Eastern Wind Integration and Transmission Study (EWITS) Results
东部风电接入和输电研究(EWITS)成果

Renewable Energy Integration:
可再生能源接入
International Experiences and Implications for China
国际经验和对中国的启示

Beijing, China
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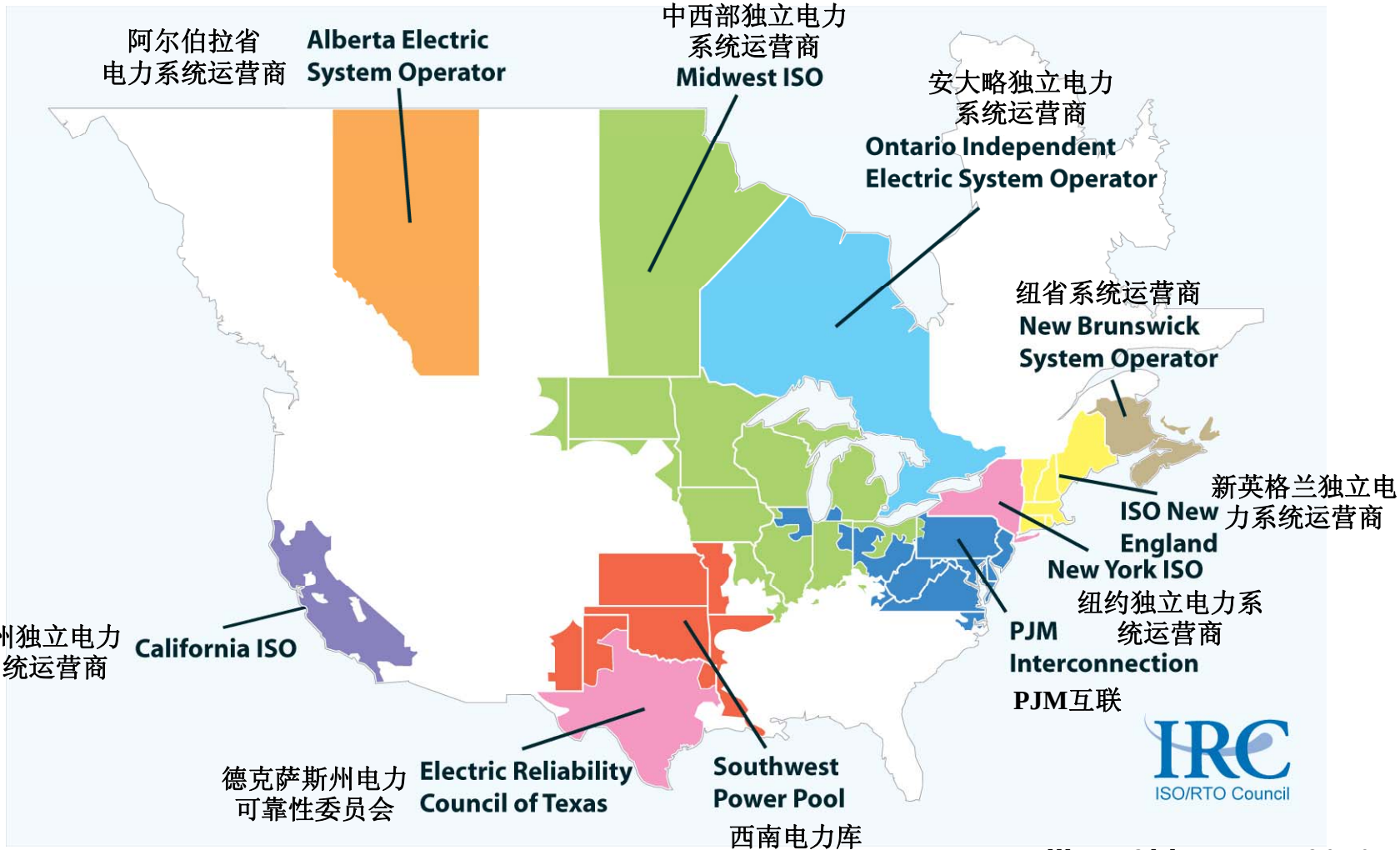
UWIG

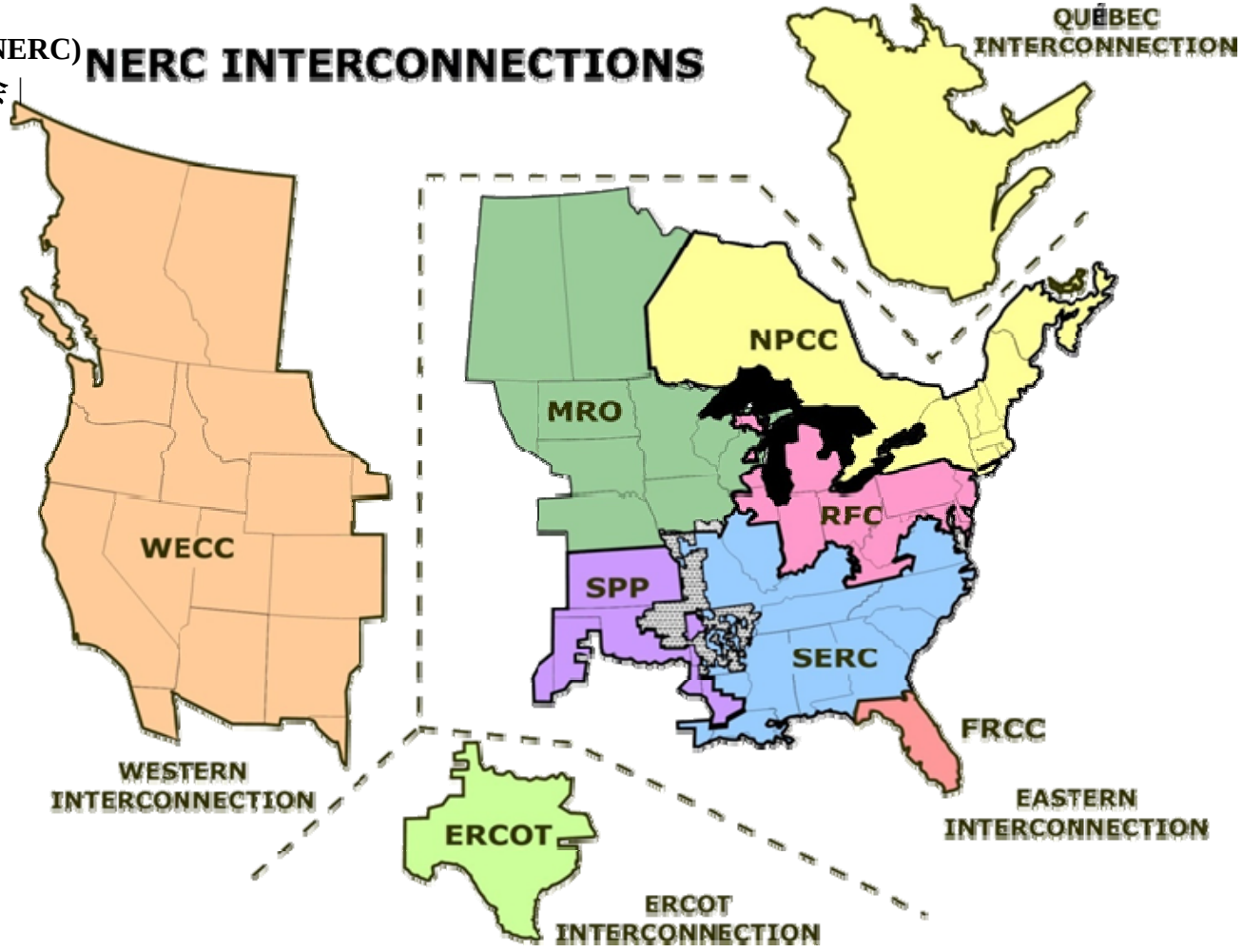
UWIG
Utility Wind Integration Group

ISOs/RTOs in North America
北美独立电力系统运营商和区域输电组织



North American Interconnections
北美互联系统

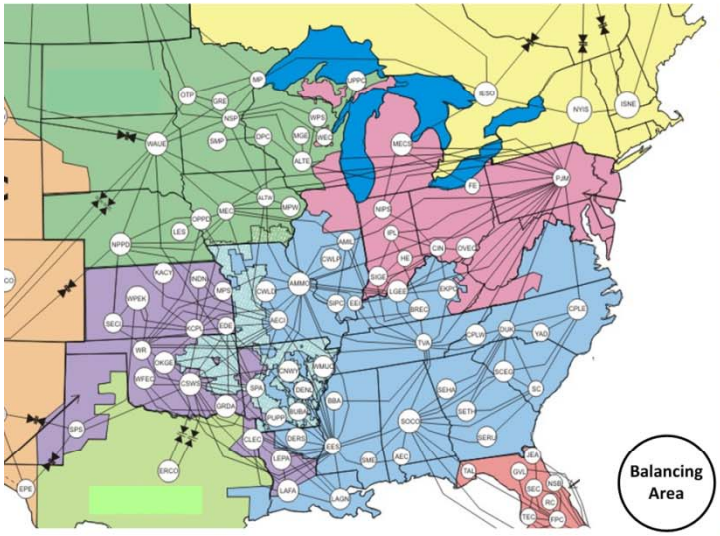
North American Electric Reliability Corporation (NERC)
北美电力可靠性委员会



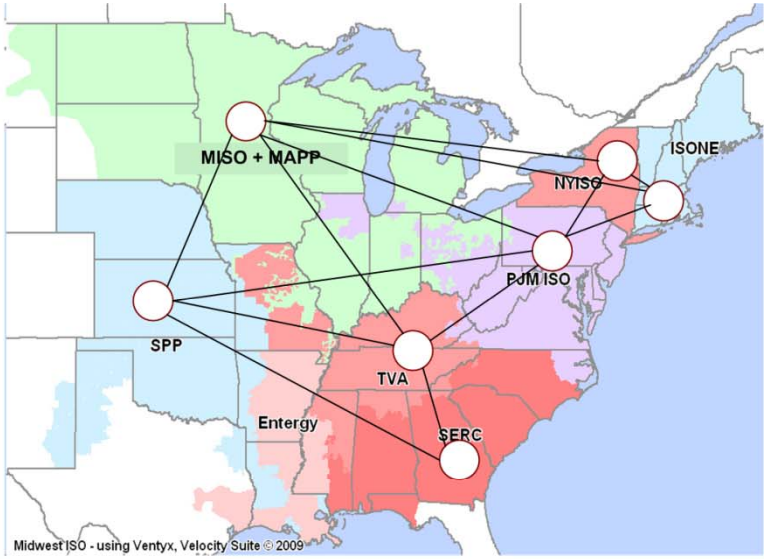
Assumptions : Power System Model for 2024
假设：2024年电力系统模型

- Loads escalated to 2024 based on regional
- 2018 power flow case, expanded to 2024
- Key assumptions
  - Per previous studies
  - Uniform structure assumed for 5 market footprints
  - No carbon tax or cap & trade as baseline

- 在区域负荷基础上，预测2024年的负荷水平。
- 由2018年的潮流方案，推测2024的情况。
- 主要假设：
  - 先前的研究
  - 假定5个市场覆盖区有统一结构
  - 以不计碳排放税及碳排放限制与贸易为基线。

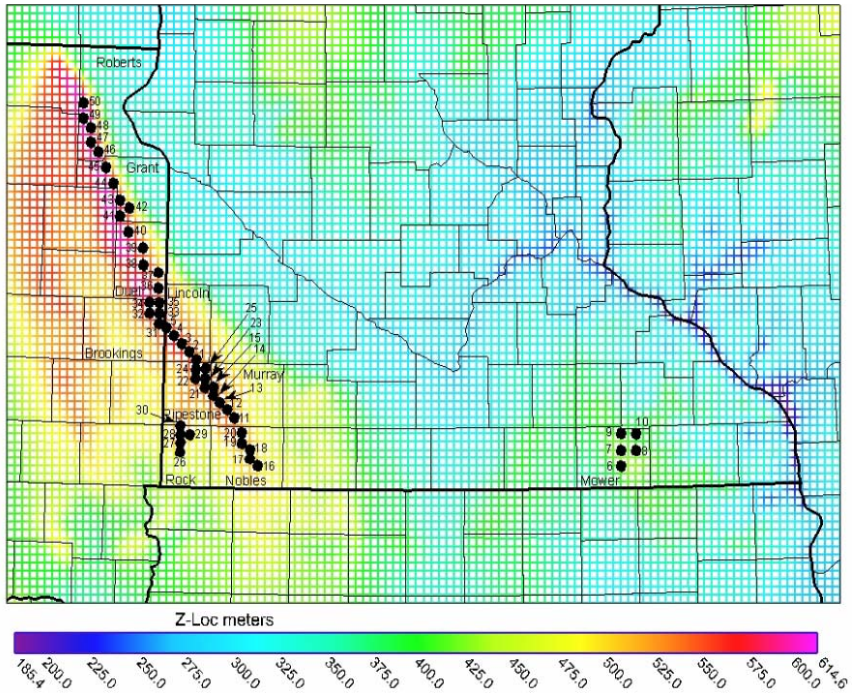


As of August 1, 2007

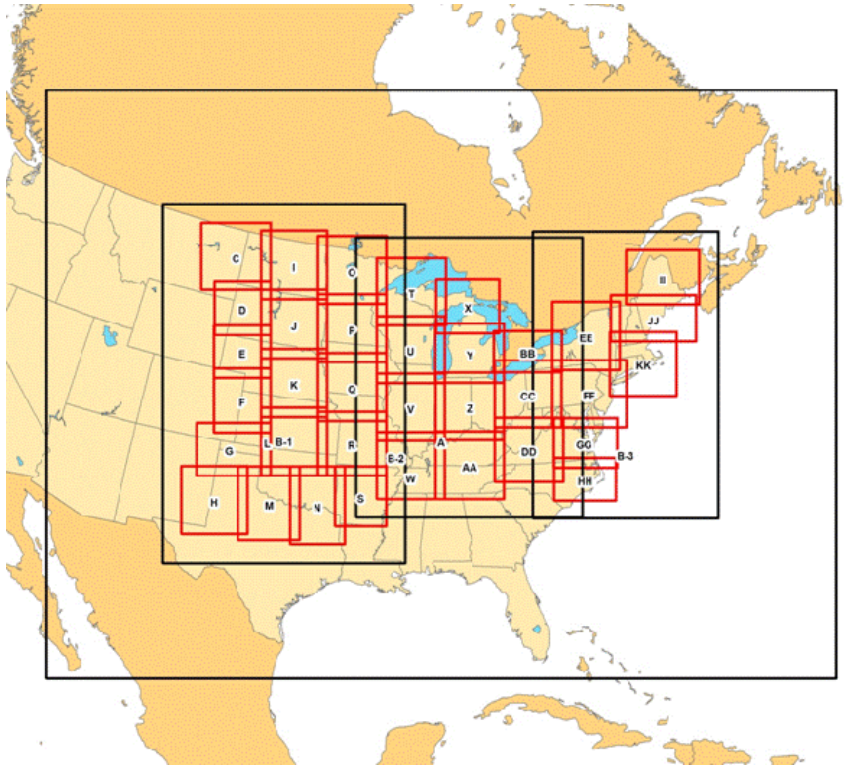


Assumption for 2024

Wind Plant Modeling Approach: "Re-creating" the Weather
风电场建模方法："重建"天气



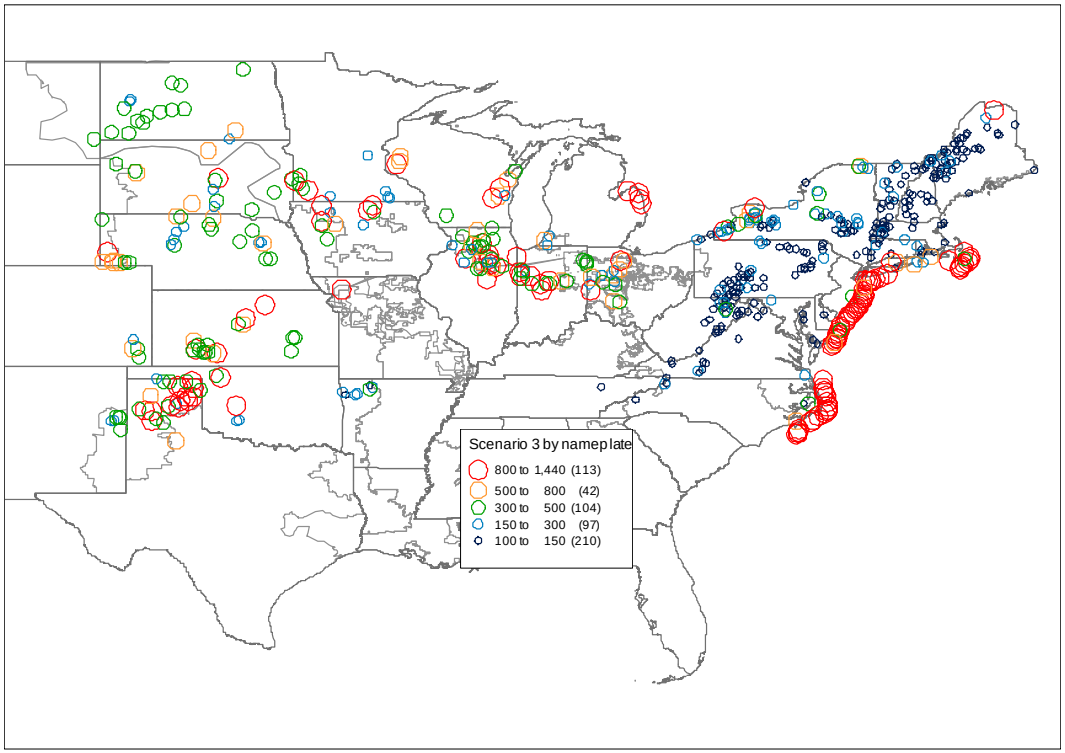
Wind plant siting
风电场选址



Mesoscale model grids
中尺度模型网格

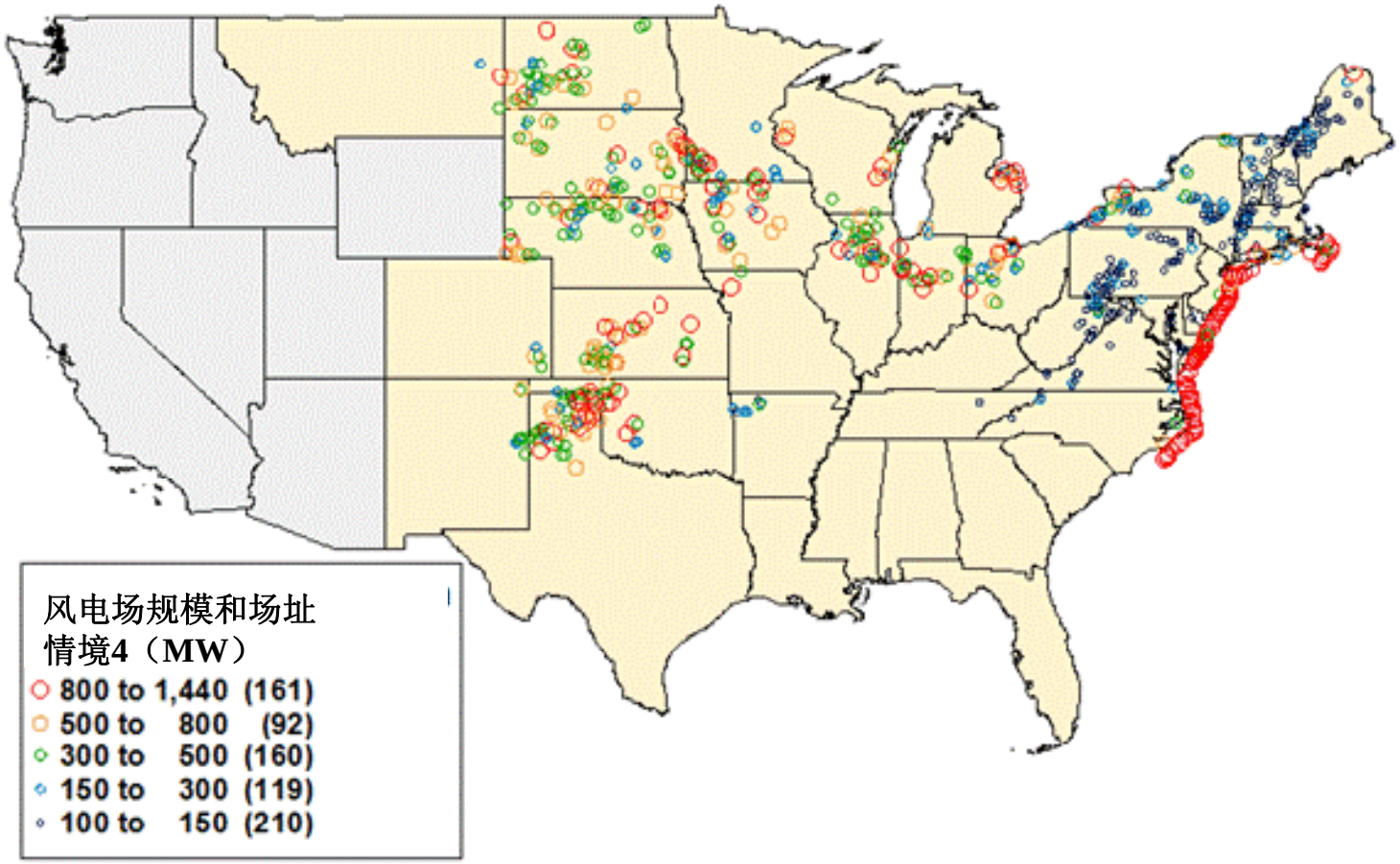
Scenario Development and Siting
情境制定和选址

- **Four Different Scenarios**
- 四种不同情境
  - **Three 20% and one 30% wind scenarios**
    三个风电占20%和一个风电占30%
    - » **Local resources with lower capacity factor onshore wind and offshore**
      利用当地资源，陆上和海上风电容量系数更低。
    - » **High capacity factor wind development in the Midwest with larger transmission component**
      开发中西部风资源，风电容量系数高，需大量输电设备。
- **All of four scenarios require a lot of wind and transmission!**
  四种情境均要求大量风能和输电能力。

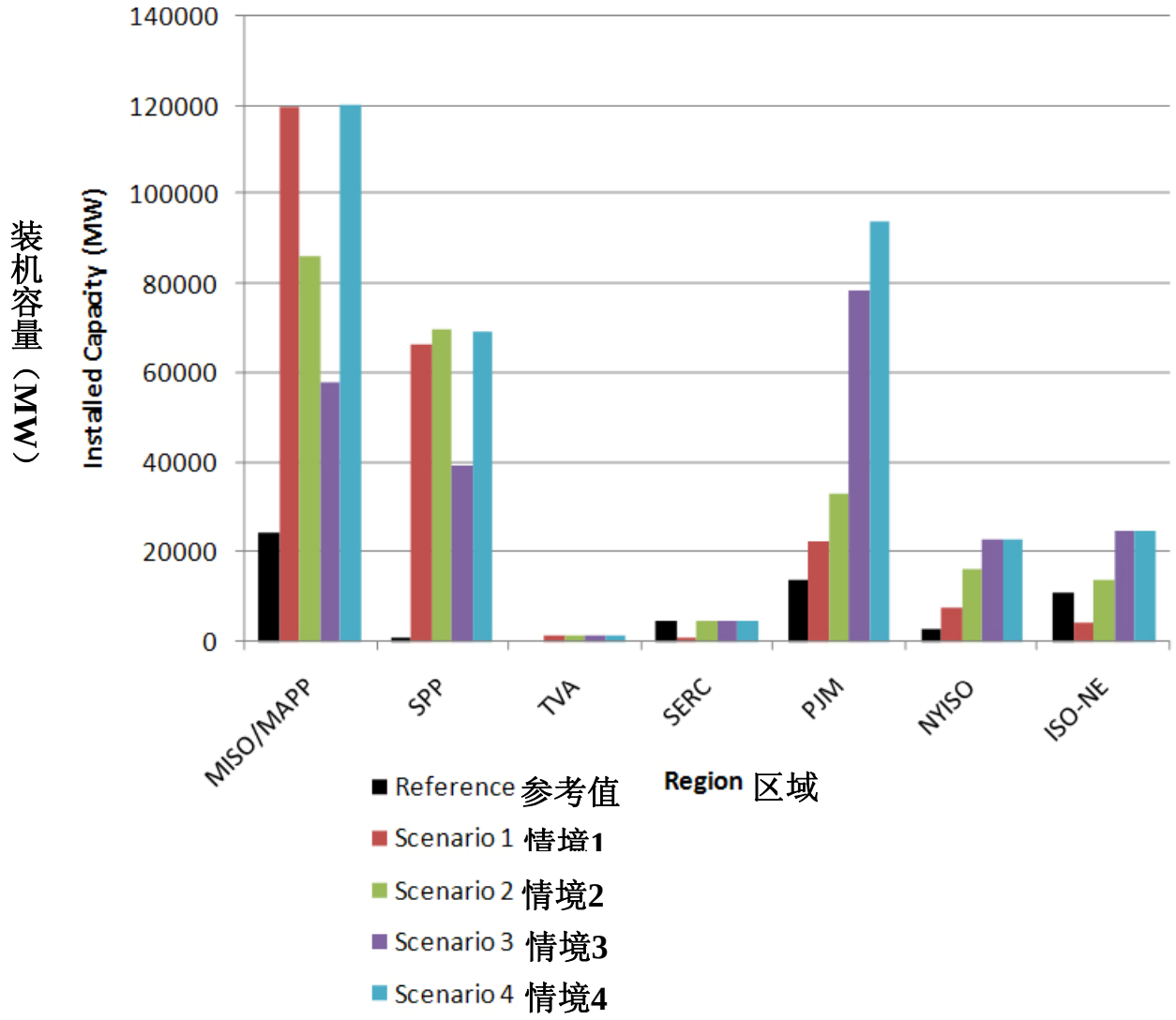


Scenario 3 Wind Plant Siting
情境三　风电场选址

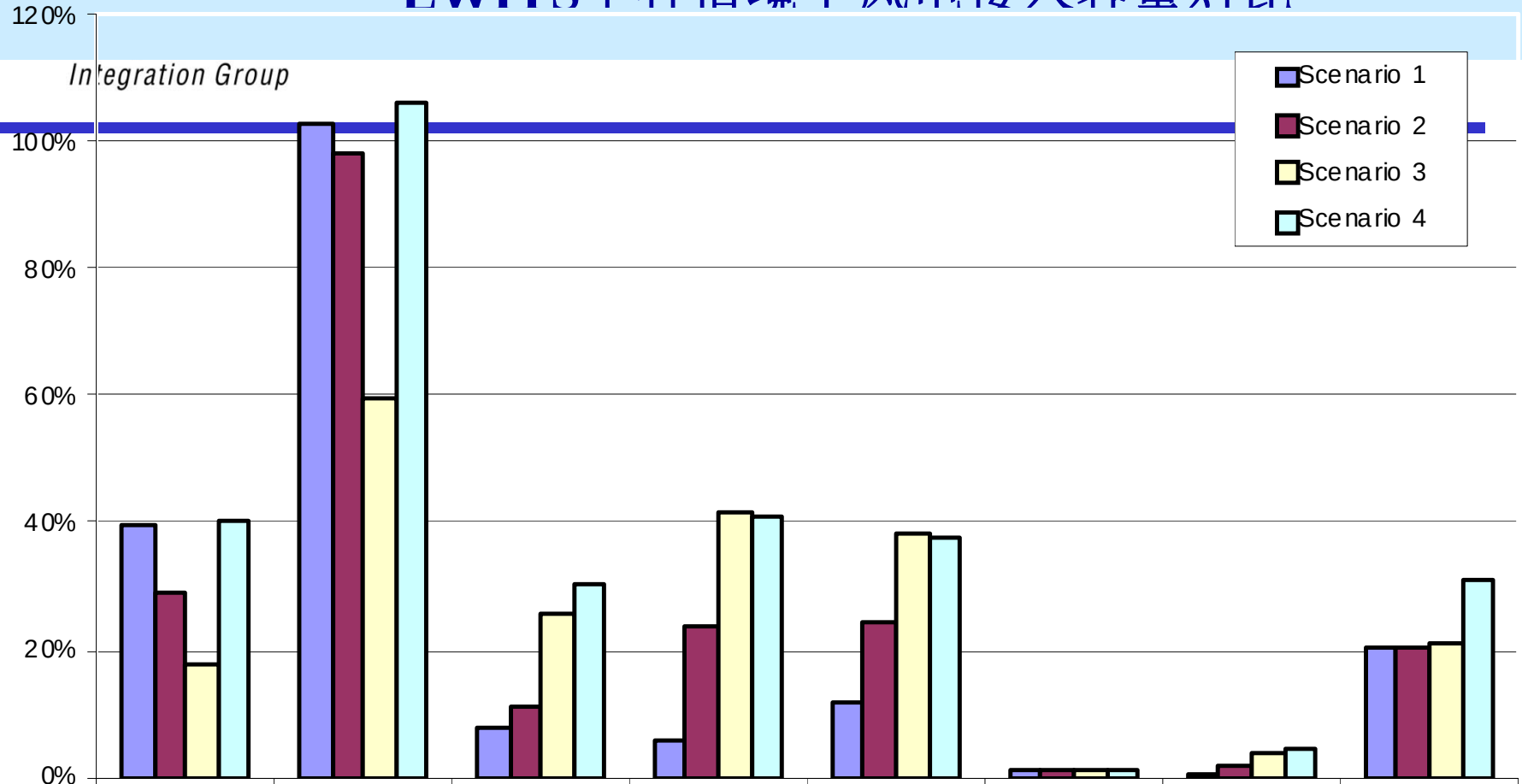
Scenario 4 - 30%
"Aggressive On- and Off-Shore"
情境4 -30%"陆上和海上风电宏伟目标"



Eastern Wind Integration and Transmission Study (EWITS) Scenarios
东部风电接入与输电研究(EWITS)情境



EWITS Wind Penetrations by Scenario
EWITS中各情境下风电接入容量对比



	MISO+MAPP	SPP	PJM	ISONE	NYISO	TVA SUB	SERCNI	Total Footprint
Scenario 1	39.9%	102.9%	7.8%	5.9%	11.5%	1.2%	0.4%	20.3%
Scenario 2	29.1%	98.2%	11.1%	23.4%	24.6%	1.2%	2.0%	20.4%
Scenario 3	18.0%	59.3%	25.6%	41.8%	38.0%	1.2%	3.7%	20.8%
Scenario 4	40.0%	106.2%	30.5%	41.3%	37.5%	1.2%	4.1%	30.7%

Region

What's Different about Planning Transmission for Wind Energy
风能的输电规划有何不同

- Planning for energy resource different from planning for capacity resource – **look at** 8760 hours
- Expect shift in time of peak period of transmission loading to shoulder periods - 60% of peak load
- New contingencies likely around times of minimum load and minimum conventional generation
- Perform reliability transmission design- NERC criteria
- Perform wind integration study to determine A/S requirements (ramping, operating reserves, extreme events)
- LOLE and ELCC calculations are likely to modify the reserve margins

- 能源资源规划不同于容量资源规划-着眼于8760小时。
- 要求把输电负荷的高峰期按时间平移至腰荷期-高峰负荷的60%。
- 最低负荷和最低常规电源出力期间可能发生的新的突发事故。
- 执行可靠性输电设计-NERC标准
- 进行风电并网研究，确定A/S需求（爬坡率、系统运行备用、极端情况）
- LOLE和ELCC计算可能改变备用裕度。

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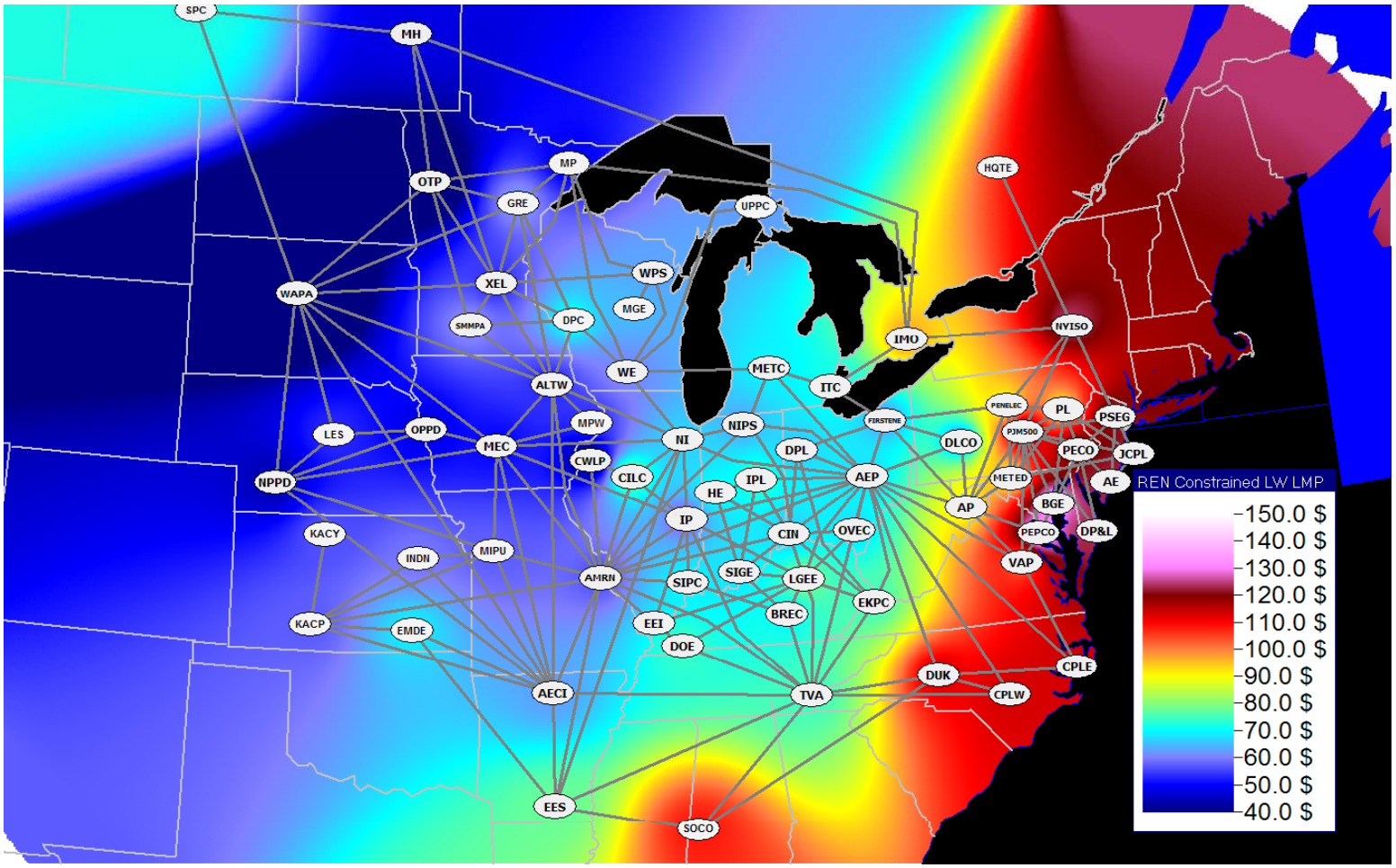
Full Constrained Case
Annual Load Weighted LMP
全约束案例-年负荷权重节点边际价格



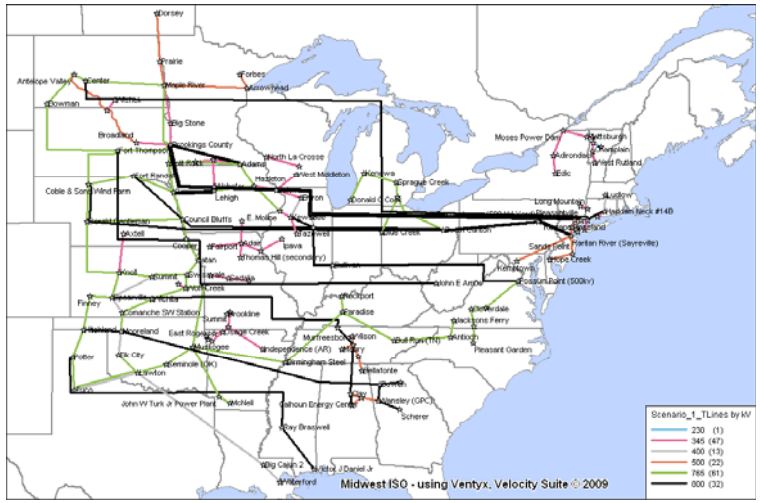
Source: MISO

Transmission Concepts, not "Plans"
输电概念，非“规划”

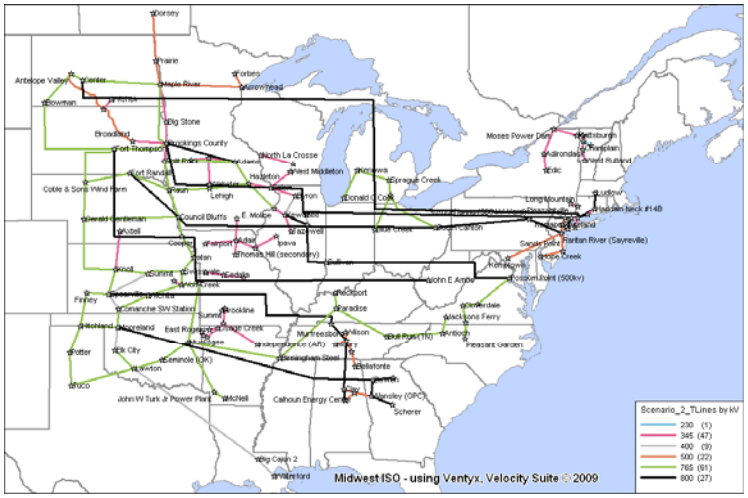
- Looks at the end of a planning horizon, rather than the beginning
  着眼于规划周期的末期，而不是起始期。
- Significant additional analysis needed to engineer details of plan
  需要重点分析规划的工程细节。
  - AC analysis
    AC分析
  - Stability and dynamics
    稳定性和动态分析
  - Further operational assessment
    进一步的运行评估

Overlays for 4 Scenarios
四种情境的覆盖范围

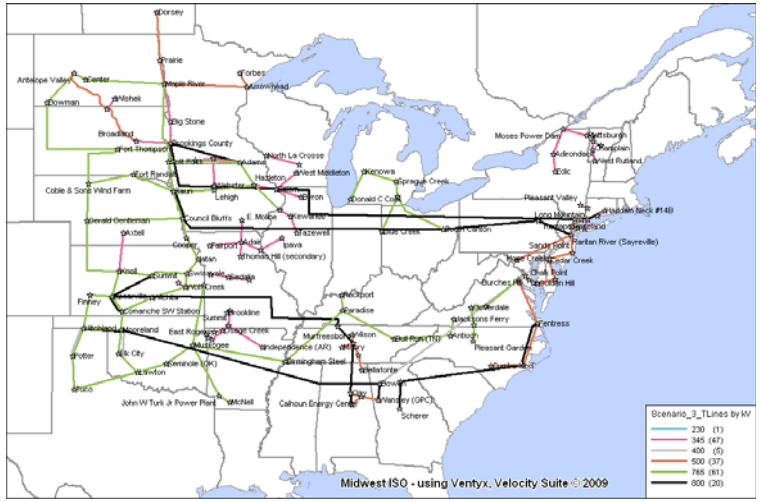
Scenario 1



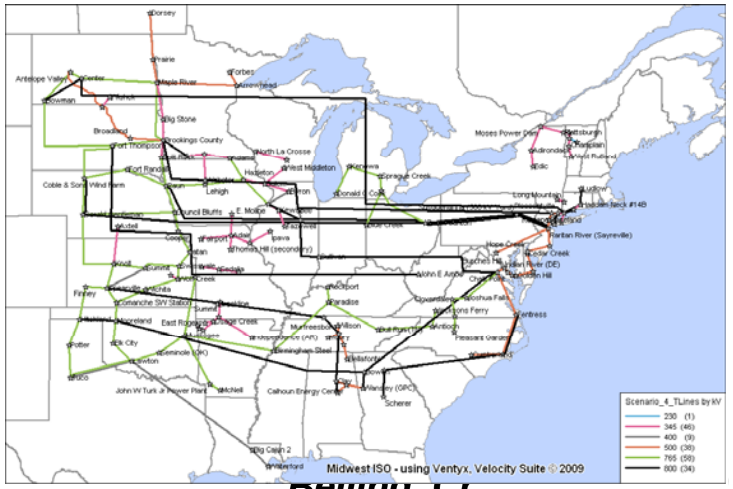
Scenario 2



Scenario 3



Scenario 4



Transmission Requirements
输电要求

- The conceptual transmission overlays consist of multiple 800kV HVDC and EHV AC lines; regional AC upgrades also needed
- Similar levels of new transmission are needed across the 4 scenarios; some transmission elements are common to all overlays
- The modeling indicates that a fair amount of wind can be accommodated provided that adequate transmission is available.
- Transmission provides capacity benefits in its own right, and enhances the reliability contribution of wind generation by a measureable and significant amount.
- The EHV DC transmission in overlays could provide other operational and reliability benefits not evaluated here

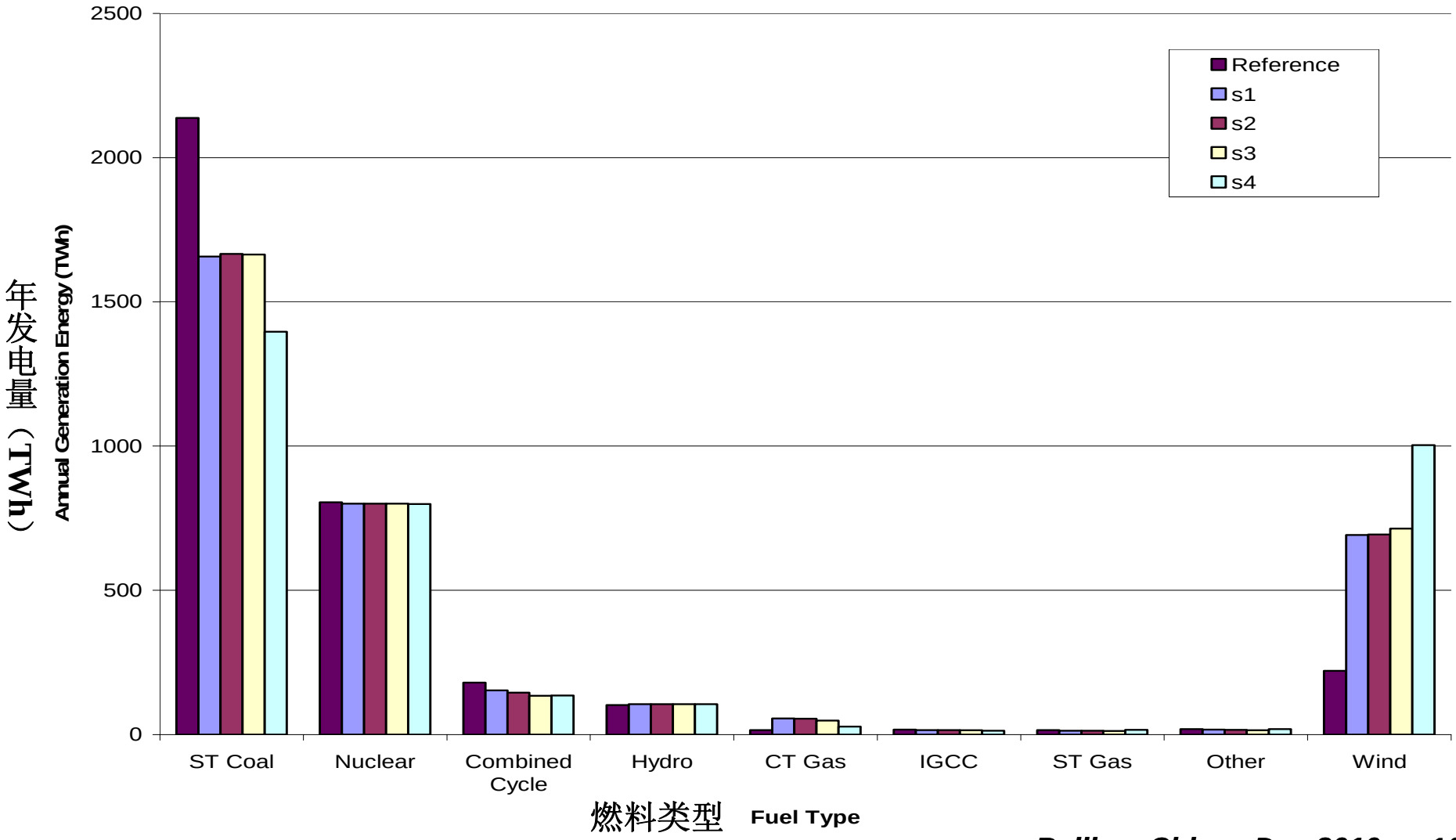
- 规划概念中输电网的覆盖区域包括多条800kV高压直流输电和超高压交流输电线路； 区域交流输电网同样需要升级。
- 4种情境下均需要新增相似规模的输电线路；某些输电元件在所有覆盖区域都很常见。
- 模拟结果表明：只要有充足的输电容量，系统就能够消纳非常大规模的风电。
- 输电系统本身能够提供容量效益，并大大提升风电的可靠性贡献。
- 输电网覆盖区域内的超高压直流输电能够提高运行与可靠性效益，在此不作评估。

Evaluating Operating Impacts
评估运行影响

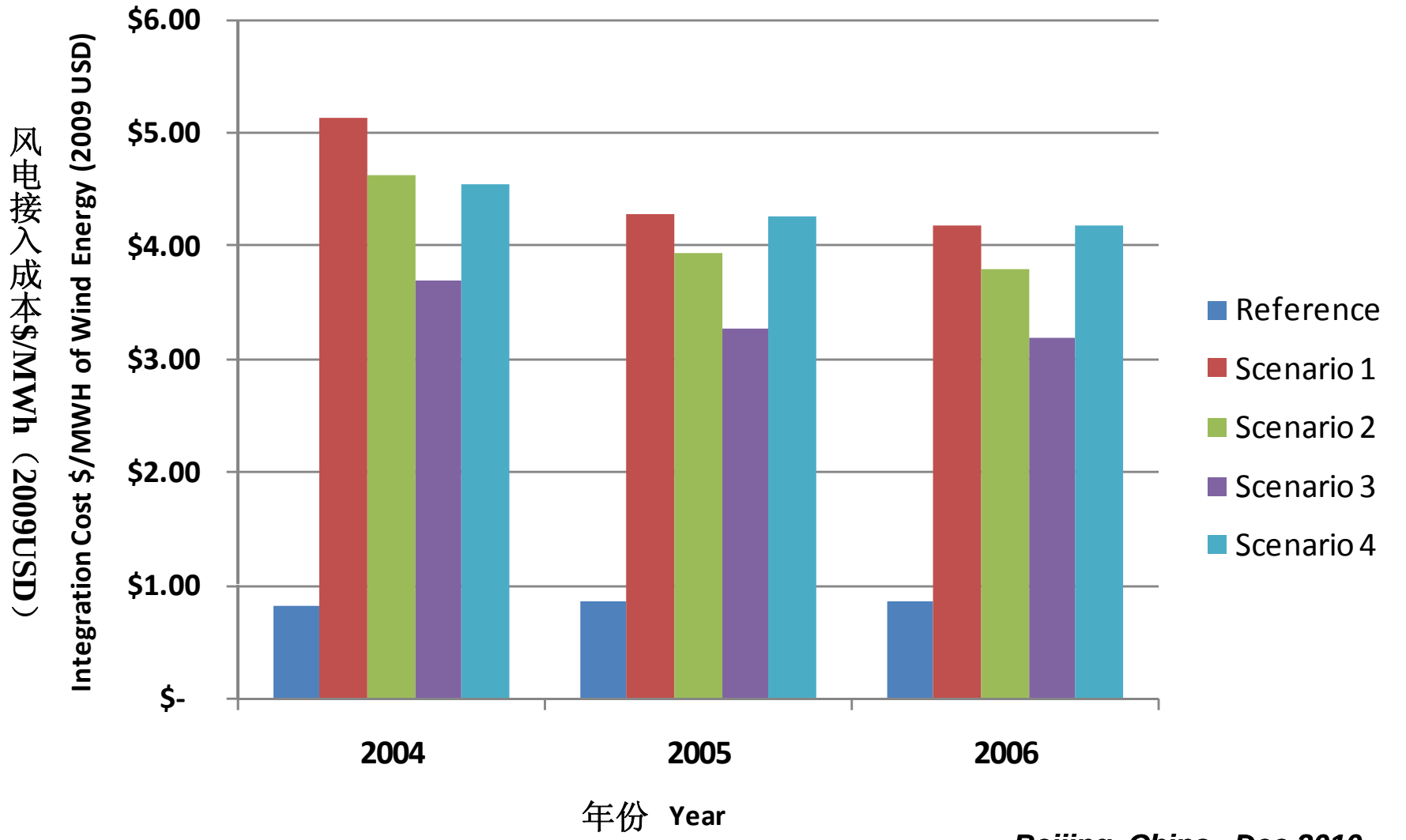
- Based on chronological production simulations (PROMOD)
  - Hourly granularity
  - Mimic market operation
    - » Day-ahead commitment to forecast load and forecast wind generation
    - » Re-dispatch to actual load and actual wind
    - » Carry additional regulation and other reserves to address increased variability and uncertainty due to wind generation
- Analyzing impacts within the hour
  - Use high-resolution wind and load data
  - Apply mathematical and statistical techniques to estimate incremental requirements

- 基于连续时间生产模拟（PROMOD）
  - 小时级间隔
  - 模拟市场运作
    - » 通过日前计划预测负荷和预测风电发电出力。
    - » 针对实际负荷和实际风电出力进行再调度。
    - » 进行附加调整和额外备用，以应对因风电带来的波动性和不确定性。
- 分析小时内的影响
  - 采用高分辨率的风数据和负荷数据
  - 运用数学和统计学方法估计新增要求。

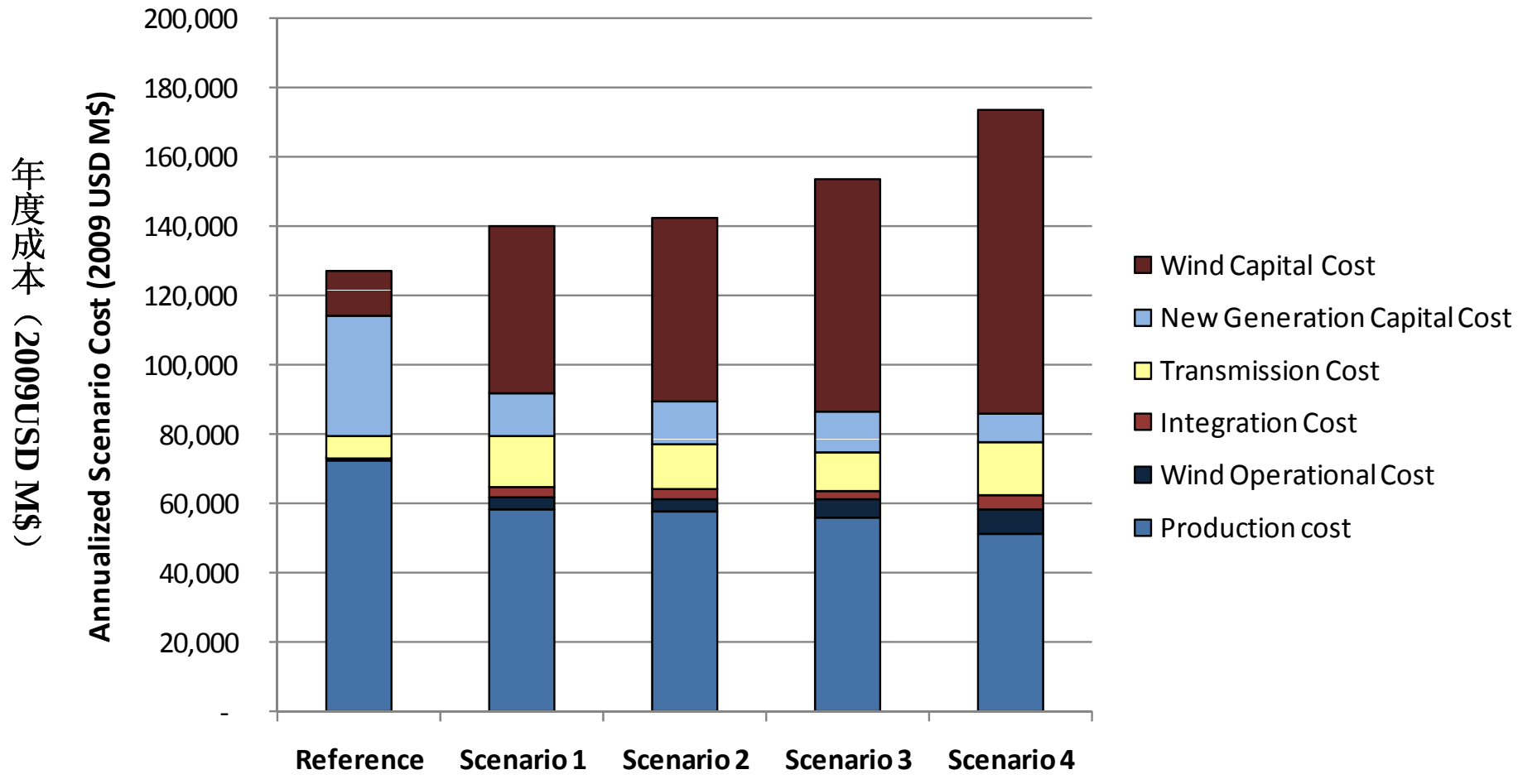
Generation Displaced
被替代的发电量



Wind Integration Costs
风电接入成本

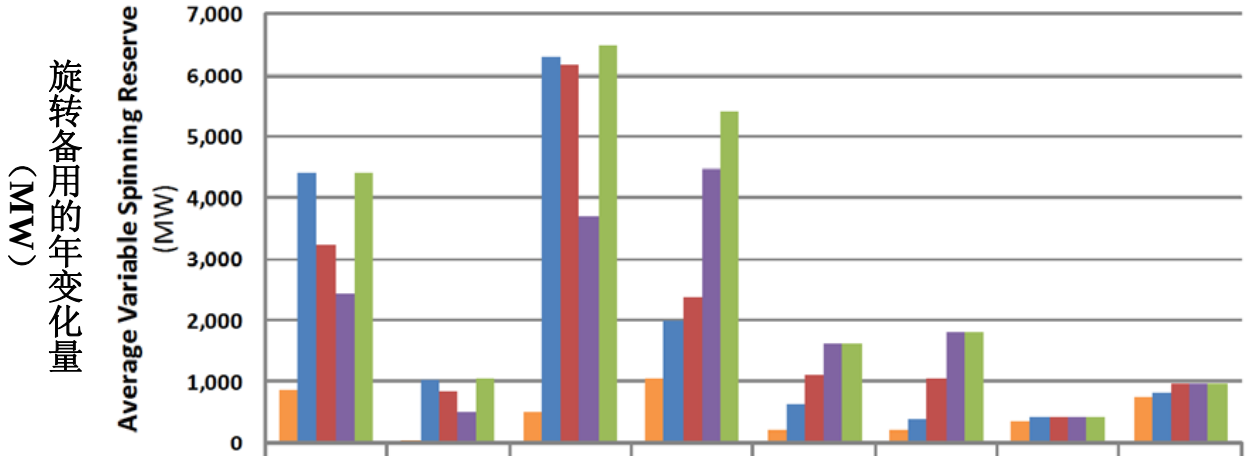


Total Scenario Cost
总成本



Results – Reserve Requirements
研究结果- 备用需求

- Wind variability (as function of generation level and scenario) use to calculate incremental regulation amount
  根据风电的波动性（用发电水平与情境的函数来表示）计算新增的调节量。
- Results is a profile that varies hourly with the amount of wind generation
  研究结果可图示为大量风电接入时的小时级变化情况。



	MISO	MAPP	SPP	PJM	NYISO	ISO-NE	TVA	SERC
Load Only	885	43	514	1055	217	202	365	741
Actual Wind S1	4,424	1,020	6,308	1,994	618	399	420	816
Actual Wind S2	3,245	835	6,176	2,359	1,118	1,046	418	955
Actual Wind S3	2,419	503	3,695	4,463	1,614	1,789	418	955
Actual Wind S4	4,423	1,038	6,487	5,410	1,614	1,789	418	955

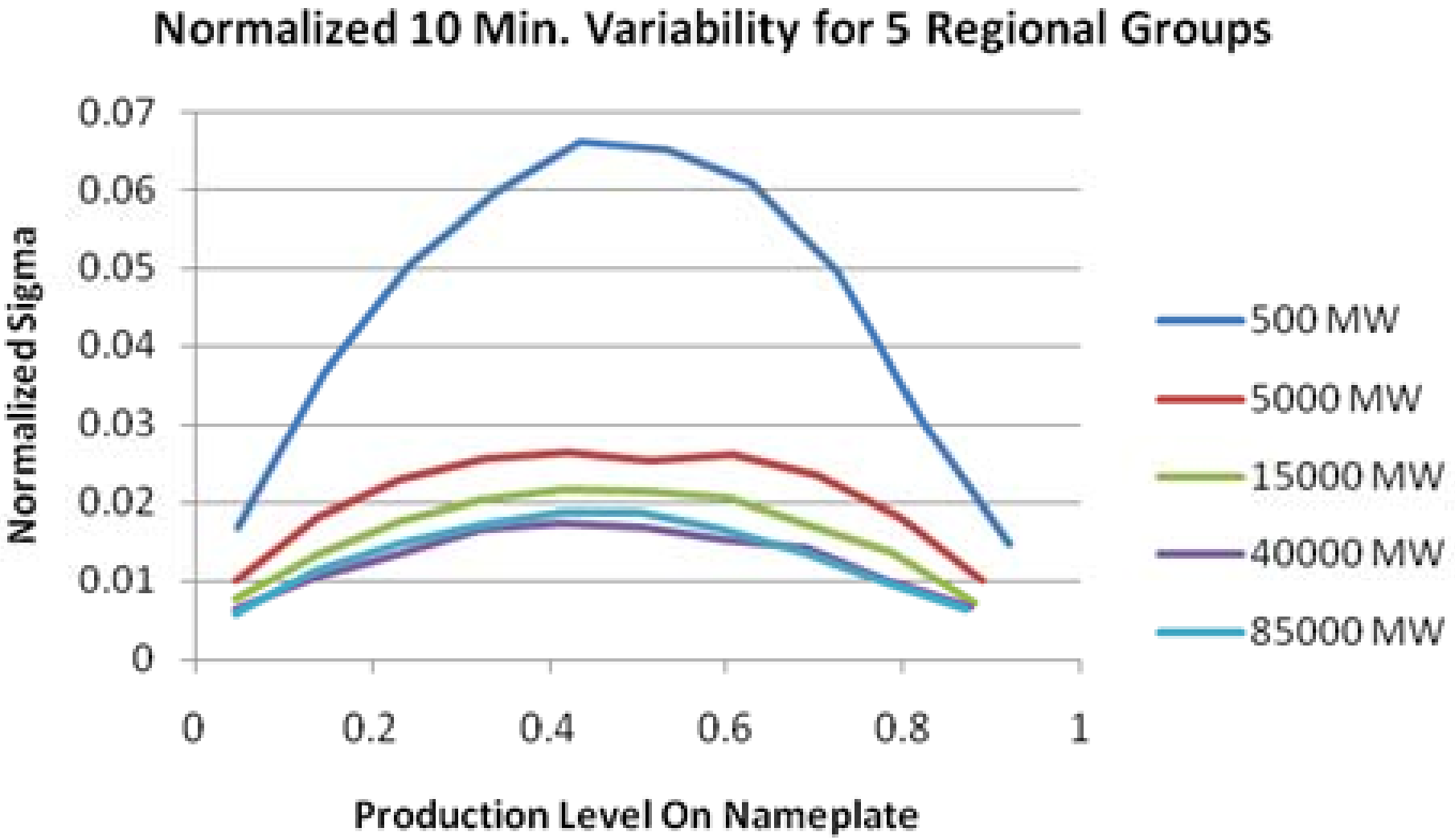
Region
区域

Wind Generation Impact on Reserves
风力发电对备用的影响

- Operational assumptions for 2024 played important role in reducing reserve requirements
- The geographic size of the market areas assumed in the study allows substantial benefits of geographic diversity to be realized.
- The pooling of larger amounts of load and discrete generating resources via regional markets also realizes the benefits of diversity.
- With sub-hourly energy markets, changes in load and wind that can be forecasted over a short interval are compensated for a very economic manner.

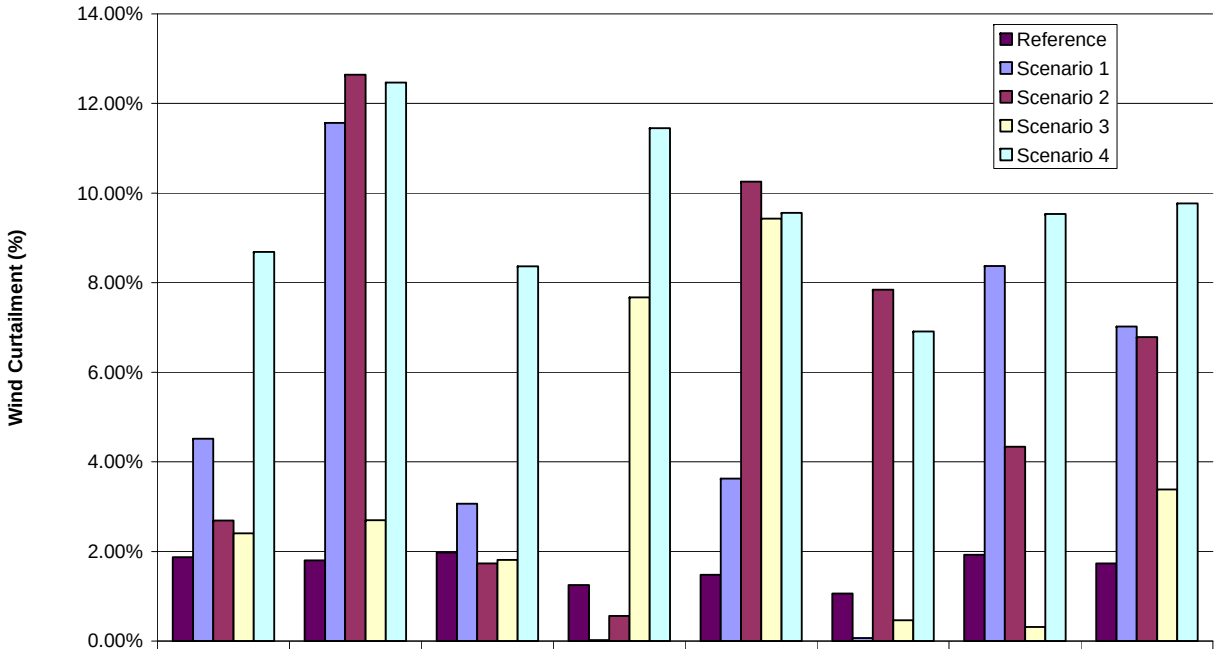
- 对2024年所做的运行假设在降低备用需求方面有很大影响。
- 研究中关于市场区域所覆盖地理范围的假设能够保证认识到由于地理多样性带来的效益。
- 通过区域电力市场汇集更多的负荷和分布式的发电资源，同样能够实现多样性的好处。
- 利用小时内能源市场，对预测出的短期负荷与风速变化用经济的方式进行补偿。

EWITS Variability With Aggregation Level
EWITS不同综合出力水平下的波动性



Curtailment by Scenario and Region
各情境和各区域的弃风量

- Possible reasons for curtailment:
  造成弃风的可能原因：
  - Transmission congestion
    输电阻塞
  - Minimum generation
    最小出力
  - Ramp/reserve limitations
    爬坡率/备用限制
- SPP curtailment high in all but S3
  除了情境3，其他并行过程都存在大量弃风
- “Local Wind” S3 has lowest curtailment across footprint
  “当地风能”情境3，其覆盖范围内的弃风量最小
- Curtailment causes explored in sensitivity cases
  弃风原因可在敏感性方案中做进一步探究



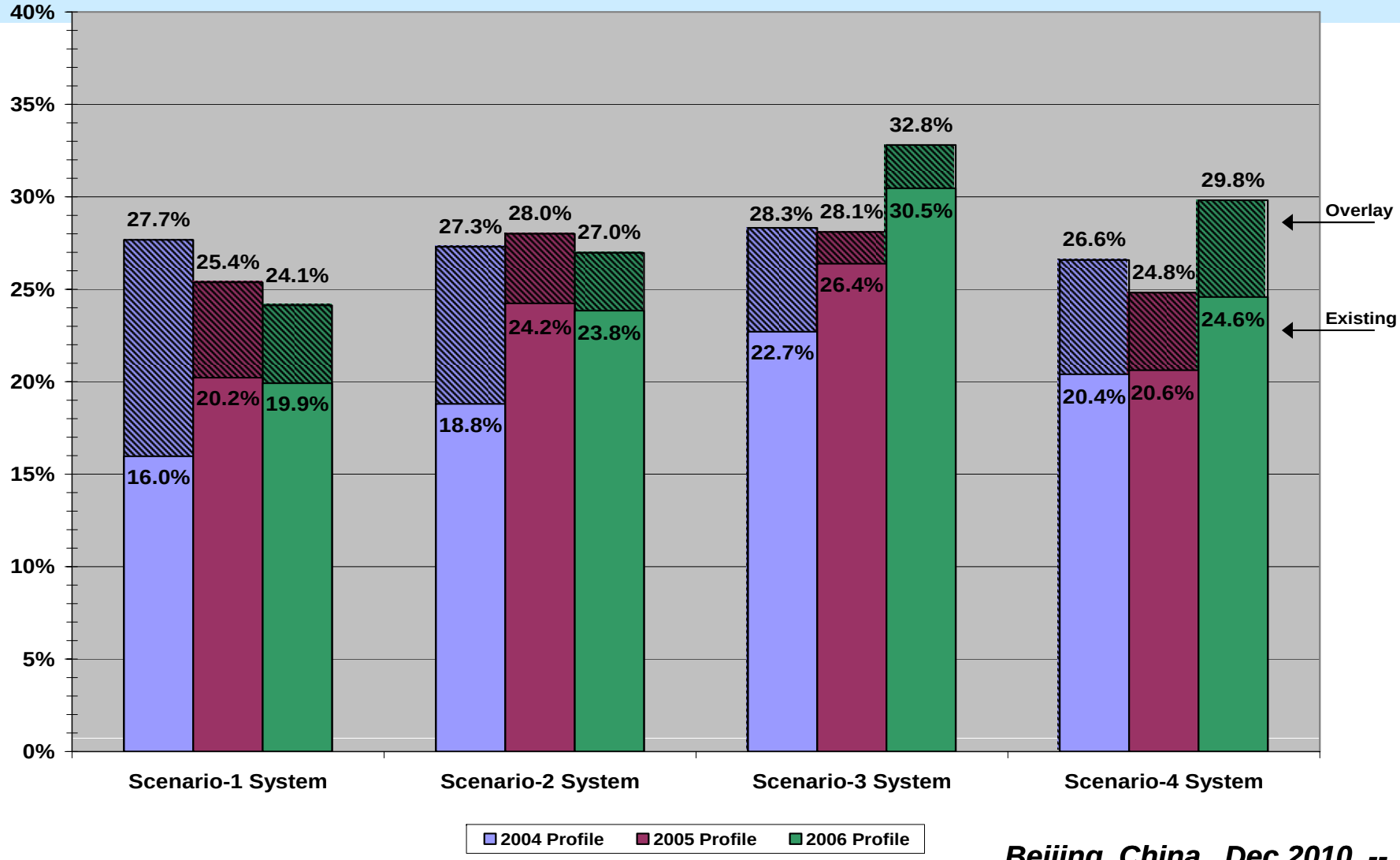
	MISO/MAPP	SPP	PJM	ISONE	NYISO	SERCNI	TVASUB	Total Footprint
Reference	1.87%	1.80%	1.98%	1.25%	1.48%	1.06%	1.93%	1.73%
Scenario 1	4.51%	11.57%	3.07%	0.02%	3.63%	0.07%	8.37%	7.02%
Scenario 2	2.69%	12.64%	1.73%	0.56%	10.25%	7.84%	4.34%	6.79%
Scenario 3	2.41%	2.70%	1.81%	7.67%	9.43%	0.47%	0.32%	3.39%
Scenario 4	8.69%	12.46%	8.37%	11.45%	9.56%	6.91%	9.53%	9.77%

情境（1-4）有效负荷承载能力的研究系统

已有的&覆盖区的输电联络线极限ELCC（%）（阴影部分为覆盖区ELCC的新增值）

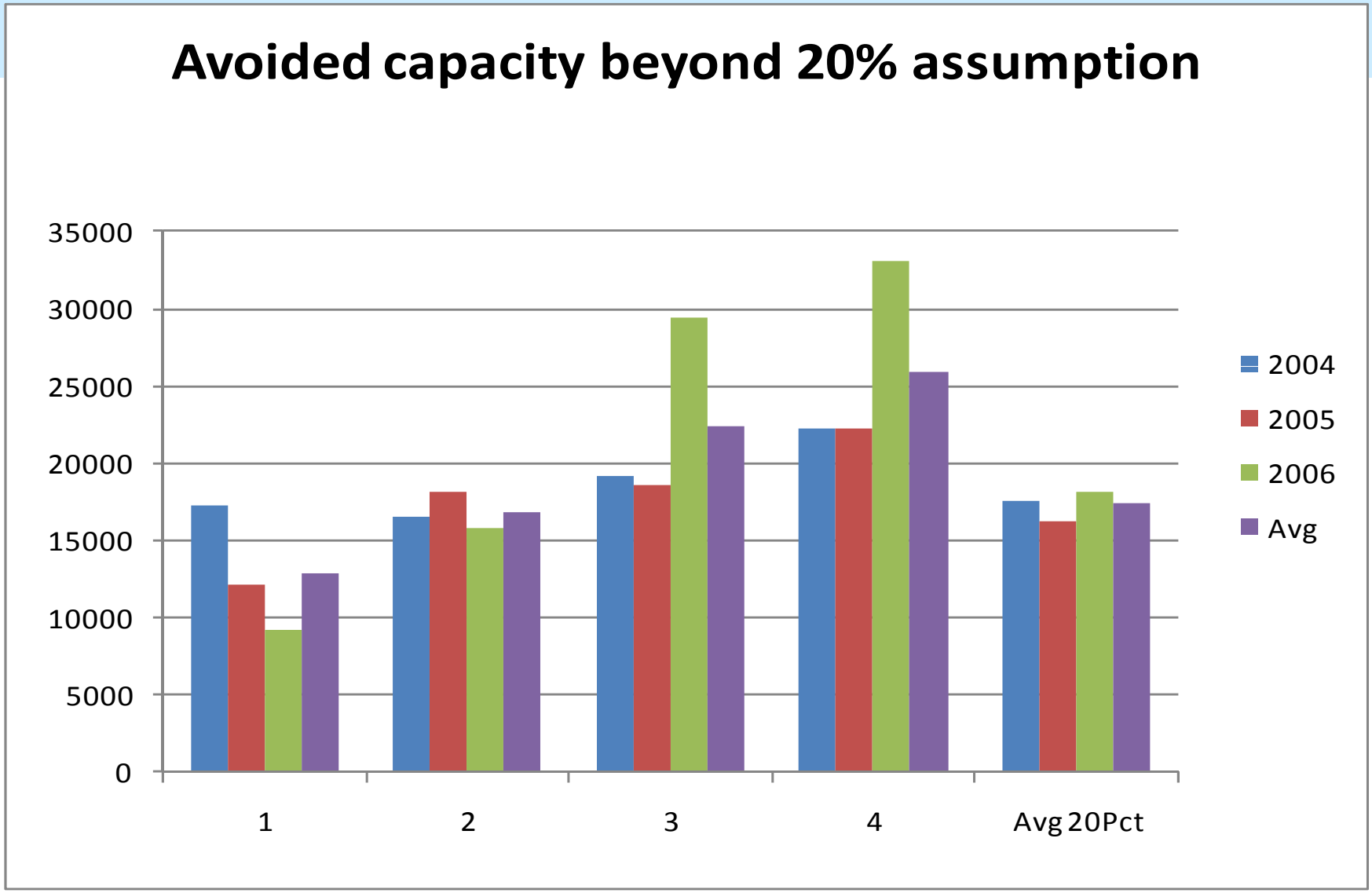
Study System ELCC Scenarios (1 - 4)

Existing & Overlay Transmission Tie Limits - ELCC (%) {Shaded Area shows Increased ELCC of Overlay}



Wind with Transmission Can Reduce Other Generation Builds

风电与输电系统能减少其他发电设施的建设



In Summary…
结论…

- What system operational impacts and costs are imposed by wind generation variability and uncertainty? ***With large balancing areas and comprehensive markets, the costs of integration for all scenarios is less than $10/MWH of wind, or less than $0.002/kWH of load.***
- What are the benefits from long distance transmission that accesses multiple wind resources that are geographically diverse? ***The study results show that long-distance (and high capacity) transmission can assist smaller balancing areas with wind integration, allowing penetrations otherwise not feasible.***
- What are the benefits from long distance transmission that move large quantities of remote wind energy to urban markets? ***The cost of transmission can be overcome by the higher quality of wind resources in remote areas. Transmission has other value for the robustness of the system that were not evaluated in this study.***
- How do remote wind resources compare to local wind resources? ***In the Eastern Interconnection, the NREL meso-scale data shows that the higher quality winds in the Great Plains have capacity factors 6 top 7% higher than on-shore wind resources close to the high-load density urban centers in the east. Off-shore plants have capacity factors on par with Great Plains resources but cost of energy is higher due to higher capital costs.***

- 风电的波动性和不确定性带来了哪些系统运行影响和成本？**由于采用大范围电力平衡区域和综合市场，所有情境下的接入成本低于风电的$10/MWH，低于负荷的$0.002/kWH。**
- 为接纳地理上分布的多风资源（风电）采用远距离输电式有什么好处？**研究结果表明，长距离（大容量）输电能够帮助小的平衡区域接入更多风电，允许更高的风电穿透功率；若没有远距离输电则是不可行的。**
- 采用长距离输电将偏远地区的大量风电送入城市市场有什么好处？**偏远地区更高质量的风电接入效益可以抵消输电成本。输电对系统鲁棒性也有一定好处，在此未作评估。**
- 与当地风能资源相比，偏远地区风能资源有何优势？**在美国东部互联系统中，NREL中尺度数据表明，与东部的靠近负荷密集城市的风能相比，大平原上高质量风能的容量系数要高出6~7%。海上风电场具有与大平原相当的容量系数，但由于其基础建设成本更高，因此其发电成本也更高。**

Continued…
续…

- How much does geographical diversity help reduce system variability and uncertainty? ***Quite substantially.***
- What is the role and value of wind forecasting? ***With significant wind generation, forecasting will play a key role in keeping energy markets efficient and reducing the amount of reserves carried while maintaining system security.***
- What benefit does balancing area cooperation or consolidation bring to wind variability and uncertainty management? ***This and other recent studies reinforce the concept that large operating areas - in terms of load, generating units, and geography – combined with adequate transmission, are the most effective measures for managing wind generation.***
- How does wind generation capacity value affect reliability? ***Wind generation can contribute to system adequacy, and transmission can enhance that contribution.***

- 地理的多样性能够在多大程度上减小系统波动性和不确定性？非常的大。
- 风功率预测的作用和价值？在大量风电接入的情况下，风功率预测在保持电力市场的高效性、以及在保证系统安全的前提下减少系统备用方面起着至关重要的作用。
- 平衡区域合作或联合对风电波动性和不确定性管理方面有什么好处？本研究以及之前其他的研究都强调大运行区域（主要指负荷、发电厂和地理范围）与充足的输电能力相结合，是管理风力发电的最有效手段。
- 风电容量置信度如何影响可靠性？风电能提高系统的充裕度，而输电系统能强化这种提高作用。

System Planning and Operation Recommendations
系统规划和运行的建议

- Perform detailed wind integration studies
- Deploy more flexible generation and load technologies
- Improve wind plant output forecasting tools
- Improve grid codes and wind plant models
- Aggregate wind plant output over large regions
- Improve balancing area cooperation and ACE sharing
- Recognize wind contributions to capacity value
- Create ongoing forums to share operating experience

- 进行详细的风电接入研究
- 配置更为灵活的发电和负荷技术
- 改进风电场出力预测工具
- 升级并网导则和风电厂模型
- 大区域范围内的风电厂总计出力
- 加强平衡区域的合作与区域控制偏差（ACE）共享
- 明确风电对容量置信度的贡献
- 经常性的举办讨论会，分享运行经验。

Transmission Planning Recommendations
输电规划建议

- Develop adequate transmission capacity – can't meet RPS goals without it
- Comprehensive regional planning processes
- Reassessment of transmission cost allocation
  - Customers in remote regions can't afford it
  - load pays in the end
- More certainty of transmission cost recovery
- More robust and flexible "smart" grid to enable participation of load and PHEV

- 建设足够的输电容量——否则将不可能实现再生能源配额制目标。
- 综合的区域规划程序
- 输电成本配置的再评估
  - 偏僻区域的用户没有能力负担
  - 负荷在终端支付费用
- 输电成本的回收必须有更多确定性
- 更具鲁棒性和灵活性的智能电网技术，使负荷和混合电动汽车能更多参与。

National Transmission Policy
国家输电政策

- National policy debate stimulated by two activities:
  - Success of Texas CREZ process
    CREZ －－COMPETITIVE RENEWABLE ENERGY ZONES
  - Growing recognition that RPS goals cannot be met without significant transmission build-out
- Three major transmission bills proposed in US Senate last year.
- All different, but all have three common elements:
  - Interconnection-wide transmission planning
  - High voltage backbone with broad cost allocation
  - Federal backstop siting authority
- Growing recognition of critical need for transmission

- 两个事件激发了关于国内政策的讨论：
  - 德克萨斯竞争性可再生能源区（CREZ）的成功建立。
  - 更多的意识到，如果不对输电系统进行大范围的扩建，那么将无法完成可再生能源配额制目标。
    RPS: Renewable Portfolio Standard
- 美国参议院去年提出了三个主要的输电议案
- 议案各不相同，但都有三个共同点：
  - 大范围互联输电计划
  - 以高压输电为主干、大范围成本分摊
  - 政府支持的选址授权
- 更多的意识到输电的重要性

Market Operation and Transmission Policy Recommendations
关于市场运作和输电政策的建议

- Develop well-functioning day-ahead, hour-ahead, and real-time energy and price responsive load markets and expand access to those markets
- Adopt market rules and tariff provisions that are more appropriate to weather-driven resources
  - Elimination of imbalance penalties
  - Sub-hourly scheduling is critical
- Make better use of physically (in contrast with contractually) available transmission capacity
- Eliminate pancaked rates

- 开发功能优良的天前、小时前以及实时的能源和价格响应负荷市场，扩大市场准入。
- 采用更适用于天气相关能源资源的市场法则和价格规定。
  - 取消不平衡处罚
  - 小时内开机计划至关重要
- 更好地利用物理的可用输电容量（与合同的相对应）。
- 消除Pancaked rates

（Pancaked rates： an artificial barrier to efficient trading because they add a charge every time a transaction can be seen to cross a corporate boundary.）

and the conclusion is…
结论是…

- There are no fundamental technical barriers and the cost is moderate for the integration of 20% wind energy into the electrical system, but …
- It will not be achieved with business as usual
- There needs to be a continuing evolution of transmission planning and system operation policy and market development for this to be achieved.

- 不存在任何根本的技术障碍，且20%风电接入电力系统其成本是适中的，但是…
- 不可能用像以往那样的商业模式来实现；
- 为了实现这一目标，需要持续不断地完善输电规划、系统运行相关法规及市场开拓。

For More Information
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