DEMAND RESPONSE AND SECTOR COUPLING: ENABLERS FOR THE INTEGRATION OF RES
需求侧响应和部门耦合：可再生能源并网的促成因素

Dr. Marian Klobasa, Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe
Marian Klobasa 博士，德国弗劳恩霍夫系统与创新研究所，卡尔斯鲁厄

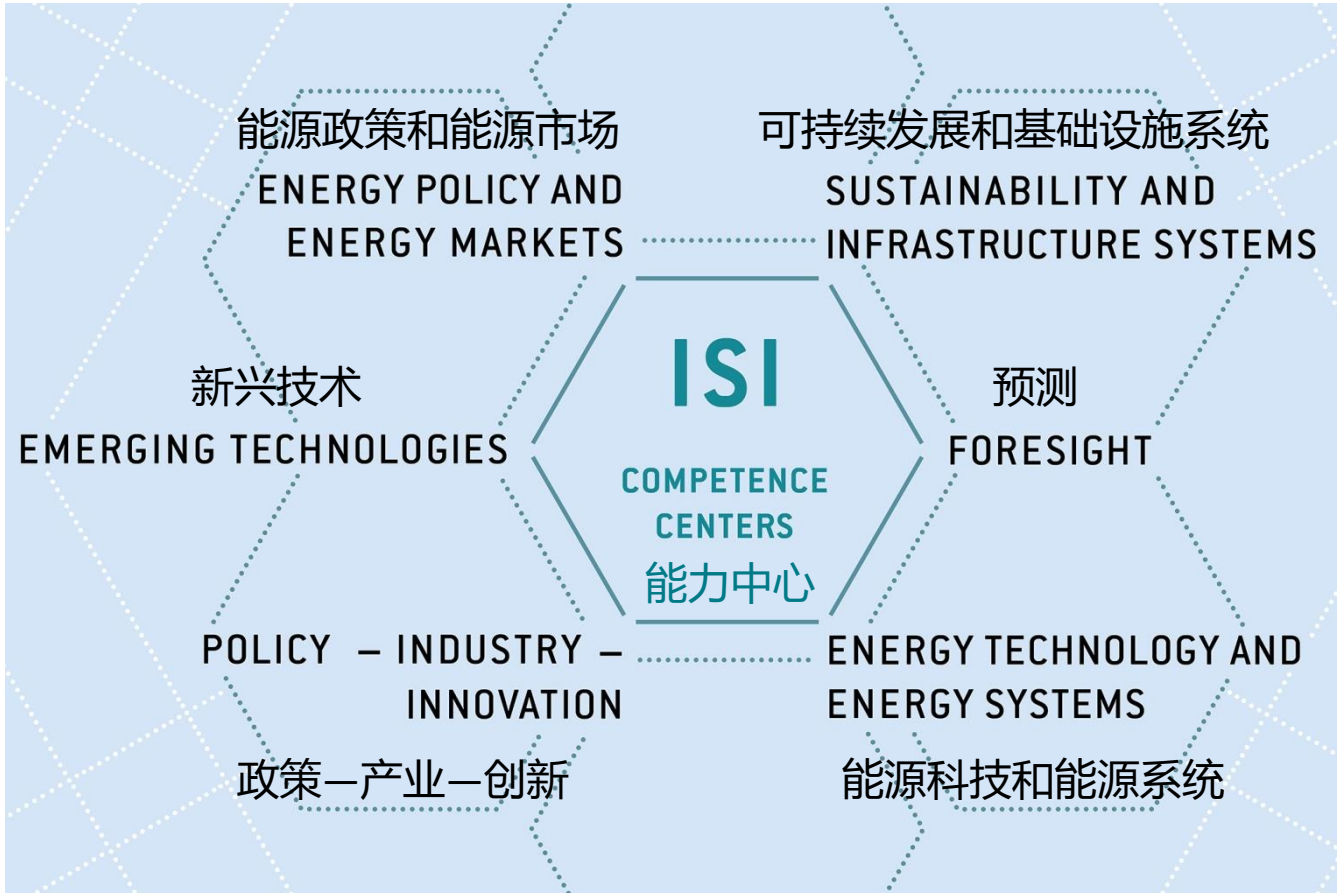
Fraunhofer ISI

AGENDA 日程

- Status Quo of demand response in Germany and Europe
  德国和欧洲需求侧响应的现状
- Challenges with increased renewable generation
  可再生能源发电增长带来的挑战
  - System operation of transmission grids 输电网的系统运行
  - Grid infrastructure and grid congestions 电网的基础设施建设以及电网堵塞
  - Generation and demand at low voltage levels 低电压水平下的发电和需求
- Enablers for an efficient integration of renewable energies
  可再生能源并网的促成因素
  - Demand response 需求侧响应
  - Sector coupling 部门耦合

FRAUNHOFER INSTITUTE FOR SYSTEM AND INNOVATION RESEARCH ISI弗劳恩霍夫系统和创新研究所

- **Total Number of staff 31 Dec 2017: 224**
  员工总数：224人，截至2017年12月31日
- **Budget 2017: approx. € 23.9 million**
  2017年预算：约为2390万欧元
  - of this € 20.2 million external earnings and
    其中2020万欧元为外部收益
  - € 3.7 million basic funding
    370万欧元为基出资金
- **420 research and consultancy projects per year**
  每年420个研究和咨询项目



Fraunhofer ISI

Status Quo of demand response in Europe

欧洲需求侧响应的现状

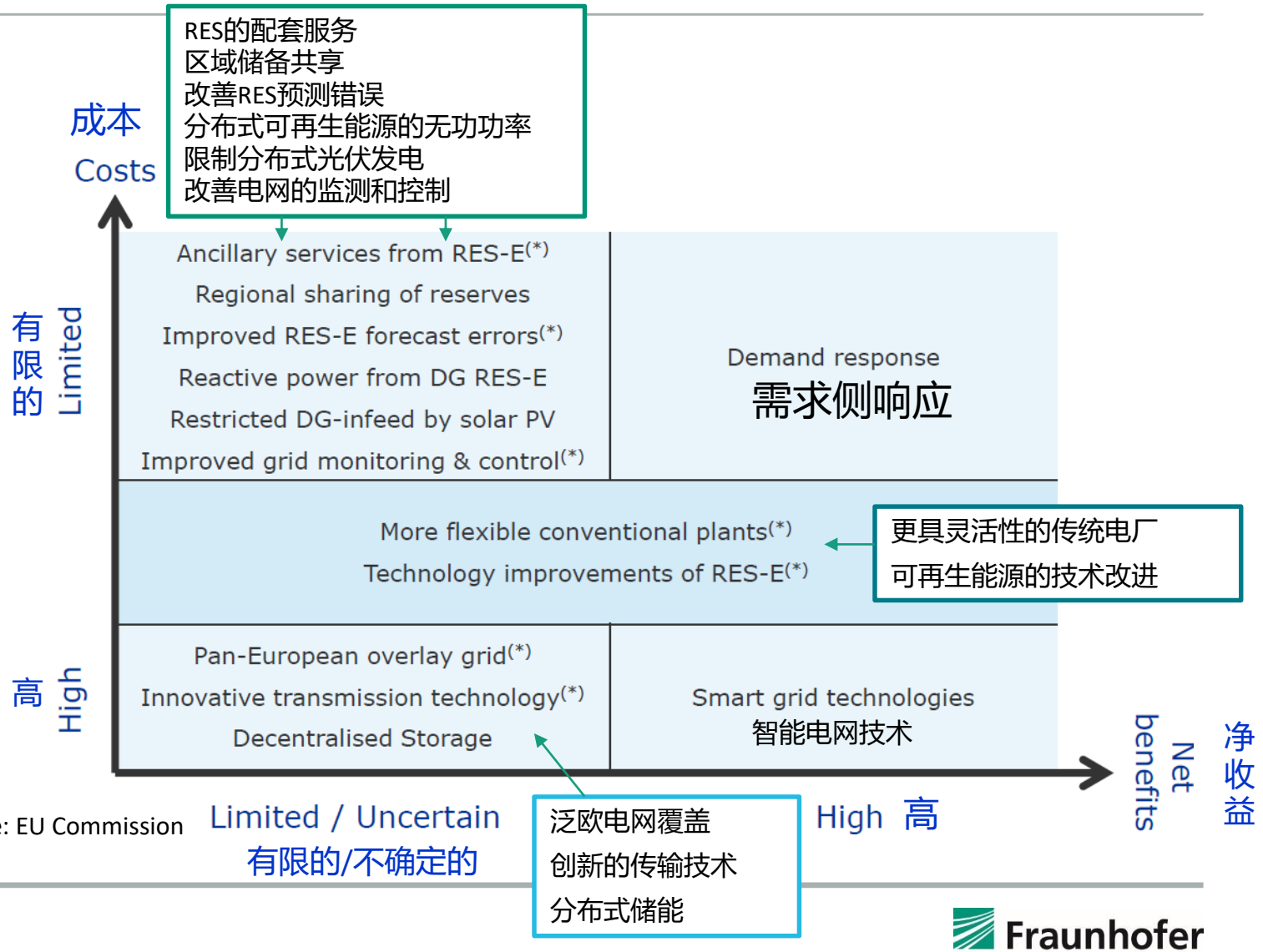
EU wide solutions to integrate renewable generation
欧盟范围内可再生能源发电并网的解决方案

Established measures 现存措施

- Improved RES forecast 完善RES的预测
- Regional sharing of reserves 区域储备共享
- Restricted DG-infeed of solar PV
  限制分布式光伏发电
- Grid monitoring/control 电网监控/控制

Measures in development 正在开发的措施

- Ancillary services from RES RES的配套服务
- Decentralised storage 分散存储
- Demand response 需求侧响应
- Smart grid technologies (DSOs)
  智能电网技术 （配电系统运营商）



Source: EU Commission

Demand Response and Demand Flexibility
需求侧响应和需求灵活性

- Demand response describes a voluntary change in the electricity demand of individual end customers from their usual consumption pattern as a result of
  需求侧响应是指由于以下两点引起的电力需求侧终端用户日常消费模式的自愿改变：
  - changes in electricity prices over the course of the day (**indirect** load management) or
    每日电价的变动（**间接**负荷管理）或
  - bonus payments (**direct** load management) with the aim of ensuring a balance between demand and production.
    奖励支付（**直接**负荷管理）旨在确保需求和生产间的平衡。
- Demand flexibility describes the implementation of measures to increase the flexibility of electricity demand, e.g. through technical or organisational adjustments
  需求灵活性是指通过一些措施的实施来增加电力需求的灵活性，如通过技术上的或者组织上的调整

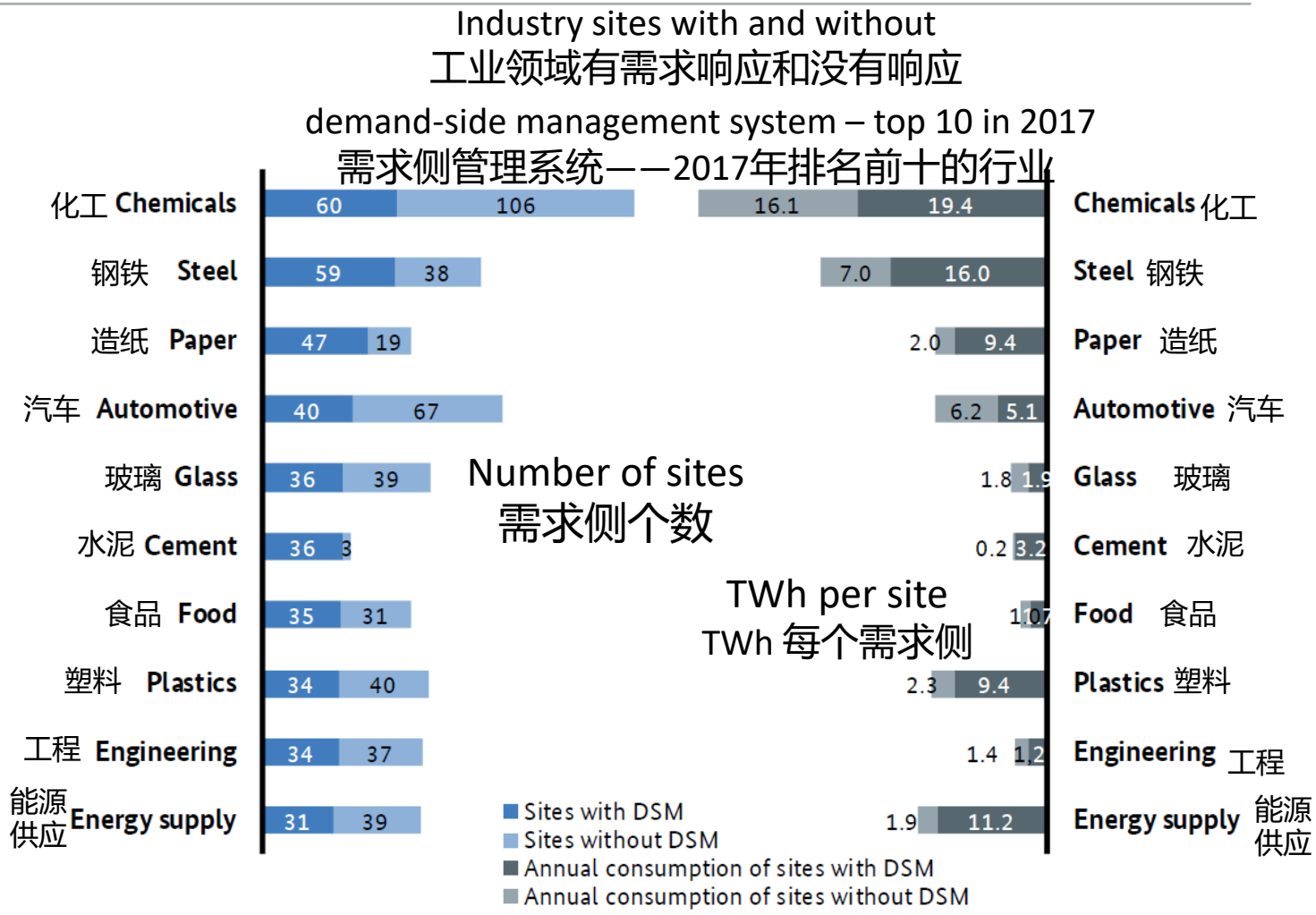
Main Benefits of Demand Response and Demand Flexibility
需求侧响应和需求灵活性的主要好处

- Benefits of load flexibility from the system perspective
  - Balancing electricity demand and supply
  - Support in case of network bottlenecks
  - Avoidance of peak loads
  - Increasing the utilisation of electricity grids and generation facilities
- Benefits from the user‘s point of view
  - Reduction of electricity costs
  - Reduction of network costs
  - Additional revenue potential (e.g. system services)

- 从系统角度分析负载灵活性的好处
  - 平衡了电力需求和供应
  - 在网络遇到瓶颈的情况下提供支持
  - 避免了峰值负荷
  - 提高了电网和发电设施的利用率
- 从用户角度来分析负载灵活性的好处
  - 降低了电费
  - 降低了电网费用
  - 带来获得额外收入的潜力（例如系统服务）

Demand response in Industry – Status Quo Germany
工业领域需求侧响应——德国现状

- Demand response system already used in Industry
  需求响应系统已应用于工业领域
- Main application is peak load reduction due to grid tariffs
  最主要的应用是由于电网费率导致的峰值负荷减少
- Demand response is mainly by companies themselves
  需求响应主要由企业自身进行
- Only limited number of sites is controlled by network operator or service provider
  只有少数由电网运营商或服务提供商来主导



Challenges for RES Integration

可再生能源并网的挑战

Challenges due to high wind and pv generation风能和光伏的高产量带来的挑战

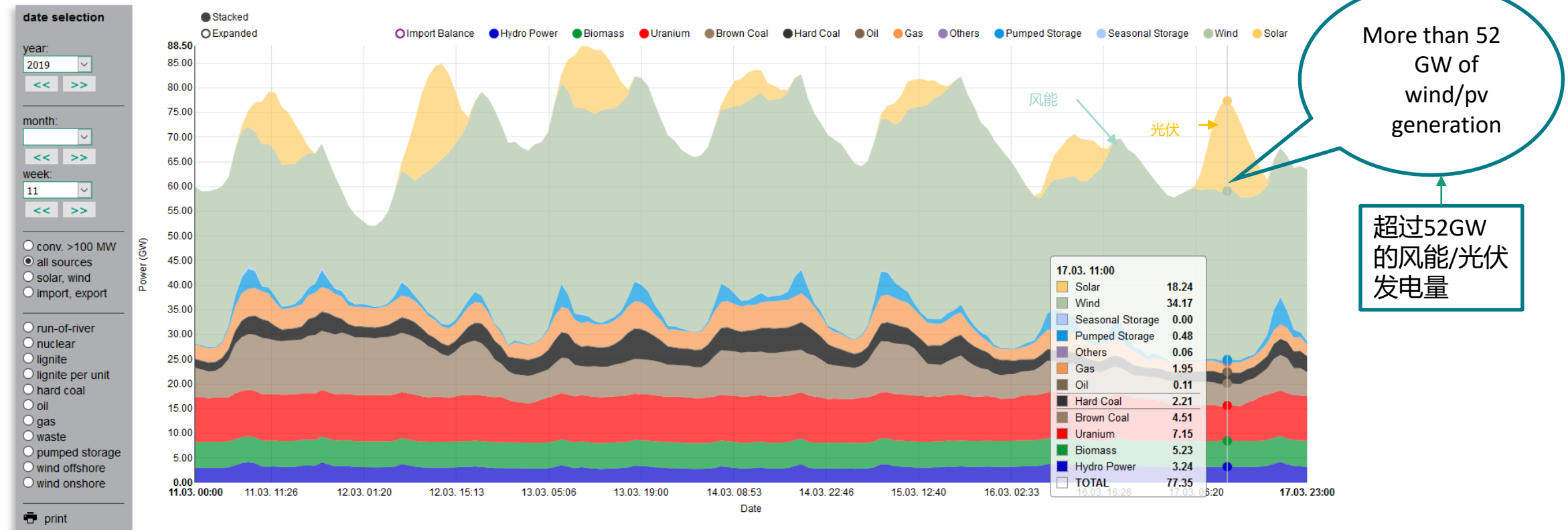
Fraunhofer ISE

ENERGY CHARTS

Publishing Notes | Data Protection | EN

Home | Power | Energy | Emissions | Climate | Prices | Map of power plants | Information

Electricity production in Germany in week 11 2019　德国2019年第11周的电力生产数据



Fraunhofer ISI

RES generation has strong impact on market prices可再生能源产电极大影响了市场价格

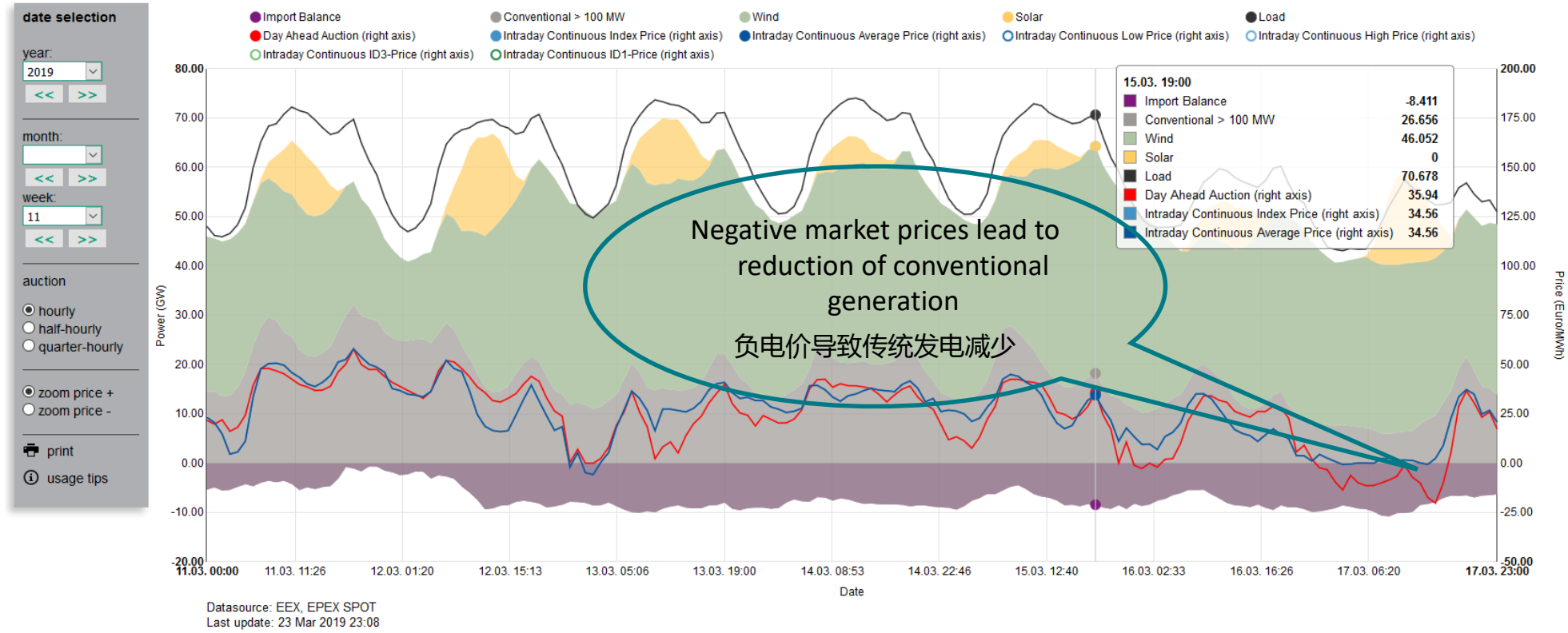
Fraunhofer ISE

ENERGY CHARTS

Publishing Notes | Data Protection | ▾

Home | Power | Energy | Emissions | Climate | Prices | Map of power plants | Information

Electricity production and spot prices in Germany in week 11 2019 德国2019年第十一周电力生产和实时电价数据



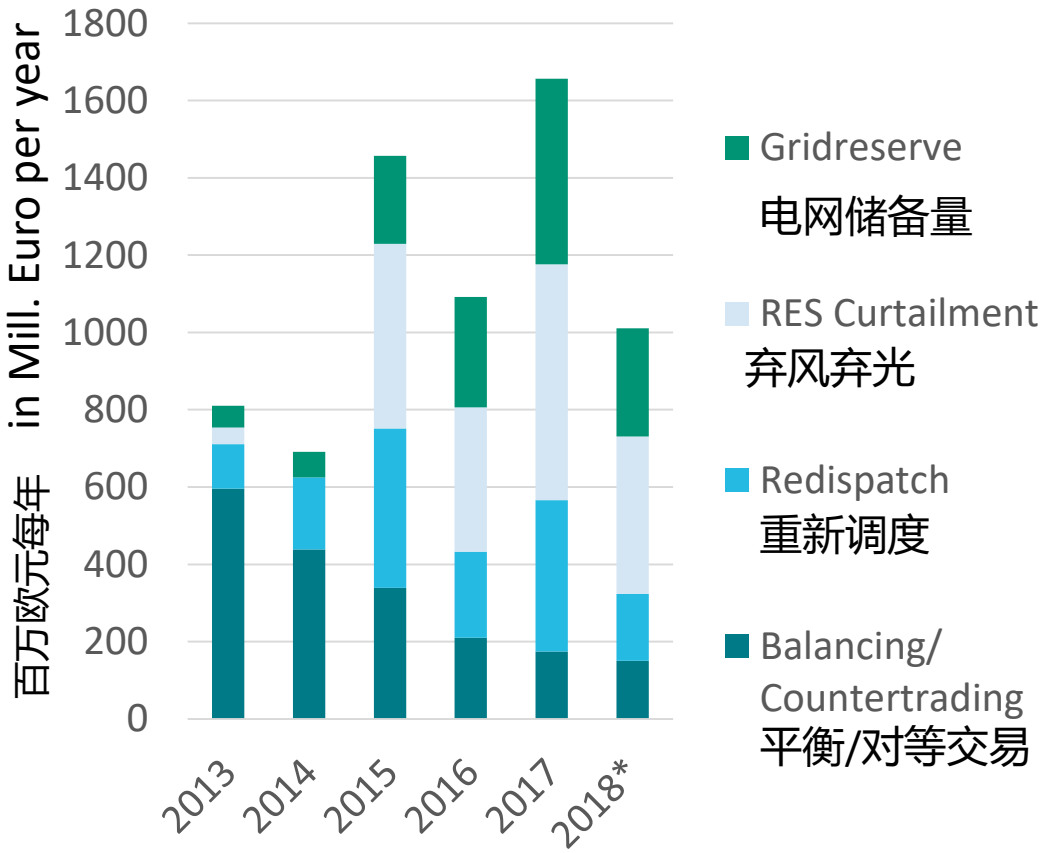
Fraunhofer ISI

RES generation impacts on system operation costs of the transmission grid可再生能源发电对输电网系统运行成本的影响

- Delayed grid extension lead to higher system operation costs of the transmission grid
  电网扩建的延期导致输电网系统运行成本增加
- but balancing costs decreased substantially
  但平衡成本大幅下降
- System grid operation costs vary with yearly RES generation (e.g. in low wind years)
  电网系统运行成本随每年的可再生能源发电量而变化(例如在少风年份)
- Commissioning of new lines decrease redispatch volumes
  新线路的调试会减少重新调度的数量

=> congestion management costs become substantial part of transmission system operational costs

拥堵管理成本成为传输系统运营成本的重要组成部分



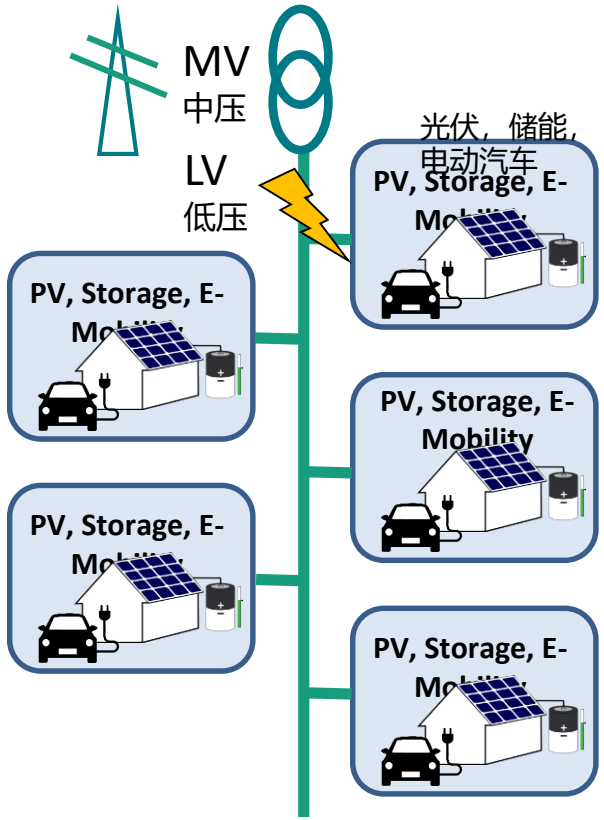
* 2018: only until Sep. 2018　2018年只到9月份

Source: German Regulator 2019

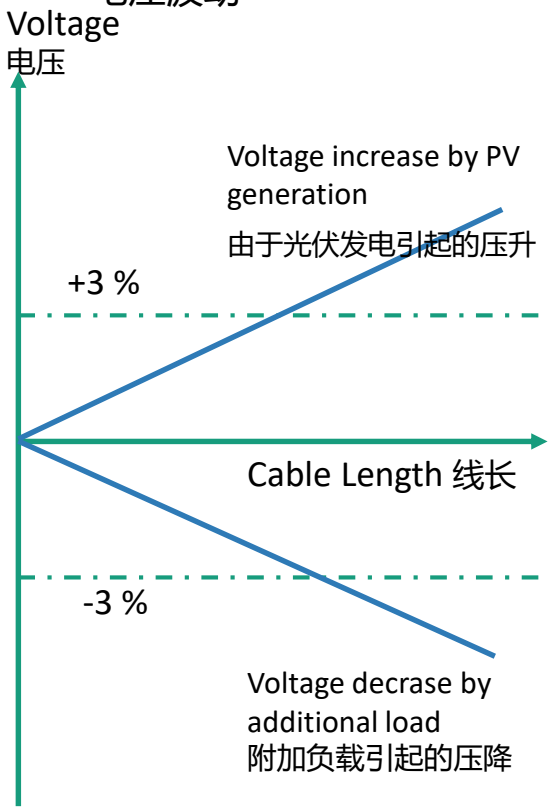
Fraunhofer ISI

Challenges in distribution grids
配电网遇到的挑战

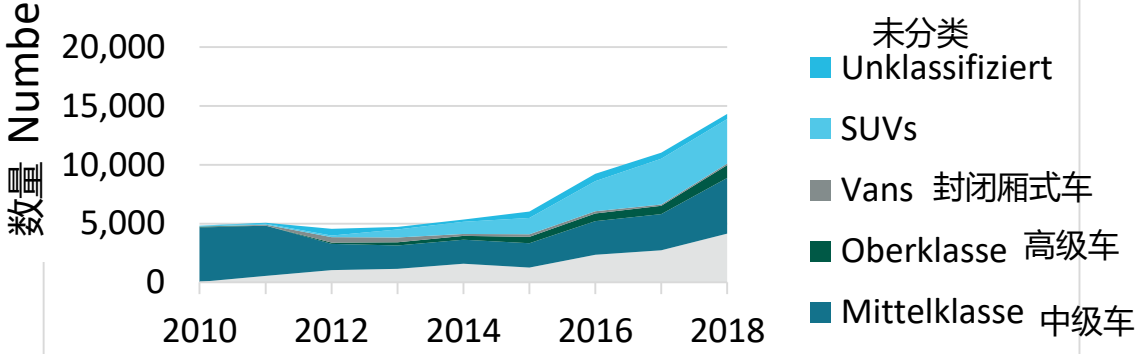
Power congestions
电力阻塞



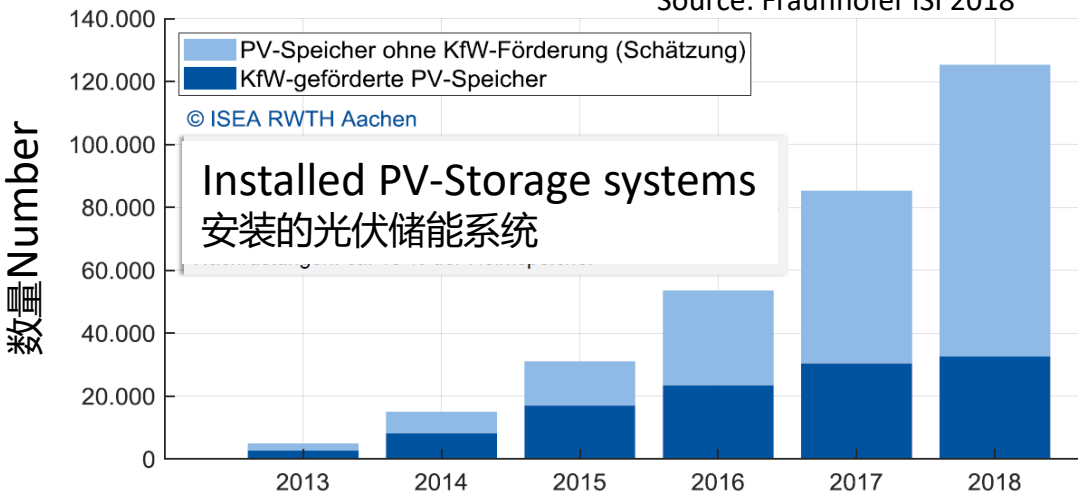
Voltage violation
电压波动



Sales of electric vehicles xEV (#sales/model)
电动汽车的销售量xEV(#销量/型号)



Source: Fraunhofer ISI 2018



⇒ new generators, demand and storage on distribution level
在分布式层面上新的发电设备，需求和存储

Fraunhofer ISI

Enabler for RES integration

可再生能源并网的促成因素

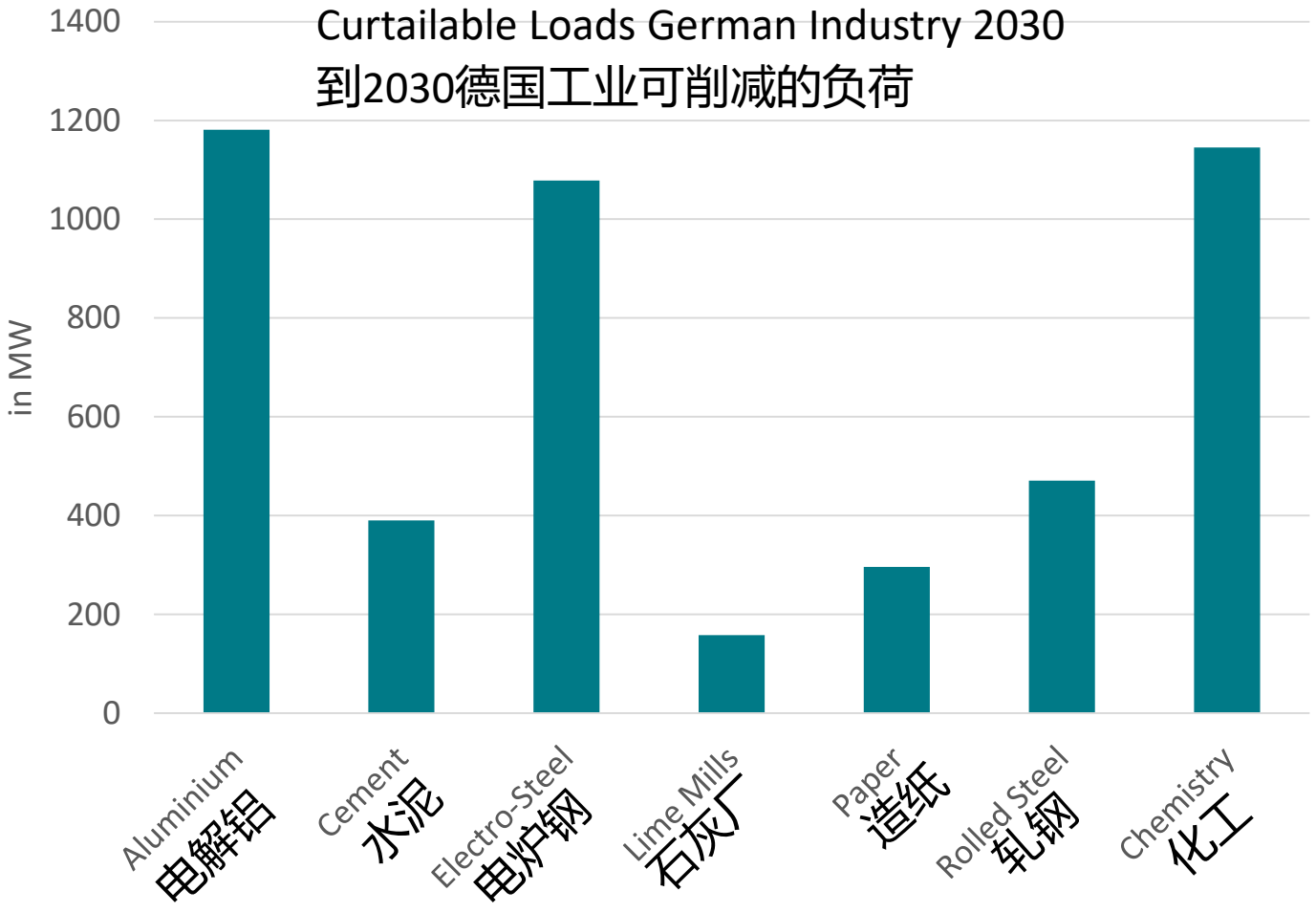
Direct Demand Response (incentive based)
直接需求响应（以奖励为基础）

- Direct remuneration for participation
- marketing opportunities (with incentives)
  - balancing market
  - system services (e.g., interruptible loads regulation)
- in other countries
  - wholesale electricity market
  - capacity market
- Technical requirements for participation (e.g. remote control, online monitoring)
- Frequently with the help of aggregators but also by suppliers
- 参与的直接计酬
- 市场机遇（含奖励）
  - 平衡市场
  - 系统服务（例如可中断负载调节）
- 在其它国家
  - 电力批发市场
  - 容量市场
- 参与的技术要求（如远程控制、在线监控）
- 通常在集成商的帮助下，但是也有通过供应商

Examples for direct demand response 直接需求响应的案例	
Prequalified capacity 对其能力的资格预审	
Immediate curtailable loads即时可削减的负载	999 MW
Fast curtailable loads快速可削减的负载	1537 MW
Remuneration 酬劳	
Capacity payments 容量付费	Tender result, up to 500 Euro per MW per week plus 400 €/MWh for activation 投标结果，最高至每周每兆瓦500欧元加上400欧元每兆瓦时（如果参与了调度）
Tender conditions 投标条件	
Tendering 投标	Weekly, 2 times 750 MW (frequency and remotely controlled activation) Duration 15 min up to 8 hours 每周两次750兆瓦（频率和远程控制的激活） 持续时间15分钟到8小时
Capacity 容量	Between 5 MW and 200 MW 在5兆瓦和200兆瓦之间

Demand response applications – Industry
需求响应的应用——工业

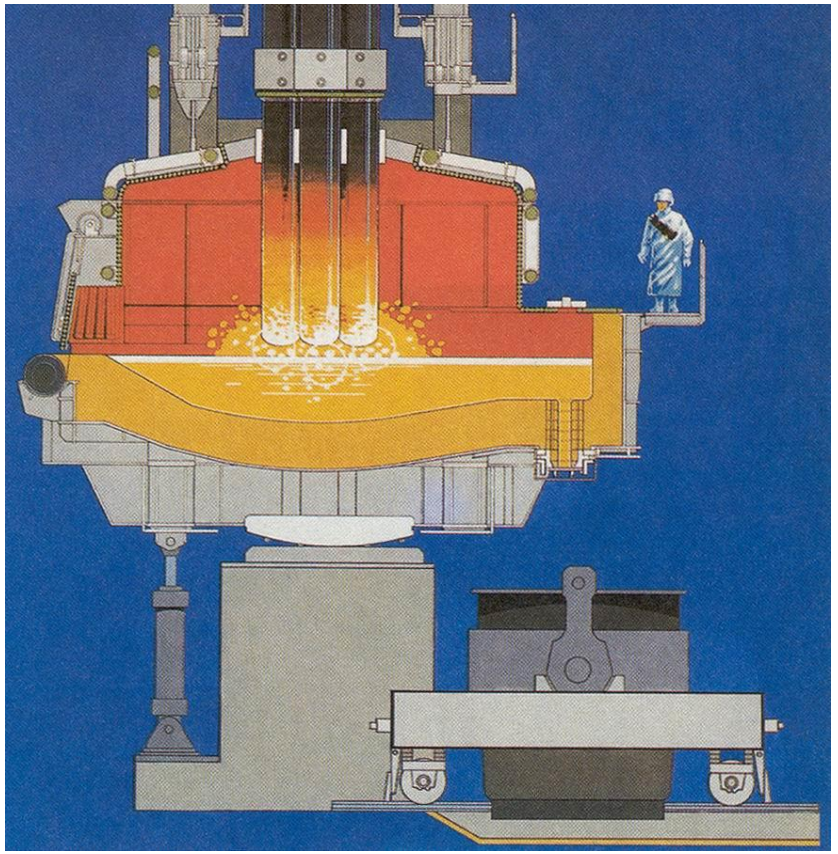
- Large curtailment flexibility in energy intensive industry
  在能源密集型企业大规模削减需求的灵活性
- Expected flexible capacity in 2030 about 3 – 4 GW
  预计到2030年灵活性调节的容量为3-4 GW
- 10 % of industry peak demand
  工业需求峰值的10%
- Applications from aluminium industry used for interruptible loads program
  来自铝行业用于可中断负荷计划的应用



Demand response applications – Steel industry
需求响应的应用——钢铁行业

- Steel production with EAF
  采用电弧炉的钢铁生产
  - Batch process
    批次加工
  - Production period 45 min
    生产周期45分钟
  - Power: 100 MW
    功率：100兆瓦
  - spec. Electricity demand:
    500 kWh/t
    具体电力需求：500千瓦时/吨
  - Capacity: 200 ton
    产能：200吨
  - Yearly Production 200 t oven: 1,5 Mio. t
    200吨电炉年产量：150万吨
  - Stahlpreis: 500 – 600 €/t (2019)
    钢铁价格：500-600欧/吨（2019年）
  - Typical Sales: 750 – 900 Mio. €
    典型销售：7.5-9亿欧元

Electric Arc Furnance – Steel Industry
电弧炉——钢铁行业

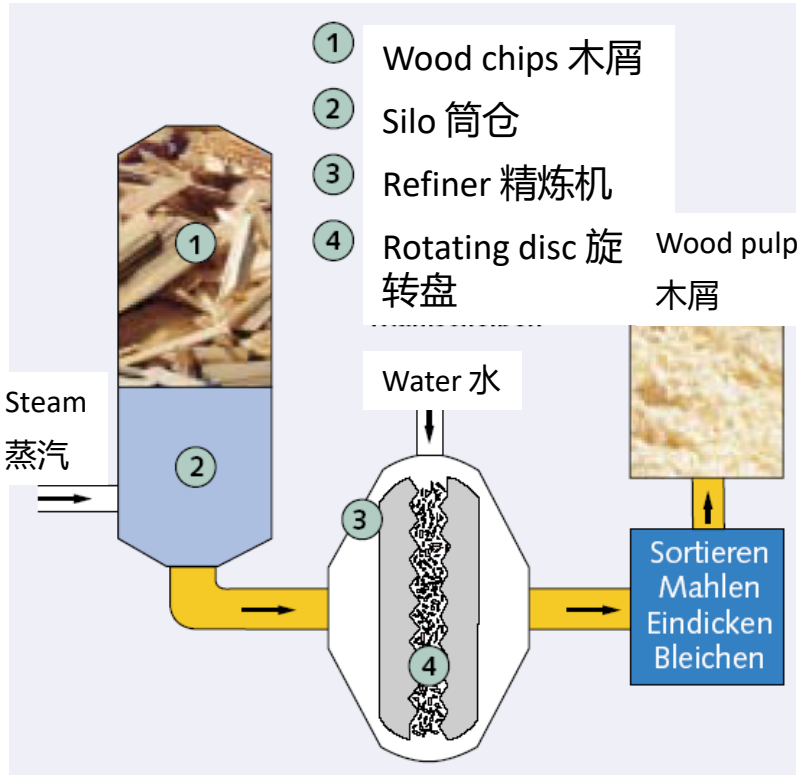


Source: Stahl-Online

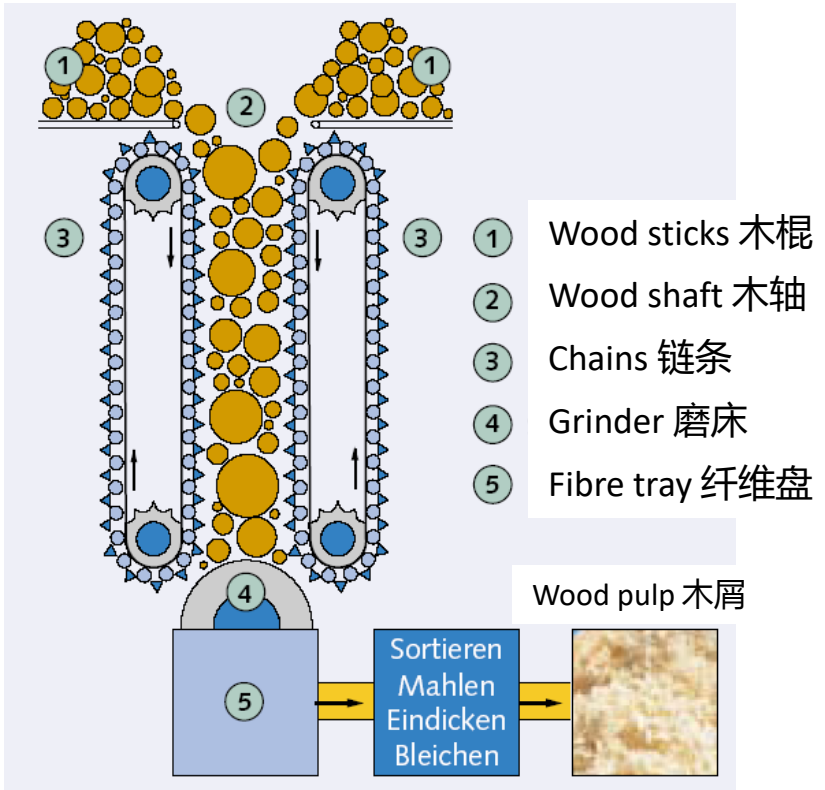
Demand response applications – Paper industry
需求响应的应用——造纸行业

- Paper making process
  造纸过程
  - Continues process
    持续生产
  - Production of basic material for paper production (wood pulp)
    生产用于造纸的基础材料（木浆）
  - Power: 15 MW (Refiner), 3 – 5 MW (Grinder)
    功率：15兆瓦（精炼机），3-5兆瓦（磨床）
  - spec. Electricity demand: > 2000 kWh/t
    具体电力需求：大于2000千瓦时/吨

Paper industry – Refiner
造纸工业——精炼机



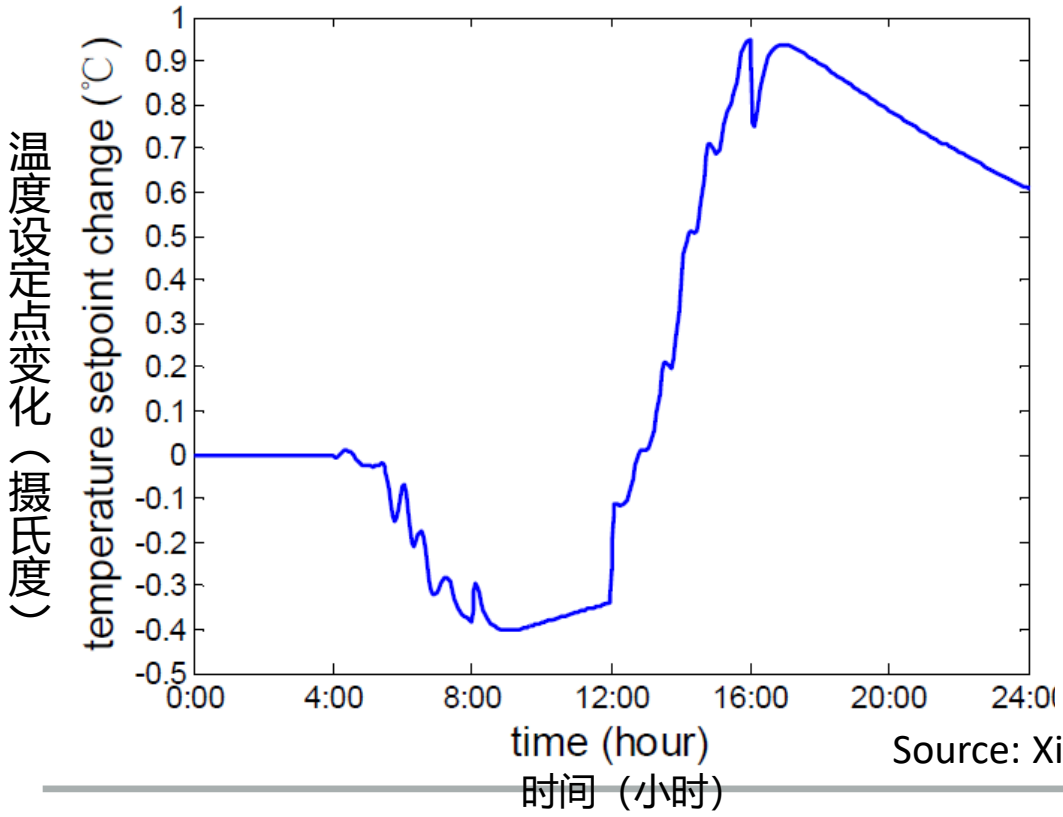
Paper industry – Grinder
造纸工业——磨床



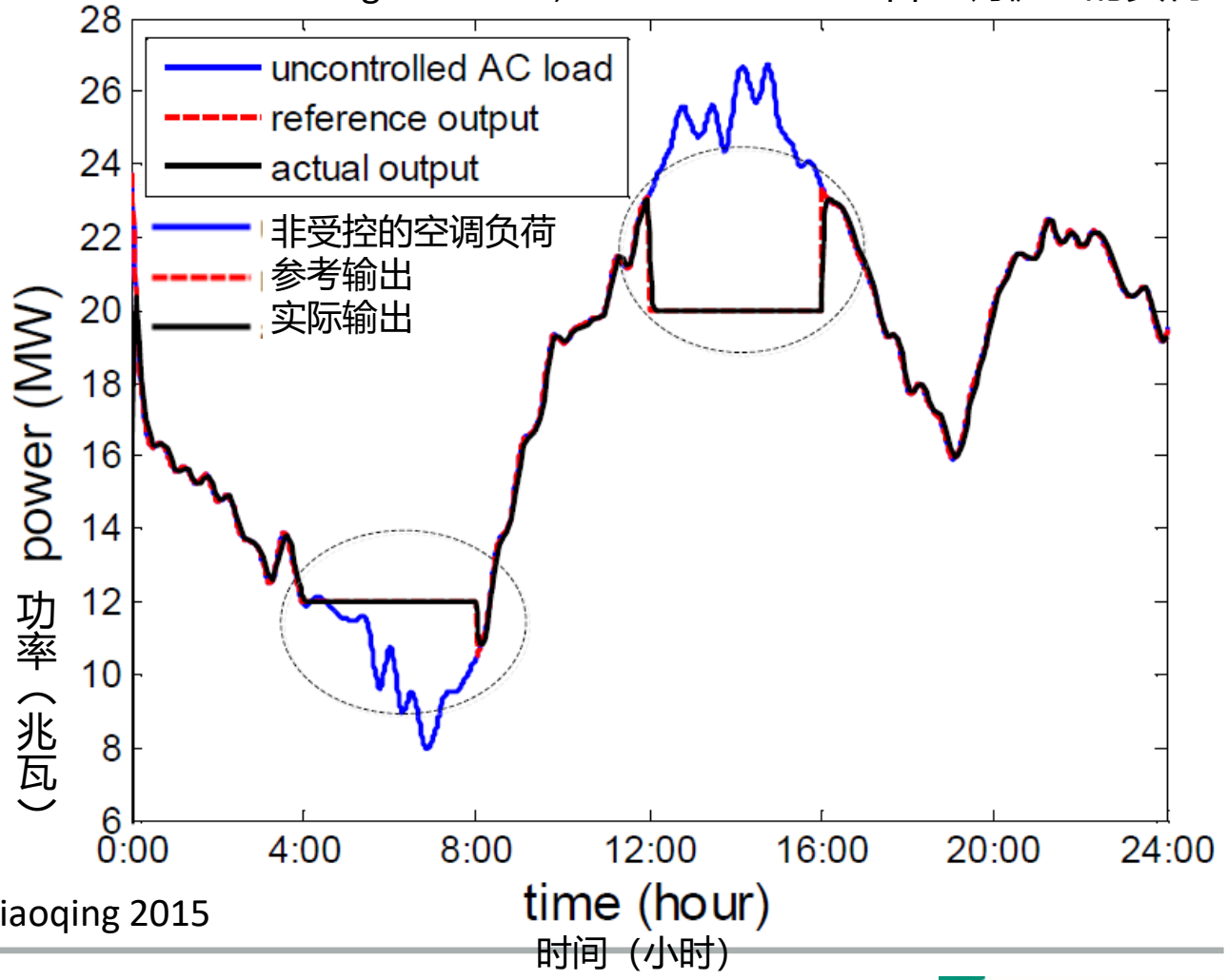
Source: VDP-Online

Demand response applications – Air conditioning
需求响应的应用——空调

- Demand response with AC-units 空调的需求响应
  - Aggregated control of AC-units 空调聚合控制
  - Adaption of temp. set points 适应温度设定点



Air conditioning load of 18,000 AC units 18000台空调机组的负荷

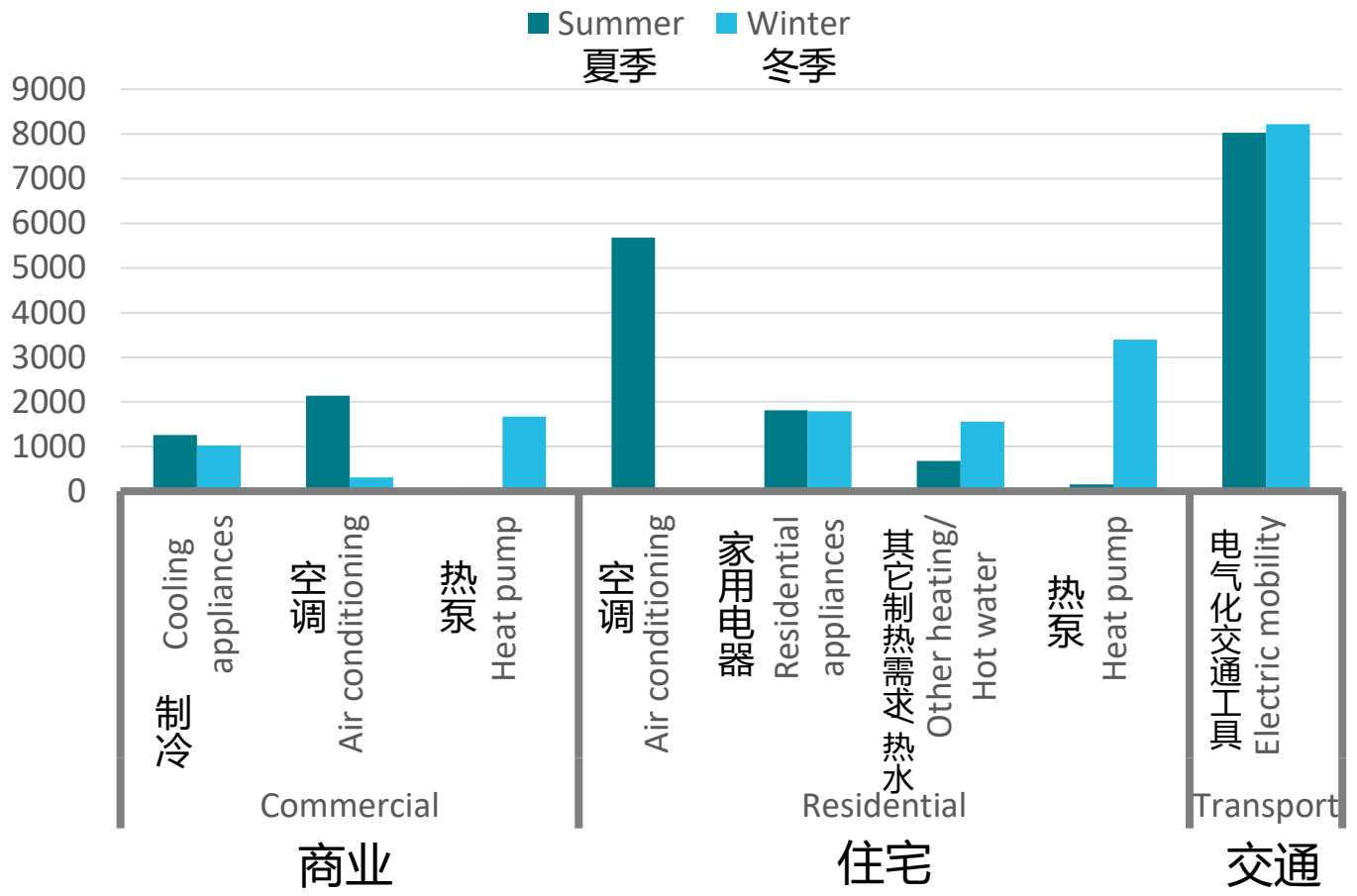


Source: Xiaoqing 2015

Demand response applications – Commercial/Residential
需求响应的应用——商业/住宅

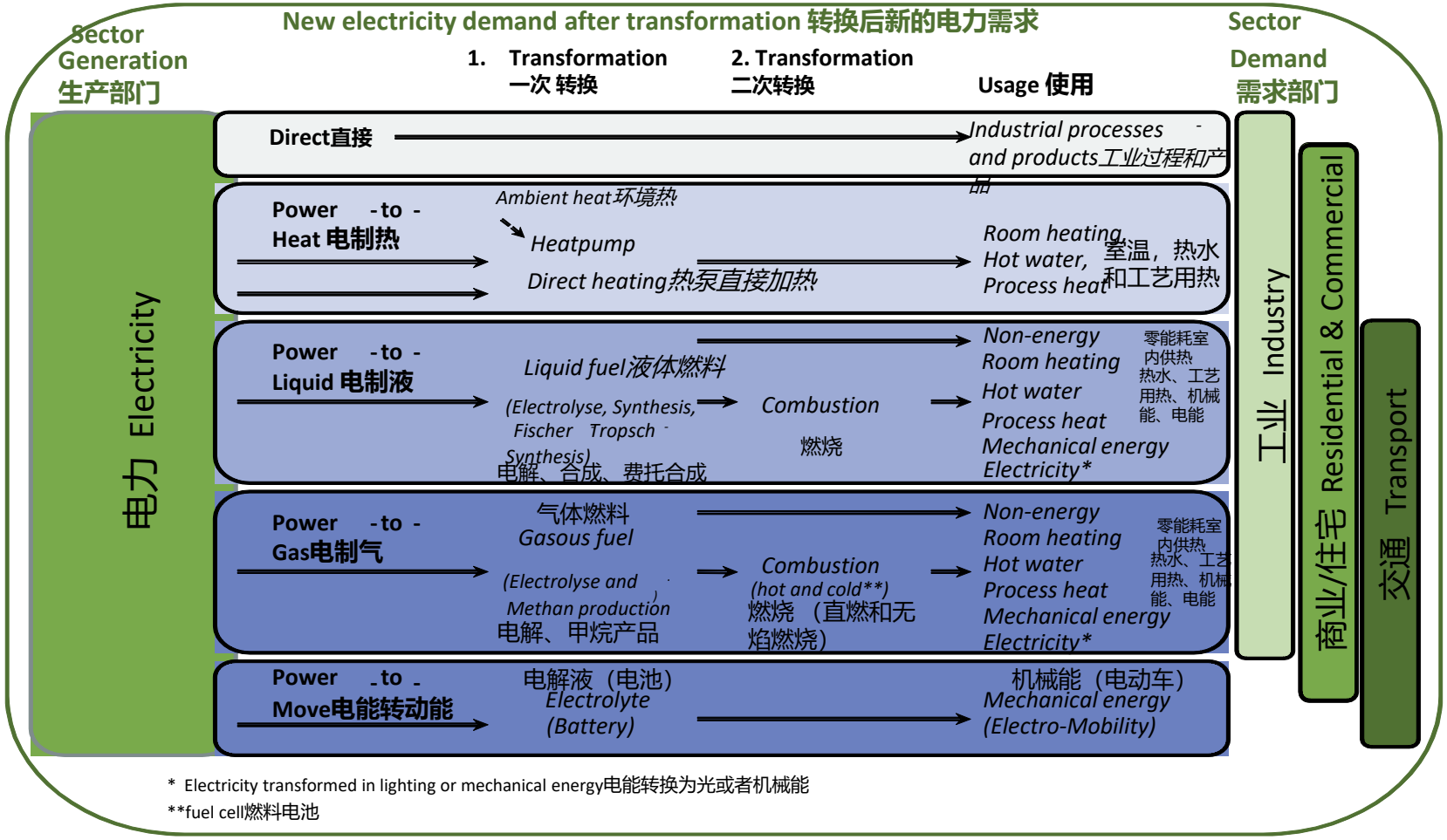
- Heating and cooling main applications for demand response
  以供热和制冷为主要应用的需求响应
- New demand from electro-mobility and heat pumps can be highly flexible
  来自电动车和热泵的新的用电需求具有高度的灵活性
- Availability depend on time of the day, season and outdoor temperature
  实用性取决于每天的不同时段、季节和室外温度

Maximum load shift commercial/residential sector 2030
到2030年商业/住宅领域可转移的最大负荷



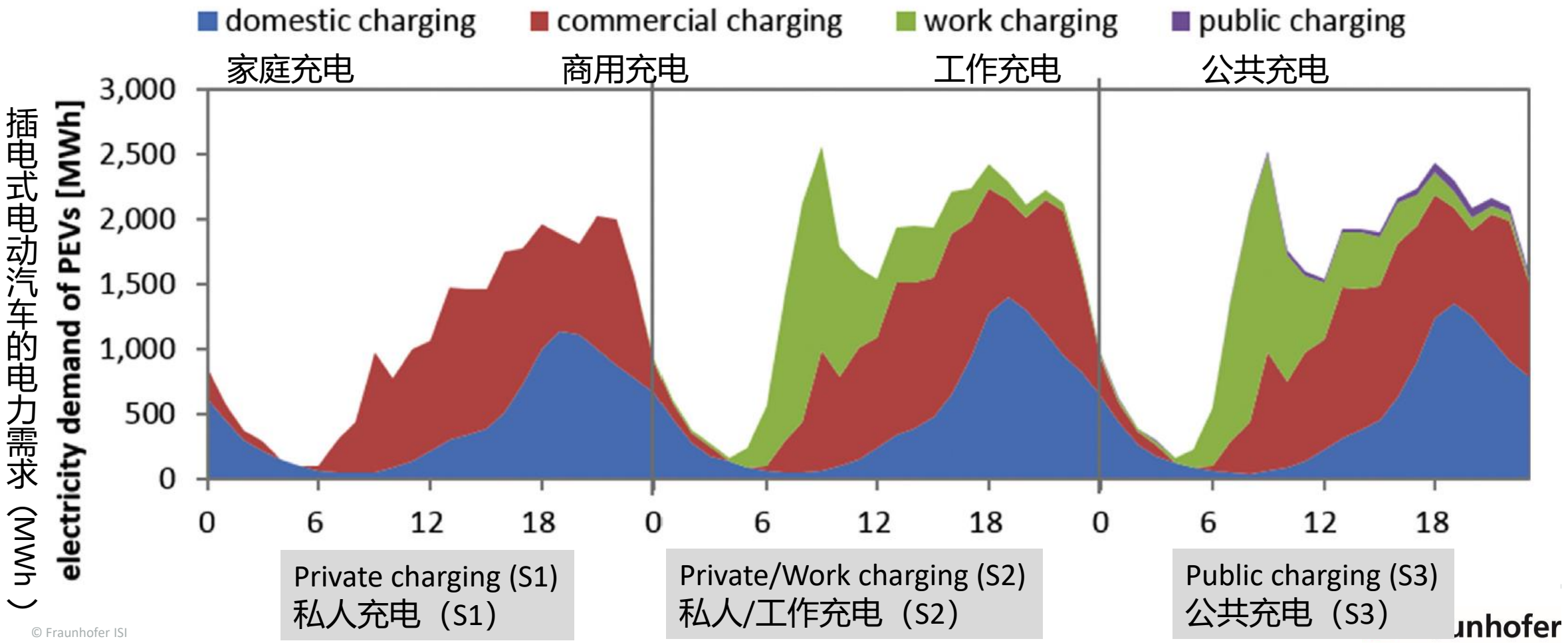
Major option for sector coupling
部门耦合的主要选项

- Electricity generation is coupled by
  发电与以下领域耦合
  - power-to-heat 电制热
  - power-to-liquid 电制液
  - power-to-gas 电制气
  - power-to-move 电转动能
  - direct electricity use 直接使用
- To 应用于:
  - demand sector 需求领域
  - heating sector 供热领域
  - transport sector 交通领域
  - industry sector 工业领域



Flexibility of electric mobility dependend on charging infrastructure
取决于充电基础设施的电动汽车灵活性

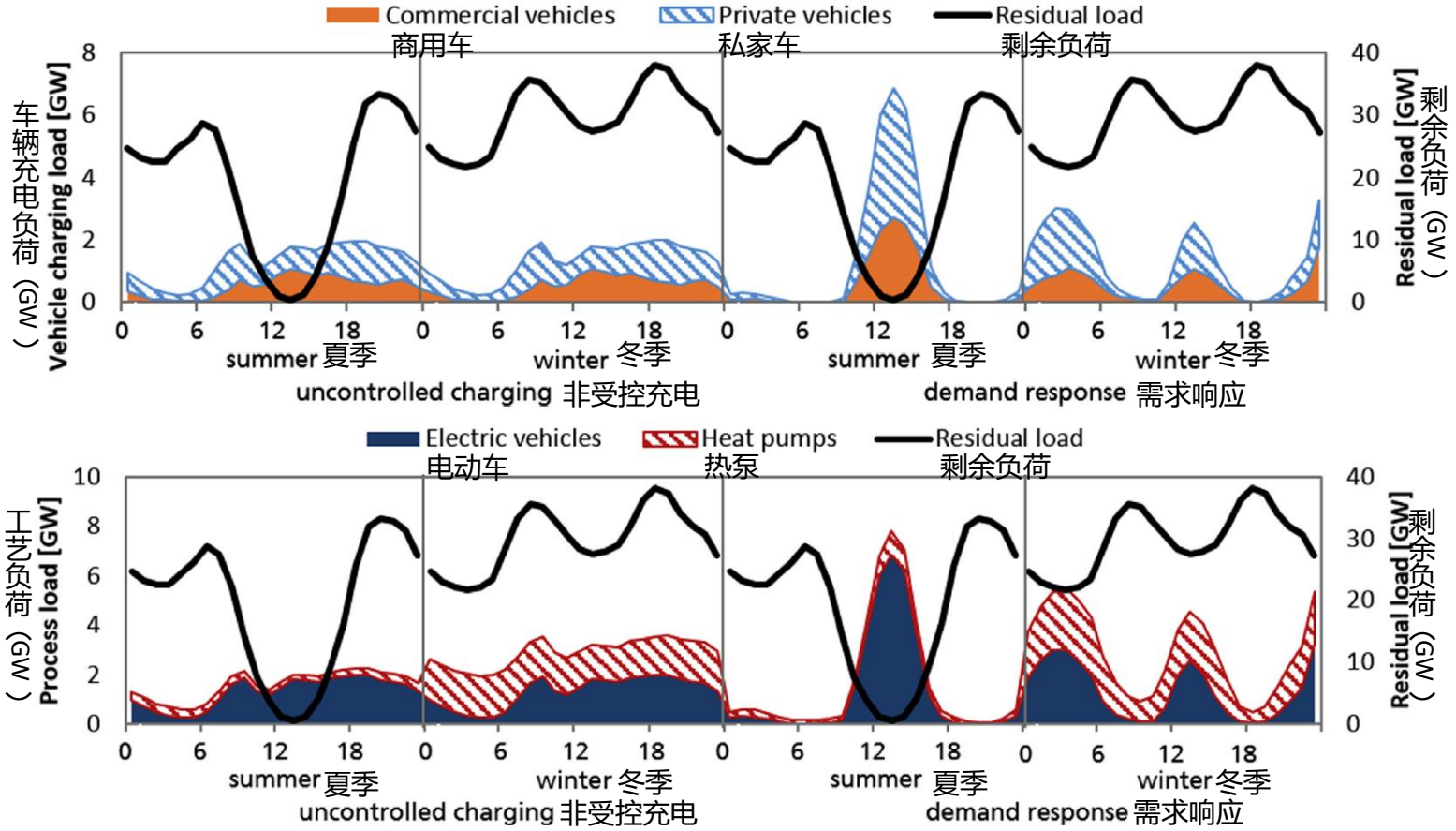
- Electricity demand of PEVs without DR depending on available charging infrastructure
  无需求响应的插电式电动汽车的电力需求取决于可用的充电基础设施



Flexibility of heat pumps and electric mobility
热泵和电动交通的灵活性

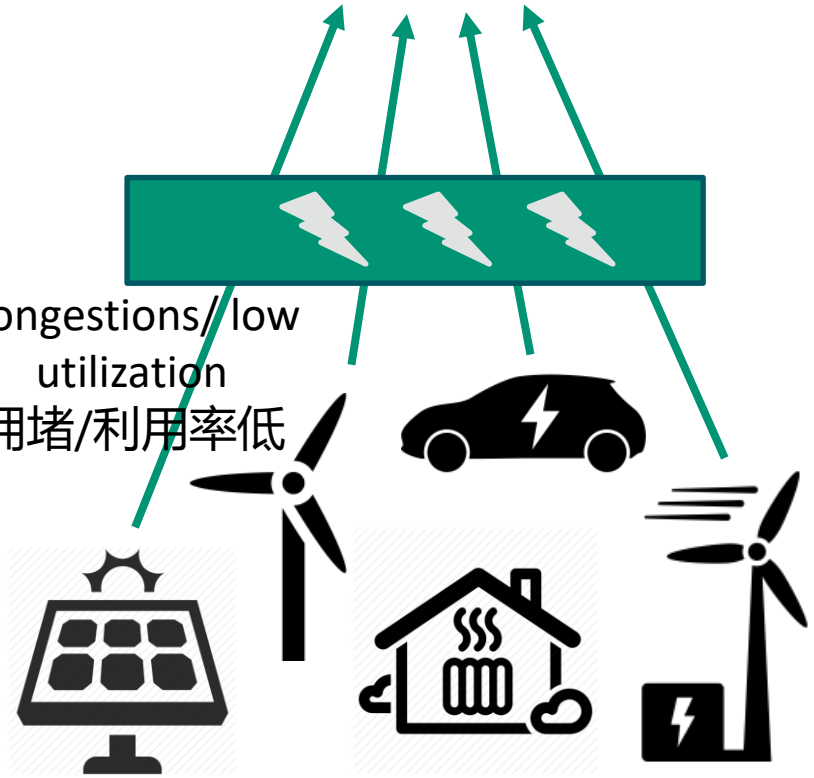
- Electricity demand of heat pumps and electric mobility provides large flexibility
  热泵和电动交通的电力需求提供了很大的灵活性
- Electricity demand grows continously until 2030 到2030年，电力需求将一直增长
  - 18 TWh for heat pumps (8 TWhs residential buildings)
    热泵：18 TWh （住宅建筑：8 TWh）
  - 12 TWh for electric mobility
    电动交通：12 TWh
  - 5 % of total electricity demand
    占总电力需求的5%
- Smart charging can reduce surplus by 25 – 30 % in 2030
  2030年，智能充电可减少25-30%的电力盈余
- Amouts of surplus still limited in 2030 (2 – 3 % of RES)
  2030年，盈余量仍然有限（可再生能源的2-3%）

Average vehicle charging, heat pumps and residual load in 2030
(with public charging, scenario S3)
2030年平均车辆充电、热泵与剩余负荷（公共充电，S3方案）



Solutions: Aggregation and specialized platforms
解决方案：聚合与专业平台

Centralised coordination of power system (Spot-Market, Redispatch etc.)
电力系统的集中协调（现货市场、再调度等）

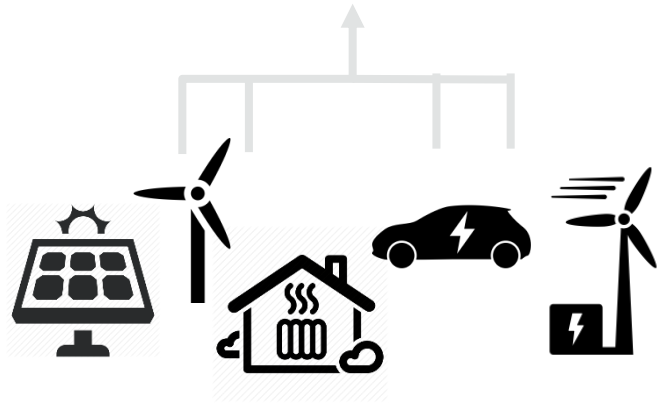


Congestions/ low utilization
拥堵/利用率低

Solution 1 方案1:
Aggregation 聚合

Solution 2 方案2:
Specialized platforms
专业平台

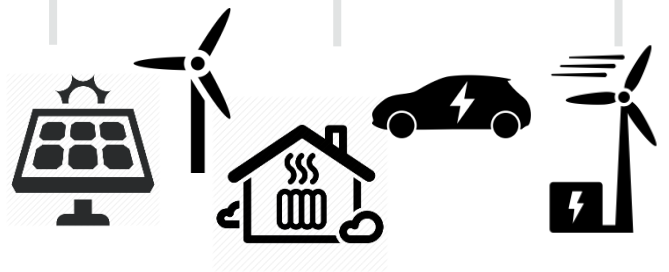
Centralized coordination 集中协调



Specialized platforms 专业平台

Specialized platforms 专业平台

Specialized platforms 专业平台

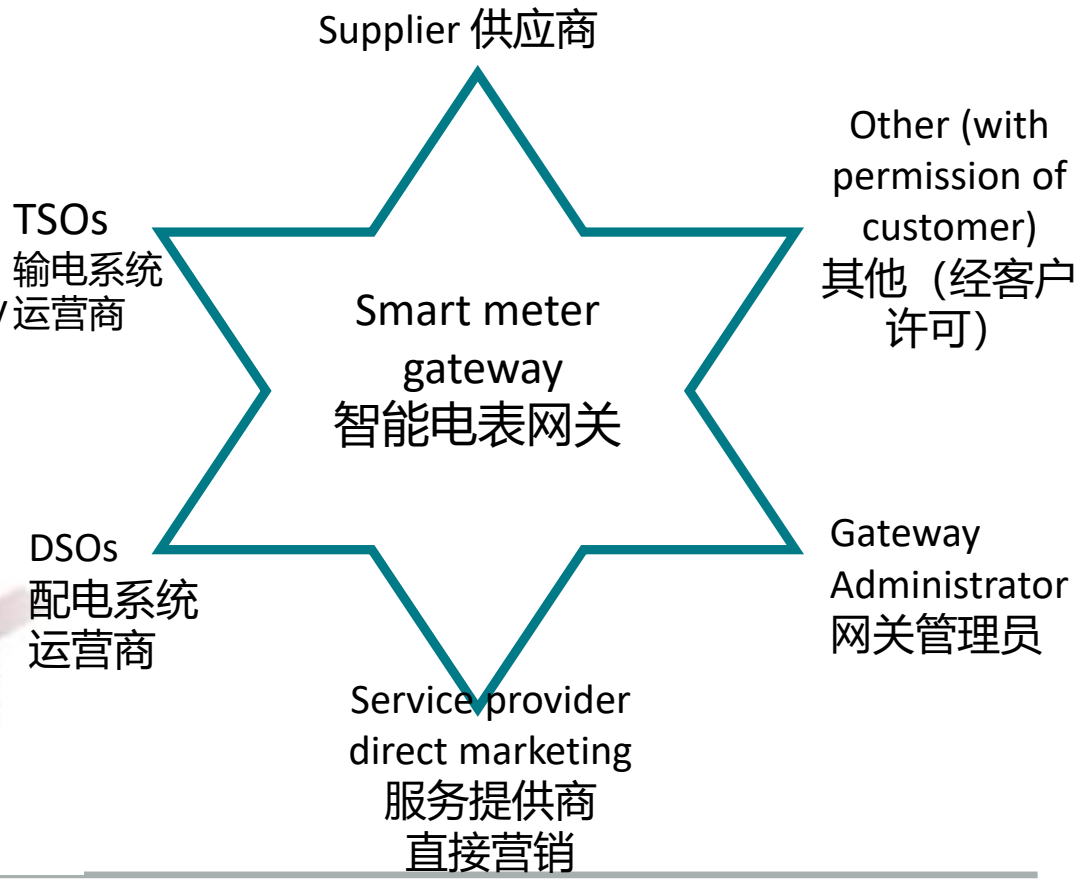


Fraunhofer ISI

Solutions: Smart meter infrastructure
解决方案：智能电表基础设施

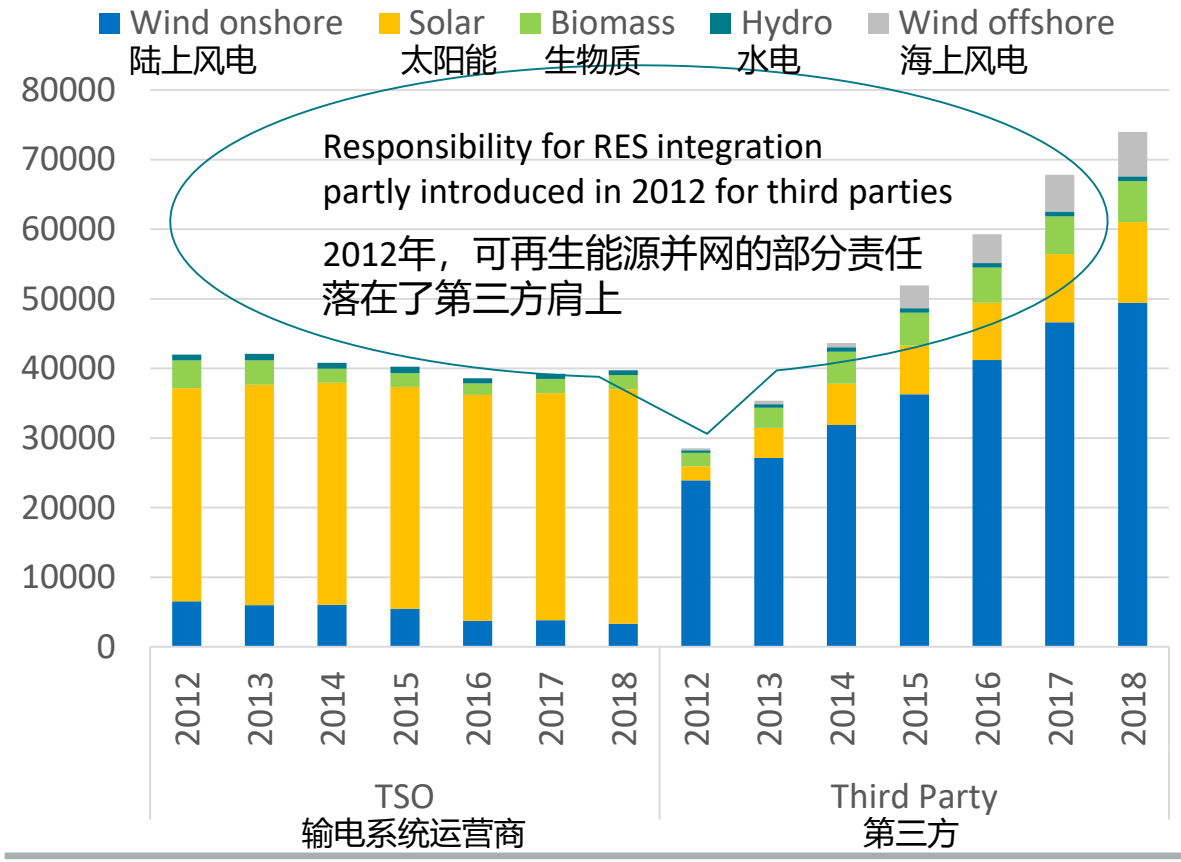
- Smart Meter Gateway: Communication with three networks
  智能电表网关：与三个网络通信
  - Local Metrological Network (LMN) – Connection between smart meter and smart meter gateway (SMGW)
    本地计量网络（LMN）- 连接智能电表与智能电表网关（SMGW）
  - Home Area Network (HAN) – Connection of smart devices with SMGW
    家庭局域网（HAN）- 连接智能设备与网关
  - Wide Area Network (WAN) – Connection with Smart Meter Gateway Administrator or external market actors
    广域网（WAN）- 连接网关管理员或外部市场参与者

Communication channels via smart meter gateway
智能电表网关的通信通道



Increase competition of marketers for RES integration
提高致力于可再生能源并网的营销的竞争力

- Large number of service providers for direct marketing of RES 大量可再生能源直接营销的服务提供商
- New and established companies 新成立和已成立的企业



Marketers 营销者	Total 总量	Wind 风电	PV 光伏	Bio 生物质	Hydro 水电
	in MW 单位：兆瓦				
Statkraft Markets	11,478	10,676	747		55
Quadra Energy	6,500	6,100	380	10	10
Vattenfall	5,610	5,050	550		10
Wind Energy Trading	4,828	3,346	1,474	5	3
Eon	4,200				
Next Kraftwerke	4,080	591	2,034	1,313	22
MVV Energie	4,000	2,500	1,350		
Energy2market	3,537	1,073	691	1,708	65
EnBW	3,450	2,910	380	40	110

Source: E&M 2018

Source: netztransparenz.de

Conclusion
结论

- RES diffusion increase grid congestions and grid costs, surplus of RES generation occure
  可再生能源的扩张增加了电网拥堵和电网成本，出现可再生能源发电盈余
- Demand response in industry provides large potential and can support security of supply
  工业领域的需求响应提供了巨大的潜力，能够支持供应安全
- Flexibility from commercial and residential sector is provided by heating and cooling appliances
  商业和住宅中的灵活性由供热与制冷设备提供
- Sector coupling important option for decarbonisation and provides additional flexibility potential
  部门耦合是实现脱碳的重要选择，且提供了额外的灵活性潜力
- Surplus situations can be handled easier with heat pumps and smart charging
  使用热泵或智能充电可以更容易地处理过剩的情况

Thank you for your attention!
感谢聆听!

Contact 联系方式:

Marian Klobasa

Fraunhofer Institute for Systems and Innovation Research ISI

弗劳恩霍夫系统与创新研究所ISI

Breslauer Straße 48, D-76139 Karlsruhe

Phone 电话: +49 721 6809 - 287;

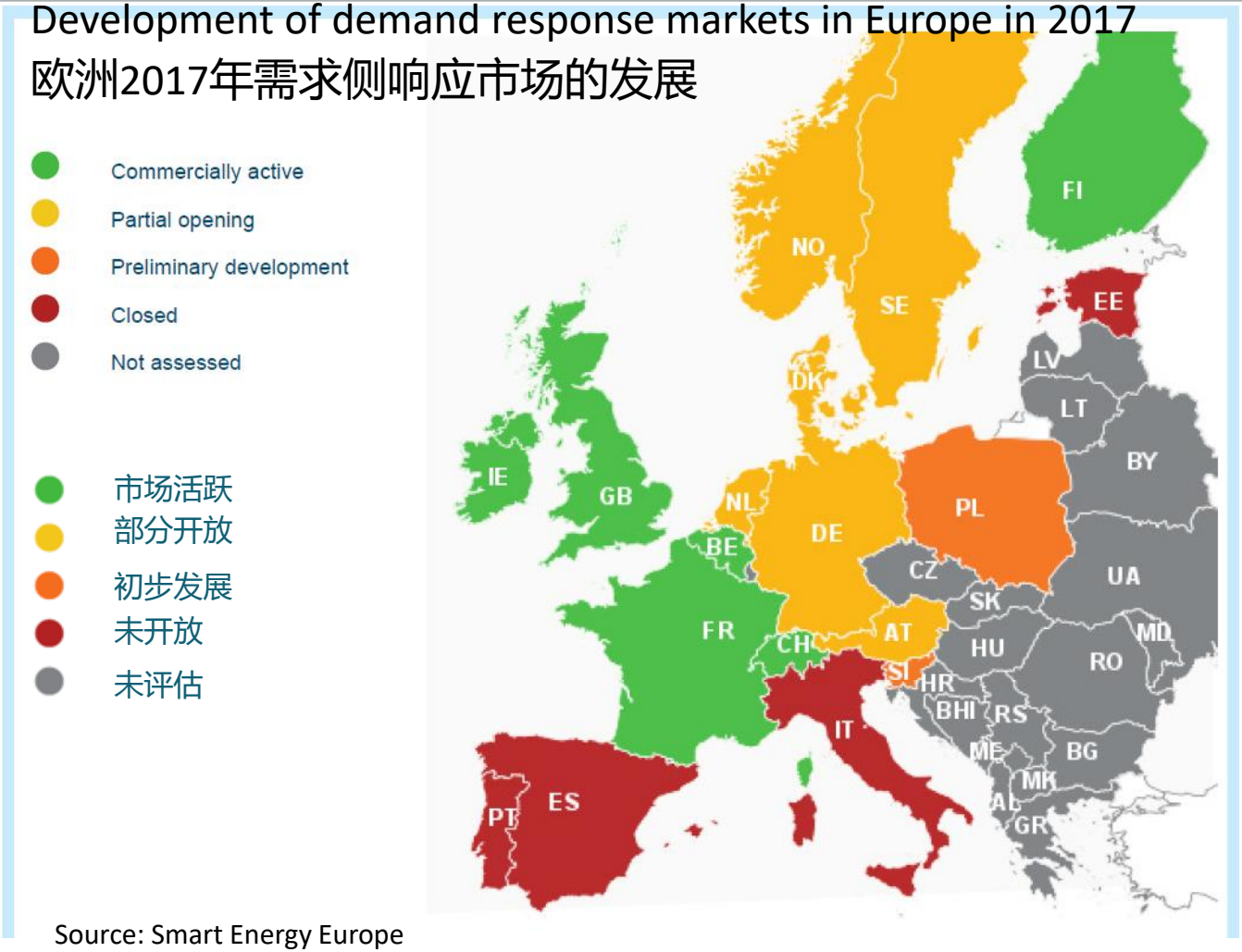
eMail 邮件: marian.klobasa@isi.fraunhofer.de

Explizit demand response in Europe
欧洲明确的需求侧响应

Dynamic development　　动态发展

- Framework conditions adapted in many countries
  框架条件适用于许多国家
- Activities of aggregators have increased
  聚合行为增加
- Discussion at EU level within CEER, Eurelectric, Entso-E, EDSO, Smart Grid Task Force
  在欧洲层面与CEER, Eurelectric, Entso-E, EDSO, Smart Grid Task Force进行磋商
- Demand response strengthen by EU commission (new directive and regulation on electricity market design)
  欧盟委员加强需求响应（针对电力市场设计出台新的指令和规范）

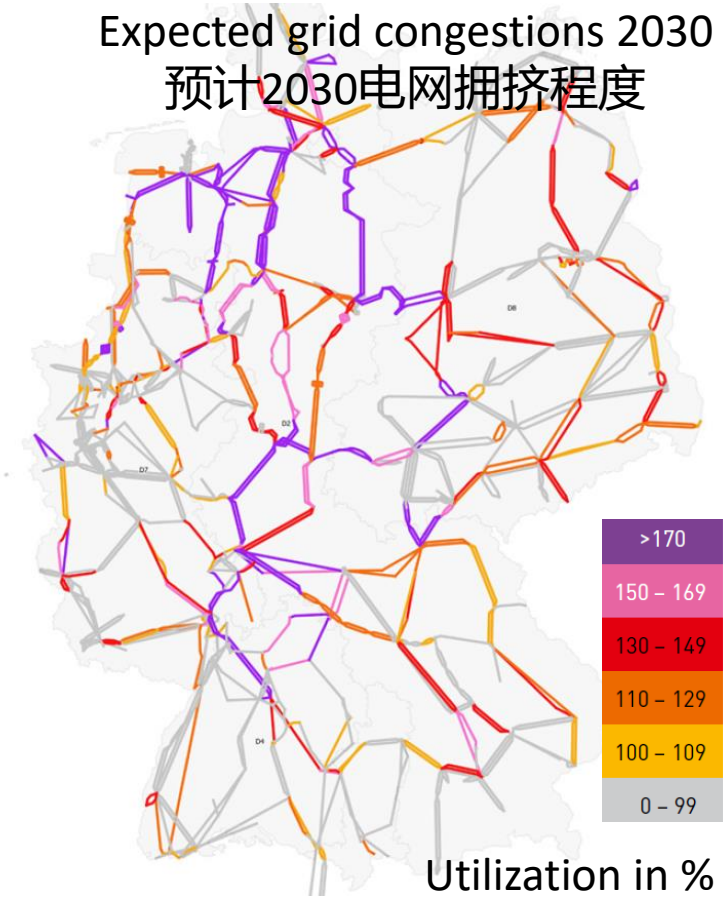
Development of demand response markets in Europe in 2017
欧洲2017年需求侧响应市场的发展



Source: Smart Energy Europe

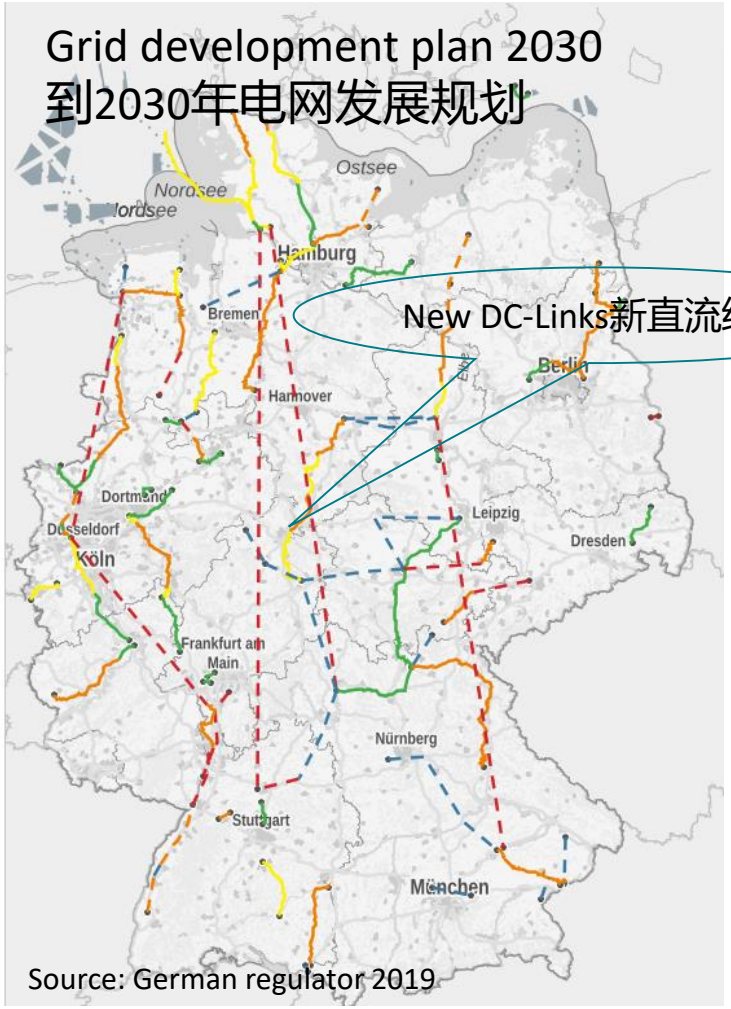
Speed-up grid development and plan transmission grid in medium and long term 加快电网发展，规划中长期输电网

Expected grid congestions 2030
预计2030电网拥挤程度



Utilization in %
(n-1)
利用率%

Grid development plan 2030
到2030年电网发展规划



New DC-Links新直流线路

Source: German regulator 2019

consenting process (step1)
正在申请的方案（第一阶段）
consenting process (step2)
正在申请的方案（第二阶段）
consenting process (step3)
正在申请的方案（第三阶段）
Consented 已获批
Realised 已实现
connection point 连接点
Offshore cluster 离岸风电群
Offshore connection 离岸风电连接

Indirect Demand Response (price based)
间接需求响应（基于价格）

- Indirect remuneration for participation via prices
  通过价格形式参与的间接计酬
- marketing opportunities　市场机遇
  - Variable electricity prices　可变电价
  - Variable network charges　可变电网费用
  - Individual grid tariffs for special customers
    针对特殊客户的单独电网电价
    - Intensive grid usage (§19 (2) Satz 2 StromNEV) 密集型的电网使用
    - Atypical grid usage (§19 (1) Satz 1 StromNEV) 非典型的电网使用
- No aggregators necessary, prices are transmitted by electricity suppliers
  价格由电力供应商传递，无需系统集成商

Indirect demand response – e.g. at gross electricity markets 间接需求响应—例如在总电力市场中	
Market participation as part of electricity tariff 市场参与作为电价的一部分	
Contracts with variable tariffs 浮动电价的合约	e.g. Next Kraftwerke „best of 96“ or „take your time“ 例如：Next Kraftwerke的„best of 96“ 或者 „take your time“计划
Direct market participation 直接市场参与	
Virtual power plants 虚拟电厂	Large industrial customers with demand and generation (e.g. VW, Daimler) 拥有需求和自发电的大型工业客户（如大众、戴姆勒）
Market conditions 市场条件	
Tendering 投标	Day-Ahead Market: Daily auction, hourly bids 日前市场：每日拍卖，每小时出价 Intraday-Market: Daily auction, 15-min bids and continuous trading 场内交易：每日拍卖，15分钟竞价，连续交易

Sector coupling – advantages and drawbacks
部门耦合——优势和劣势

	Direct electricity use 电能直接利用	Hydrogen (electrolysis) 氢 （电解）	Hydro Carbons (PtL, PtG) 碳氢化合物（电制气，电制液）
Advantages 优势	Most efficient pathway in technical terms 技术层面最有效的路径	Technically more efficient pathway than hydrocarbons 技术层面比碳氢化合物更有效的路径	Infrastructure available in parts 部分基础设施可以利用
	In many cases the most favorable solution economically 多数情况下，是经济层面的最优方案	Easy to store, flexibility option for better integration of renewables 易于储存，对于可再生能源并网更好的灵活性选项	Usable in large number of applications with well-known technologies, existing storage systems can be used 与常规技术用途巨大，可使用现存储存技术
Drawbacks 劣势	Expansion of grid and possibly storage infrastructure needed 需要扩建电网和一些用于储能的基础设施	Construction of new and costly infrastructure needed 需要建设新的和昂贵的基础设施	CO2 input necessary, limited potentials for carbon-neutral CO2 需要CO_2的输入，碳中和的潜力有限
	High RE shares require deployment of measures providing flexibility 可再生能源高份额需要提供灵活性的调度措施	Path dependency Higher losses than using electricity directly 路径的依赖性 比起电能直接利用能量损失更高	Less economical than other options, energetically the least efficient of the three options 相较其他选项经济性最差，能源利用效率也最差
	Not feasible in certain applications (e. g. too low storage density, technically) 不适用于某些特定的应用（如：技术层面过低的存储密度）	Acceptance, because increased deployment of renewables is necessary 可接受的，因为增加可再生能源调度是有必要的	Acceptance, because the highest deployment of renewables is necessary 可接受，因为可再生能源最高阶的部署也是有必要的

Development of heat pumps, electric mobility and power-to-x
热泵、电动交通与电力转换利用的发展

- Until 2030 sector coupling grows
  到2030年，部门耦合将持续发展
  - E-Mobility up to 6 Mio. cars resp. 15 % of car stock
    电动汽车达到600万辆，占汽车存量的15%
  - Residential heat pumps up to 3 Mio. units resp. 10 % of dwellings
    住宅热泵达到3百万组，住宅占比达10%
  - PtX: Power to Gas and heat pumps in heating networks
    电力的转换利用：电制气和热泵应用于热网