中德能源与能效合作
Energiepartnerschaft
DEUTSCHLAND - CHINA

国家能源局
National Energy Administration

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Flexibility and adequacy: trends in Germany, China, and internationally
灵活性和充裕度：德国、中国和国际趋势

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giz

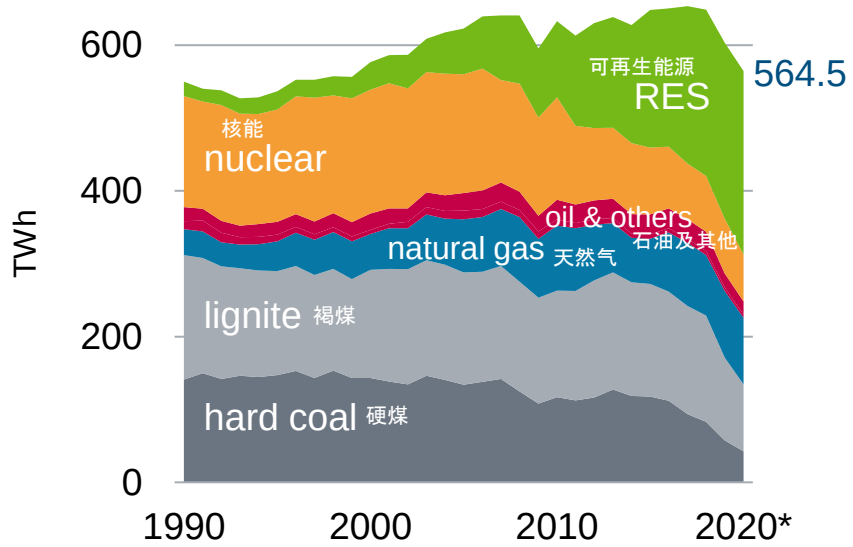
Germany's approach to flexibility and capacity adequacy: 德国灵活性及容量充裕度措施

- Why talk about flex and adequacy together?
- 为什么将灵活性和充裕度放在一起讨论？
- How has Germany achieved flexibility?
- **德国如何**实现灵活性？
- Germany's future flexibility measures
- **德国未来**实现灵活性的措施
- How adequate is Germany's capacity?
- **德国的**产能有多充裕？
- How do China's flexibility needs compare?
- **如何比**较中国的灵活性需求？
- Conclusions
- 结论

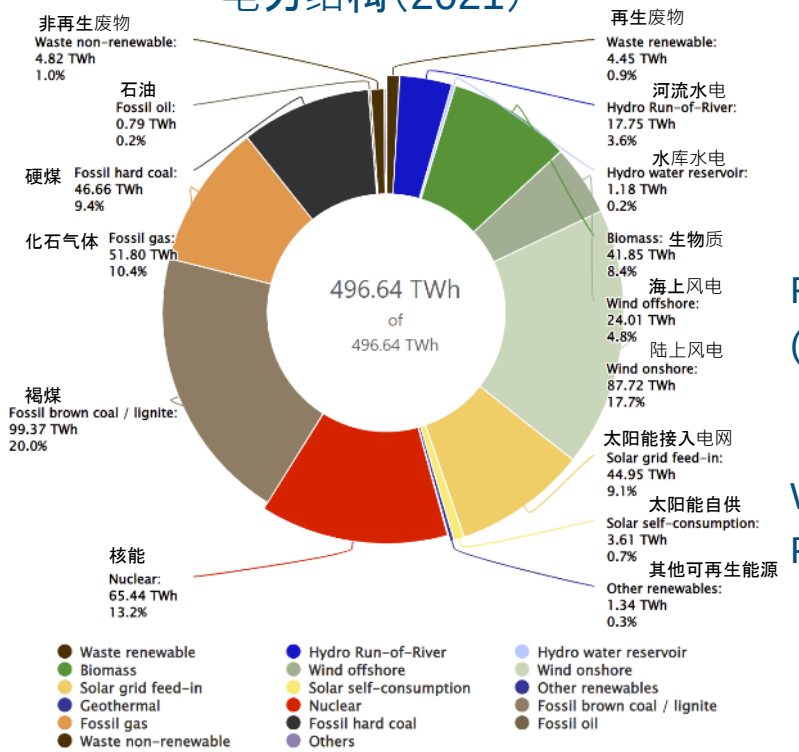
Germany's rapid increase in renewables results in much higher demand for flexibility德国可再生能源的快速增长引起了对灵活性的更高需求

Variable renewable energy in Germany has reached 33% of output
德国波动性可再生能源产量已达33%

Gross electricity generation in Germany
德国总发电量



Electricity mix in 2021
电力结构(2021)



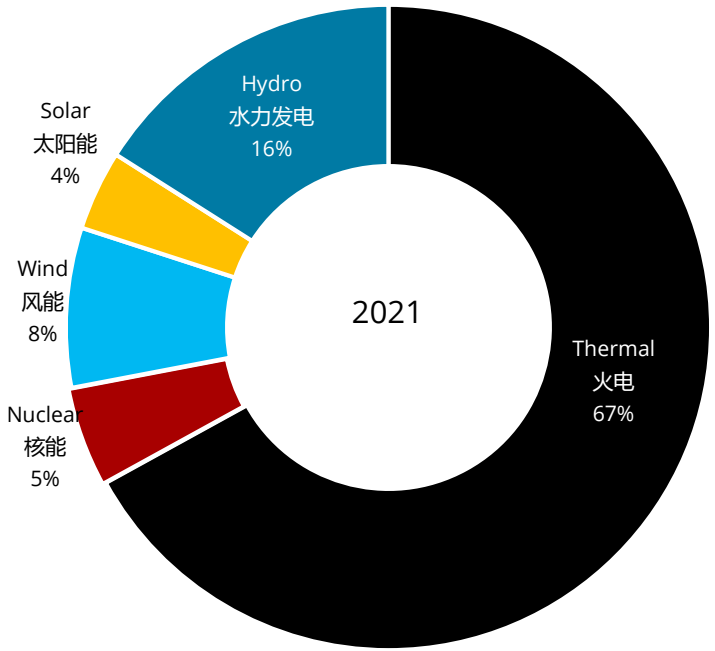
RE可再生能源: 45.7%
(VRE波动性可再生能源: 32.8%)

Wind风电: 22.5%
PV光伏: 9.8%

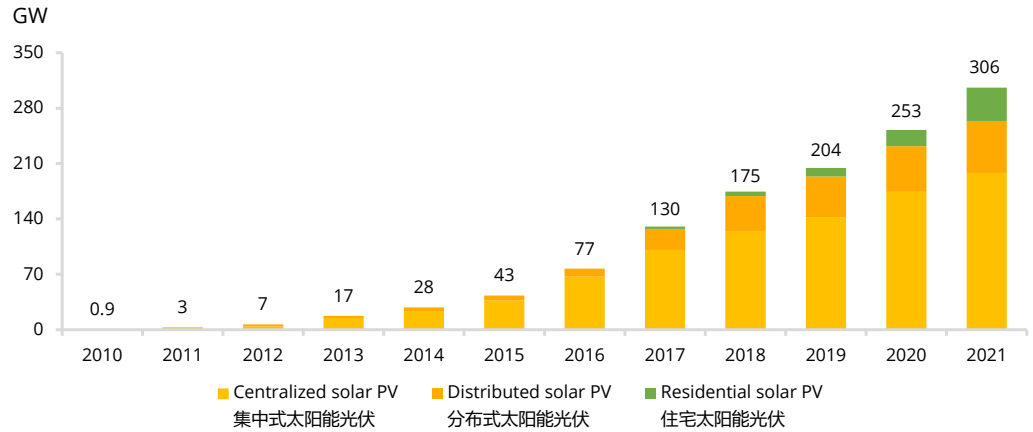
In 2022 so far, each GW of wind and solar is saving consumers €4/MWh
截止2022年，每GW风电和太阳能可以节约4欧元/MWh

China is also seeing rapid increases in wind and solar
中国的风能和太阳能也在快速增长

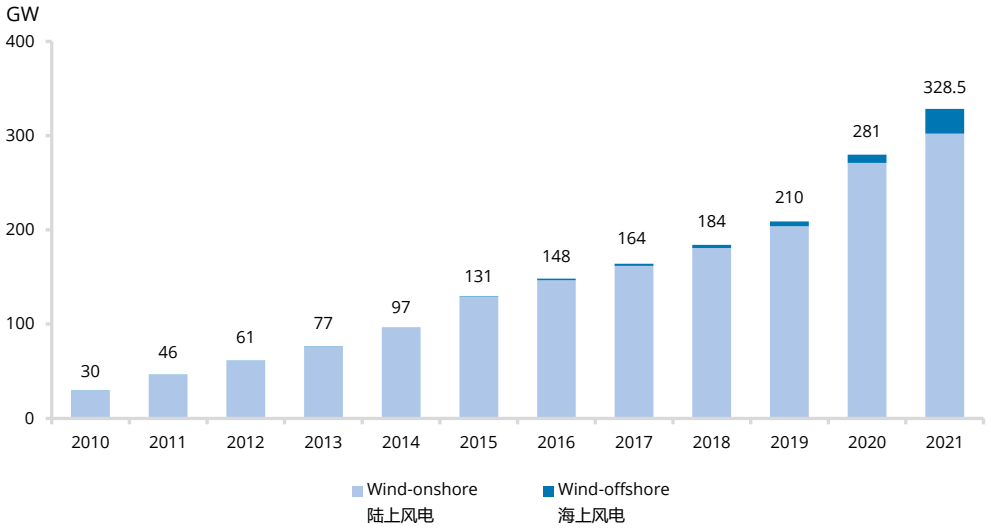
China 2021 electricity generation by fuel
中国2021年燃料发电结构



China solar capacity中国太阳能容量

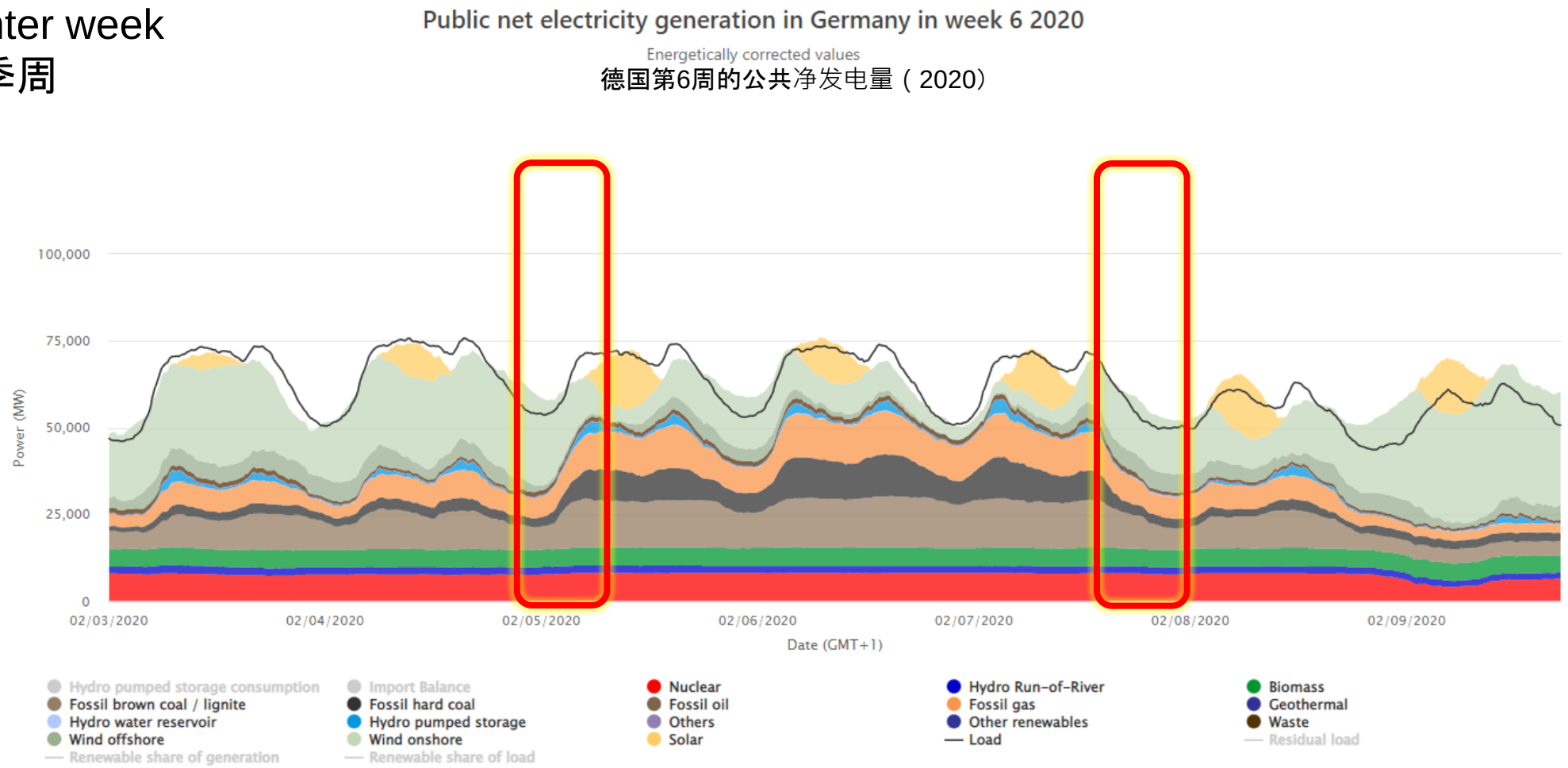


China wind capacity中国风能容量



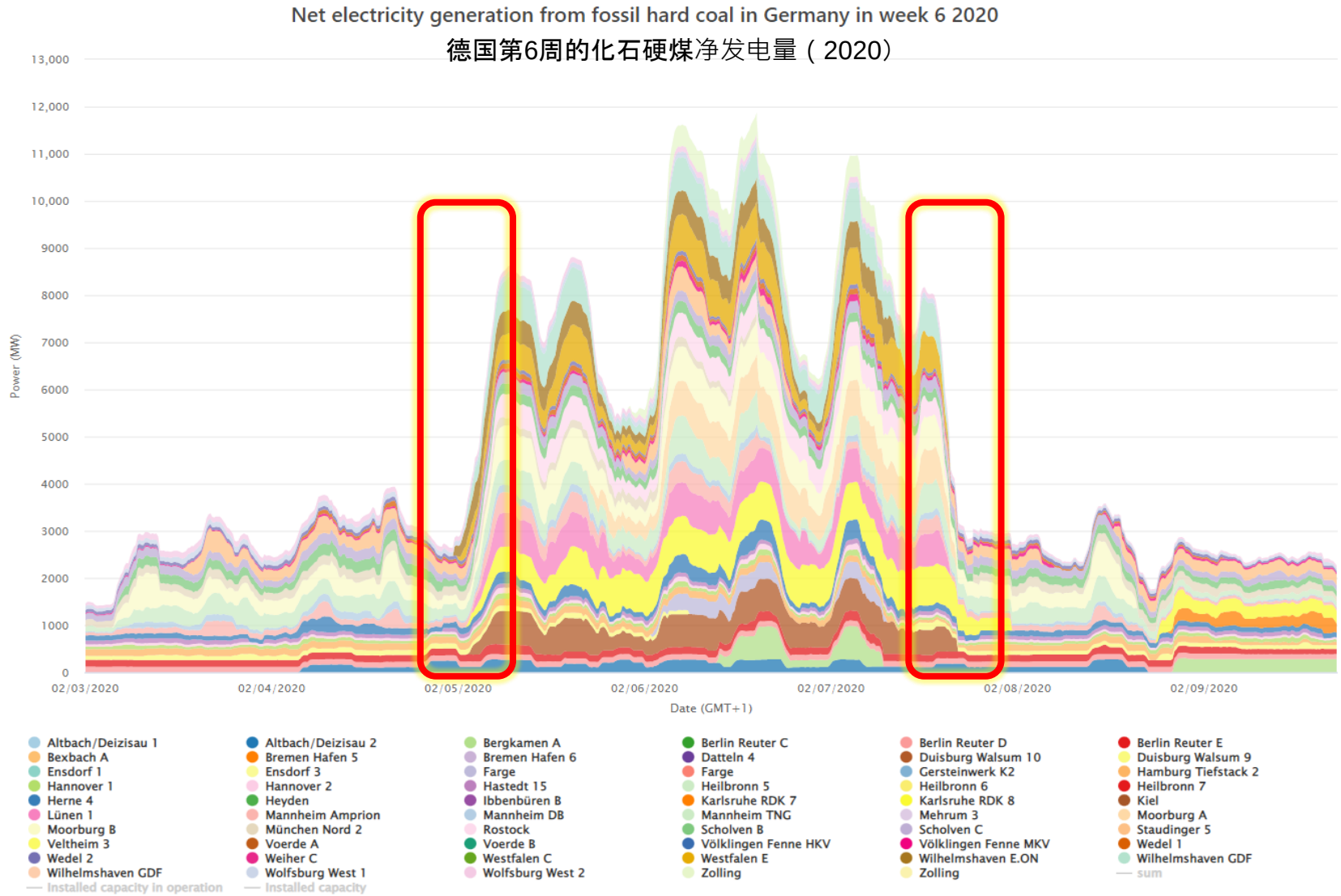
Germany has to deal with more fast ramps in both winter and summer
德国在冬季和夏季都必须处理更多的快速爬坡

Winter week
冬季周



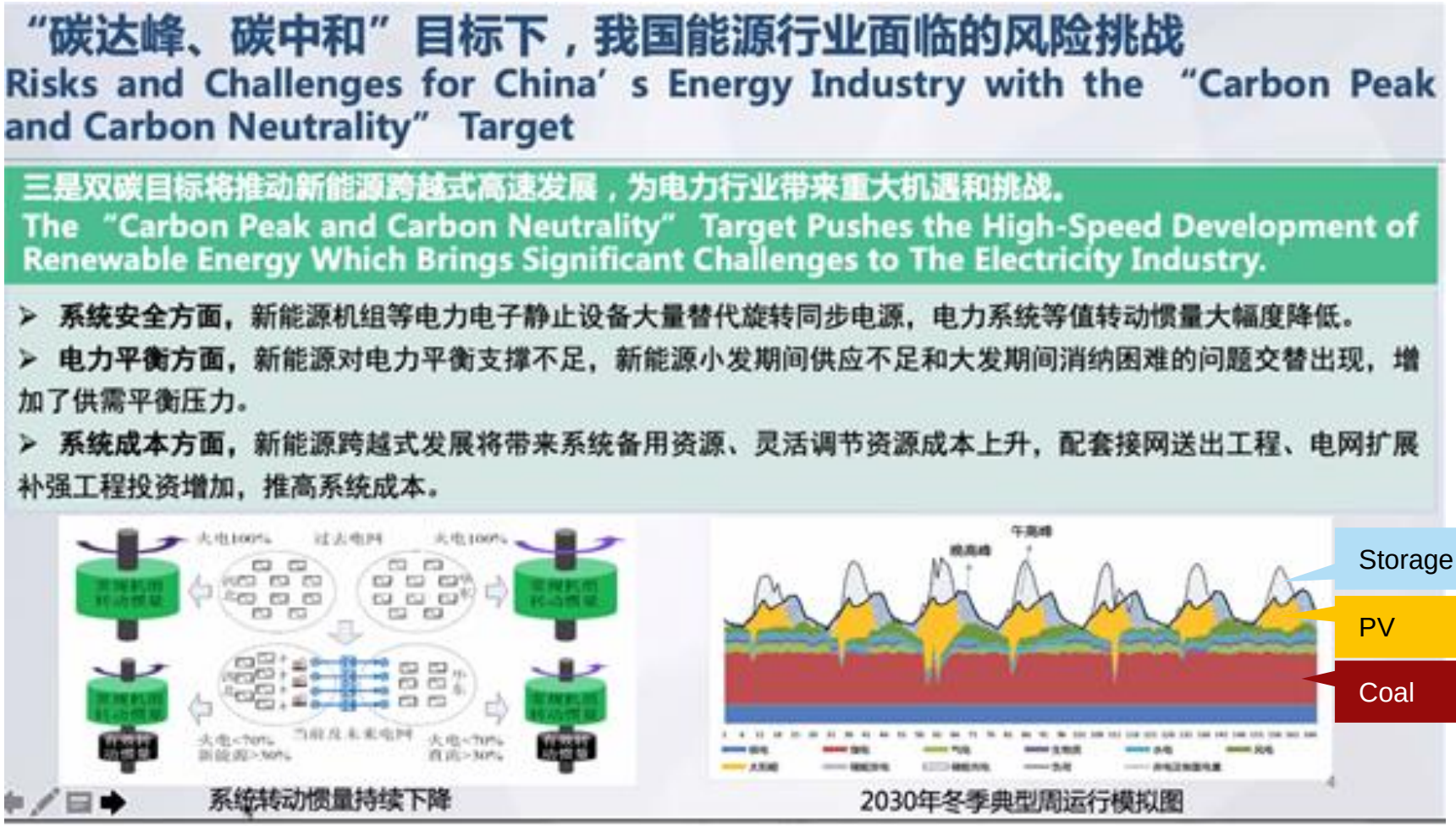
Almost all coal plants have some degree of flexibility, and no subsidy is required几乎所有的燃煤电厂都有一定的灵活性，而无需补贴

Winter week
冬季周



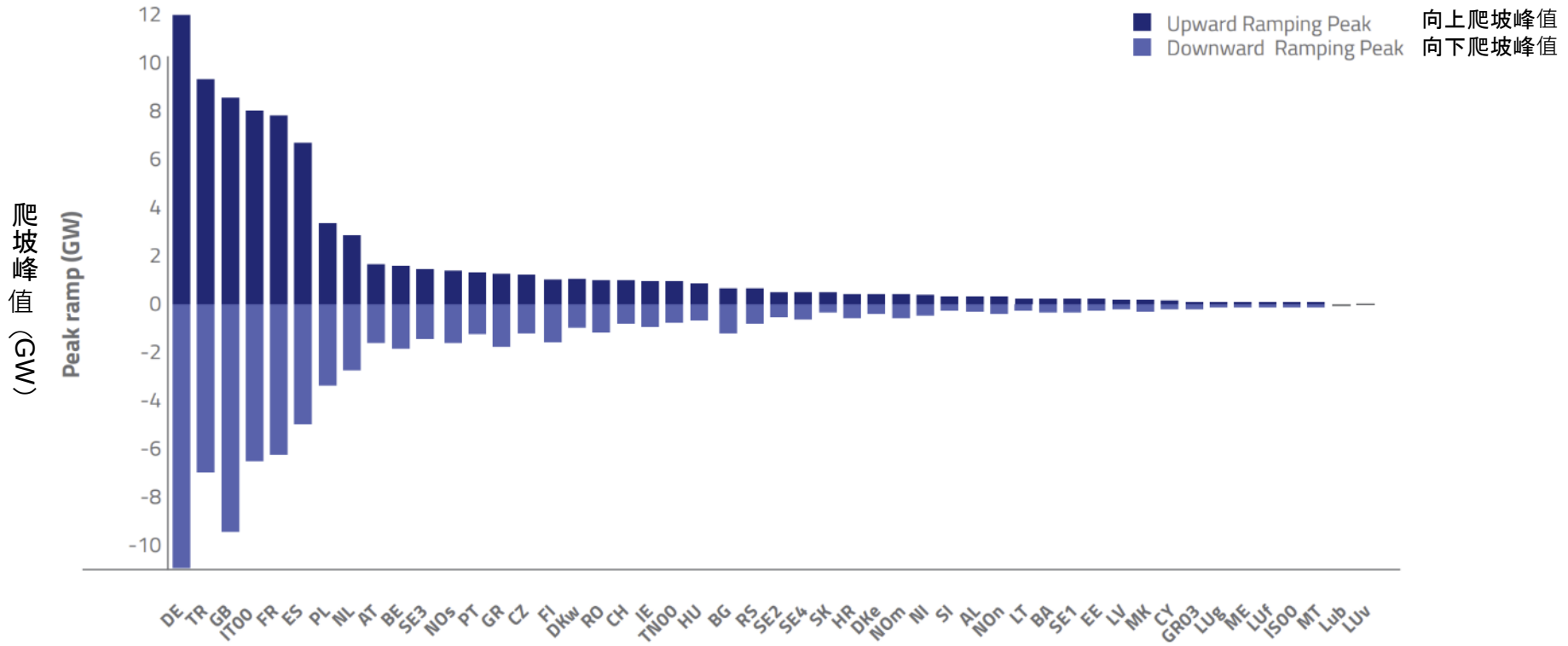
This is very different from inflexible dispatch that relies on storage

这与依赖于储能**的非灵活性**调度非常不同



Germany’s electricity zone has larger ramping needs than any other zone in Europe德国电力区比欧洲任何其他地区都需要更多的电力爬坡

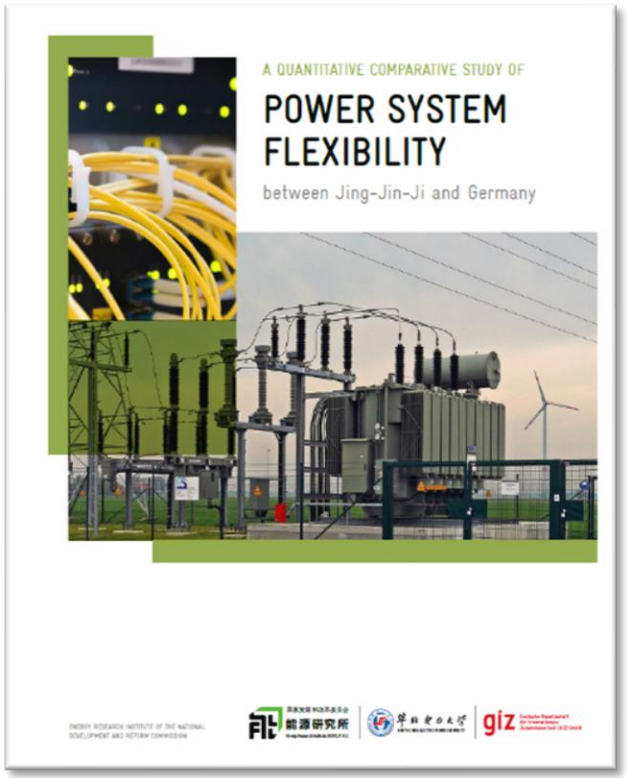
Germany’s 1-hour ramping needs 99.9 percentile德国99.9%的情况下，爬坡在一小时以内



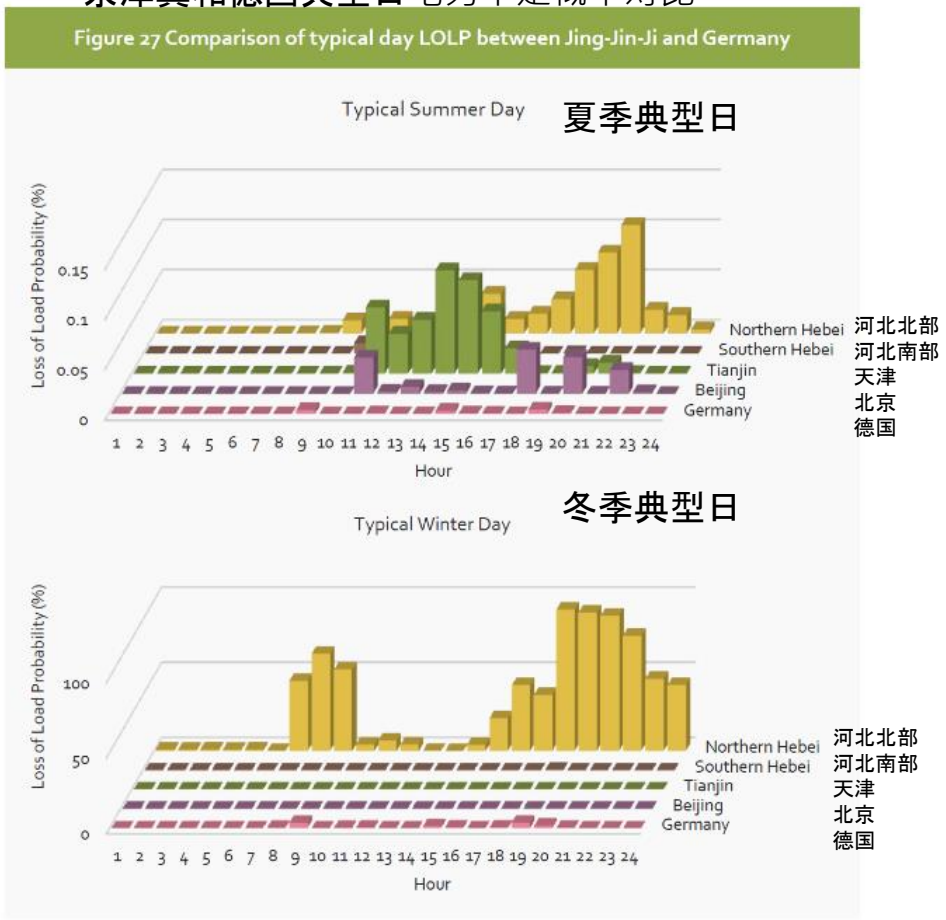
Source: ENTSO-E PowerFacts 2019

How does Germany's flexibility compare with China's? 2019 ERI report

德国灵活性与中国比较是怎样的？2019年，能源研究所（ERI）报告



京津冀和德国典型日电力不足概率对比

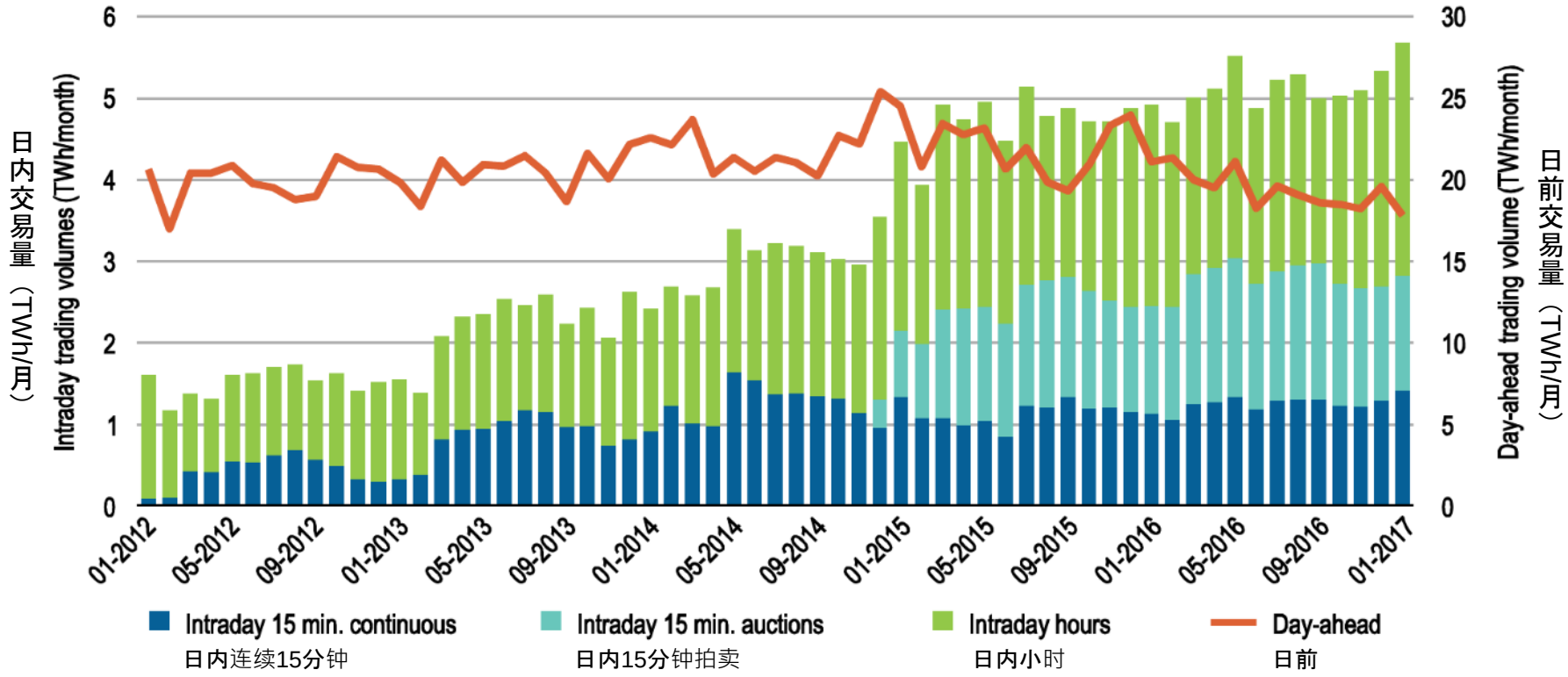


- Germany has much higher proportion of wind and solar, yet offers higher reliability
- **德国**拥有更高的风能和太阳能比例，**可以提供更高的可靠性**
- Though JJJ LOLP is small in the winter in JJJ, but significant in summer
- **尽管京津冀**电力不足在冬季很少，但**夏季**较严重
- Simulations show the lowest-cost options are improved use of existing inter-provincial transmission and coal plant flexibility upgrades, not energy storage
- **模**拟结果显示，改进现有省际输电和**煤**电灵活性升级是成本最低的选择，**而非**储能

Introduction of shorter spot market intervals has been key to price signals
引入更短的现货市场间隔一直是价格信号的关键

Volumes on Germany's spot markets (TWh); note typical monthly consumption 40-50 TWh

德国现货市场容量（TWh）；典型月耗能量40-50TWh

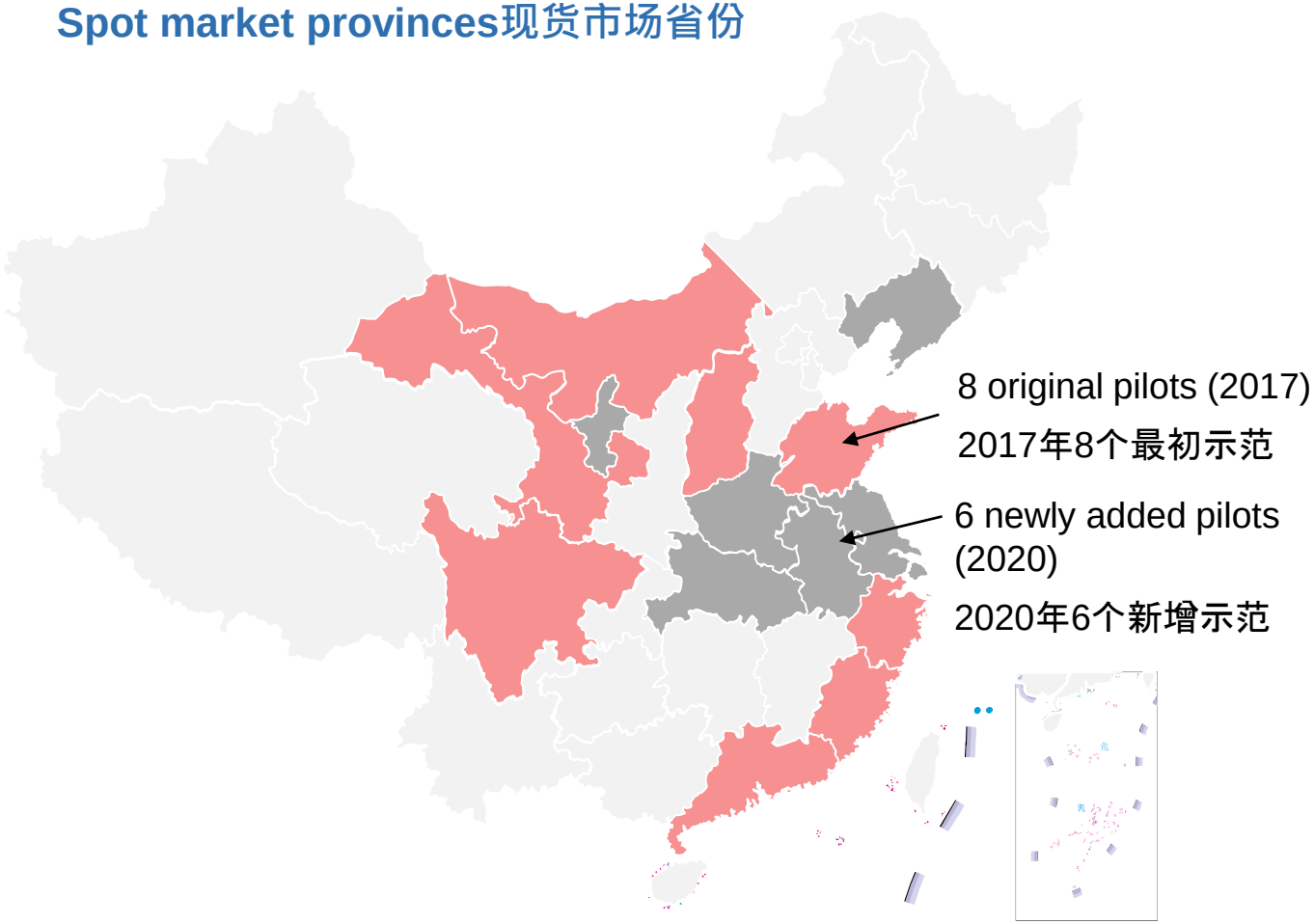


Source: 50hz, 2018

China has adopted spot market pilots and aims for national spot market by 2030

中国已经开展了现货市场试点，并计划到2030年建立全国现货市场

Spot market provinces现货市场省份



- Only a few provinces have engaged in continuous trading
- 只有少数几个省份进行了持续的交易
- During power shortages, spot market sometimes stop operating
- 在电力短缺期间，现货市场有时会停止运作
- Narrow range of trading
- 交易范围窄
- Volume low
- 低交易量
- Prices below operating cost
- 低于运营成本的价格

So far, Germany has mainly relied on the market, though policy has also encouraged flexibility

目前，德国主要依靠市场力量，尽管政策也鼓励灵活性

- Spot market accounts for the majority of electricity traded in the German system
- 现货市场占德国电力交易市场的大部分
- Spot price variation from high to low levels throughout the day encourages plant owners to operate flexibly
- 现货价格在一天中由高到低的变化鼓励电厂业主更为灵活的运营
- Several factors commonly mentioned account for a small amount of flexibility:
- **通常提到的几个因素占灵活性的一小部分**
  - Imports and exports make up around 10% of power supply on a typical day
  - 进出口约占电力供应典型日的10%
  - Energy storage is also a minor factor so far
  - 储能也是一个很小的因素

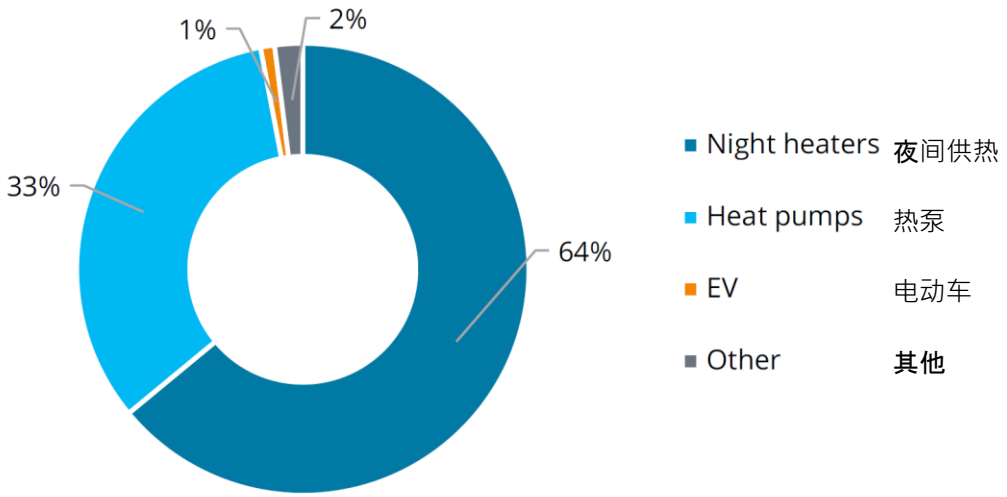
To reach 100% renewables in the power sector by 2035, Germany will need new flexibility options

为了实现2035年100%可再生能源目标，德国需要新的灵活性选择

- Customer-sited batteries
- 用户端电池
- Demand response / demand-side flexibility
- 需求响应/需求侧灵活性
- Aggregation
- 聚合
- Energy communities
- 能源社区
- Vehicle-to-grid (V2G)
- 车辆到电网（V2G）

Germany is working on demand response and aggregation
德国正致力于需求响应和聚合

Proportion of load-control agreements in Germany
德国负荷控制协议的比例



Source: BNetzA 2021

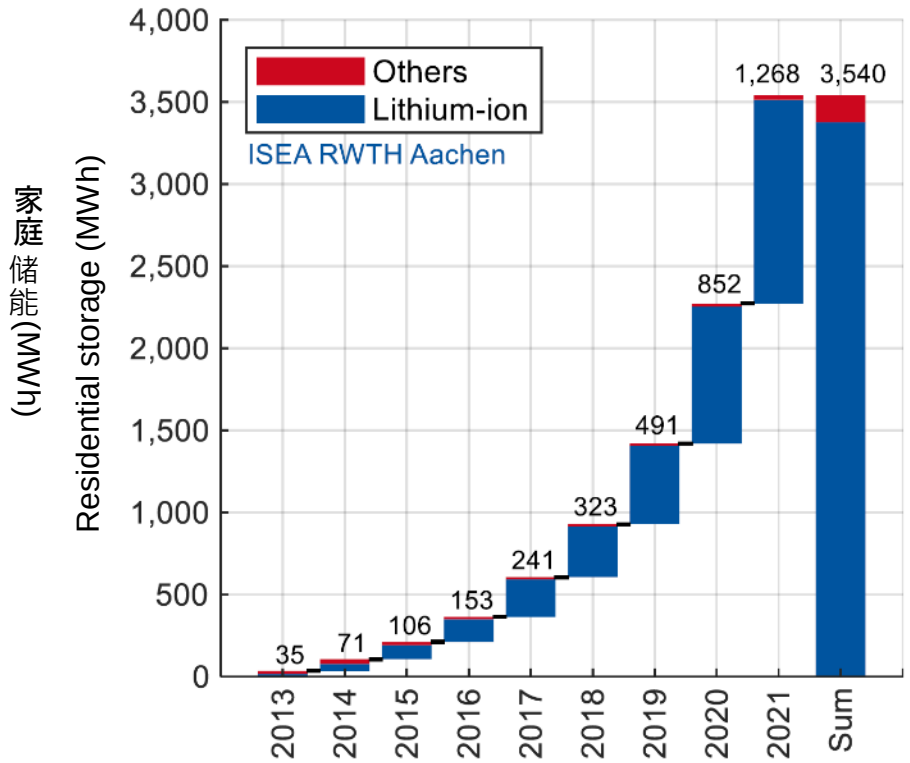
- Current German load control mostly covers heating
- **德国目前的**负荷控制主要是供热
- New 2022 Energy Law amendment may lead to requirements for grid operators to offer rewards for customers that provide flexibility, such that it is voluntary for customers and non-discriminatory with other flexibility providers
- 2022**年新修**订的能源法可能会要求电网运营商为实施灵活性的客户提供奖励，客户是自愿的并且对其他灵活性提供者无歧视
- Heat pump market expected to double or triple, from 150,000 per year to up to 500,000 per year
- 热泵市场预计将翻倍或翻三番，从每年**15万台增加到每年50万台**

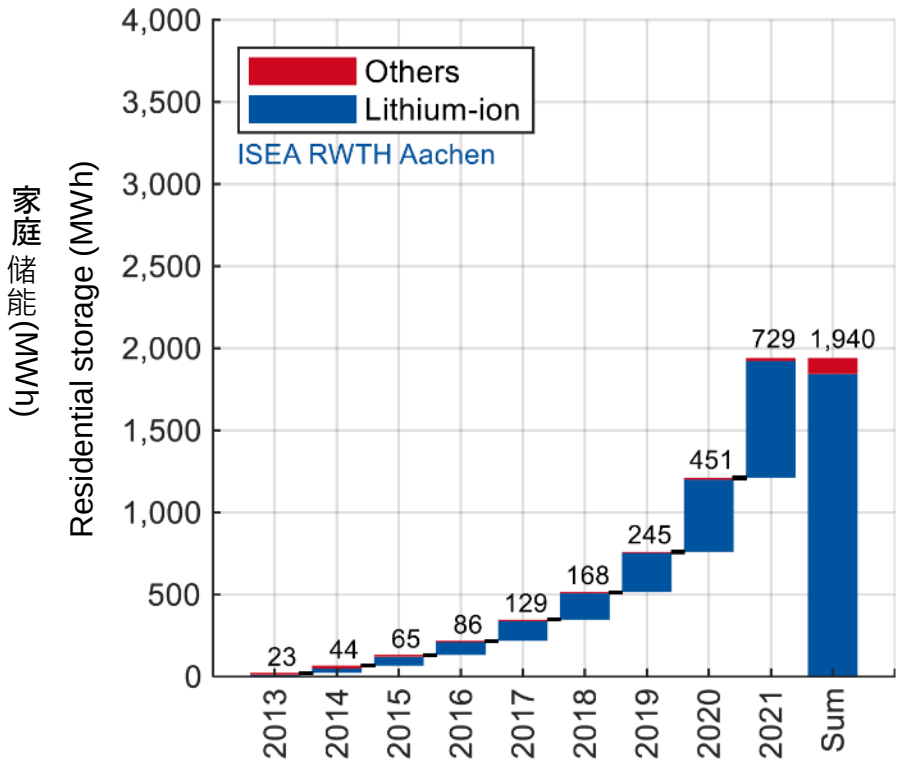
Home energy storage market is booming in Germany

家庭储能市场在德国蓬勃发展

Home energy storage systems in Germany, 2013-2021: capacity (MWh, left) and power (MW, right)

德国家庭储能系统，2013-2021：容量（MWh, 左）和功率（MW，右）





Source: Figgener et al, RWTH Aachen 2022

Energy storage market is booming (2)
储能市场蓬勃发展（2）

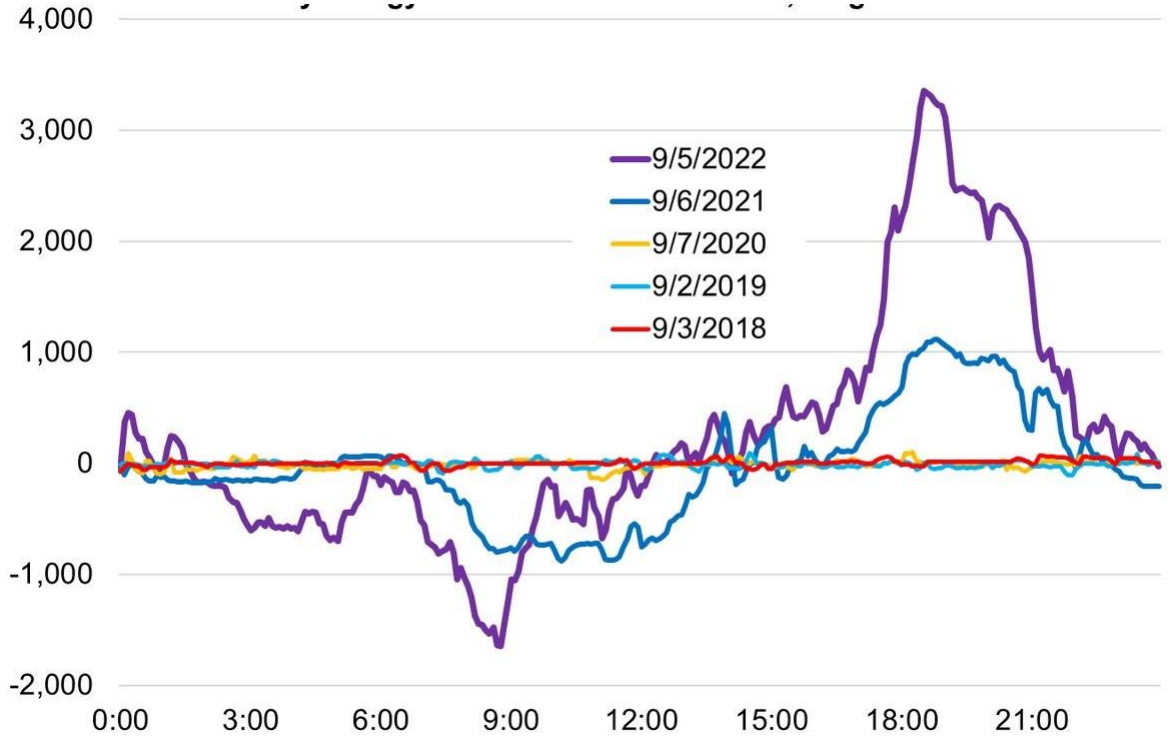
- Most of Germany's energy storage market is for home use, typically paired with residential solar
- 德国储能市场大部分是家用，通常与住宅太阳能搭配使用
- Germany added 145,000 home energy storage systems in 2021, and reached 450,000 total systems
- 德国2021年新增14.5万台家用储能系统，总量达45万台
  - Home energy systems reached 3.5 GWh or 2 GW in total
  - 家庭能源系统总量达3.5GWh或2GW
  - Annual installations likely to increase by 60-100% in 2022
  - 2022年安装量可能增加60-100%
  - If used for grid stability, could provide up to a fourth of peak ramping needs
  - 如果用于稳定电网，可提供多达1/4的峰值爬坡需求
- Industrial, commercial, and utility storage is also rising, but smaller
- 工业、商业和公用事业储能在持续增加，但规模较小
  - Large-scale storage systems reached 0.75 GWh and 0.6 GW in total
  - 大型储能系统总量达0.75 GWh和0.6 GW

Germany battery operation likely similar to California in size and flex

德国电池储能的规模和灵活性与加州类似

California peak summer day battery net output, 5-minute intervals, 2018-2022

加州夏季电池净输出峰值，5分钟间隔，2018-2022年



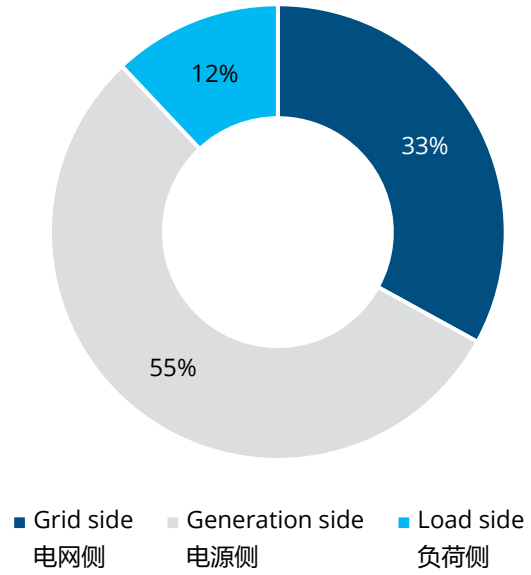
Source: CAISO 2022

China’s battery storage focuses on generation and grid-sited storage

中国的电池储能主要集中在电源侧和电网侧

Distribution of battery storage by location, 2021

电池储能的分布情况，2021



Source: State Grid 2022

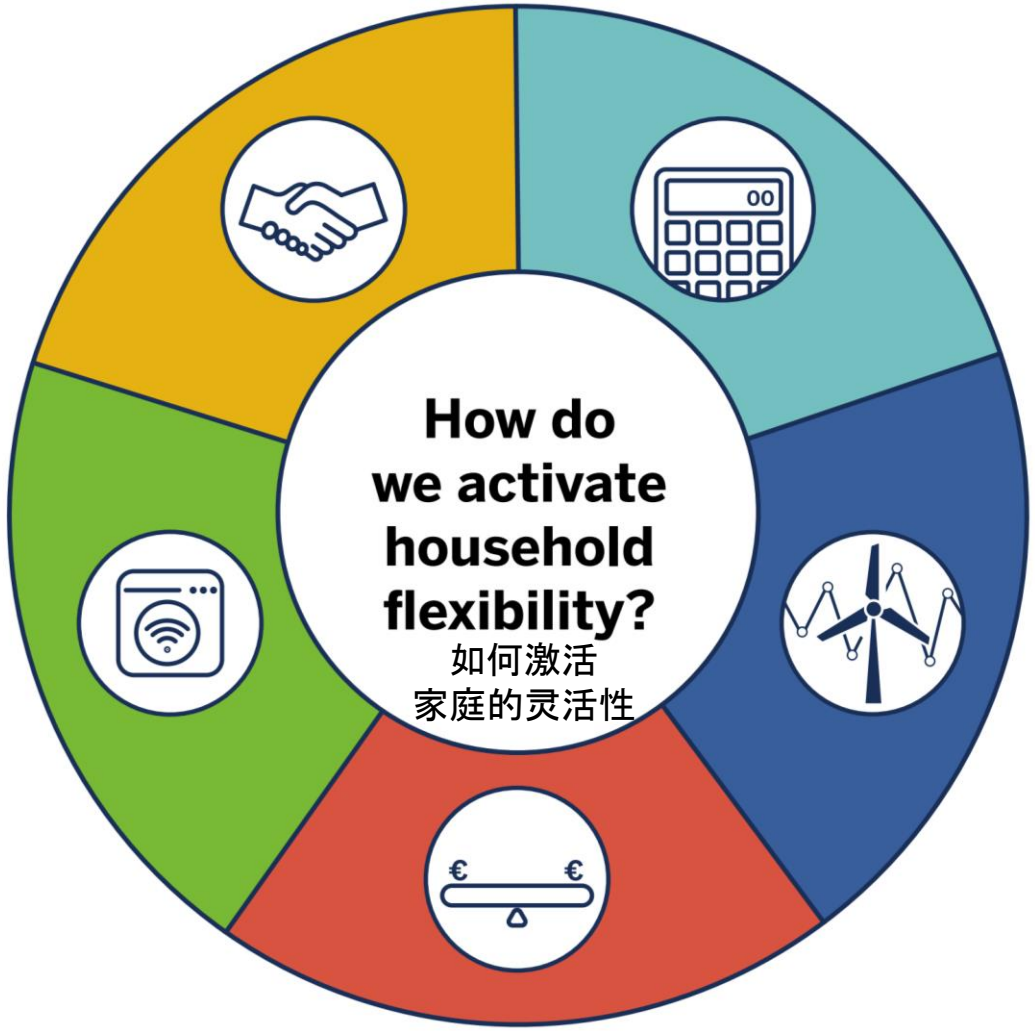
Provinces with mandates for energy storage paired with RE

储能和可再生能源配套的省份

Source: various reports compiled by GIZ

Unlocking demand-side flexibility requires additional policies

解锁需求侧灵活性需要更多的政策支持



Create robust tools for measuring and valuing customer flexibility
创建强大的工具来衡量和评价客户灵活性

Incentivise flexibility through energy market price signals
通过能源市场价格信号激励灵活性

Ensure a level playing field for demand-side resources
确保为需求侧资源提供公平的竞争环境

Accelerate installation of flexible assets in homes
加速家庭灵活性设施的安装

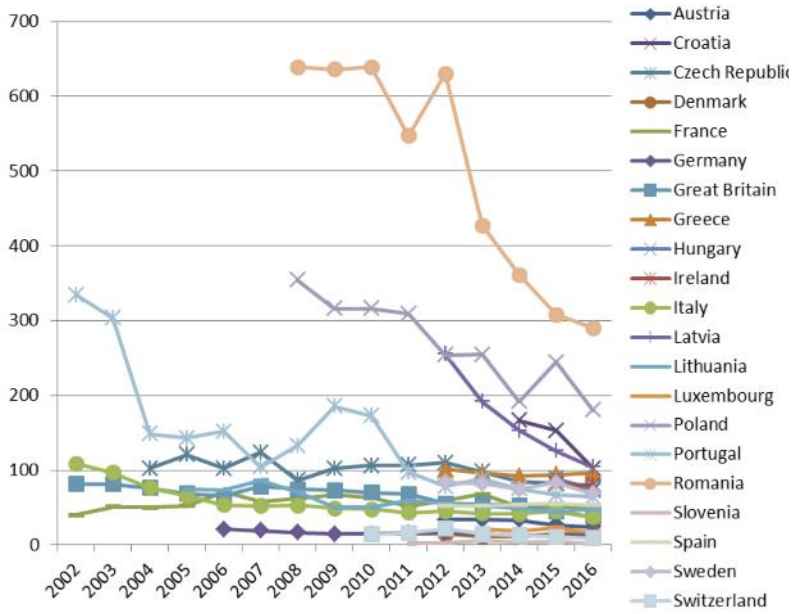
Make flexible actions easy and safe for customers
使客户的灵活性行动容易而简单

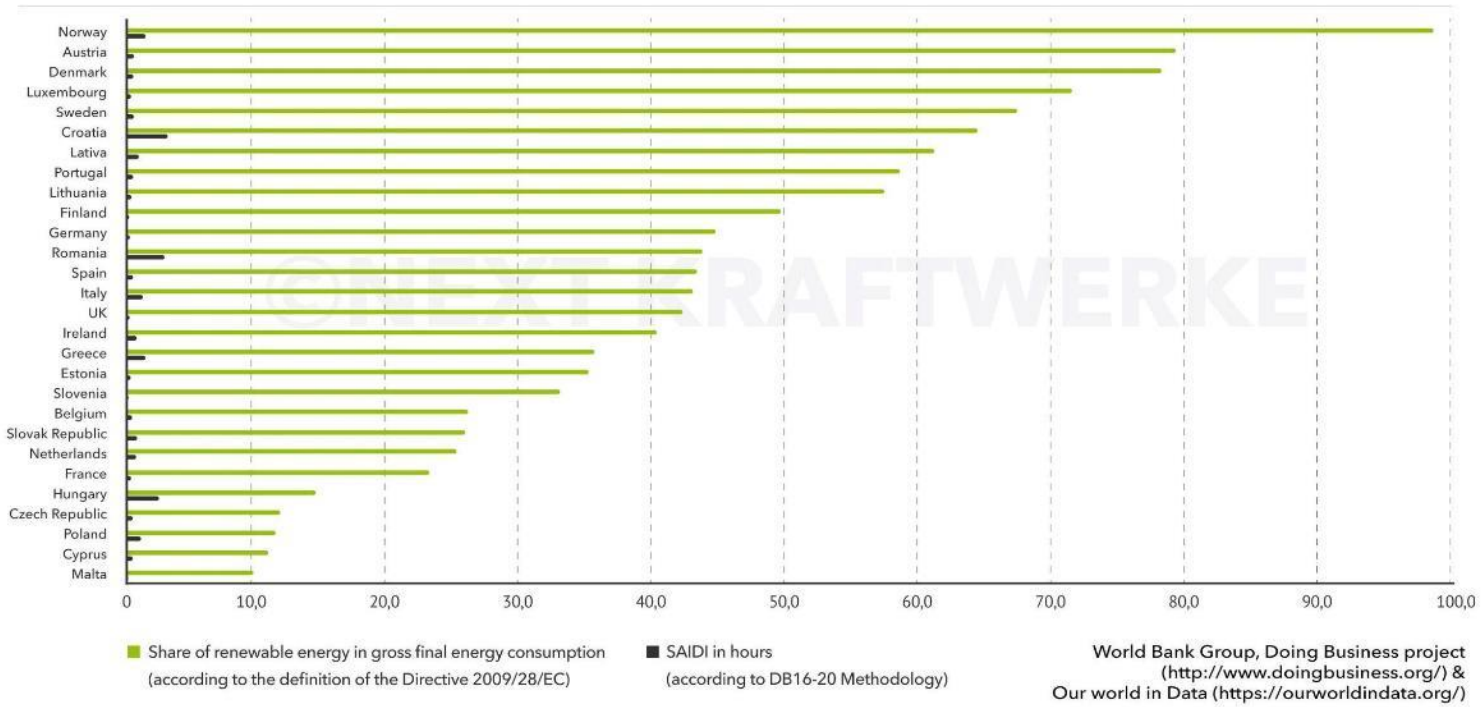
Germany’s power system is highly reliable

德国电力系统可靠度高

System Average Interruption Duration Index (SAIDI, minutes) and renewable energy share

系统平均中断时间指数（SAIDI，分钟）和可再生能源份额



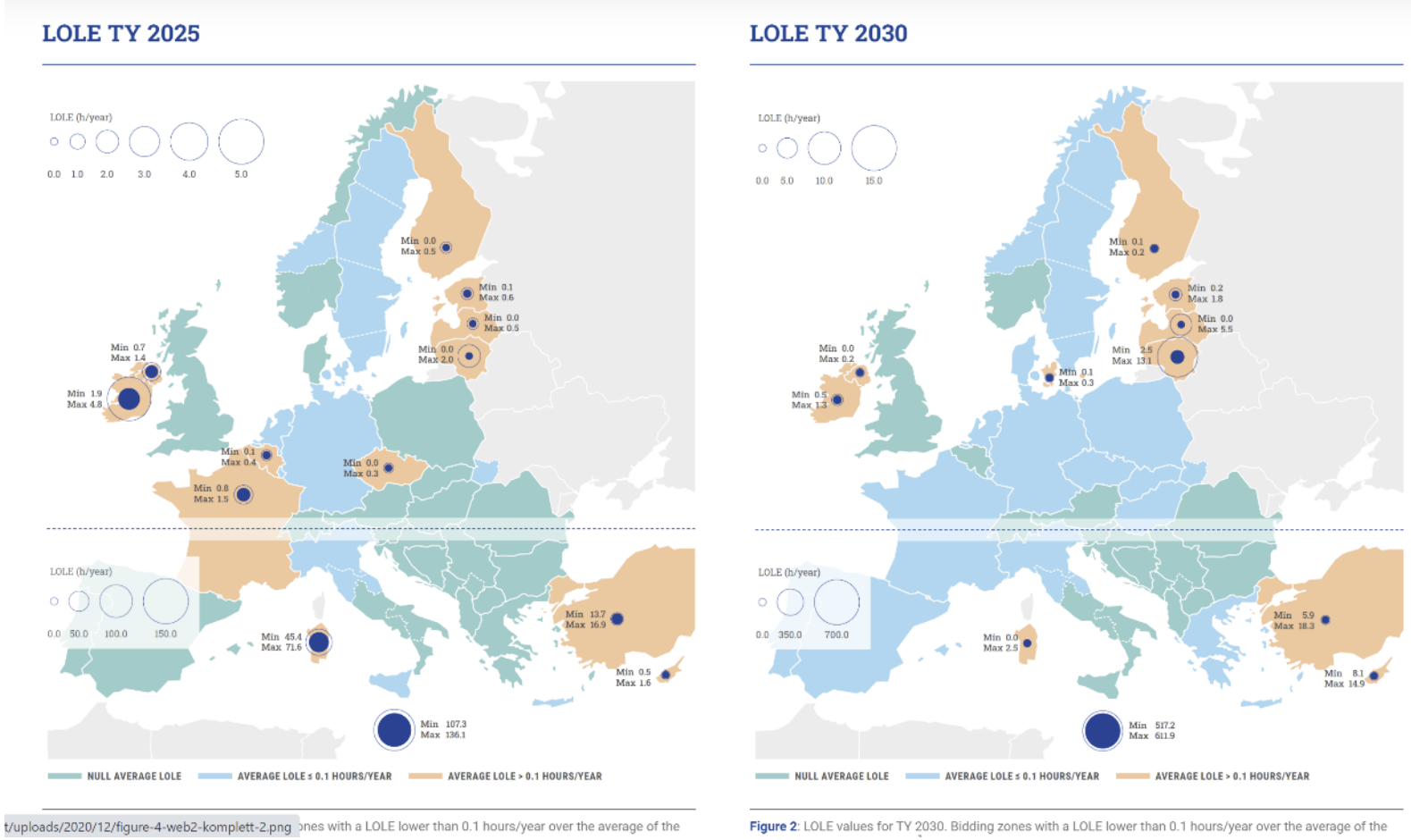


Source: CEER 2018, NextKraftwerke 2021

ENTSO-E projects Germany will remain reliable through 2030

ENTSO-E预测德国将在2030年之前保持可靠状态

- Germany's loss-of-load-probability (LOLP) in 2030 is 20 times safer than the EU standard
- 德国2030年的电力不足概率（LOLP）比欧盟标准安全20倍
- LOLP determined by Monte Carlo simulations of weather, plant and transmission outages, demand
- 电力不足（LOLP）取决于天气、工厂和传输中断、需求的蒙特卡洛模拟
- Simulation uses weather from past years with low wind and sun
- 模拟使用过去几年的低风和低日照天气数据
- Excess capacity in neighbor countries helps explain Germany's situation
- 邻国的过剩容量有利于德国现状



t/uploads/2020/12/figure-4-web2-komplett-2.png ones with a LOLE lower than 0.1 hours/year over the average of the

Figure 2: LOLE values for TY 2030. Bidding zones with a LOLE lower than 0.1 hours/year over the average of the

Recent BMWK stress test also suggests no physical shortage

最近德国联邦经济和气候保护部（BMWK）的压力测试也表明没有实质性的短缺

- BMWK asked Germany's four TSOs to perform two stress tests in mid-July and early September 2022 of the security of the power grid this winter in the face of worsened external conditions (gas supplies, drought, French nuclear outages)
- Grid stress test finds that hourly crisis situations in the power system are very unlikely this winter, but cannot be entirely excluded
- Main response is to activate coal reserve (already undertaken)
- Germany will establish a new deployment reserve of two nuclear power plants in the south of Germany until April 2023

- 面对恶化的外部条件(天然气供应、干旱、法国核中断)，BMWK要求德国四家输电系统运营商（TSOs）在2022年7月中旬和9月初对今冬电网安全性进行了两次压力测试
- 电网压力测试发现，今年冬季电力系统出现小时危机的可能性很小，但不能完全排除
- 主要对策是激活煤炭储备(已经开始)
- 德国将在2023年4月之前，在德国南部建立两个核电站的新部署储备

Germany and the 2022 energy crisis

德国和2022年能源危机

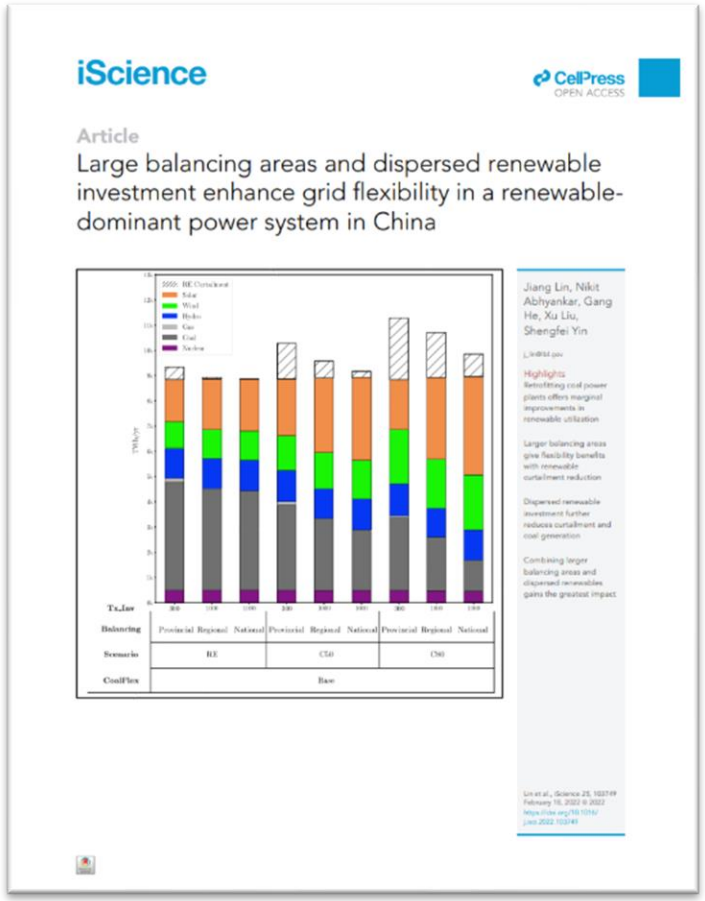
- Germany's power markets have worked to promote renewables and renewable integration
- **德国**电力市场一直致力于促进可再生能源发展和整合
- Germany's power markets are well-supplied from the perspective of capacity adequacy
- **从容量充裕度的角度来看，德国**电力市场**供**应充足
- Germany is making progress with new flexibility—both policies and technologies
- **德国在新的灵活性方面正取得**进展，无论**是政策**还是技术

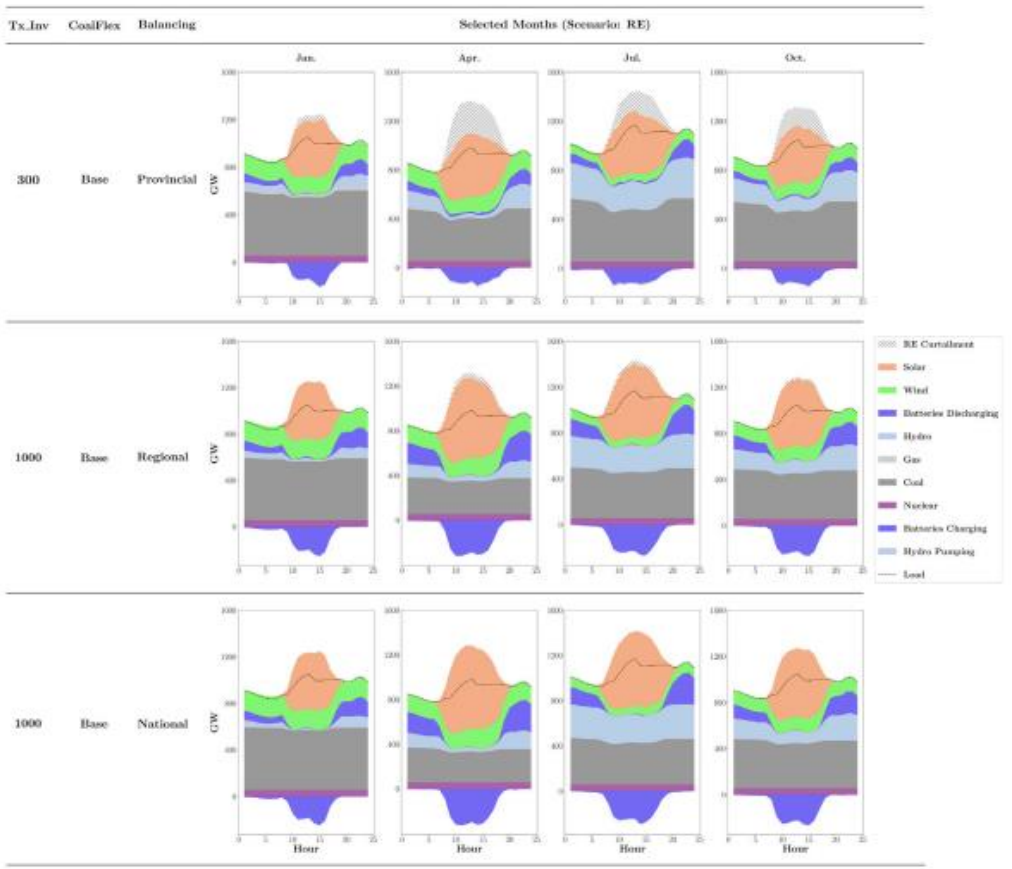
But但是…

- Europe is presently experiencing a crisis in energy costs
- **欧洲目前正在**经历能源成本危机
- Two main causes: sudden need to stop gas and outages at French nuclear fleet
- **两个主要原因： 突然停气和法国核**电机组的停运
- Electrification, renewables, storage, and demand response are the main long-term measures to solve these problems
- 电气化、可再生能源、储能和需求响应是解决这**些**问题的主要长期策略
- Energy reserve system more necessary
- **能源**储备体系更加必要

2022 Berkeley study found greater transmission flexibility offers lowest-cost solution for VRE integration

2022年伯克利实验室研究发现更大的传输灵活性为可再生能源整合提供最低成本解决方案





- Jiang Lin et al. modeled various flexibility measures for 2030
- Jiang Lin等学者对2030年各类灵活性措施进行了建模
- Combining larger balancing areas and distributed energy offers the lowest-cost solution to renewable integration under all scenarios
- 在任何情景下，结合更大的平衡区域和分布式能源可以为可再生能源整合提供最低成本解决方案
- Coal plant flexibility upgrades require substantially higher costs for less benefit
- 煤电厂的灵活性改造需要更高的成本，但收益较低

Source: Jiang Lin et al, iScience, 2022

2019 IEA study found that inter-provincial trading and other flexibility measures more effective than dedicated peaking plants

2019年国际能源署的研究发现，省际交易和其他灵活性措施比专用调峰电厂更有效

- Efficient spot power markets and bi-direction inter-provincial trading are the lowest cost and highest benefit solutions for flexibility
- 高效的电力现货市场和双向的省际交易是成本最低、效率最高的灵活性解决方案
- Implementation of these solutions reduces costs by 15% and emissions by 750 million tons in 2035
- 这些措施的实施可以在2035年减少15%的成本和7.5亿吨排放
- Smart charging of approximately 250 GW of peak EV charging load and 800 terawatt hours of total annual EV charging load can reduce cost by 5% and reduces peak load by 15%
- 对250 GW的电动汽车充电高峰负荷和800 TWh的电动汽车充电负荷进行智能充电，能减少5%的成本和15%的尖峰负荷
- **China can accommodate a larger share of VRE with a mix of flexible generation technologies without dedicated plants to provide flexibility**
- **中国可以通过灵活的发电技术组合来消纳更大份额的可再生能源，而不需要专门的工厂来提供灵活性**

Source: IEA 2019

2022 Sichuan outages highlighted present grid inflexibility in China

2022年四川电力短缺凸显了中国目前电网的不灵活

- Primary cause of power shortage in Sichuan was high demand for air conditioning during heat wave combined with low output from hydro, wind, solar, and thermal generation
- Under the West-to-East hydropower development strategy, a fixed proportion of power is sent to eastern provinces from Sichuan's main hydro stations. This means that the outward transmission of hydropower from Sichuan is not just a policy decision of the grid or Sichuan, but a rigid principle that can only be changed in a grid emergency
- Most of Sichuan's high-voltage lines are designed to send power in only one direction. Of the HVDC lines, only the 500 kV Deyang-Baogui DC transmission project can transmit electricity in both directions, but this is designed for seasonal adjustment, rather than hourly adjustment as would be true for European or U.S. DC lines

- **四川**电力短缺的主要原因是高温天气对空调的**高需求**，**加之水**电、风能、**太阳能和**热电的低产量
- **在水利西**电东送开发战略下，**四川省的主要水**电站向东部省份输送固定比例的水电，这意味**着**，**四川水**电向外输送不仅是电网或四川的政**策决定**，**而是只有在**电网出现紧急情况时才能**改**变的刚性原则
- **四川的大部分高**压线路设计成只向一个方向输**送**电力。**在高**压直流输电线路中，**只有500千伏的德阳-宝**贵直流输电项目可以实现双向输电，**但**这是为季节性调整而设计的，**而不是像欧洲或美国的直流**线路那样按小时调整

Source: IEA 2019

Conclusions: Different situations, common solutions

结论：不同状况，相同解决方案

Germany德国

- Renewable energy and energy efficiency help reduce the cost of the gas crisis, assisted by:
- **可再生能源和能源效率有助于降低天然气危机的成本，其**协助因素包括:
  - High-volume day-ahead and intraday spot markets and sophisticated redispatch policies
  - **日前和日内**现货市场成交量大，再调配政策复杂
  - Flexible and bidirectional operation of interconnections
  - **灵活的双向互**连操作
- Germany's various coal plant reserves were initially designed as an emergency measure
- **德国的各种燃煤**电厂储备最初是作为一种应急措施设计的
- Capacity market not needed so far, but under debate
- **目前**还不需要容量市场，但存在争议

China中国

- Faster scale-up of domestic renewables, flexibility, storage, efficiency, and demand response all help with energy security
- **国内可再生能源、灵活性、**储能、效率和需求响应的快**速**扩大，都有助于能源安全
  - High-volume national spot market trading would help
  - **大量的国内**现货市场交易将有所帮助
  - Flexible and bidirectional operation of interconnections critical
  - **灵活和双向运行的互**连至关重要
- Reducing the cost of electrification important for energy security and decarbonization
- **降低**电气化成本对能源安全和脱碳非常重要
- Lack of flexibility leads to overinvestment in fossil capacity, stranded asset risks
- **缺乏灵活性**导致了化石产能的过度投资，资产搁浅风险

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