International Energy Agency

Grid Integration of Wind and PV

Recent IEA analysis and implications for Japan

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The Power of Transformation

Main results

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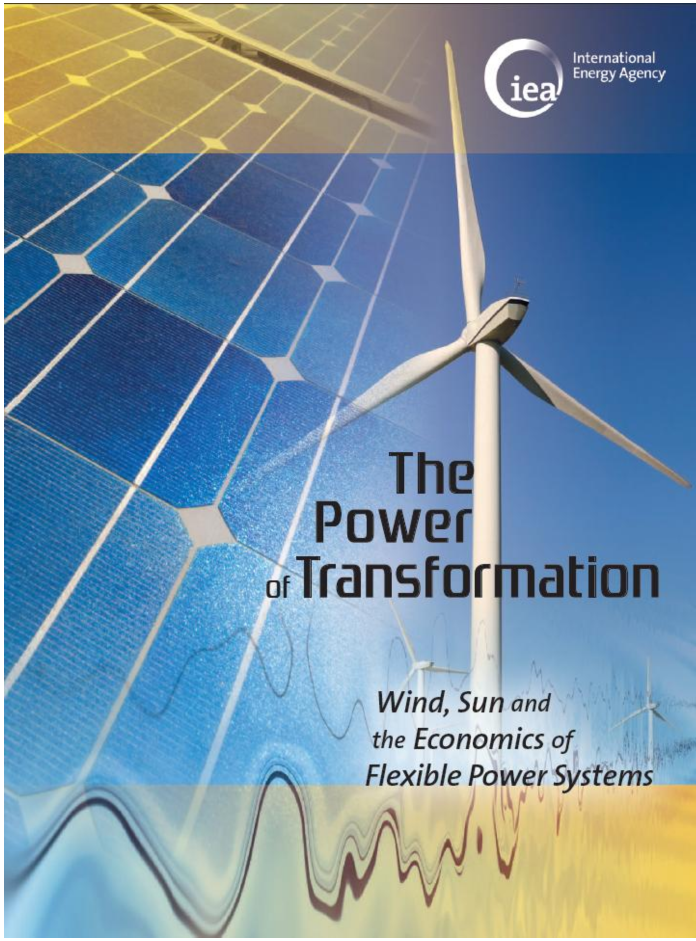
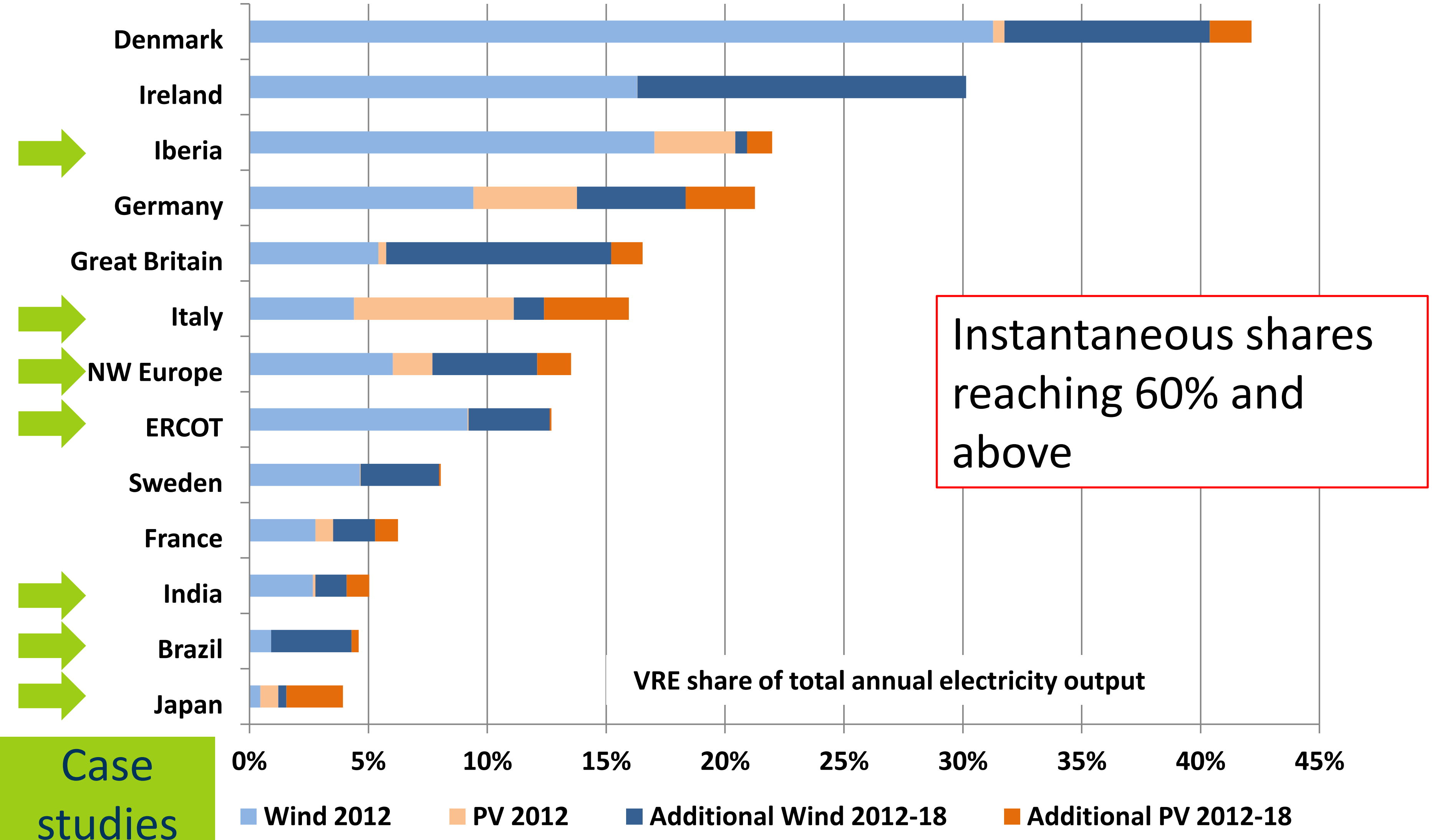
The Grid Integration of Variable Renewables Project - GIVAR

- Third project phase at a glance
  - 7 case studies covering 15 countries, >50 in-depth interviews
  - Technical flexibility assessment with revised IEA FAST tool
  - Detailed economic modelling at hourly resolution



Large-scale integration accomplished today, but more to come



Note: ERCOT = Electricity Reliability Council of Texas, United States

Source: IEA estimates derived in part from IEA Medium-Term Renewable Energy Market Report 2013.

What shapes the challenge?

Properties of variable renewable energy (VRE) ⟷ Properties of other power system components

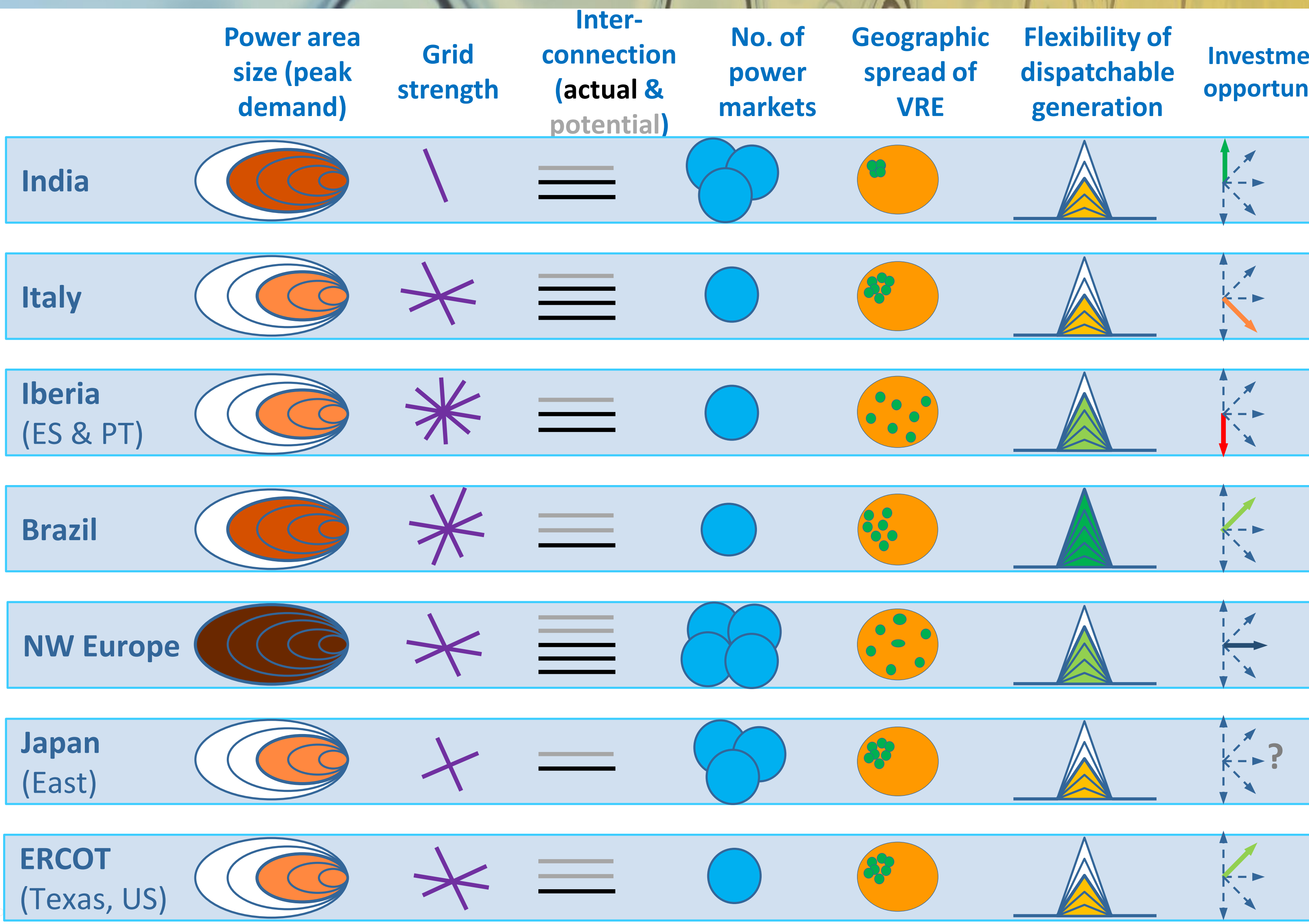
- *Interaction* of VRE and the system shape challenge

→ Integration challenge is system specific

- But: limited number of factors on each side

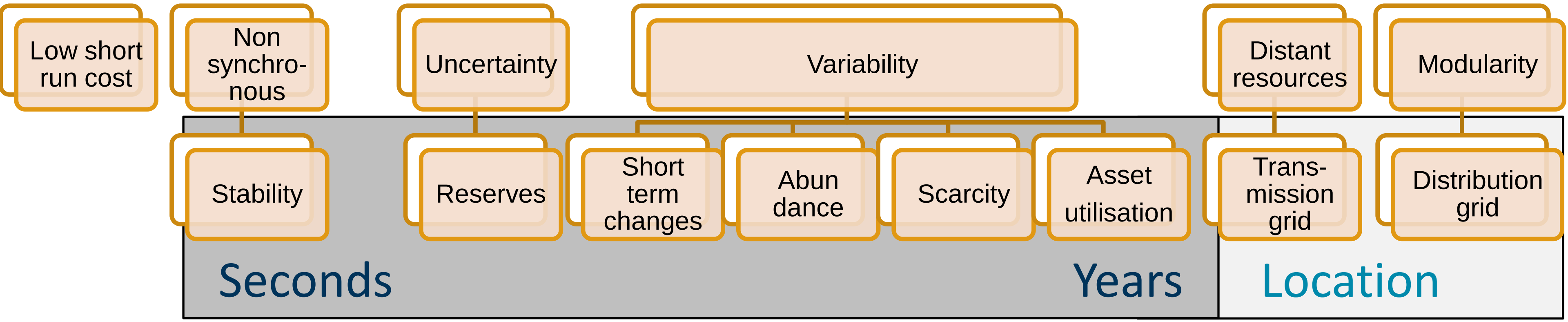
→ Learning from other system contexts is possible!

The GIVAR III case study regions



Properties of variable renewables and impact groups

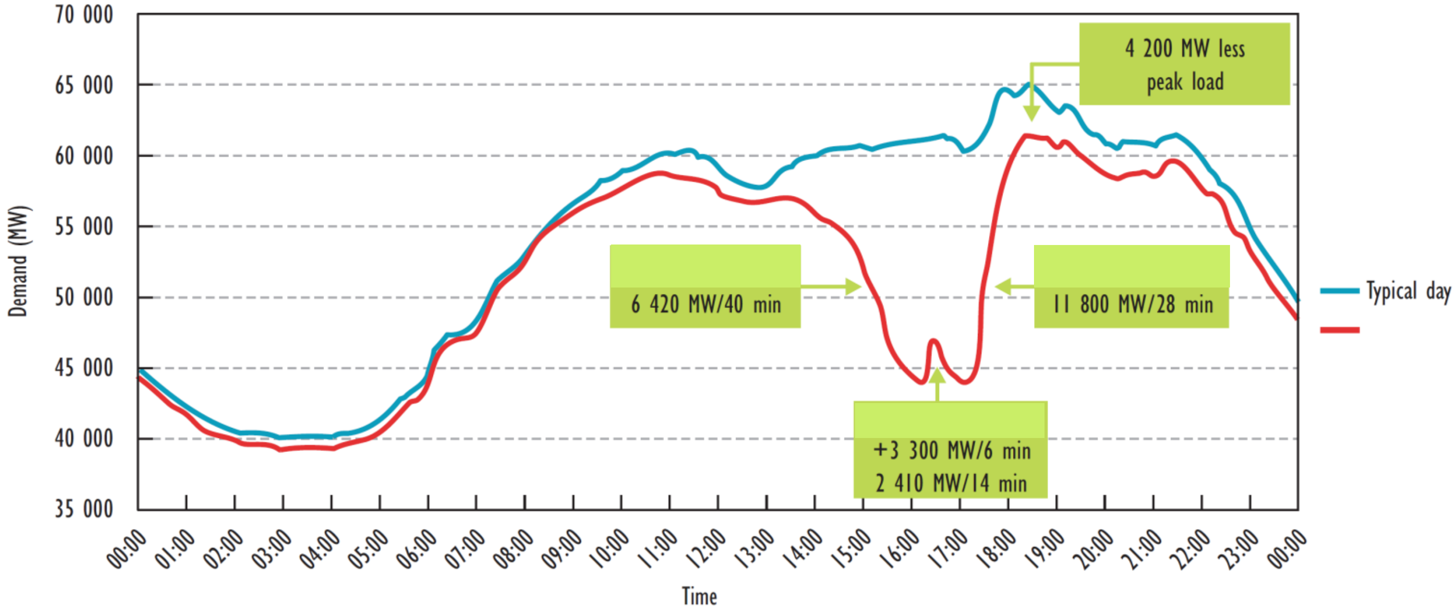
- Systems are different – impacts will vary too
- But common groups of effects



No problem at 5% - 10%, if …

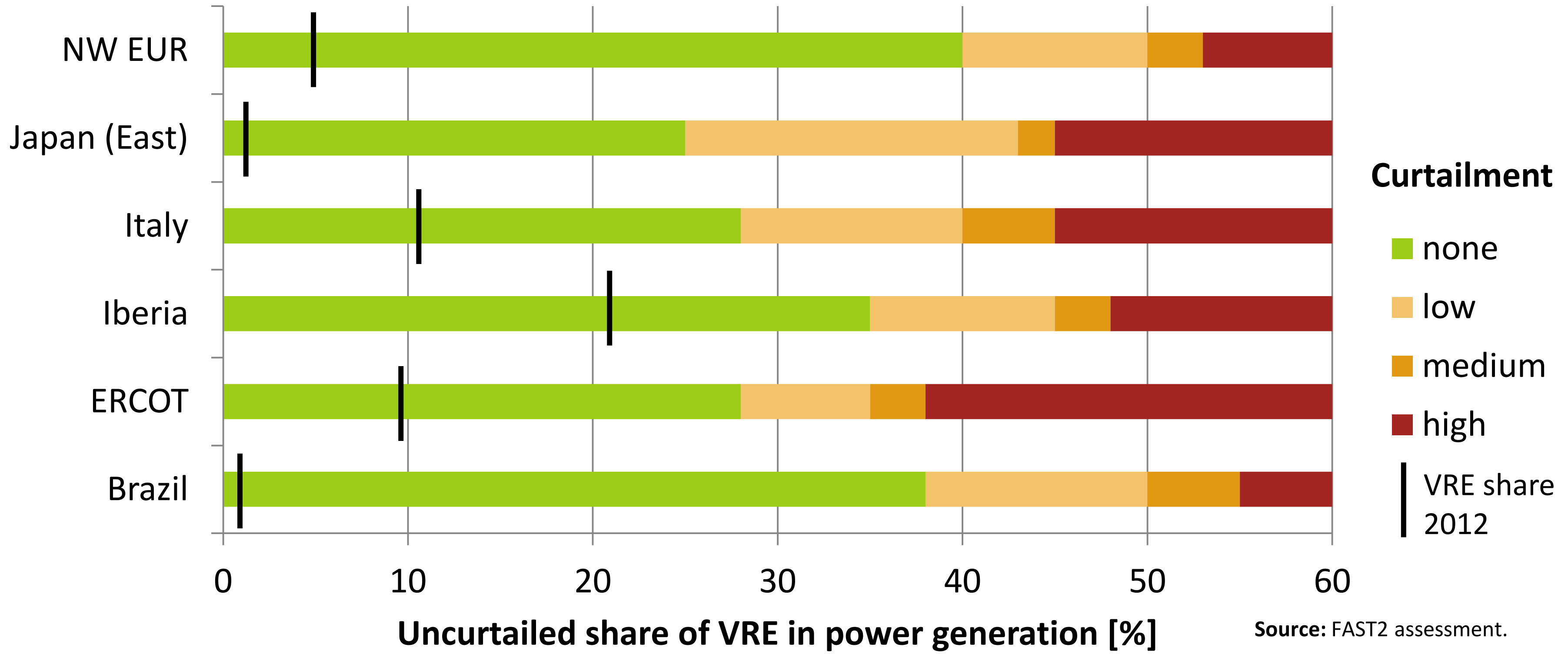
- **Power systems already deal with a vast demand variability**
  - **Can use existing flexibility for VRE integration**

Exceptionally high variability in Brazil, 28 June 2010



- **No technical or economic challenges at low shares, if basic rules are followed:**
  - **Avoid uncontrolled, local 'hot spots' of deployment**
  - **Adapt basic system operation strategies, such as forecasts**
  - **Ensure that VRE power plants are state-of-the art and can stabilise the grid**

Much higher shares technically feasible



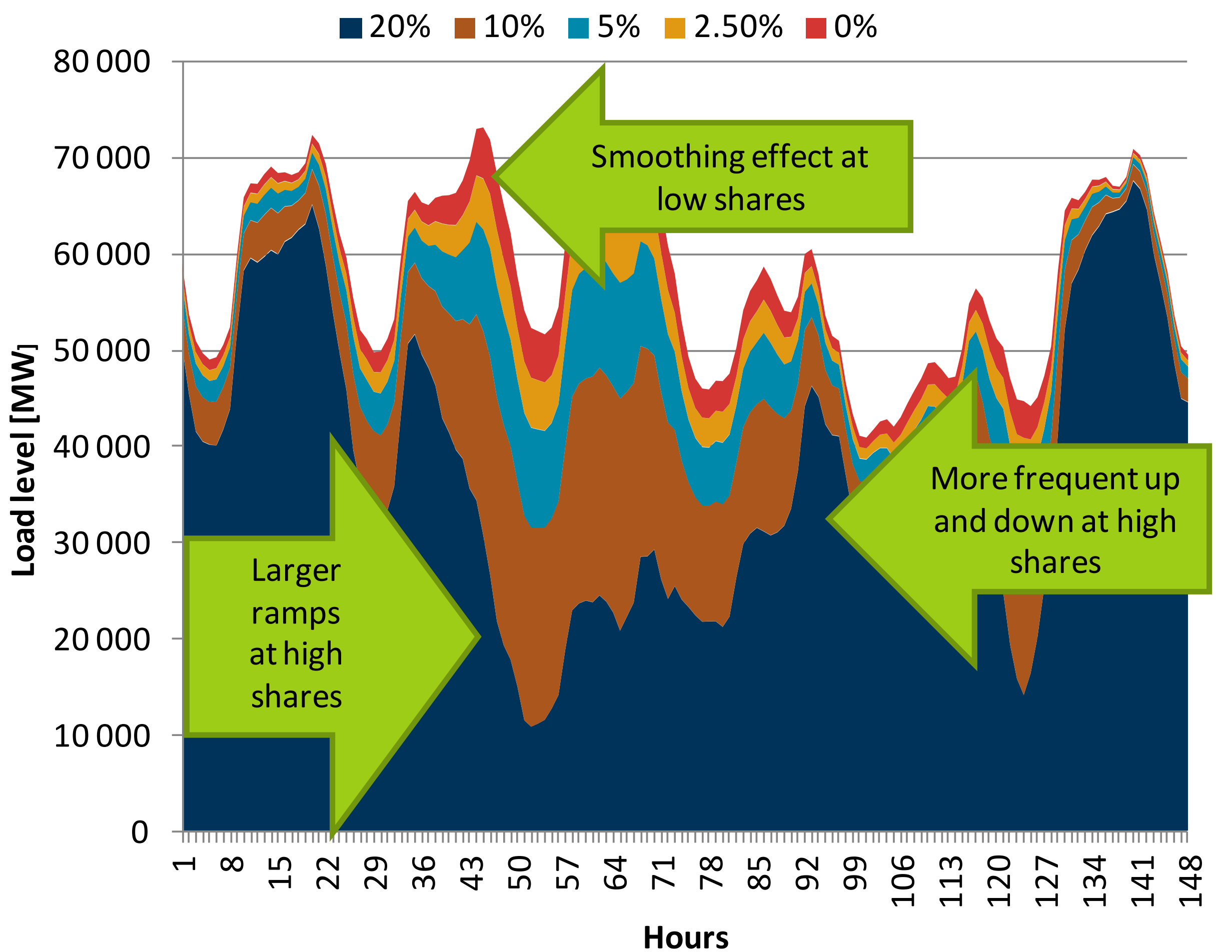
Source: FAST2 assessment.

- **FAST2 assessment: All power systems can take 25% in annual generation already today.**
- **There is no technical limit on how much variable generation a power system can absorb**
  - **But system transformation increased flexibility required for higher shares**

Main persistent challenge: Balancing

- Higher uncertainty
- Larger and more pronounced changes

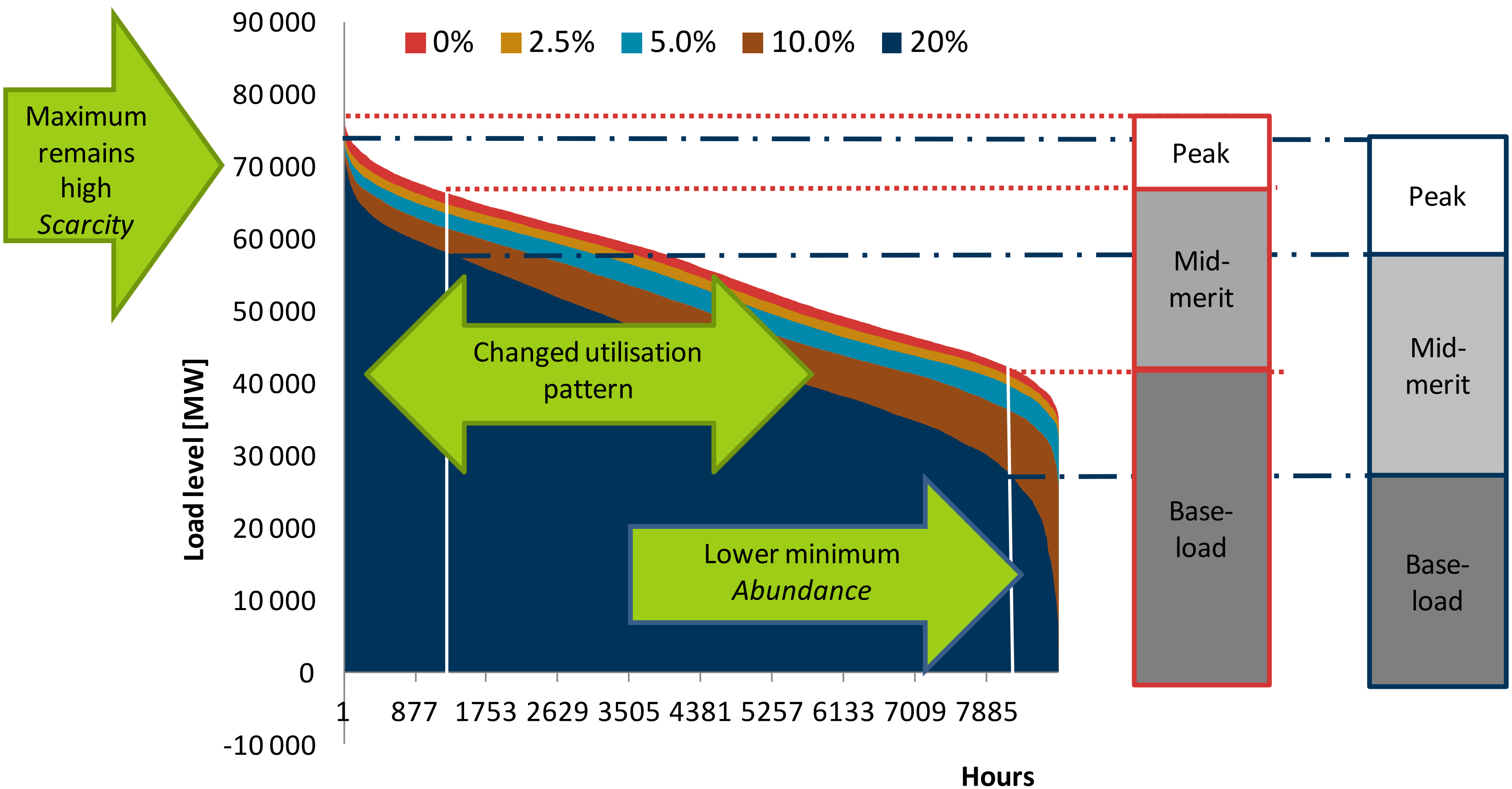
Net-load at different annual VRE shares



Note: Load data and wind data from Germany 10 to 16 November 2010, wind generation scaled, actual share 7.3%. Scaling may overestimate the impact of variability; combined effect of wind and solar may be lower, illustration only.

Main persistent challenge: Utilisation

- Netload implies different utilisation for non-VRE system



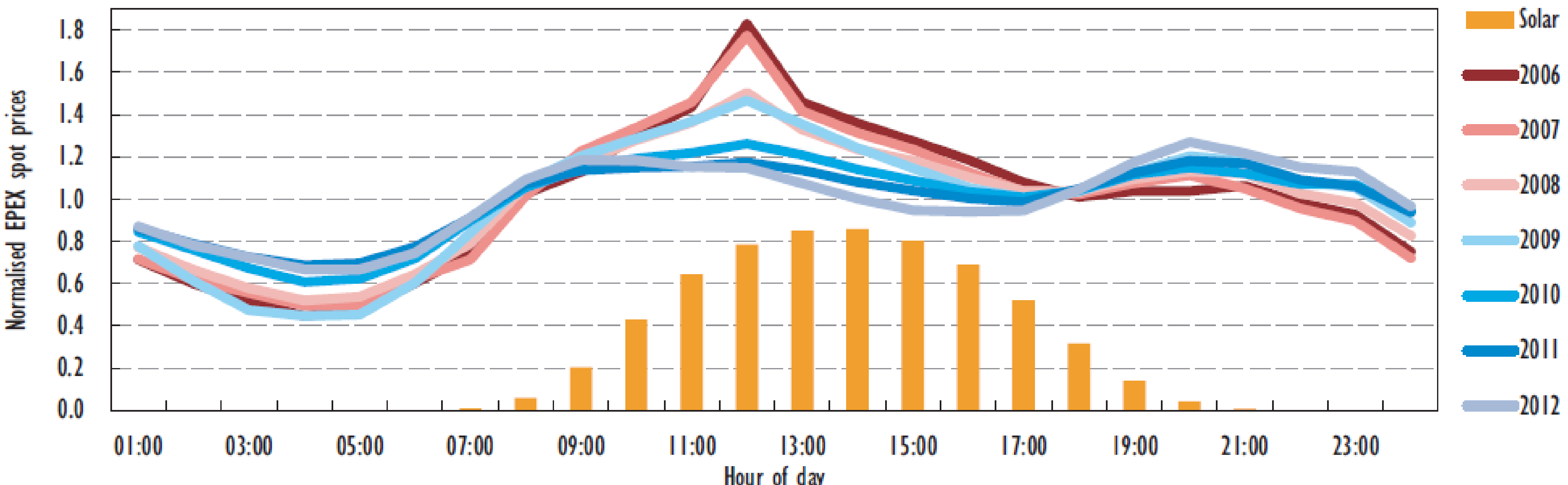
Note: Load data and wind data from Germany 10 to 16 November 2010, wind generation scaled, actual share 7.3%. Scaling may overestimate the impact of variability; combined effect of wind and solar may be lower, illustration only.

Main short-term challenges

- When VRE are added to a system with adequate capacity:
  - Situations of low load and high VRE generation
    - VRE curtailment if flexibility insufficient
    - Negative market prices due to inflexible generation and VRE support mechanisms
  - Grid bottlenecks in regions with high VRE density
    - Limitations feeding production from the distribution to the transmission grid
    - Insufficient evacuation capacity in regions with rapid build out of new VRE capacity

Main market impacts in stable systems

Shift in German spot market price structure



- Reduced market *prices* (merit order effect)
- Reduced operating *hours* (utilisation effect)
- Displacement effect mainly due to
  - low short-run cost of VRE and
  - reinforced by support policies
  - influenced by variability, in particular PV
- Economic impact on gas generation result of several factors

Integration vs. transformation

- **Classical view: VRE are integrated into the rest**
  - Integration costs: balancing, adequacy, grid

- **More accurate view: entire system is re-optimised**
  - Total system costs

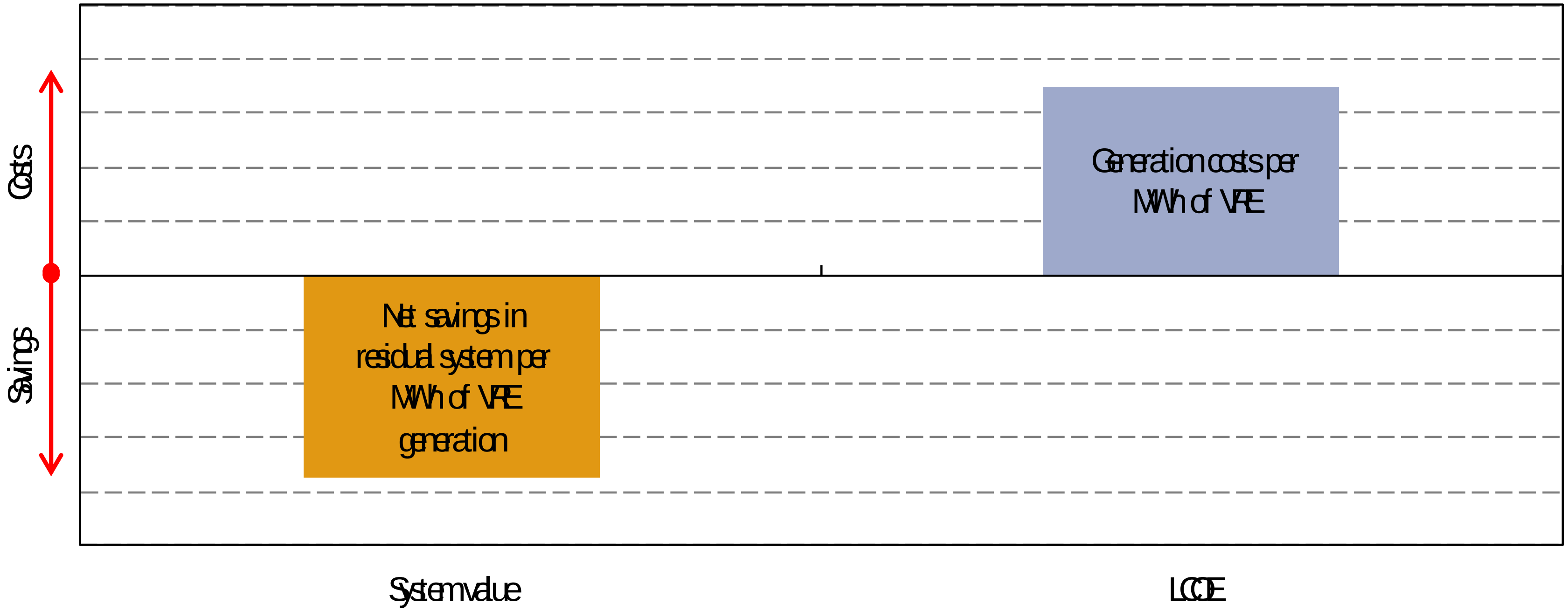
FLEXIBLE
Power system
- Generation
- Grids
- Storage
- Demand Side Integration

→ **Integration is actually about transformation**

Problems with calculating integration costs

- Decomposition always challenging:
  - Balancing, adequacy, grids
  - Uncertainty, profile, location
  - → Unclear that all effects are covered with these practices; categories not independent
- Integration cost intented to measure additional costs due to variability. BUT: additional to what?
  - Reference technology benchmark must be defined
  - Choice of benchmark drives part of result

Alternative: System value



- Benchmark VRE against net savings in residual power system – more useful than trying to calculate integration costs
- System value depends on transformation of the system

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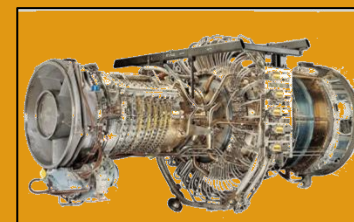
Three pillars of system transformation

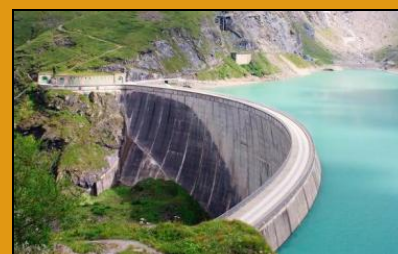
Technology spread

Geographic spread

Design of power plants

System friendly VRE





Investments

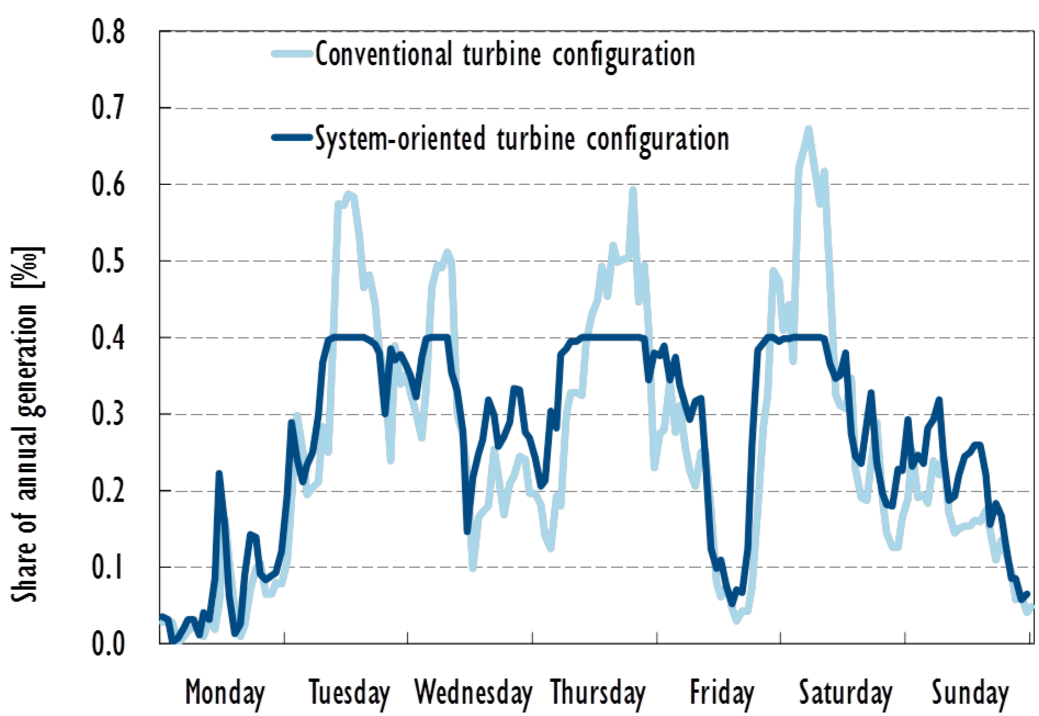
Operations

1) System friendly VRE deployment

- Wind and solar PV can contribute to grid integration
- But only if they are allowed and asked to do so!

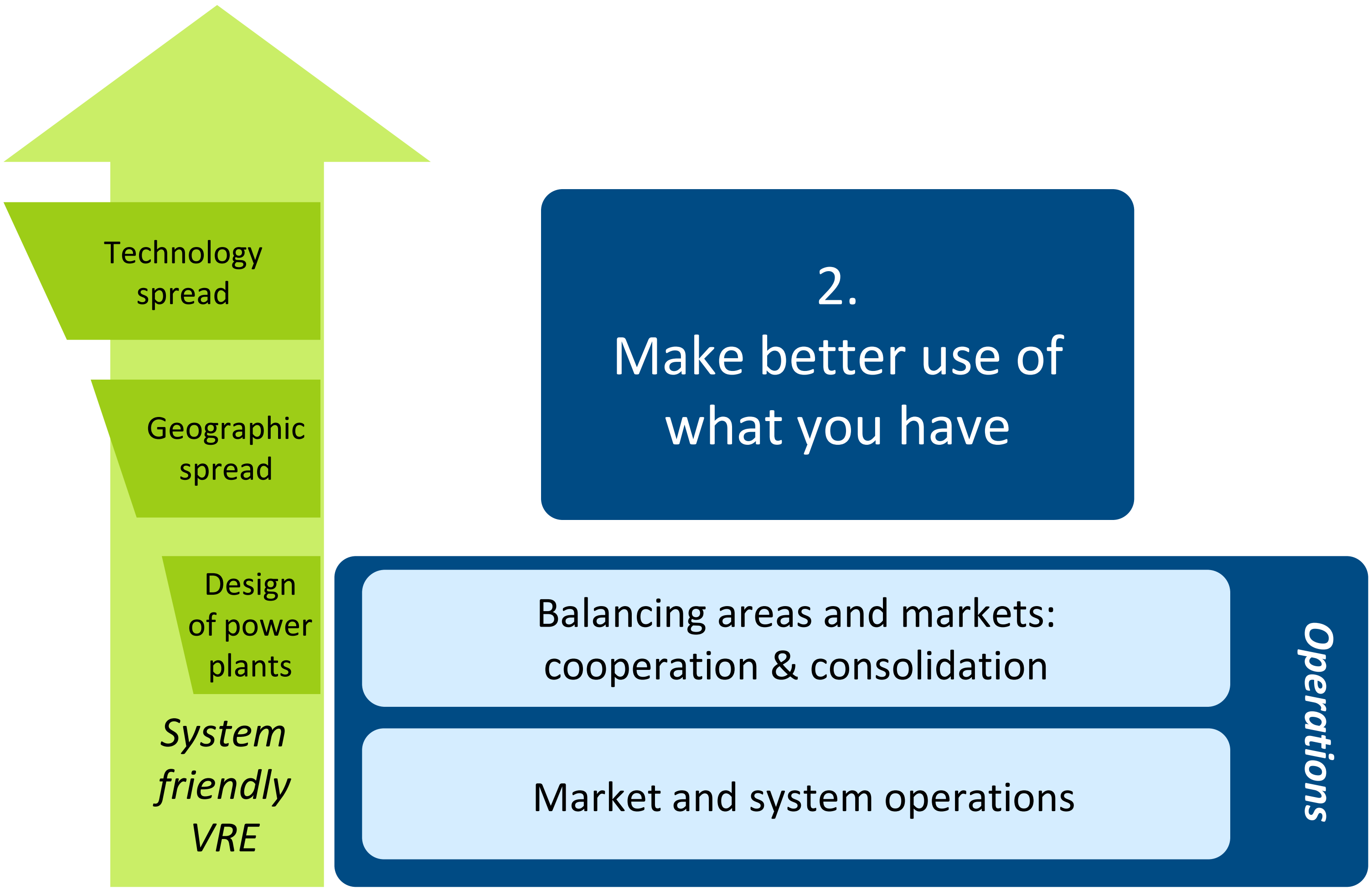
→ Take a system perspective when deploying VRE

Example: System friendly design of wind turbines reduces variability



Source: adapted from Agora, 2013

Three pillars of system transformation



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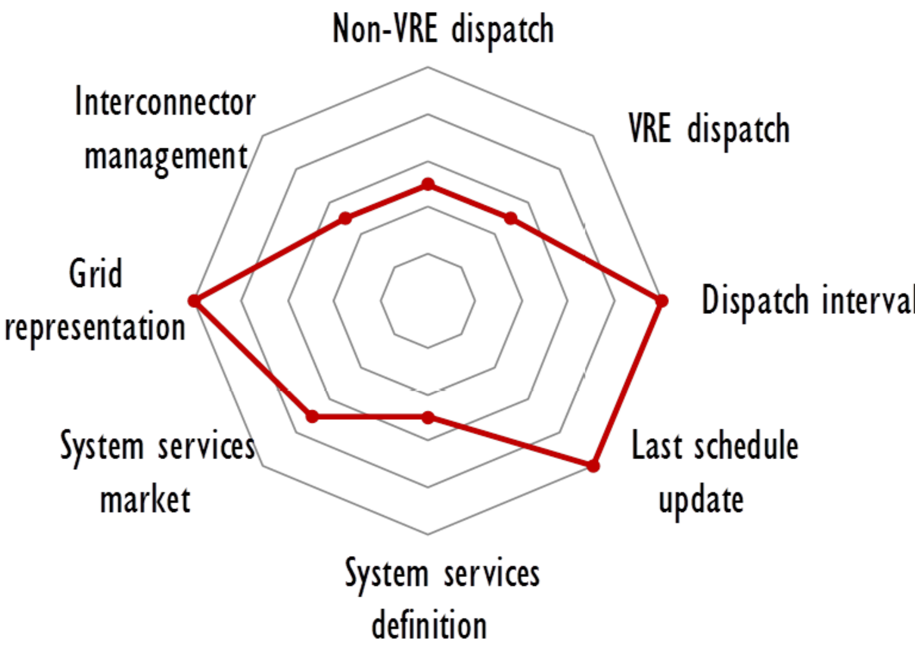
2) Better system & market operation

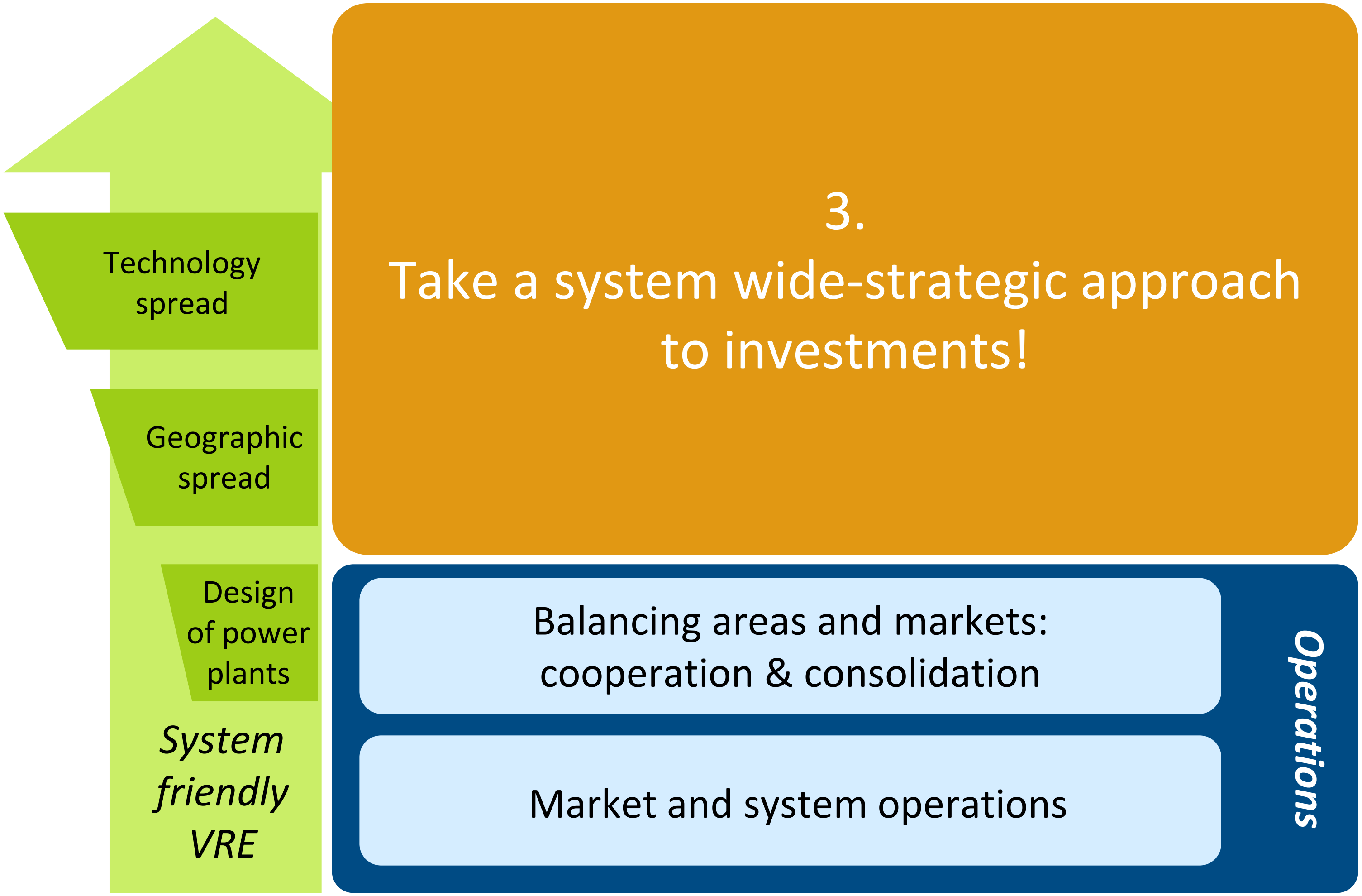
- VRE forecasting
- Better market operations:
  - Fast trading
    Best practice:
    ERCOT (Texas) – 5 minutes
  - Price depending on location
    Best practice: United States – Locational Marginal Prices
  - Better flexibility markets
    - *Updated product definitions*
    - *Full remuneration of services*
    - *Fully aligned trading of services and wholesale electricity*

Example: ERCOT market design



→ Make better use of what you have already!

Three pillars of system transformation



Transformation depends on context

Stable Power Systems

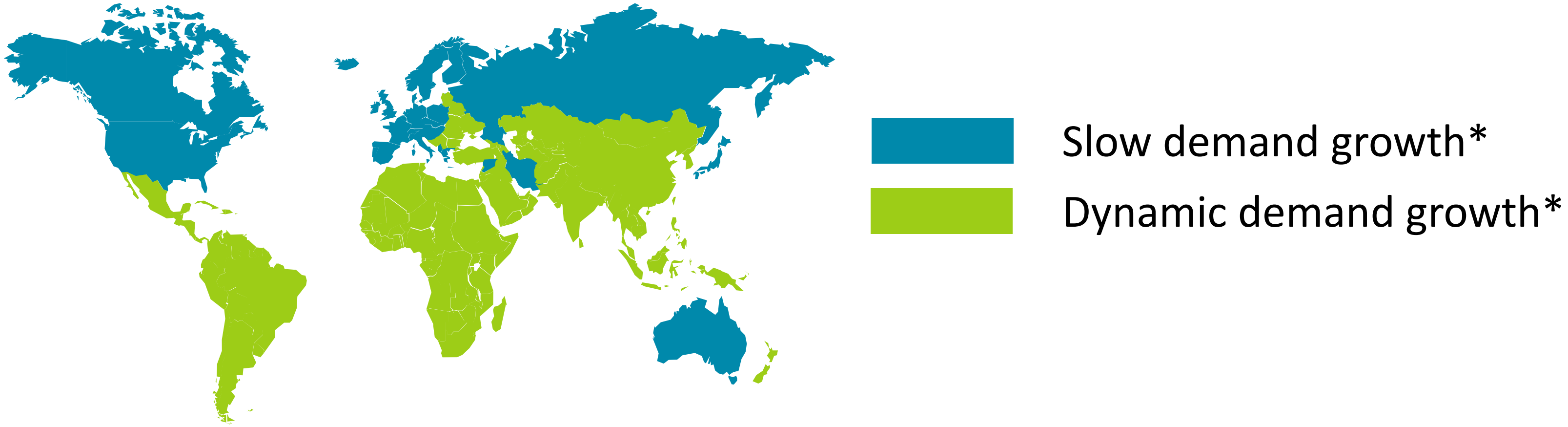
- Sluggish demand growth
- Little general investment needed short-term

Example: Europe

Dynamic Power Systems

- Dynamic demand growth
- Large general investment needed short-term

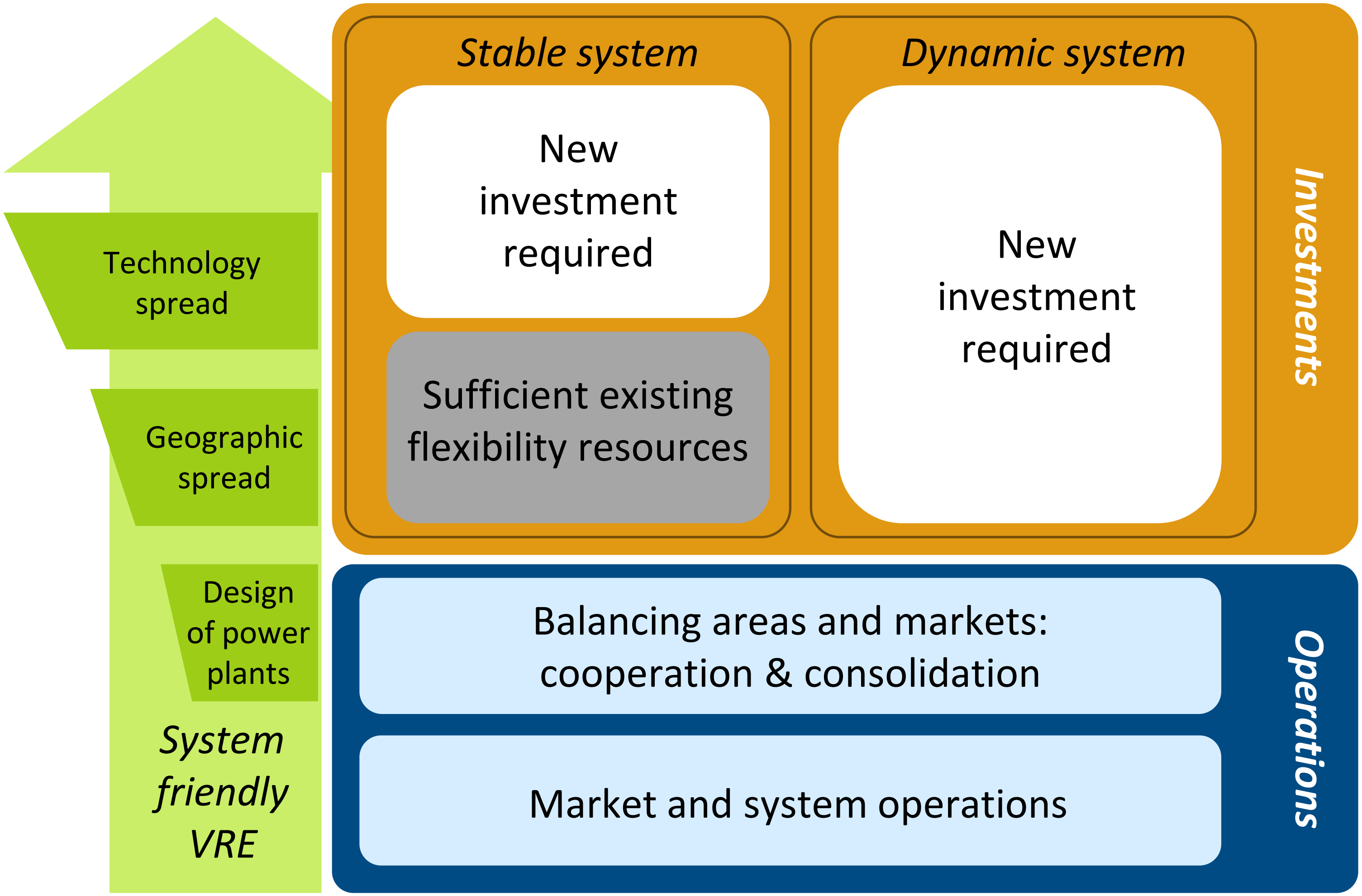
Example: Emerging economies



* Compound annual average growth rate 2012-20 , slow <2%, dynamic ≥2%; region average used where country data unavailable

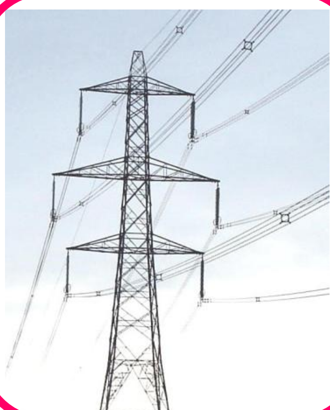
This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

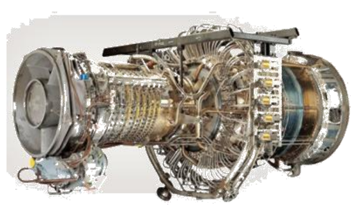
Three pillars of system transformation



3) Investment in additional flexibility

Four sources of flexibility …





Grid infrastructure

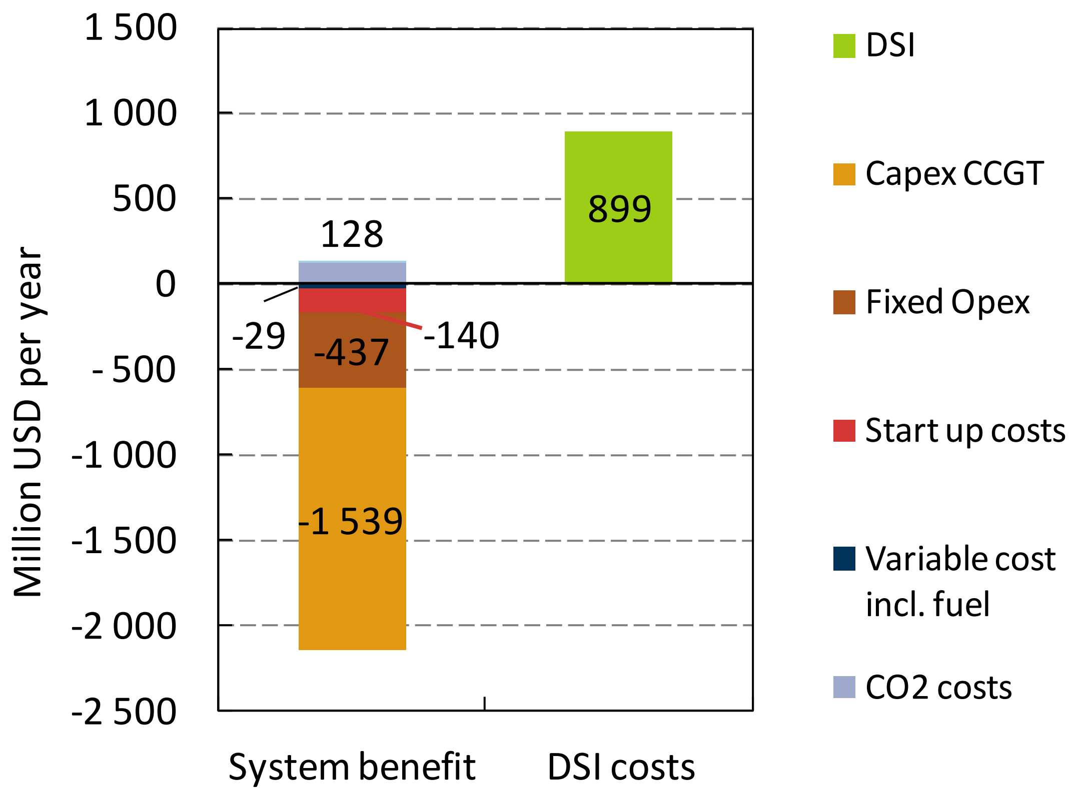
Dispatchable generation

Storage

Demand side integration

Benefit/cost of flexibility options

North West Europe - DSI



DSI assumed to be 8% of annual power demand:

- **71% made of heat and other schedulable demand** (110 TWh)
- **29% EV demand** (44 TWh)

CO_2 price USD 30 per tonne
Coal price USD 2.7/MMbtu
Gas price USD 8/MMbtu

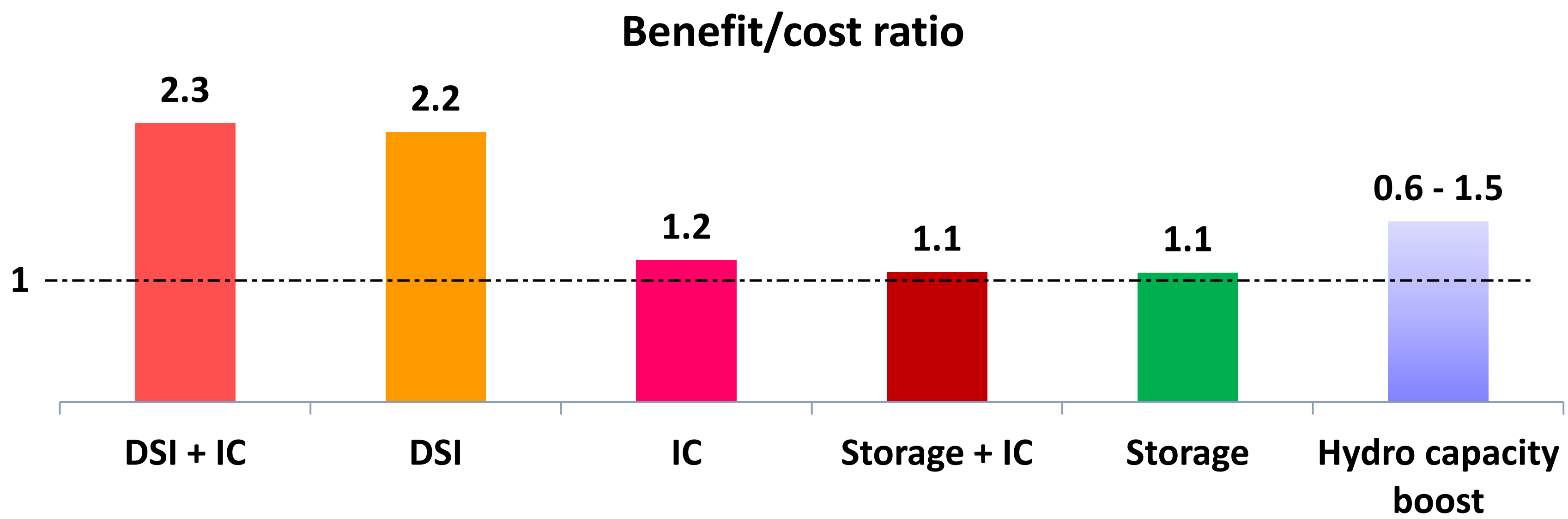
- **Overall system savings of 2.0 bln $/year**
- **DSI costs of 0.9 bln $/year**

Benefit/cost ratio: 2.2

Note: graph represents the differences between DSI scenario (DSI 8% of overall demand) and baseline scenario

Benefit/cost of flexibility options

North West Europe



- DSI has large benefits at comparably low costs
- Interconnection allows a more efficient use of distributed flexibility options and generates synergies with storage and DSI
- Cost effectiveness of hydro plant retrofit depend on project specific measures and associated investment needs

Notes:

1) CAPEX assumed for selected flexibility options: interconnection 1,300$/MW/km onshore and 2,600$/MW/km offshore, pumped hydro storage 1,170$/kW, reservoir hydro 750 $/kW -1,300$/kW (repowering of existing reservoir hydro increasing available capacity). Cost of DSI is assumed equal to 4.7 $/MWh of overall power demand (adjustment of NEWSIS results)
2) Fuel prices and CAPEX ($/kW) for VRE and flexibility options are assumed constant across all scenarios

Source: IEA/PÖYRY

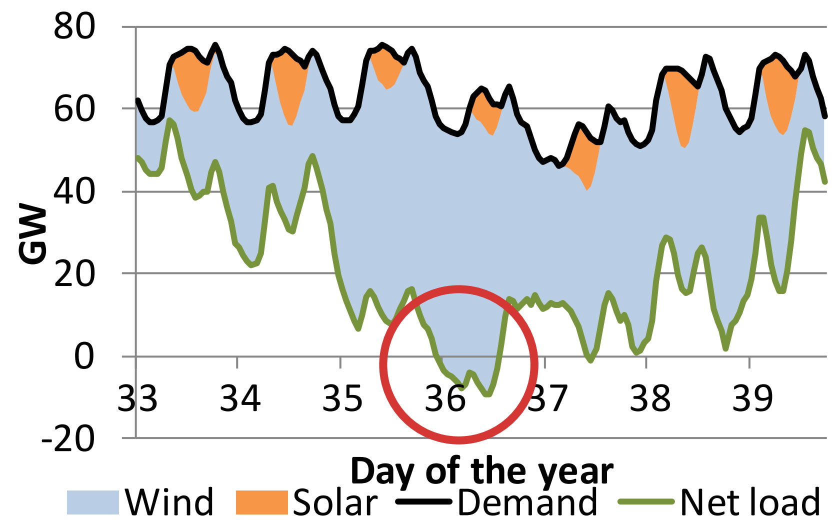
Investments in system flexibility – Need for a suite of solutions

- No single resource does it all!
- Example:
  - Abundance
    - Flexible generation ✗ ✗
    - DSI ✓
    - Storage ✓
    - Curtailment ✓
  - Scarcity
    - Flexible generation ✓ ✓
    - DSI o
    - Storage ✓
    - Curtailment ✗ ✗

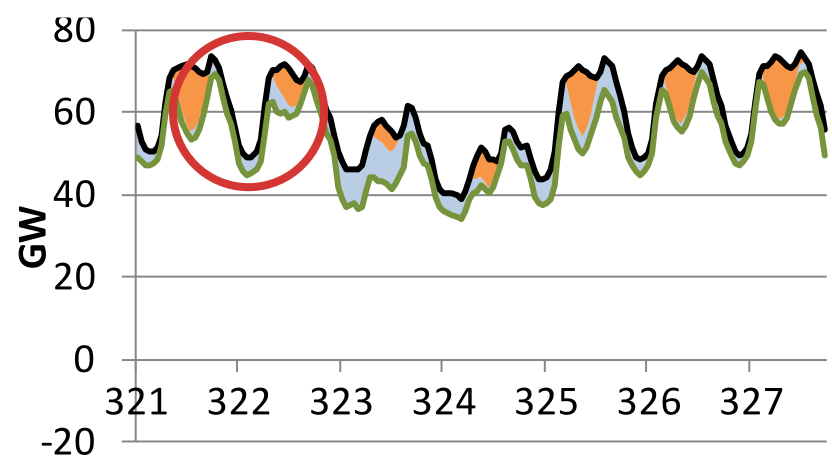
✓ ✓ : very suitable, ✓ :suitable, o : neutral, ✗ ✗ : unsuitable

Data: Germany 2011, 3x actual wind and solar PV capacity

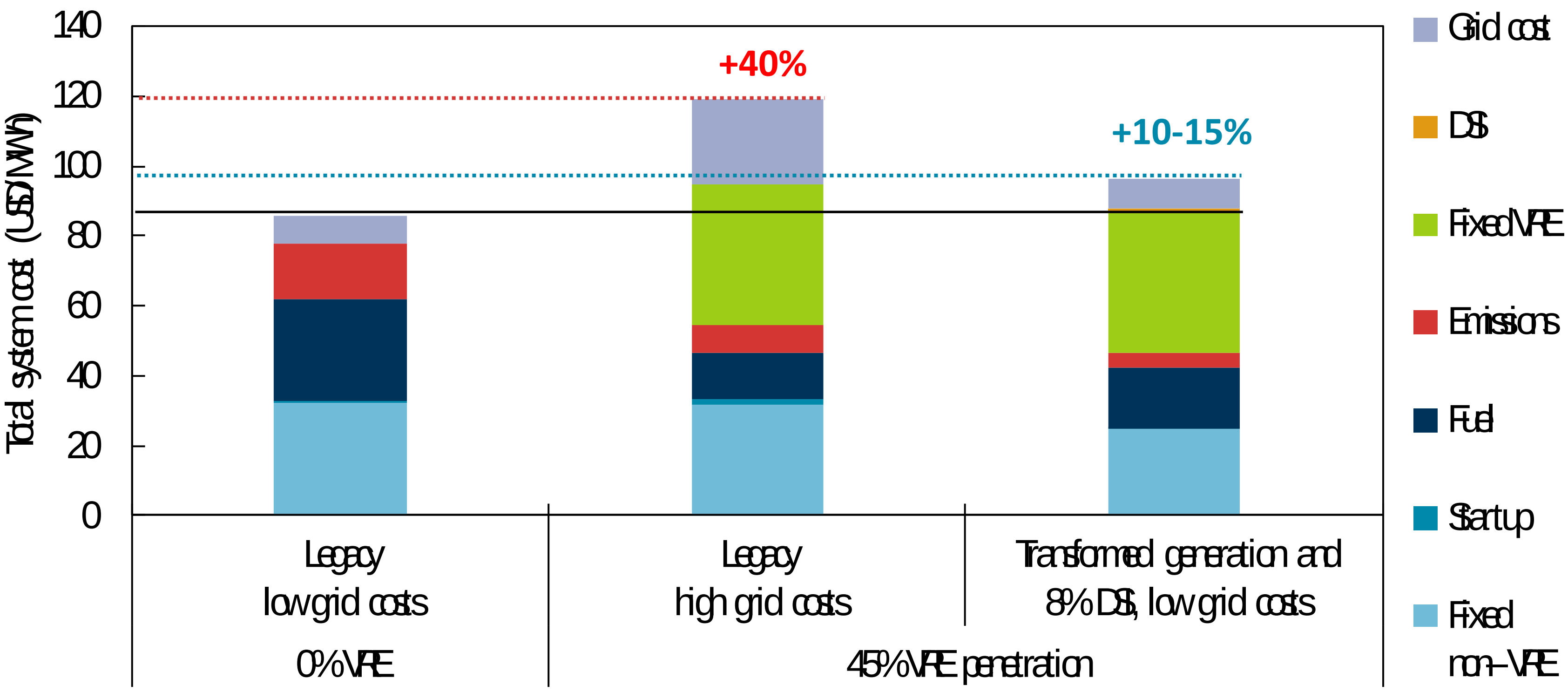
Solar and wind can be abundant …



… or scarce.



Cost-effective integration means transformation of power system

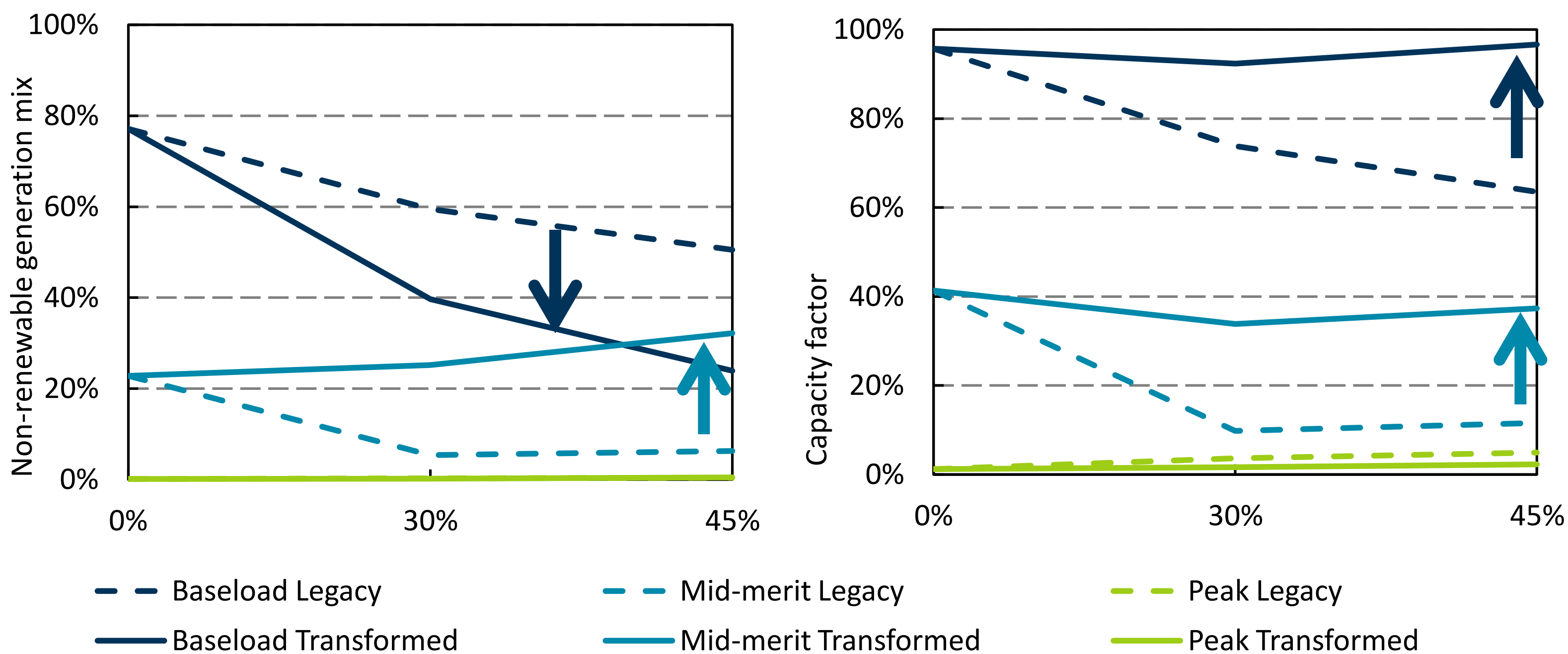


Test System / IMRES Model

- Large shares of VRE can be integrated cost-effectively
- But adding VRE rapidly without adapting the system is bound to increase costs

Power plant utilisation and in stable systems – modelling results

- Transformation of the system
  - Re-establishes mid-merit plants (gas) market share at the cost of baseload plants (coal)
  - Re-establishes capacity factors of all technologies



Recommendations 1/2

- All countries where VRE is going mainstream should:
  - Optimise system and market operations
  - Deploy VRE in a system-friendly way to maximise their value to the overall system
- Countries beginning to deploy VRE power plants (shares of up to 5% to 10% of annual generation) should:
  - Avoid uncontrolled local concentrations of VRE power plants ("hot spots")
  - Ensure that VRE power plants can contribute to stabilising the grid when needed
  - Use state of the art VRE forecast techniques

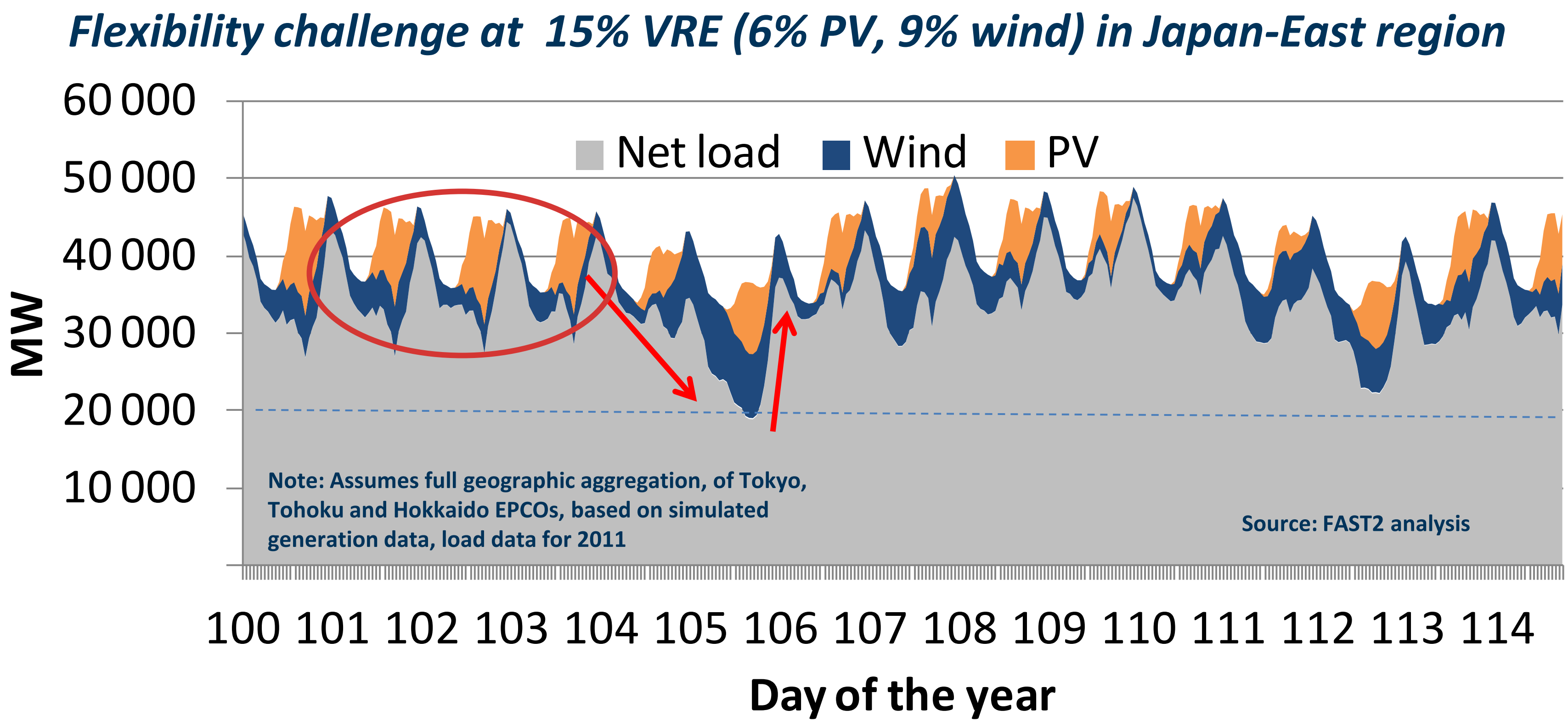
Recommendations 2/2

- Countries with stable power systems should seek to
  - Maximise the contribution from existing flexible assets
  - Consider accelerating system transformation by decommissioning or mothballing surplus inflexible capacity

- Countries with dynamic power systems should
  - Approach VRE integration as a question of holistic, long-term system transformation from the onset
  - Use energy planning tools and strategies that appropriately represent VRE's contribution at system level

Focus on Japan 1: System Operation

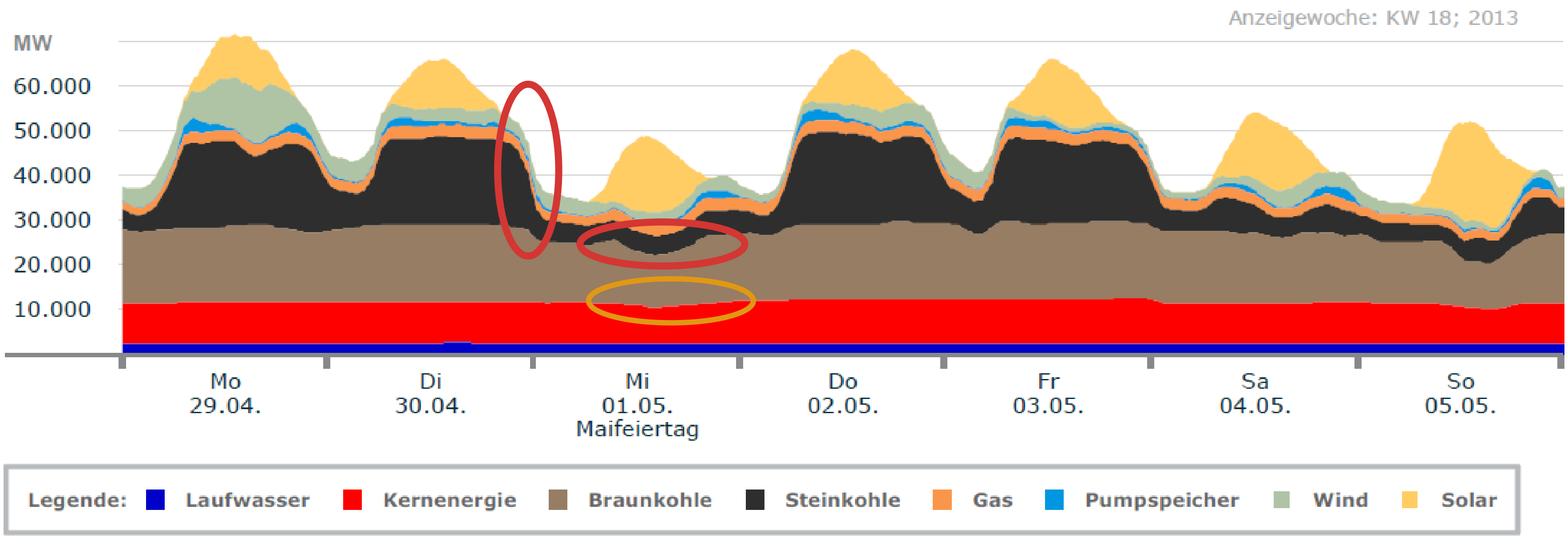
Variable renewables in the Japanese system



- **Main question:**
  - **Mobilizing flexibility on an island with large shares of baseload generation**

Flexibility: ask for it…. and it appears

A sunny 1st May 2013 in Germany – actual production



Source: Fraunhofer ISE

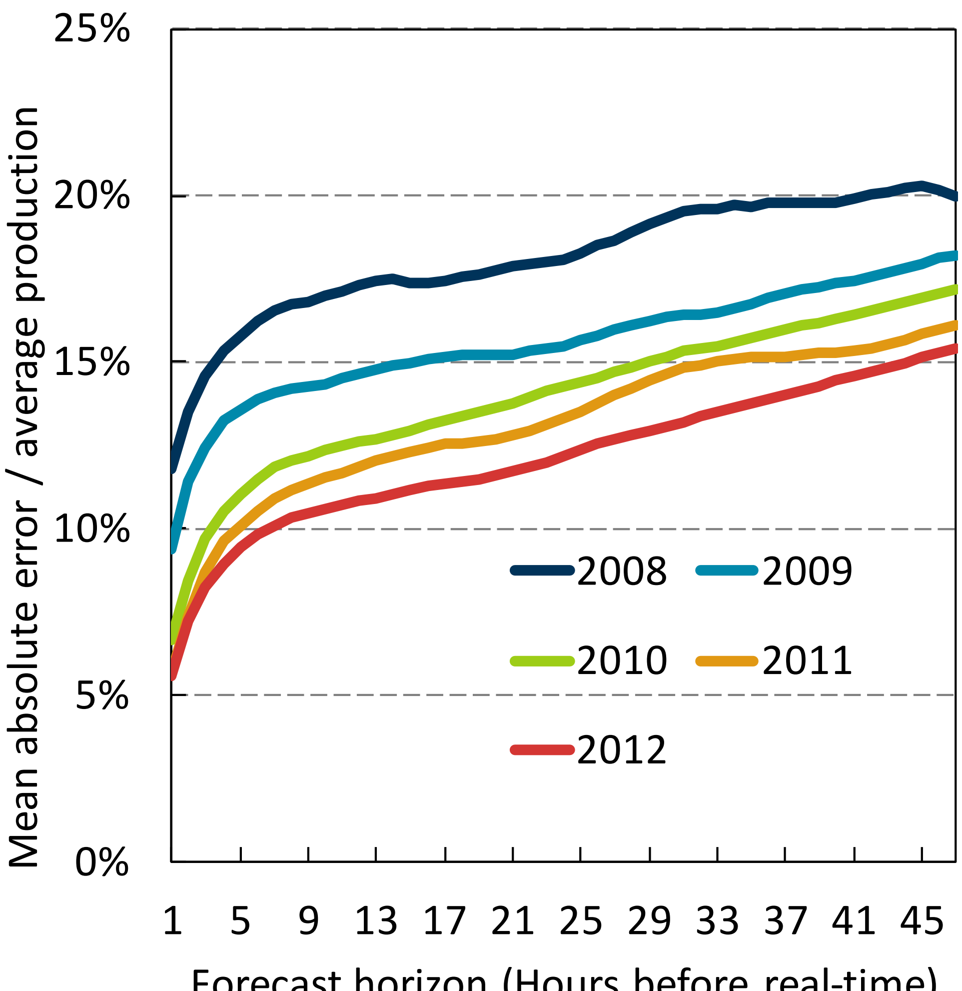
- **German hard coal plants carry most of ramping duty in Germany**
  - Lignite and nuclear ramp as well, even nuclear at some times
- **Ramping costs can be minimised at low cost; retrofits are possible e.g. Flexible Coal: Evolution from Baseload to Peaking Plant (NREL, 2013)**

VRE production forecasts

Where do Japanese EPCOs stand?

- Forecasting of VRE production key strategy for cost-effective operation
- Forecasts improve dramatically with shorter horizon
- Real-time generation data key for short-term accuracy
- More mature for wind than for PV

Accuracy of wind forecasts in Spain

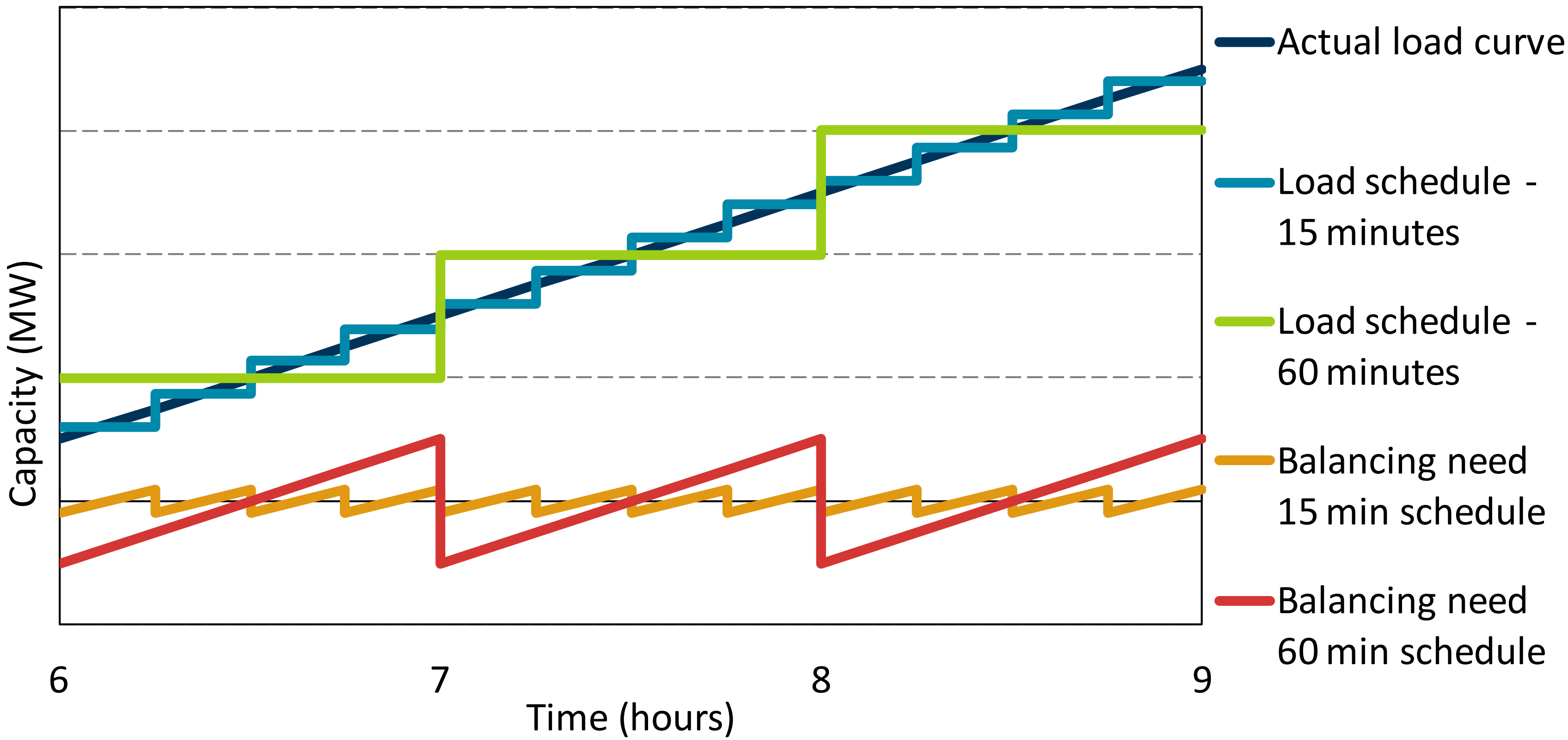


Source: REE

Generation and transmission schedules

Are EPCOs going with the flow?

Impact of scheduling interval on reserve requirements, illustration



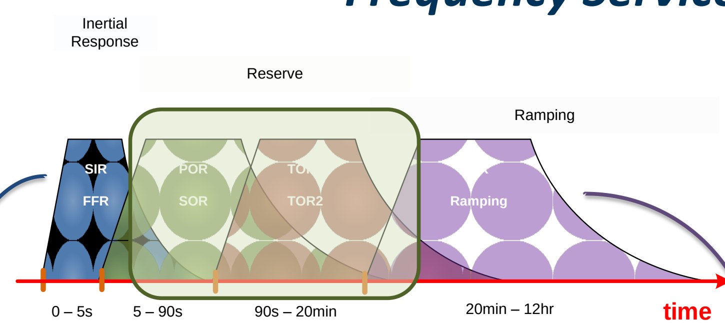
- **Short scheduling intervals (5min best practice)**
- **Adjust schedules up to real time (5min best practice)**

System service definitions

Prepared for a variable future?

- Are your operating reserve and system service definitions VRE ready?
  - Example Ireland DS3 programme

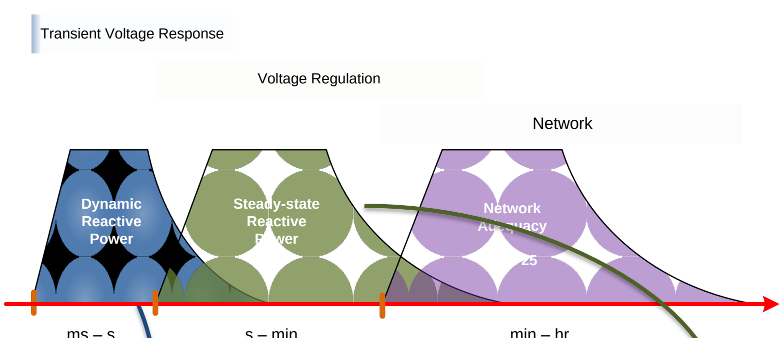
Frequency Services



- Synchronous Inertial Response
- Fast Frequency Response
- Fast Post-Fault Active Power Recovery

- Ramping Margin

Voltage Services



- Dynamic Reactive Power

- Steady-state Reactive Power

Source: EirGrid

Focus on Japan 2:
Flexibility investments

?

Grid infrastructure

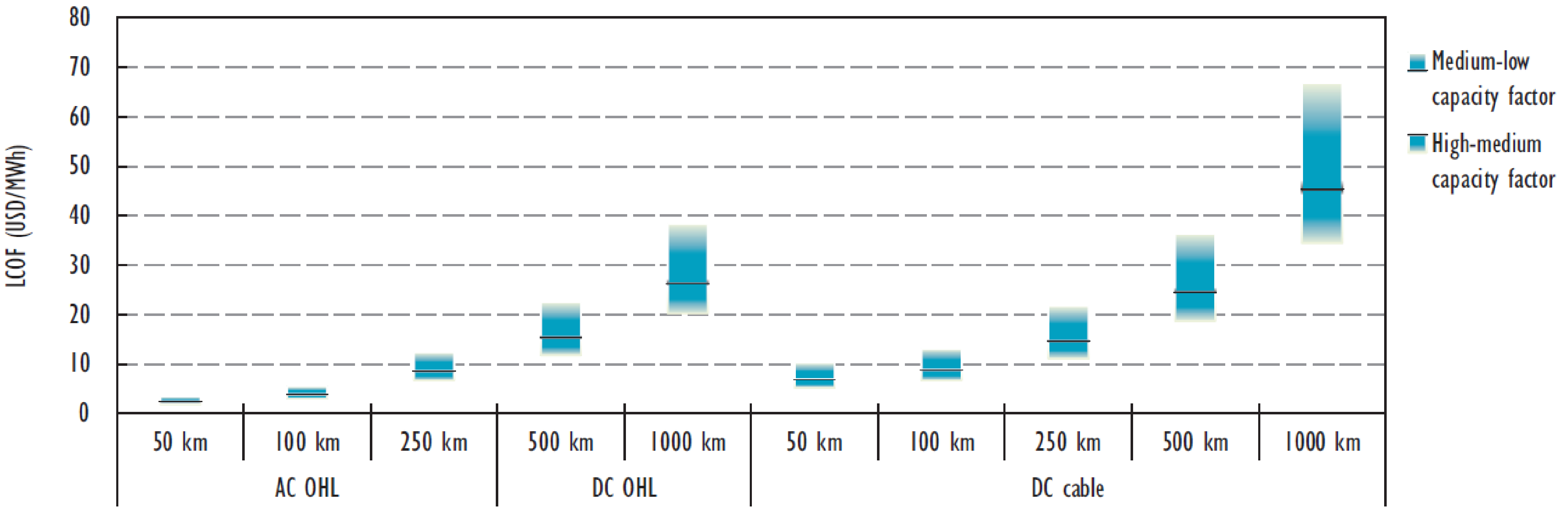
Dispatchable generation

Storage

Demand side integration

Flexibility options - Transmission

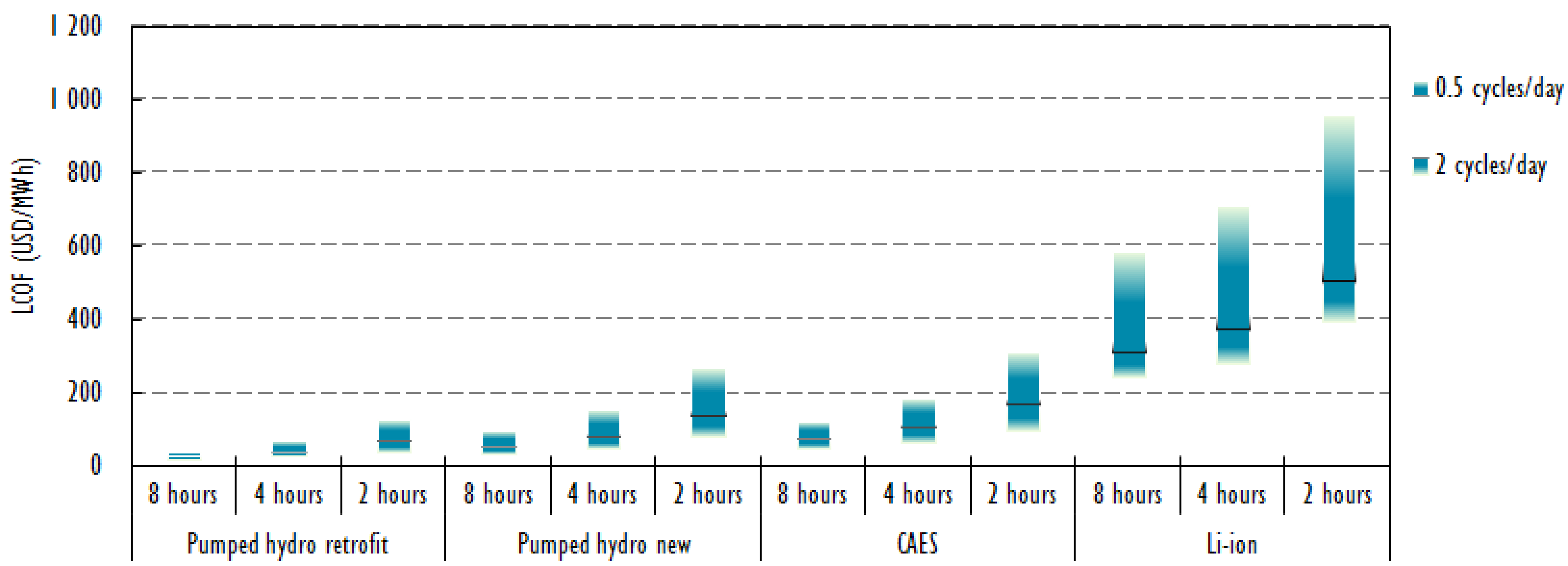
Where do you get inexpensive flexibility?



- **Interconnection can offer low-cost flexibility**

Flexibility options – Electricity Storage

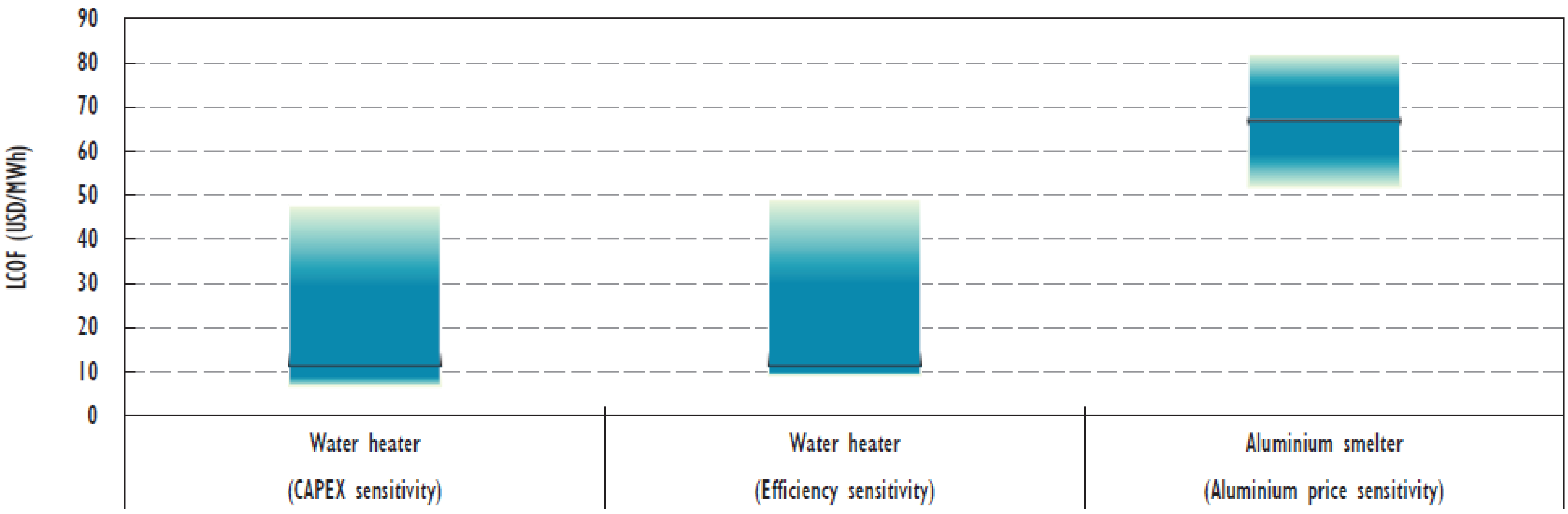
Where do you get inexpensive flexibility?



- Storage shows relatively high LCOF compared to other options
- But not only costs count – also the value matters

Flexibility options – DSI

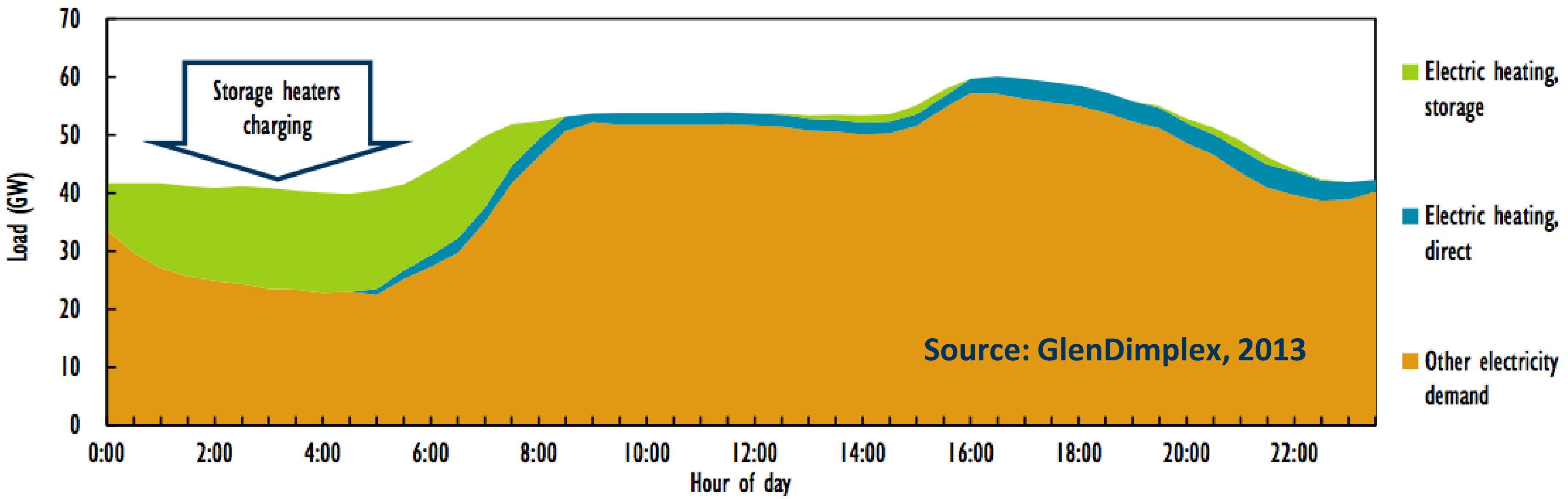
Where do you get inexpensive flexibility?



- DSI potentially very favourable benefit/cost ratio
- Moving demand to when wind blows and sun shines increases firm capacity credit of variable sources
- But what is the real potential?

Demand Side Response – already present today

Today's load shape already contains DSI – Electric heating in Great Britain

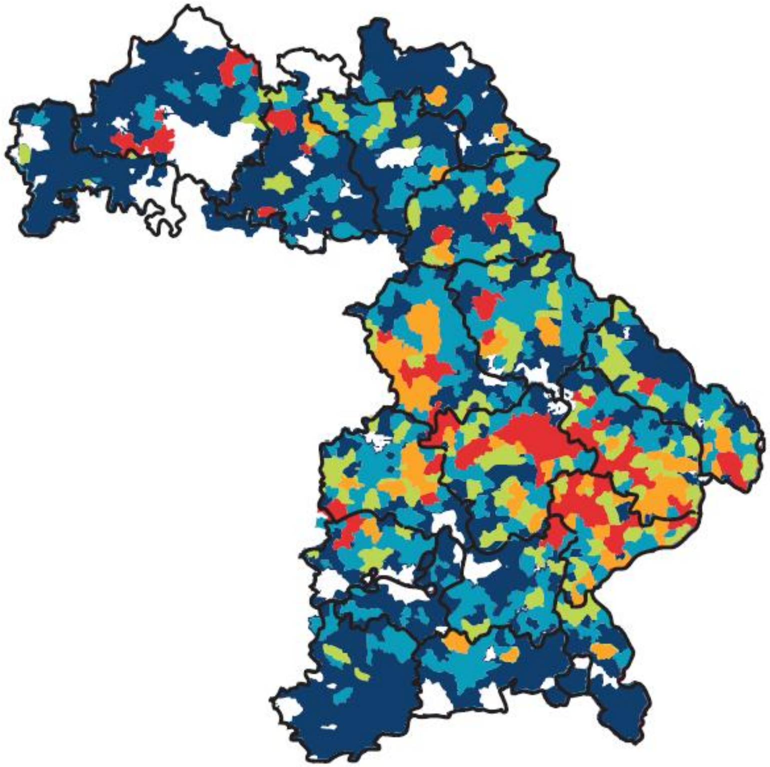


- **Electric heating systematic demand side strategy used today**
- **Flexibility source used in UK (Island) when inflexible nuclear was added to the system**

Focus on Japan 3:
System friendly VRE deployment

Local hot-spots 1/2

How to get into trouble with PV

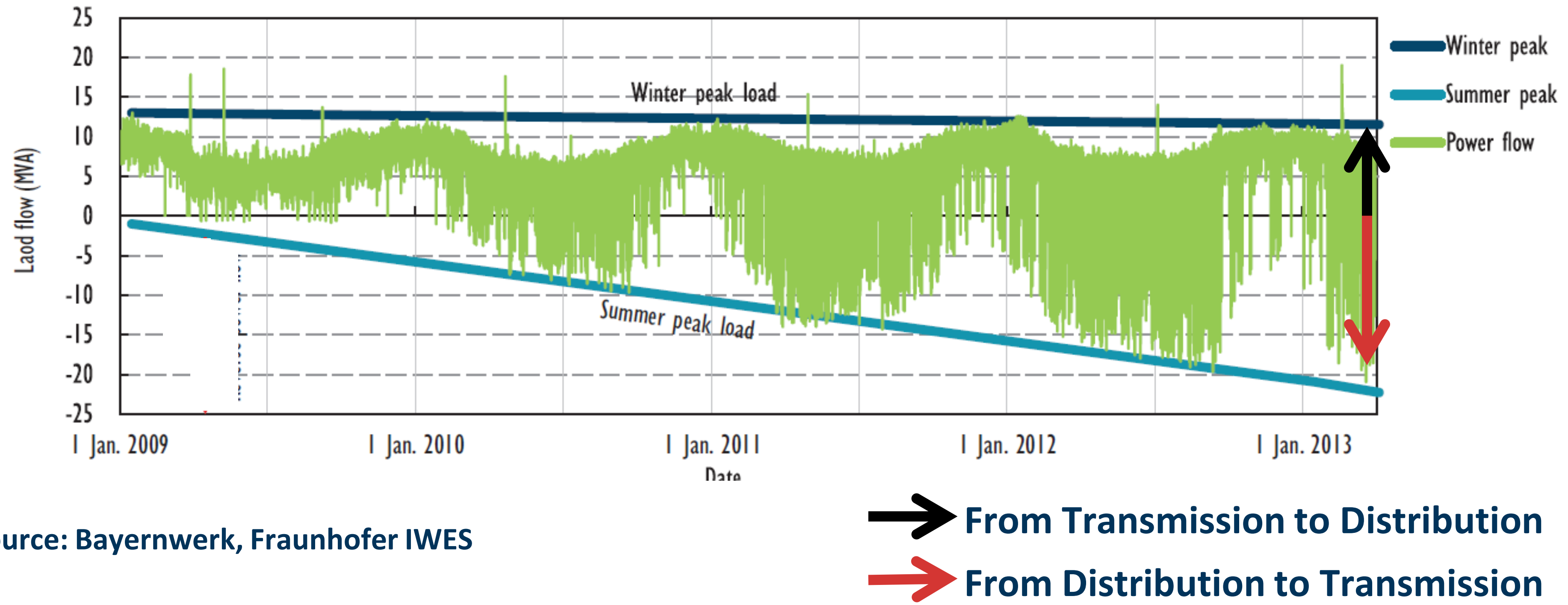


- **Distribution of solar PV installations in the grid area of Bayernwerk AG, Bavaria, Germany**

Local hot-spots 2/2

How to get into trouble with PV

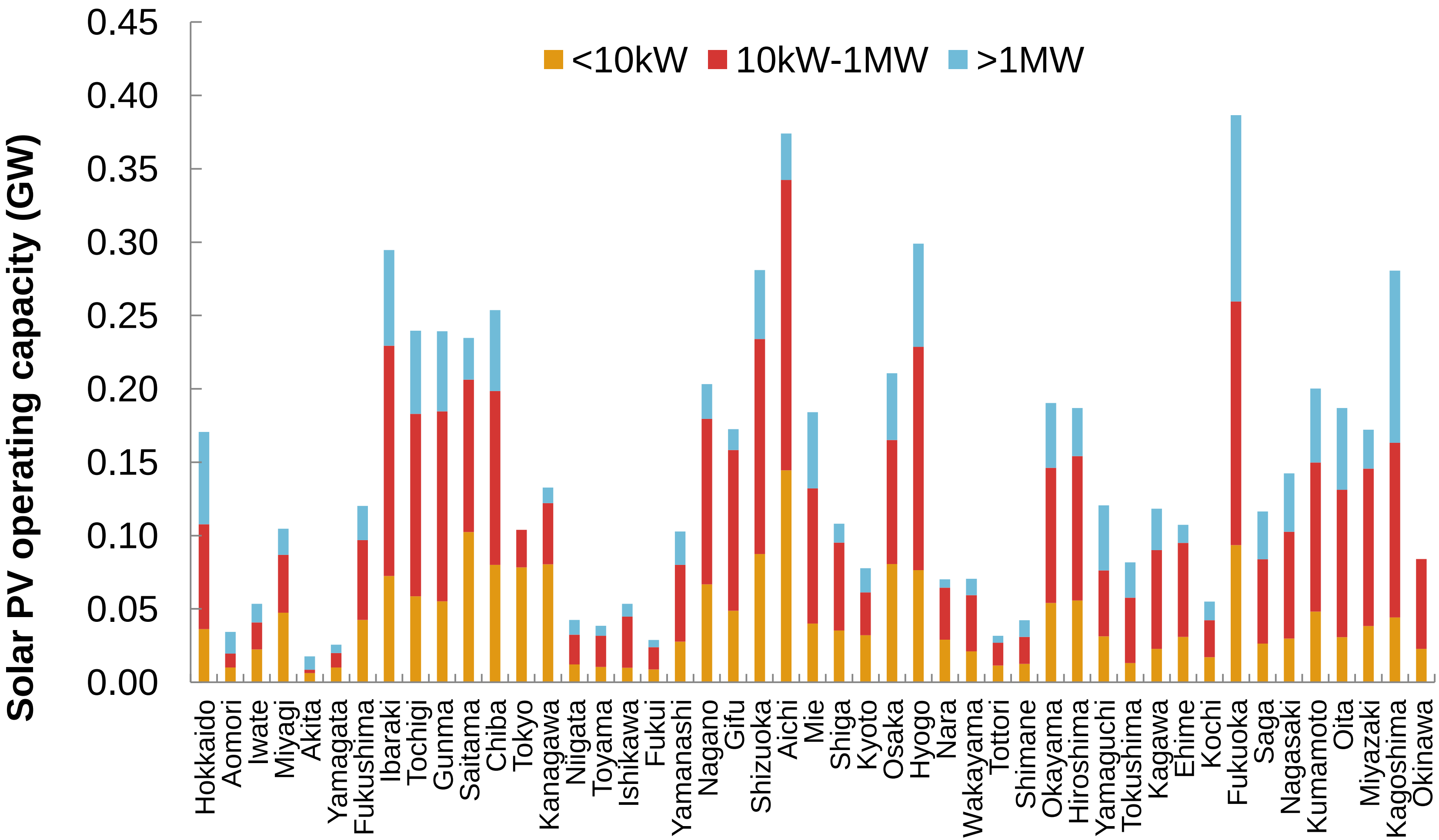
Power flows across HV-MV transformer example form Bavaria, Germany



Source: Bayernwerk, Fraunhofer IWES

- Reverse flows no big technical issue
- But too high concentration can imply costly retrofits

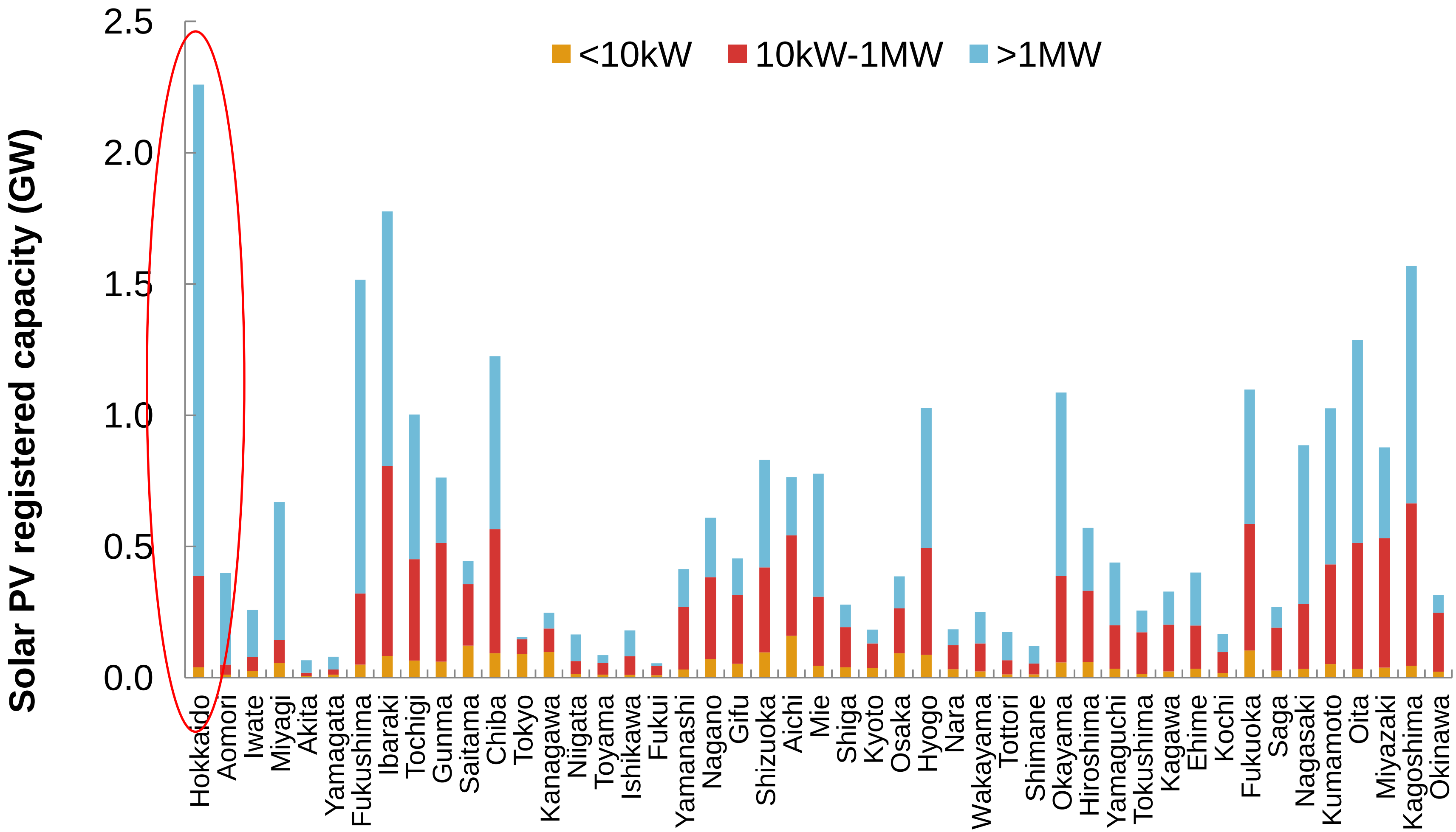
Local hotspots – situation in Japan



Source: METI, as of Dec 2013

- **Installed capacities are well spread!**

Local hotspots – situation in Japan

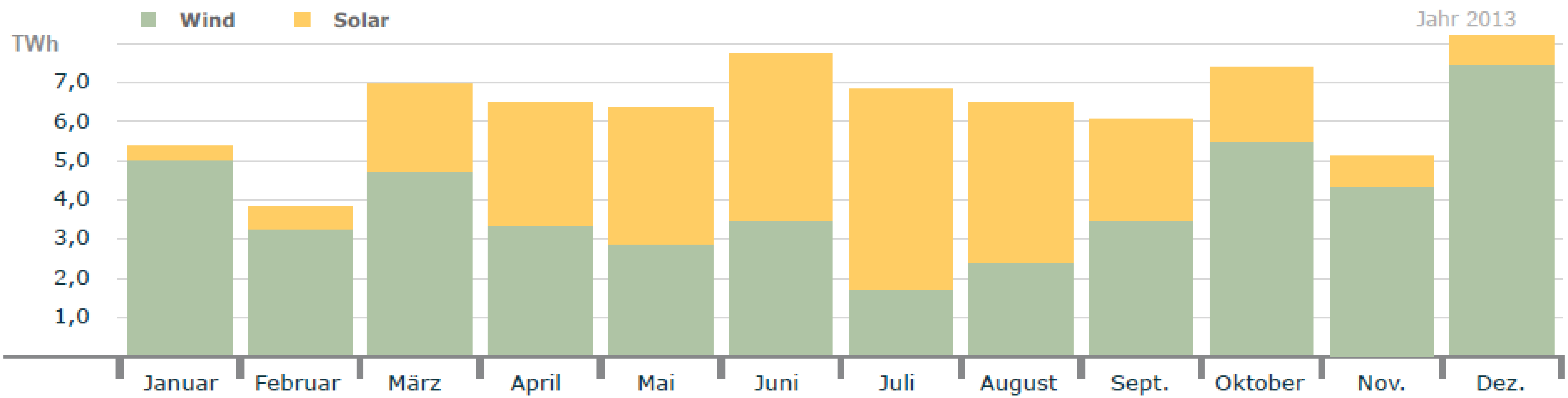


Source: METI, as of Dec 2013

- **But what about the future?**

Reaping technology synergies

Monthly production, wind and PV, Germany, 2013



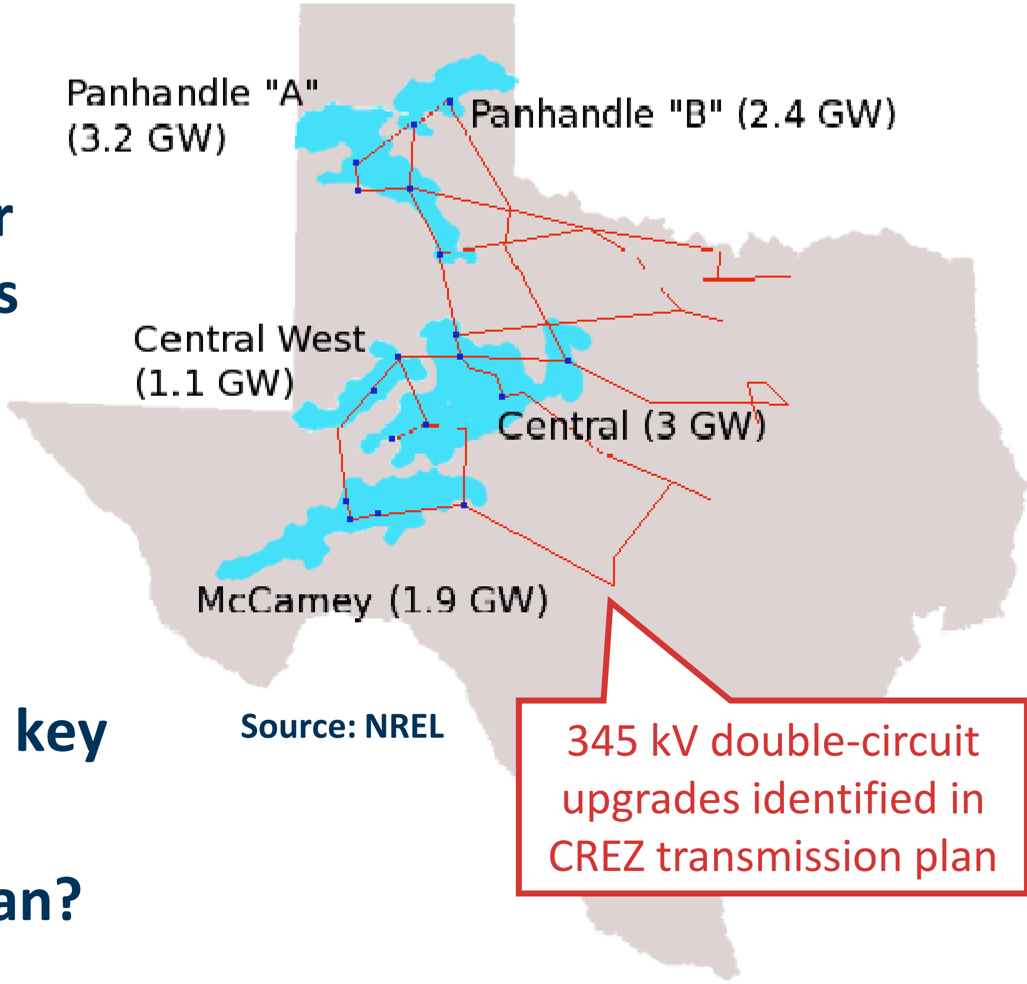
Source: Fraunhofer ISE

- Very strong focus on PV currently in Japan
- Deployment of *a portfolio* of renewables key strategy
  - Complementarities: wind, solar PV
  - Flexibility: hydro power, biogas
  - Firm capacity: biomass and geothermal

Getting the grid - transmission

- Importance of coordinated development of grid and generation well understood
- Chicken and egg problem for first-off, distant VRE projects
  - Competitive Renewable Energy Zones (CREZ), Texas
  - Irish gate system
- Appropriate cost recovery is key
- What is the approach in Japan?

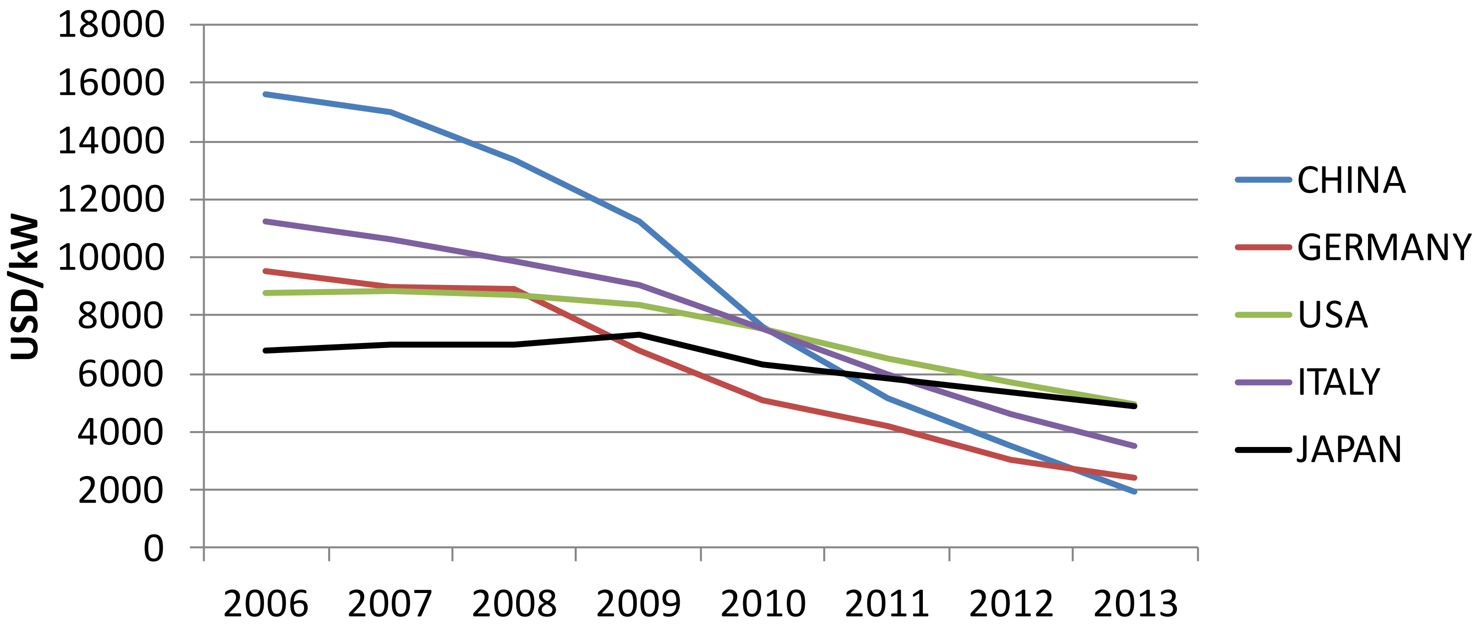
CREZ, Texas



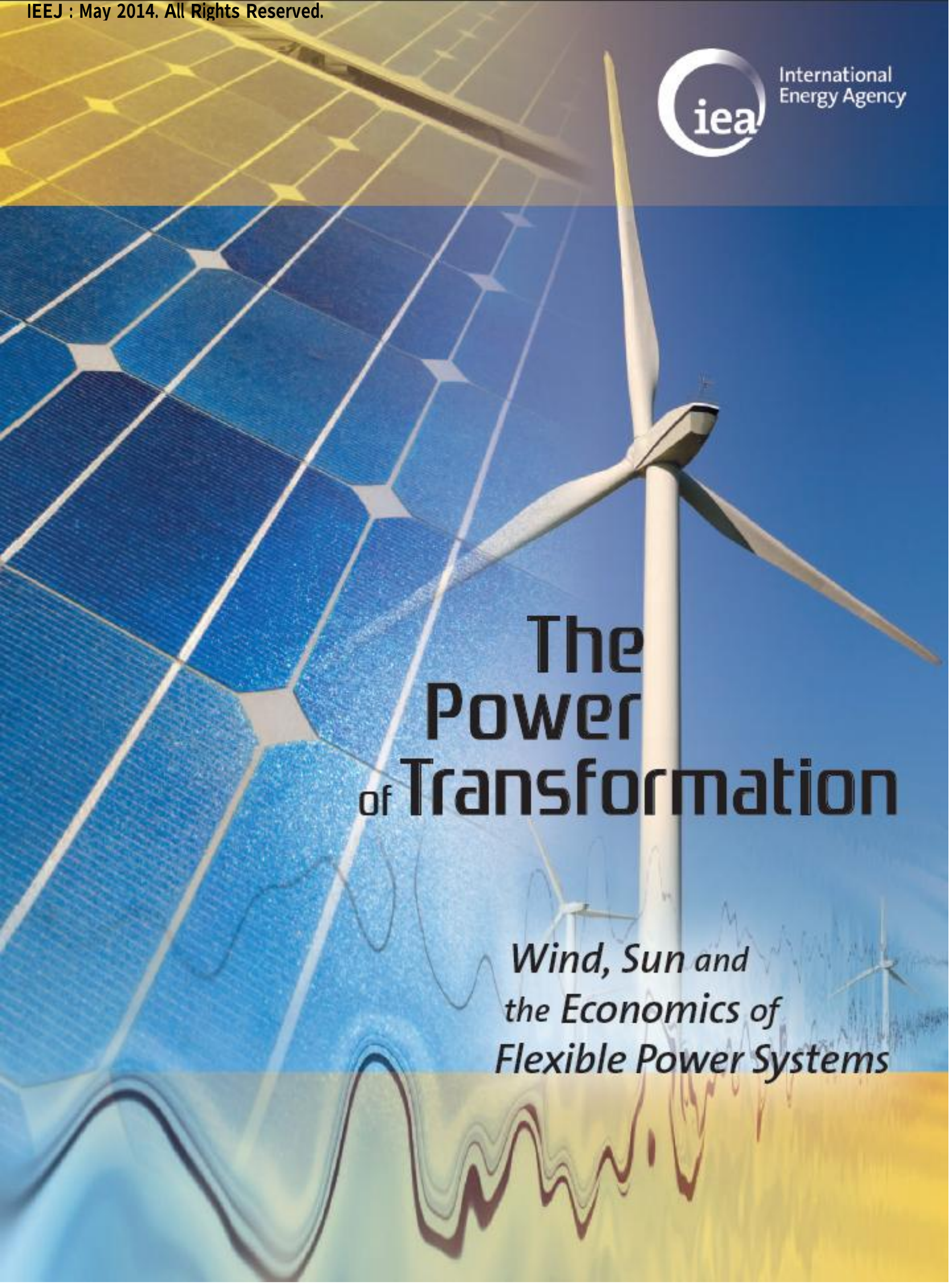
Source: NREL

Policy support to drive down costs

System costs for domestic PV systems in selected markets



- **Japan evolved from a low-cost market to highest cost market**
- **What is the reason behind the high system costs?**
- **How can the Japanese FIT system be enhanced further?**



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