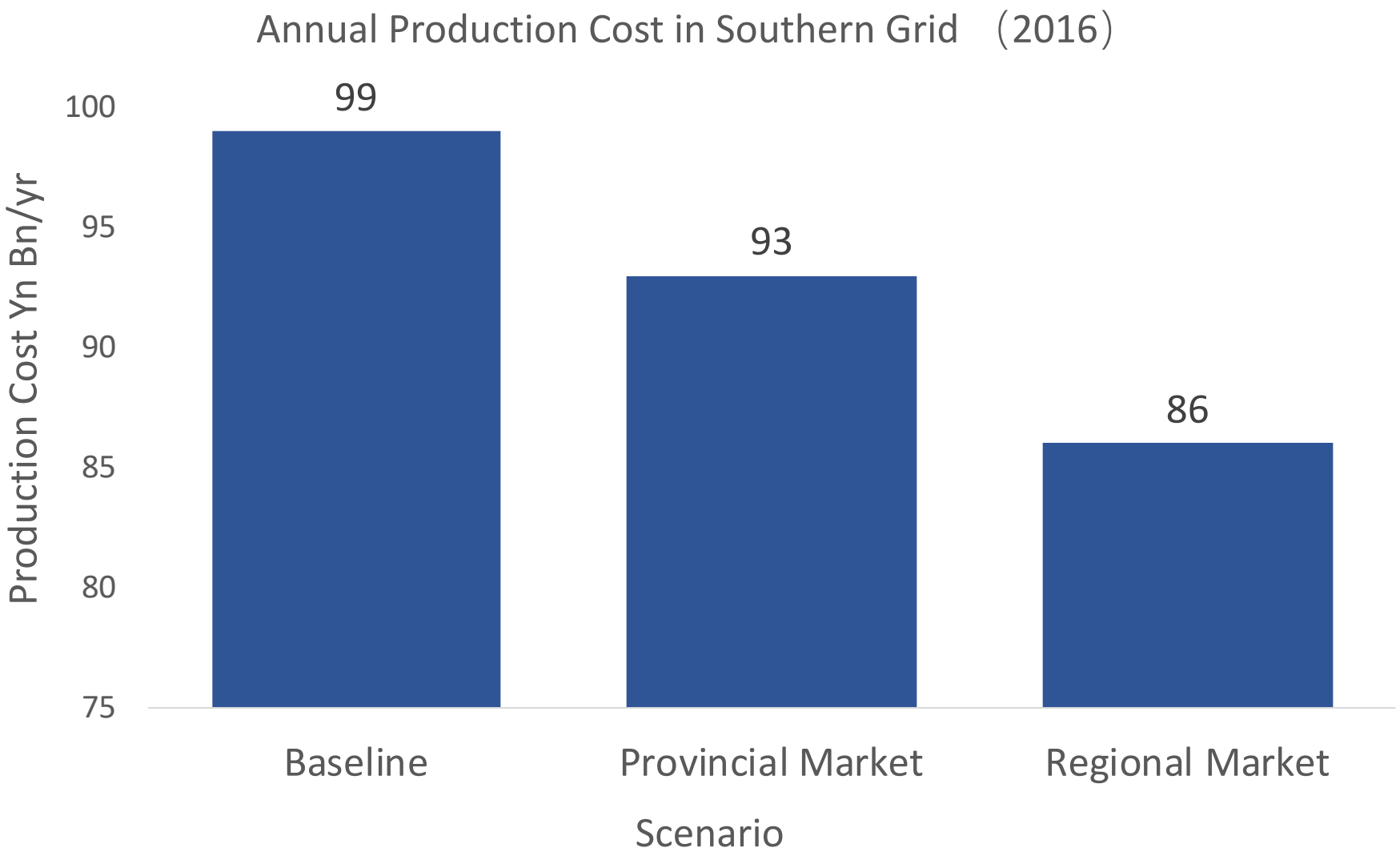



Highest Hourly Marginal Cost (2016)
Highest Hourly Marginal Cost (Yn/MWh)
800
700
600
500
400
300
200
100
0
0
2500
5000
7500
Cumul_Hour
Baseline
Provincial Market
Regional Market

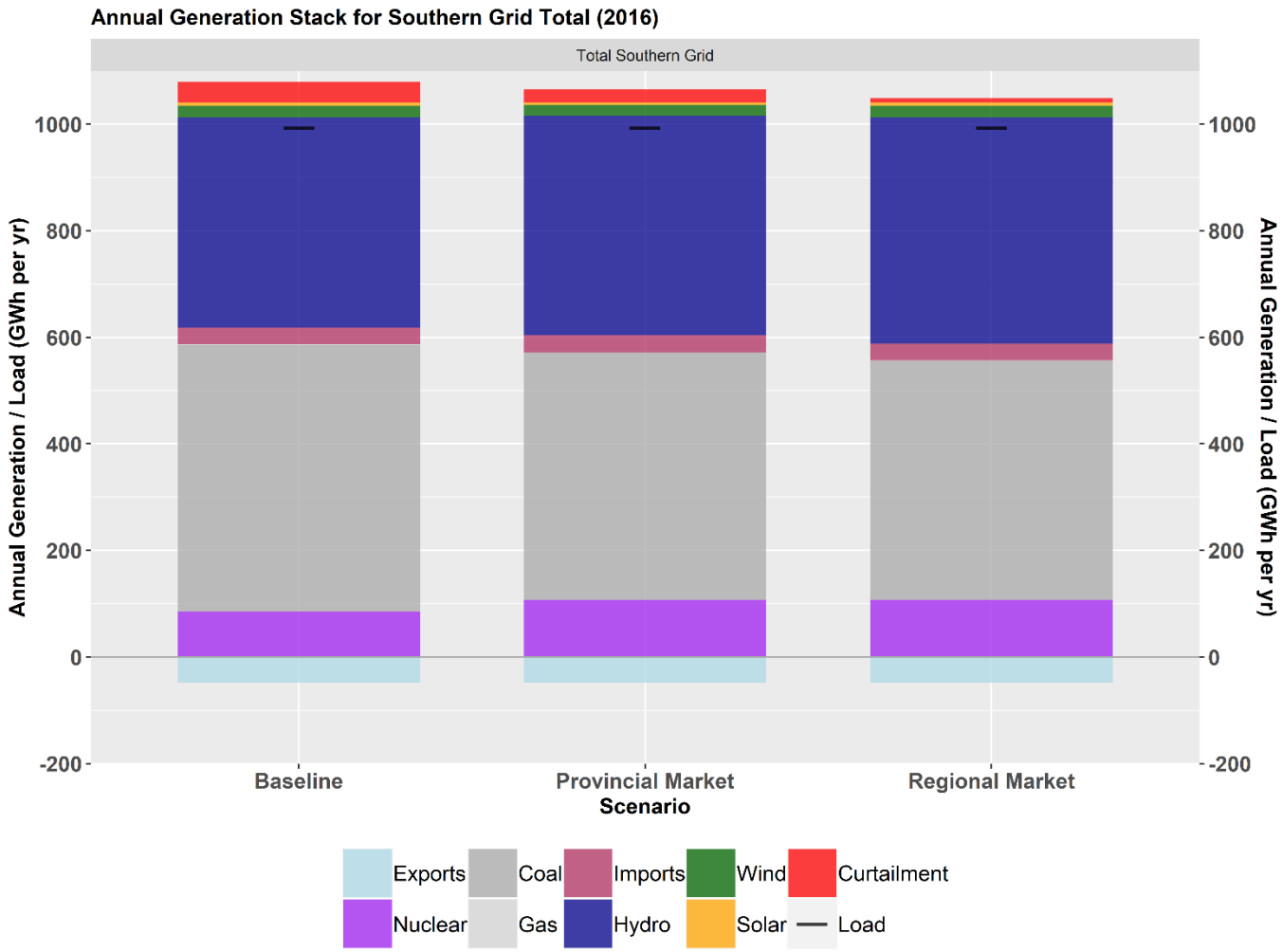
Market allows plants with lower marginal costs to generate more electricity市场优化电源效率，低边际成本电源获更多发电小时数



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

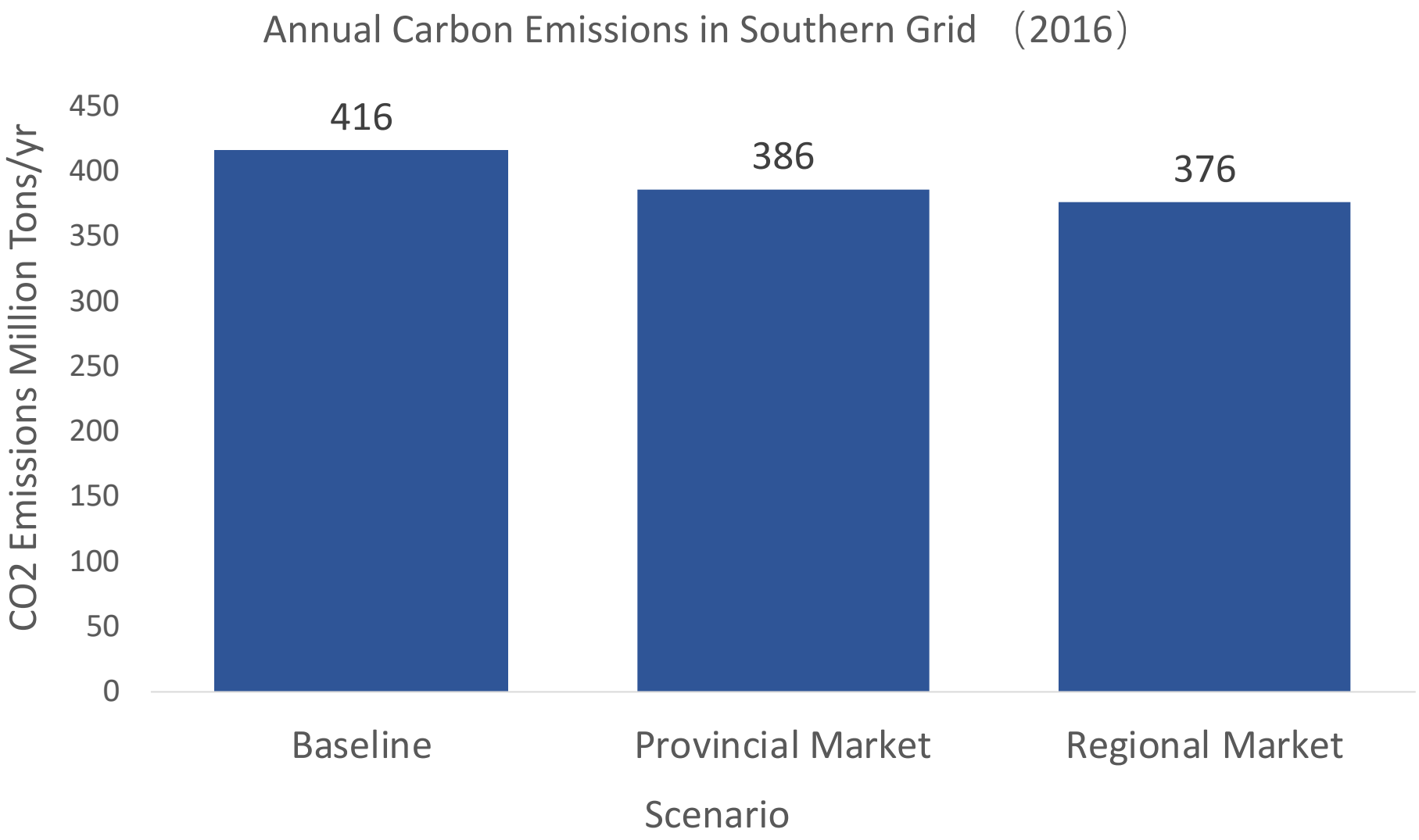


Regional markets reduce coal generation by over 10% and renewable curtailment 区域市场降低煤电10%，减少弃风弃光弃水



Note: Curtailment includes RE as well as Hydro curtailment

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



Sensitivity Analysis 敏感性分析

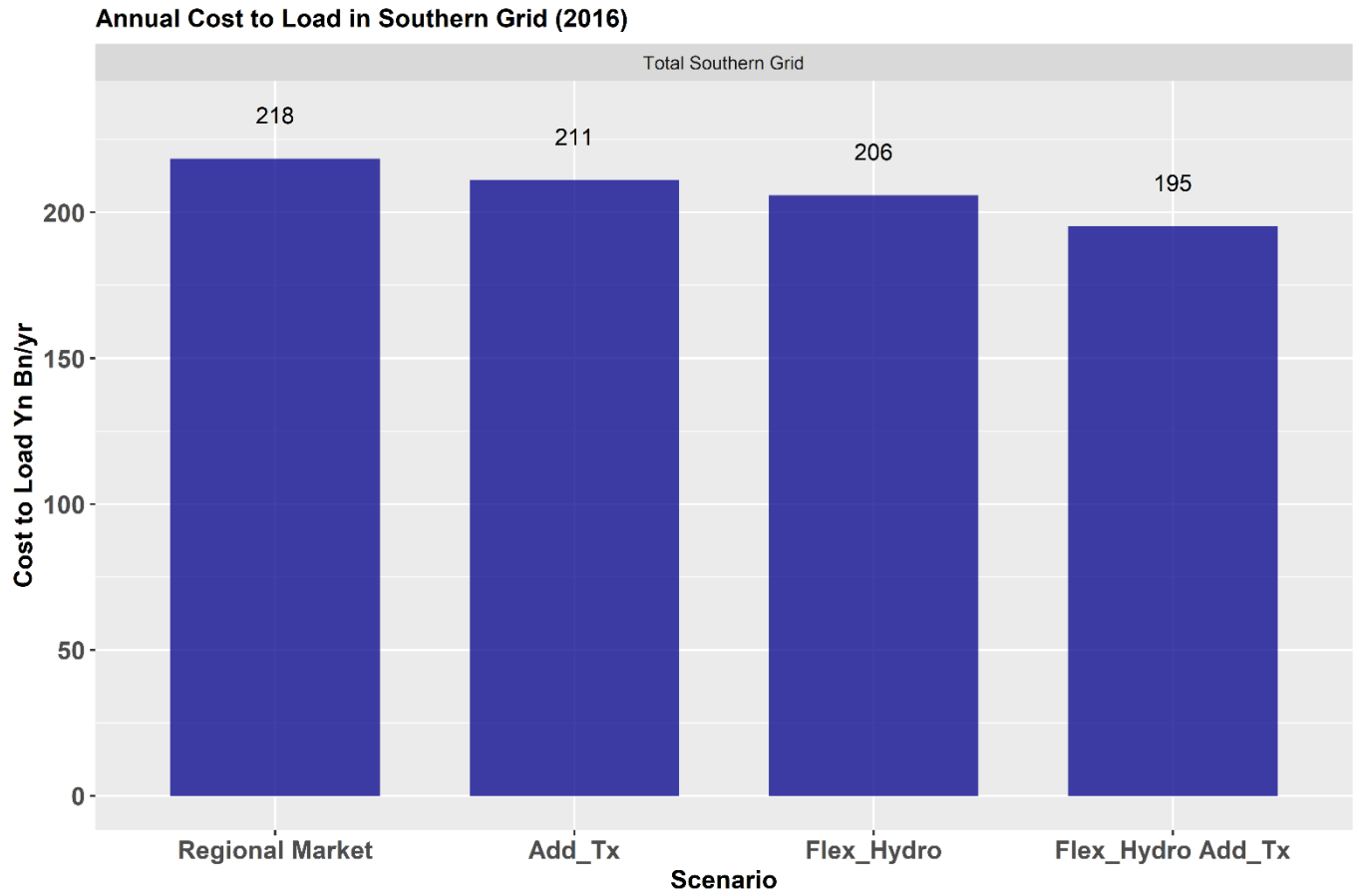
Sensitivity analysis was conducted on the following parameters: 针对传输能力和水电灵活性进行敏感性分析

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 overall cost to load would reduce further by ~3.5% 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 fixed dispatch while following the monthly energy budgets), overall 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%

- With flexible hydro as well as additional transmission investments both - cost to load reduces by ~10% to 195 billion Yn/yr.

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 as a whole (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 to almost 0).电力市场大幅消除弃风弃光弃水现象（33TWh到几乎完全消除）
- Market operations lead to more efficient dispatch of the thermal fleet and overall reduction in the production costs (6%-13%).电力市场使高效机组优先调度，降低生产成本6%-13%
- Markets can reduce the CO_2 emissions by 10%. 电力市场减少二氧化碳排放约10%
- Regional market reduce coal generation by 10%区域电力市场减少煤电生产10%
- Under current demand situation, enhancing the inter-provincial transmission capacity leads to minor reduction in the electricity costs. 现有电力消费情况下，省间传输线能力的扩大只带来成本的小幅下降
- Flexible hydro dispatch generates more savings than enhancing transmission capacity. 现有情况下，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 recommendations 政策建议

Step 1: Creating provincial markets 第一步是建立省内电力市场

- to reduce cost to consumers, carbon emissions, and curtailment of renewable and hydro 减少消费者成本、碳排放、以及弃风弃光弃水
- with appropriate financial arrangements to recover the fixed costs of the generation assets 设计合理的财务支持政策保证回收电厂的固定成本

Step 2: Expanding the provincial markets to a regional market 第二步是把省内电力市场扩大到区域市场

- To help integrate higher-level of renewable and hydro resources 帮助消纳更多的可再生能源和水电
- To further reduce costs to consumers and carbon emissions进一步降低消费者成本和碳排放
- To accelerate the transition to a carbon neutral power system加速电力系统清洁零碳化

Thank You!

Jiang Lin
J_lin@lbl.gov

Nat Simons Presidential Chair in China Energy Policy

Berkeley Tsinghua Joint Research Center on Energy and Climate Change
China Energy Group
Lawrence Berkeley National Laboratory
Berkeley, CA 94720
http://china.lbl.gov
http://btjrc.lbl.gov