# System Integration of Renewables

| | |
|---|---|
| 14h00 | **Integration Challenges and Solutions** |
| 15h30 | Q&A |
| 16h00 | Coffee Break |
| 16h30 | **Best Practice and Key Policy Steps** |
| 17h30 | Q&A |
| 18h00 | Session ends |


System Integration
of Renewables 1
Challenges and Solutions
Hugo Chandler, M.Sc. D.I.C.
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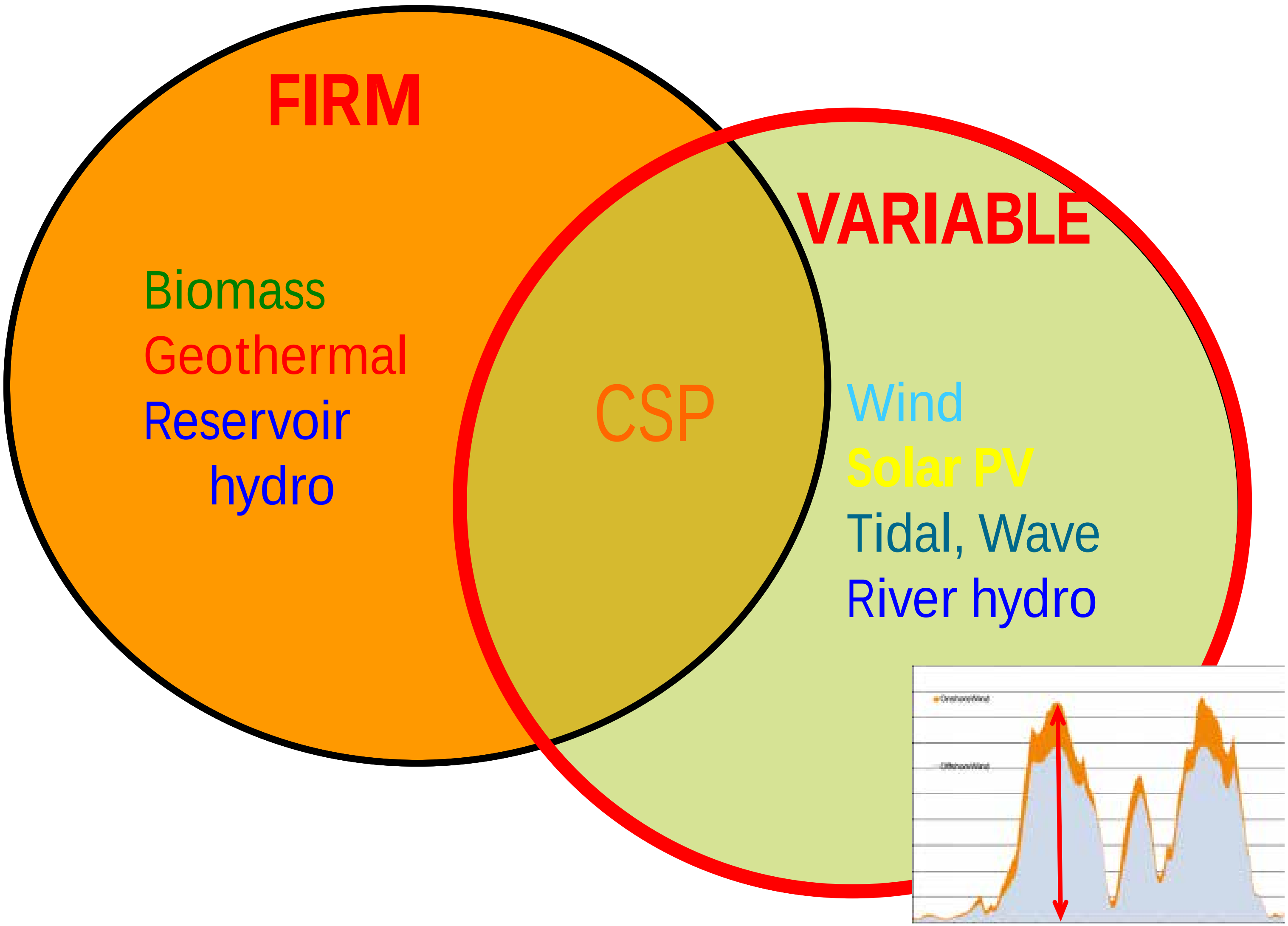
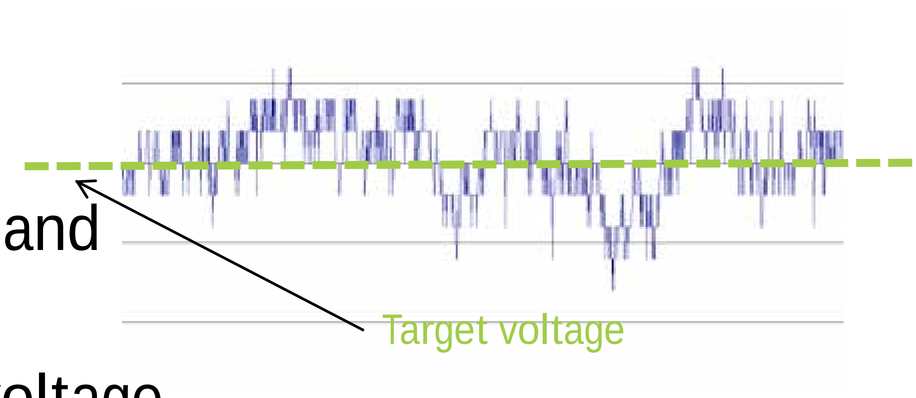
# Integration of Renewables: the Basics

# Our focus today: *variable* renewables

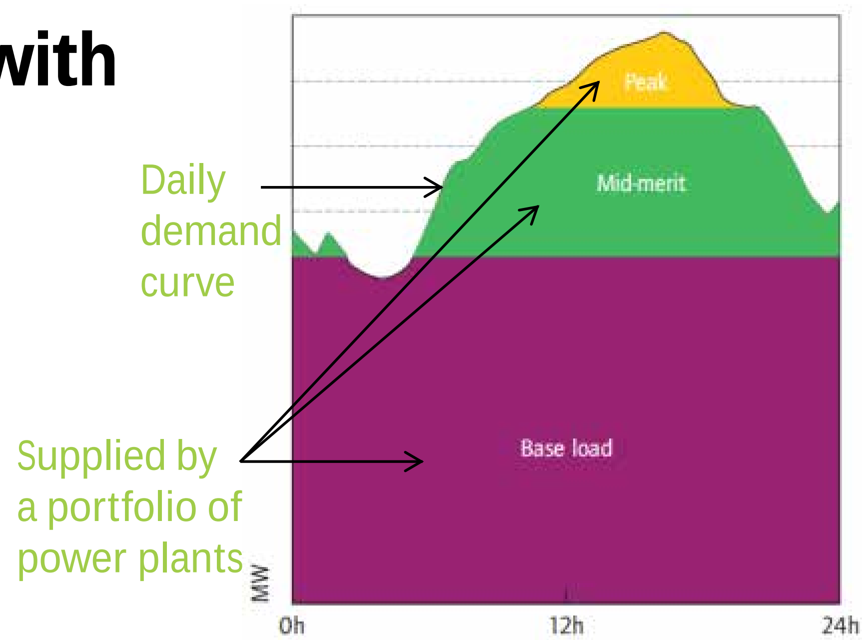


# Overview of integration challenges 1/2

- **Electrical stability**
  - Timeframe: seconds and sub-second
  - Support for system voltage and frequency



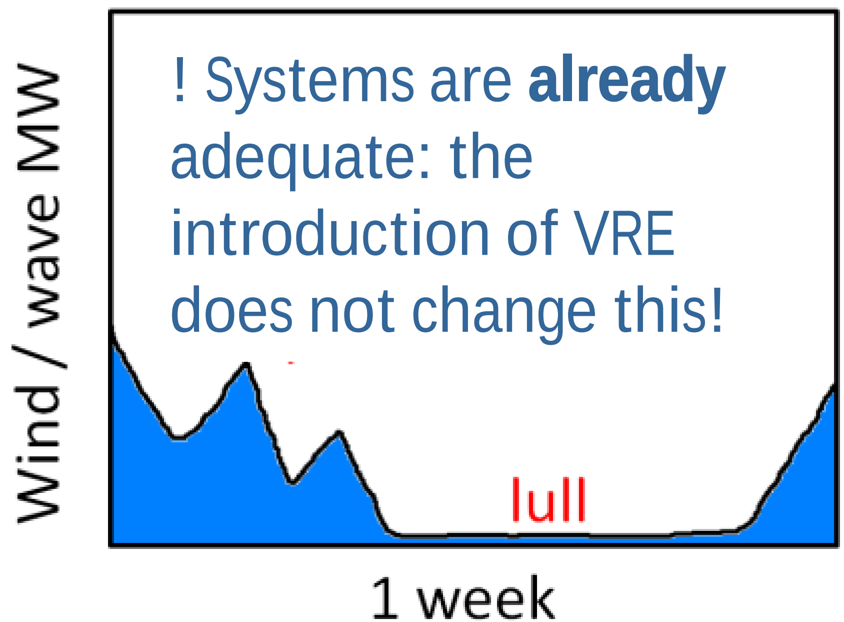

- **Balancing supply with demand**
  - Minutes - days
  - Must match instantaneously



# Overview of integration challenges 2/2

- **Transmission grid**
  - Are resources connected to consumption centres?
  - Is the grid strong and managed optimally?


- **Maintaining adequate power to meet demand**
  - When the wind doesn't blow, are customers served?

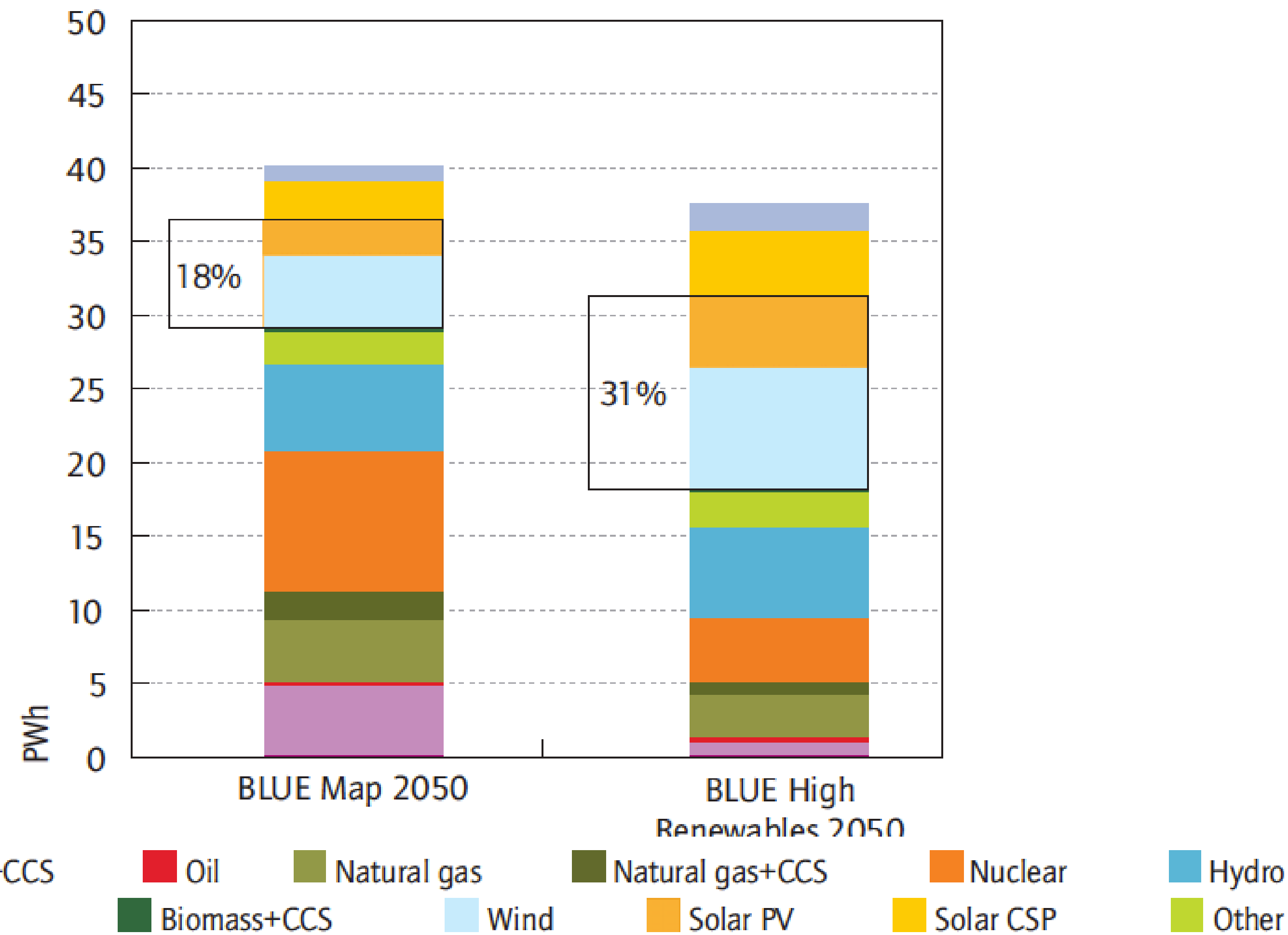


# Change is upon us!

Denmark in 1980

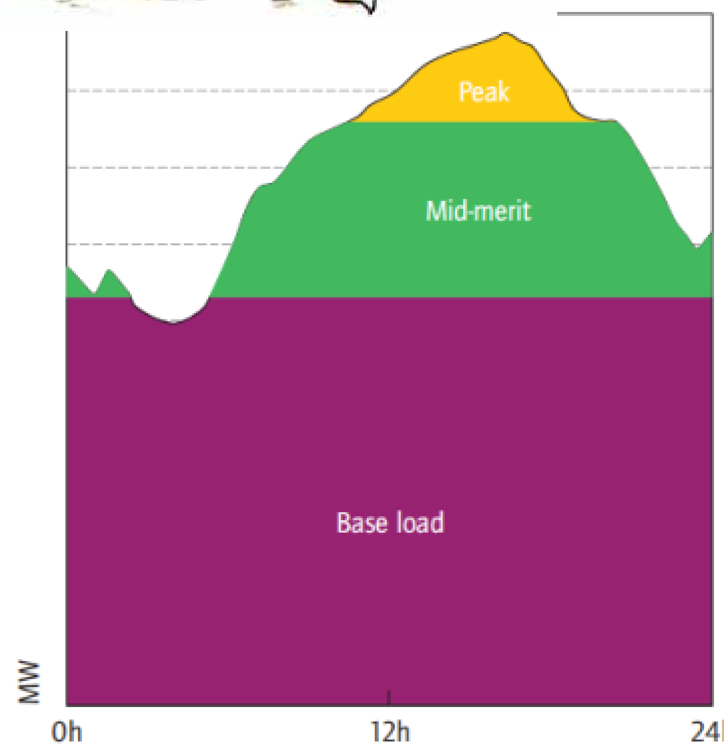
# And will only accelerate...

## Electricity in 2050?




TODAY's FOCUS:

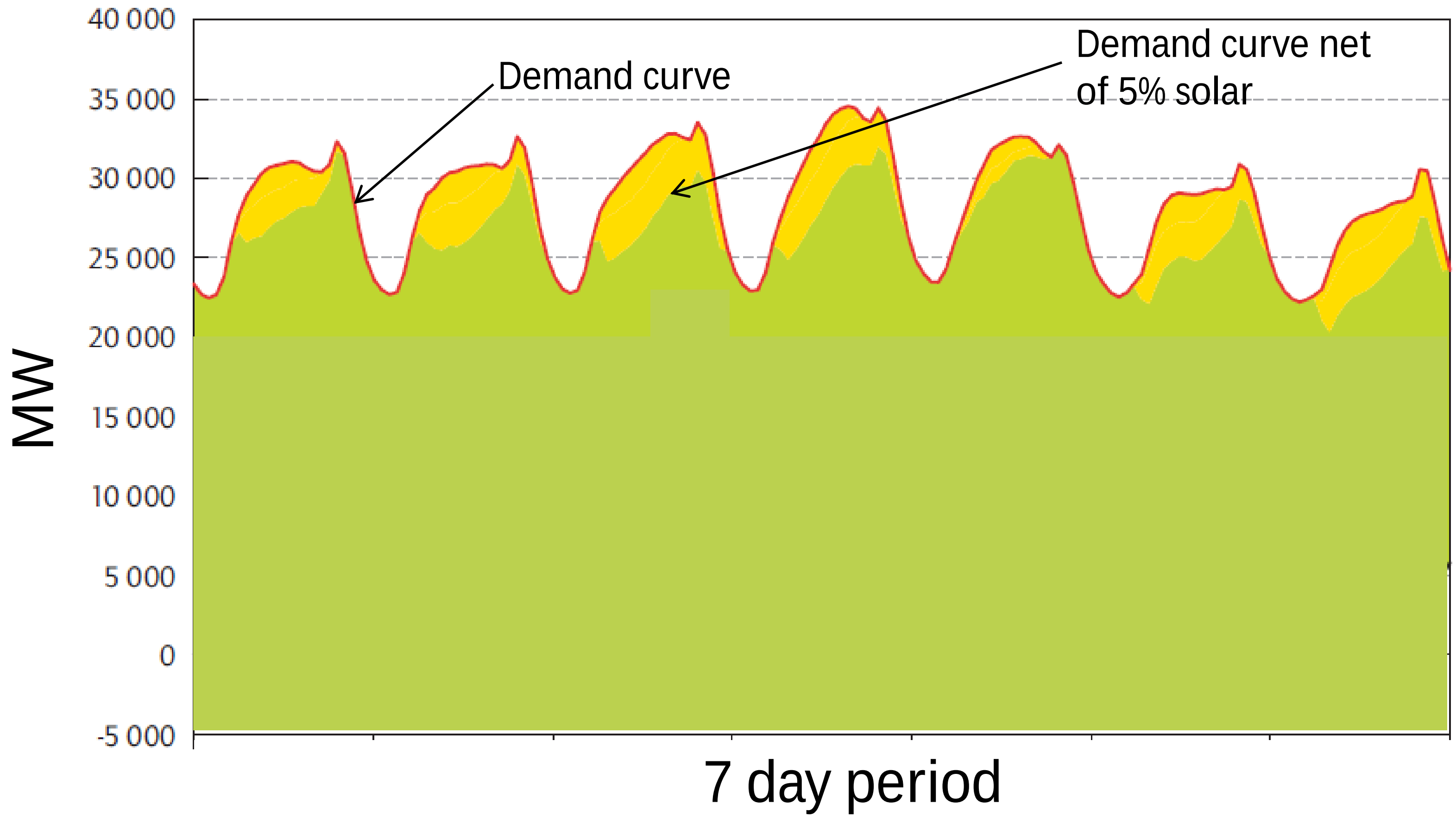
The impact of wind and solar power on the balancing of supply and demand for electricity



# What changes with wind and solar in the power generation portfolio?

# Is variability really a new challenge?

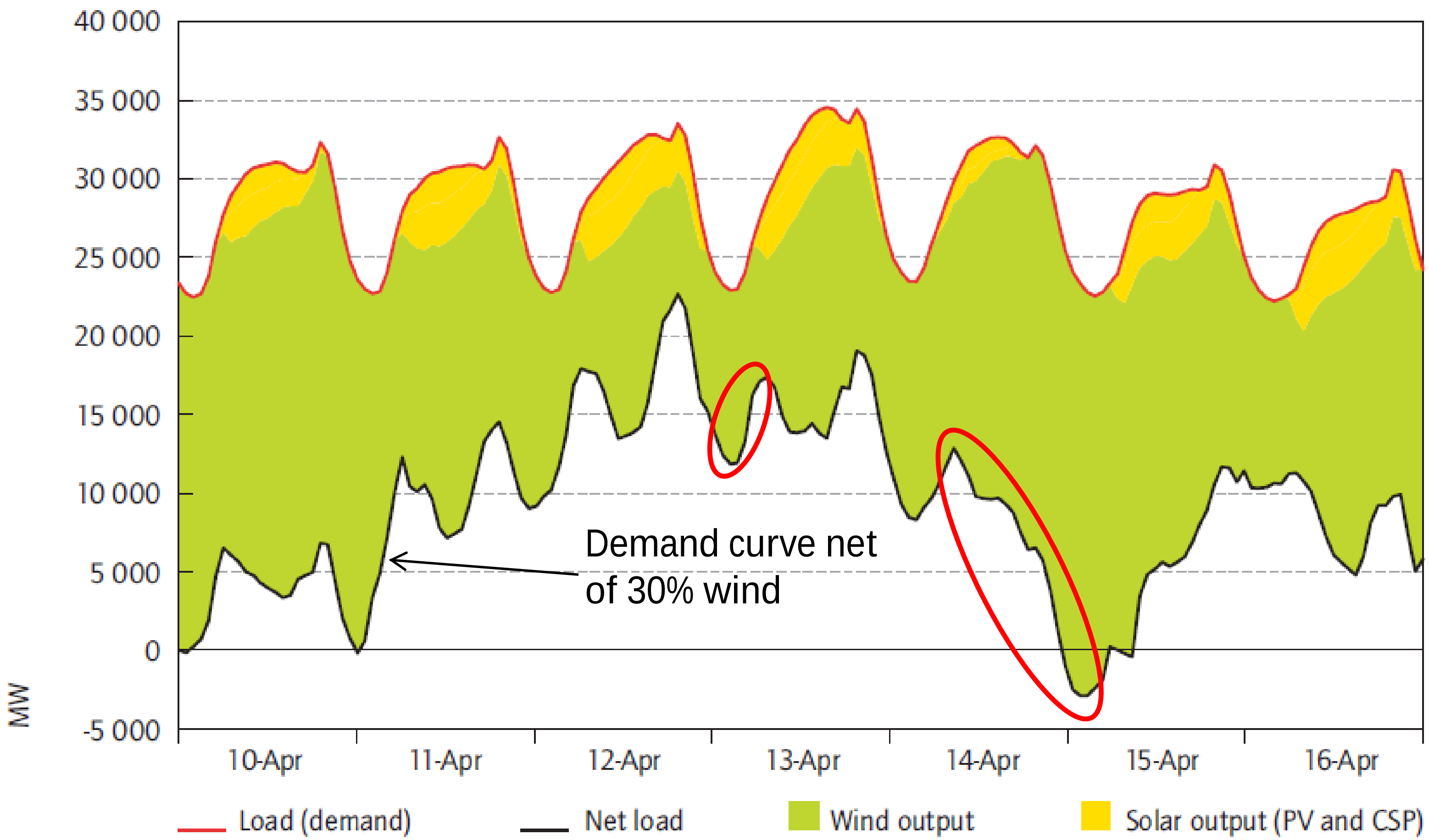
- Demand is variable too
  - Although it fluctuates quite regularly






Source: WWSIS Study, NREL 2010

# But the challenge is greatly increased at high wind penetrations



# When is the challenge greatest?

- When the wind is **negatively correlated** with demand. For example:
  - Demand is falling when the wind is rising
    - Because power plants will *already* be ramping down… So how much faster they can do so, will be limited
  - Demand is rising when the wind is dropping
    - Power plants are *already* ramping up fast…
- Renewable output may also be **positively** correlated with demand.
  - For example: when solar PV is installed in countries with high air-conditioning demand



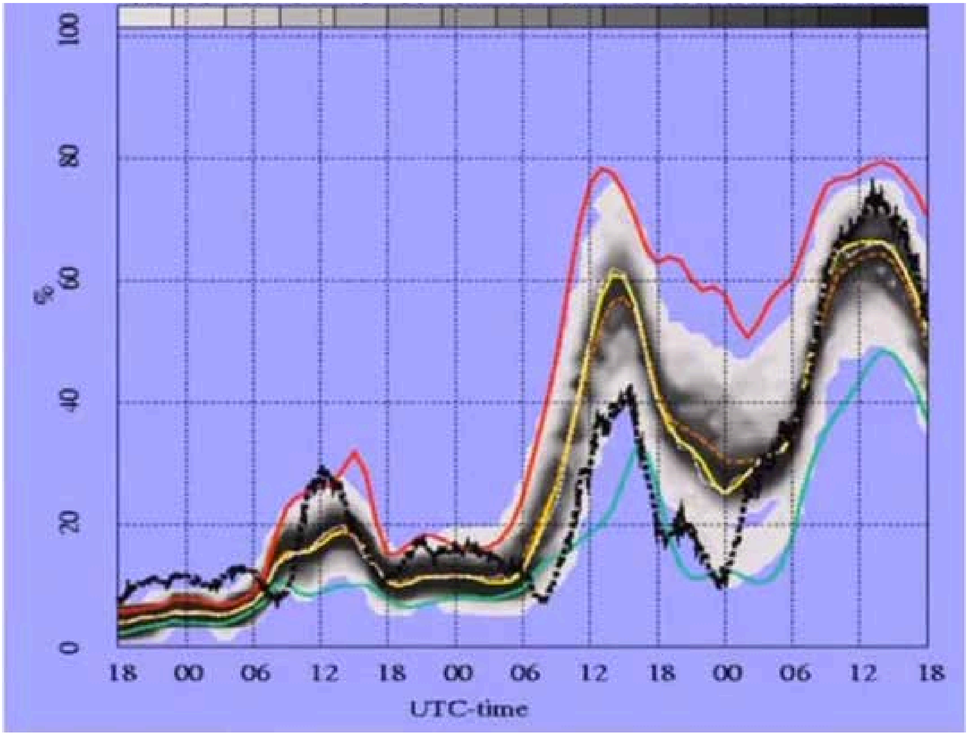
Source: WWSIS Study, NREL 2010

# What about uncertainty?

- Uncertainty is not new either!
  - Demand is not perfectly predictable on a daily basis
  - Also unexpected peaks (cold snap, social event)
- But wind and wave are much less predictable
- Solar PV fluctuates regularly
  - Particularly over large areas
  - And daytime output is always above 20%
- Tidal power highly predictable: 12 hour cycle

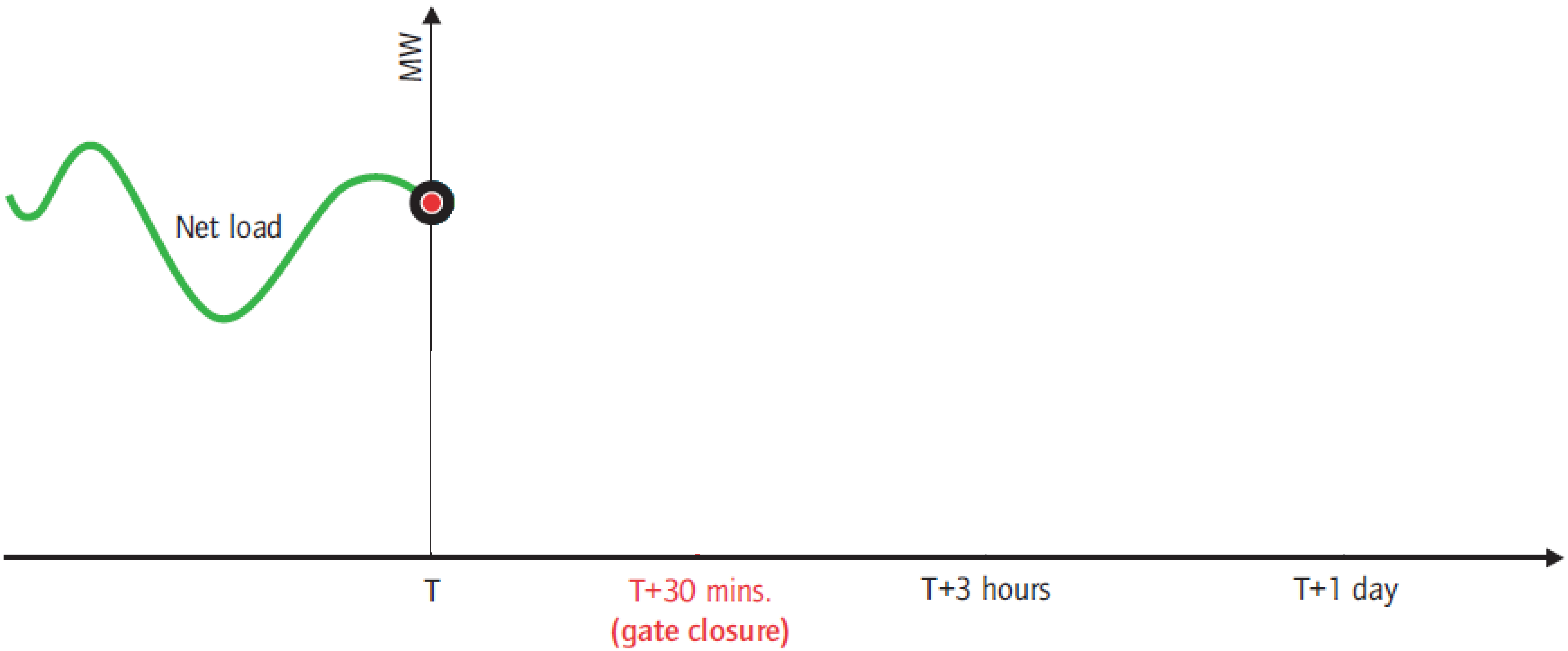
# Forecasting to manage uncertainty

- Centralised, market-wide forecasting now common in OECD countries
- Multiple forecast technologies used in unison
  - “Ensemble forecasting”



# An accurate forecast means...

## ... less reserve requirement against uncertainty




T: Time of operation (instant when electricity is produced and consumed)

Uncertainty of net load at time T (MW)

Flexible resource held against uncertainty of net load at time T (MW)

Net load at time T

Givar_Fig24

# What can we do to minimise variability and uncertainty?

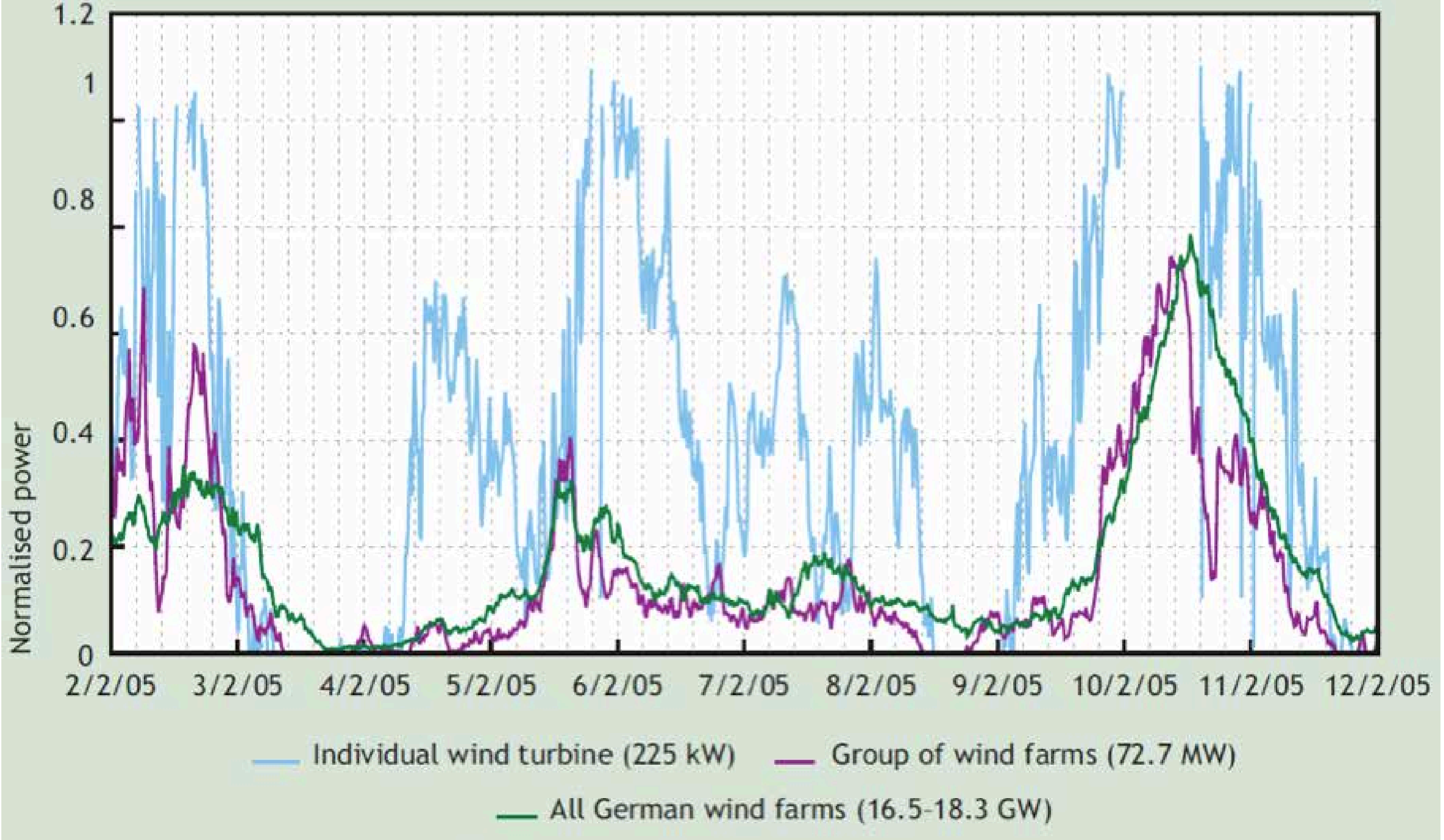
# Three pathways to less of a problem

1. Deploy power plants over a wide area

2. Deploy a portfolio of different technologies

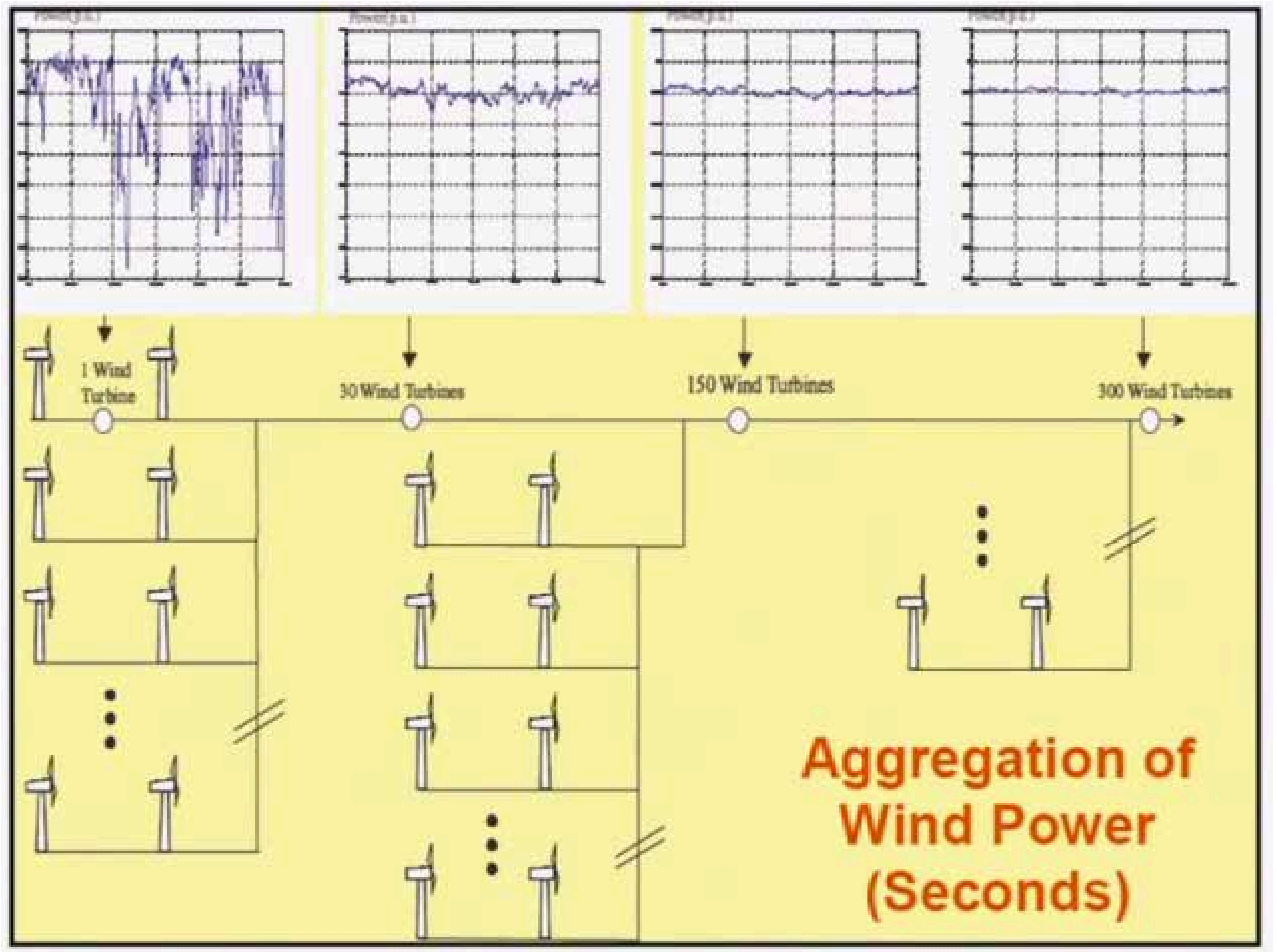
3. Curtail output in times of congestion / surplus
   - But as little as possible

# 1. Deploy over a wide area

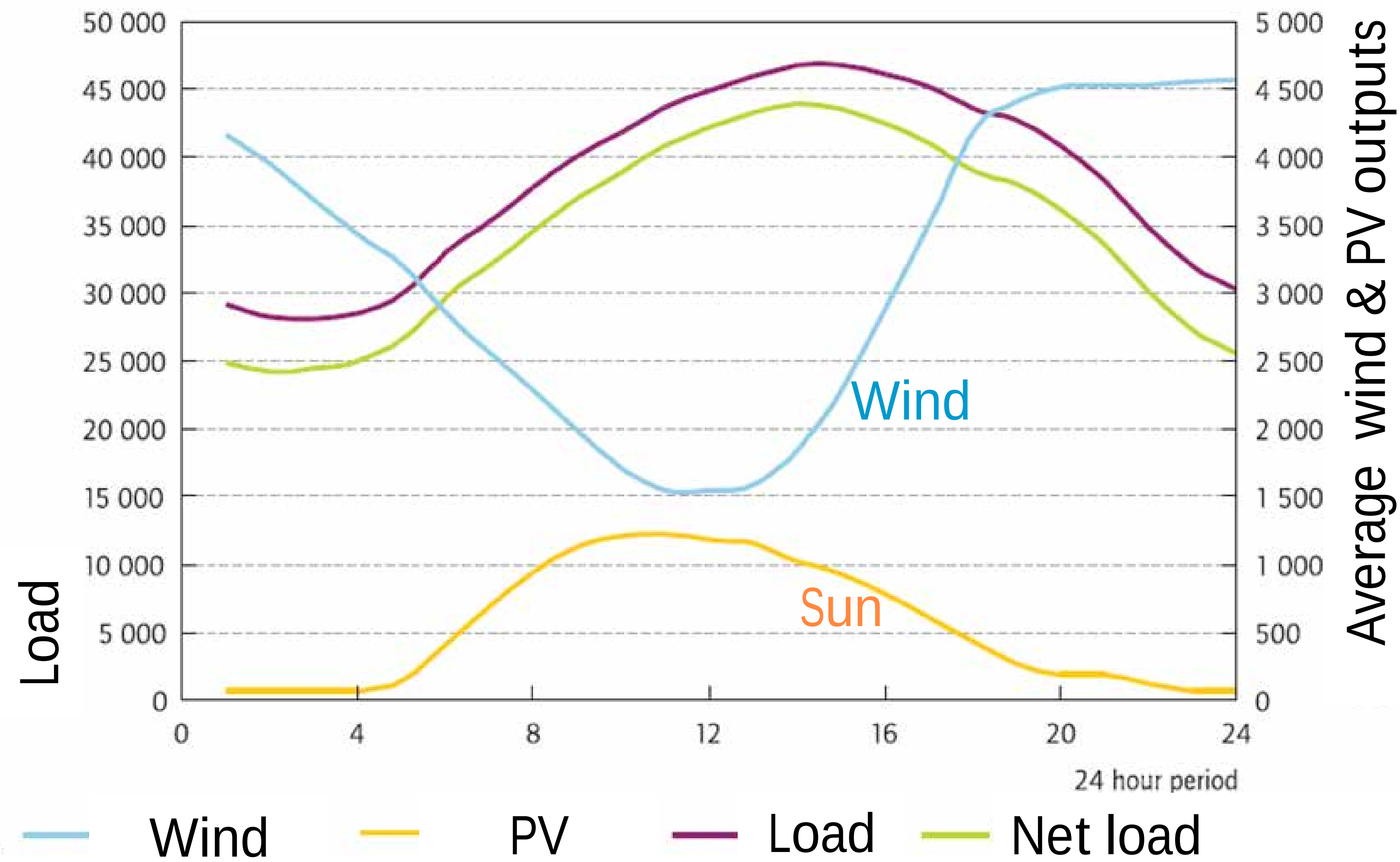



*Source: Wind Energy Report Germany 2006, ISET, Kassel, 2006.*

# … particularly marked in short periods



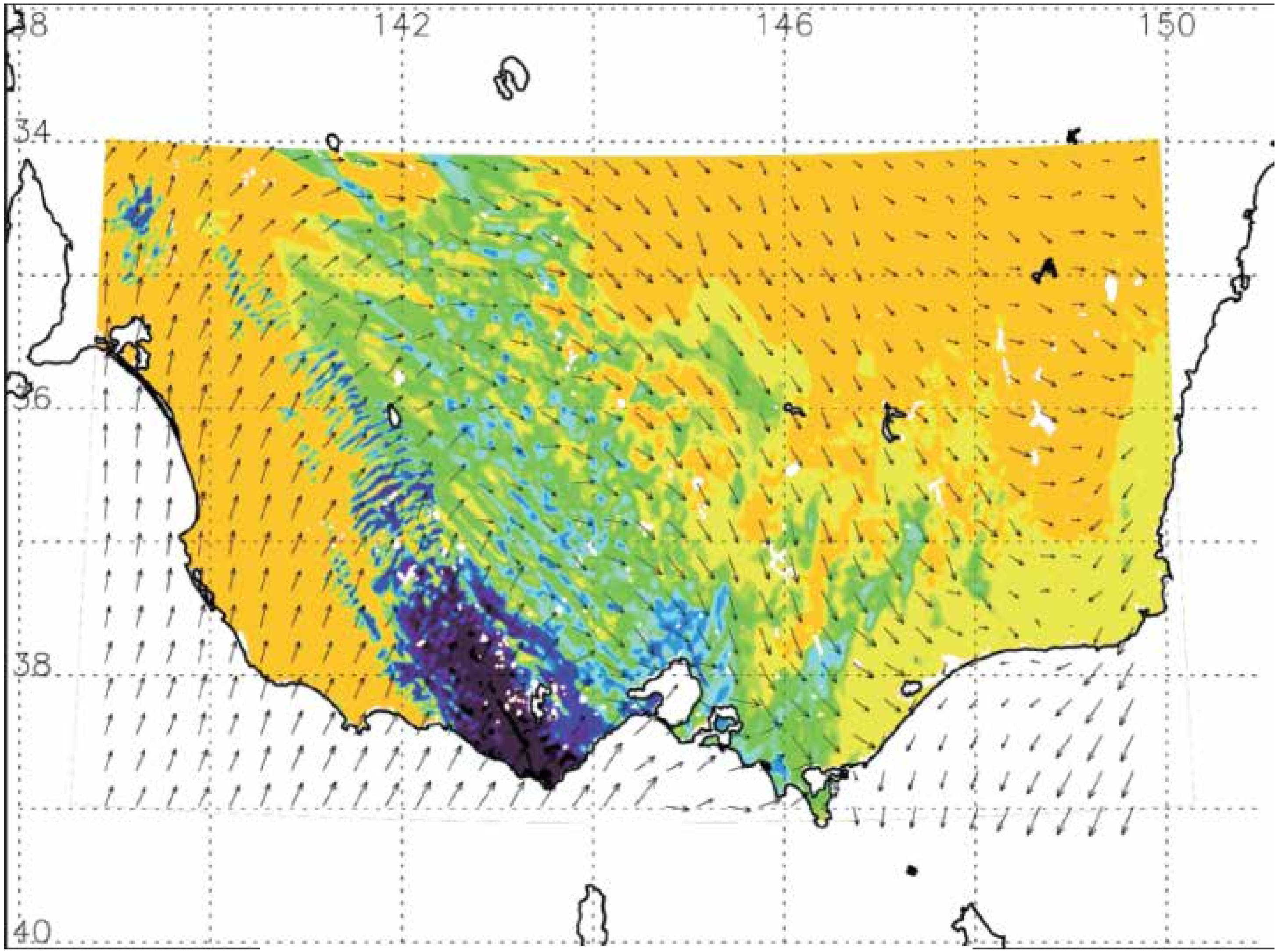
# 2. Deploy a portfolio of technologies






Source: NERC, 2009

# Both principles should inform planning




**Victoria, Australia, on a December day**



Source: University of Melbourne, 2010

# And once variability and uncertainty have been minimised? What then?

# Flexible resources

- Electricity **resources that can ramp up and down** as the weather changes

- Some will **exist already** against variability and uncertainty in demand

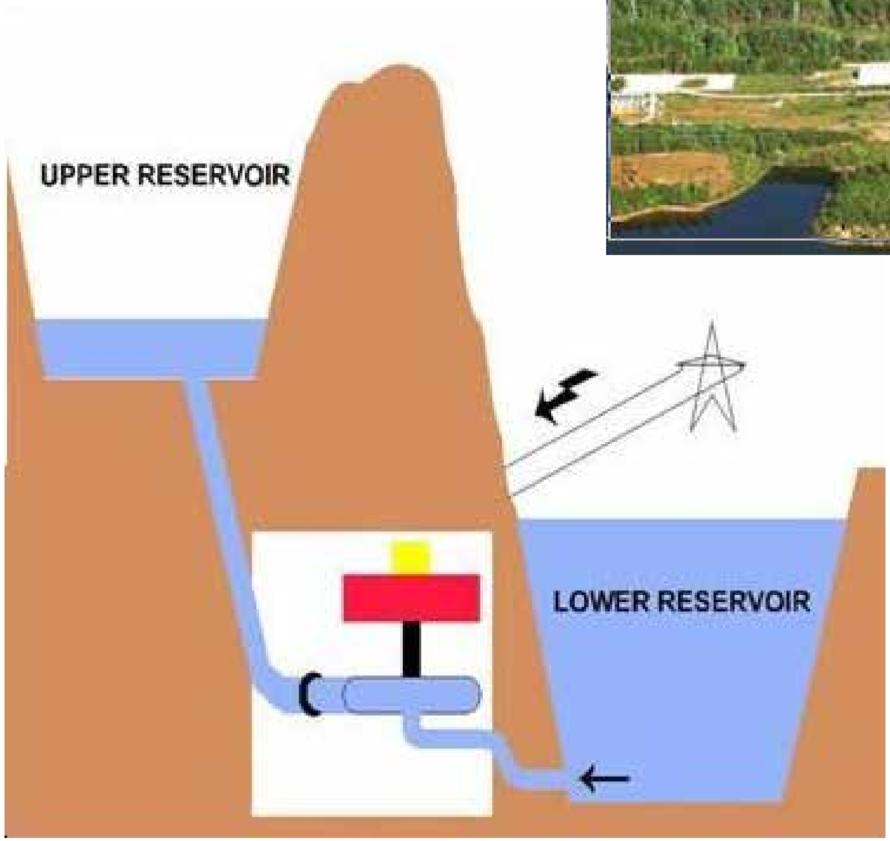
- Four types resource
  1. "Dispatchable" power plants
  2. Energy storage facilities
  3. Interconnections (trade with other markets)
  4. Modifiable demand

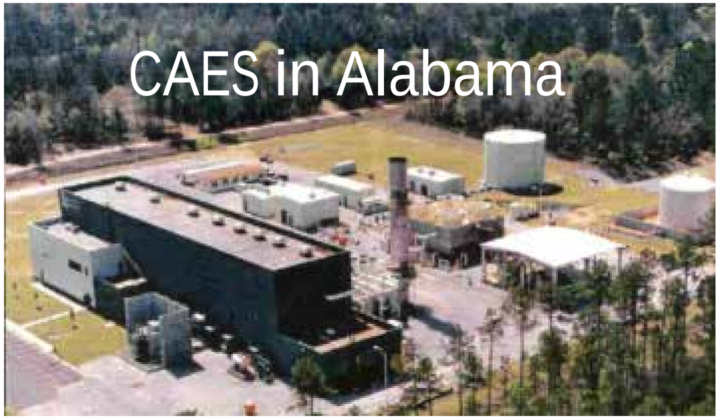
# Dispatchable power plants

- Power on demand
  - Conventional: nuclear, coal, gas, oil
  - Renewable: geothermal, biomass, reservoir hydro, CSP

# Storage facilities

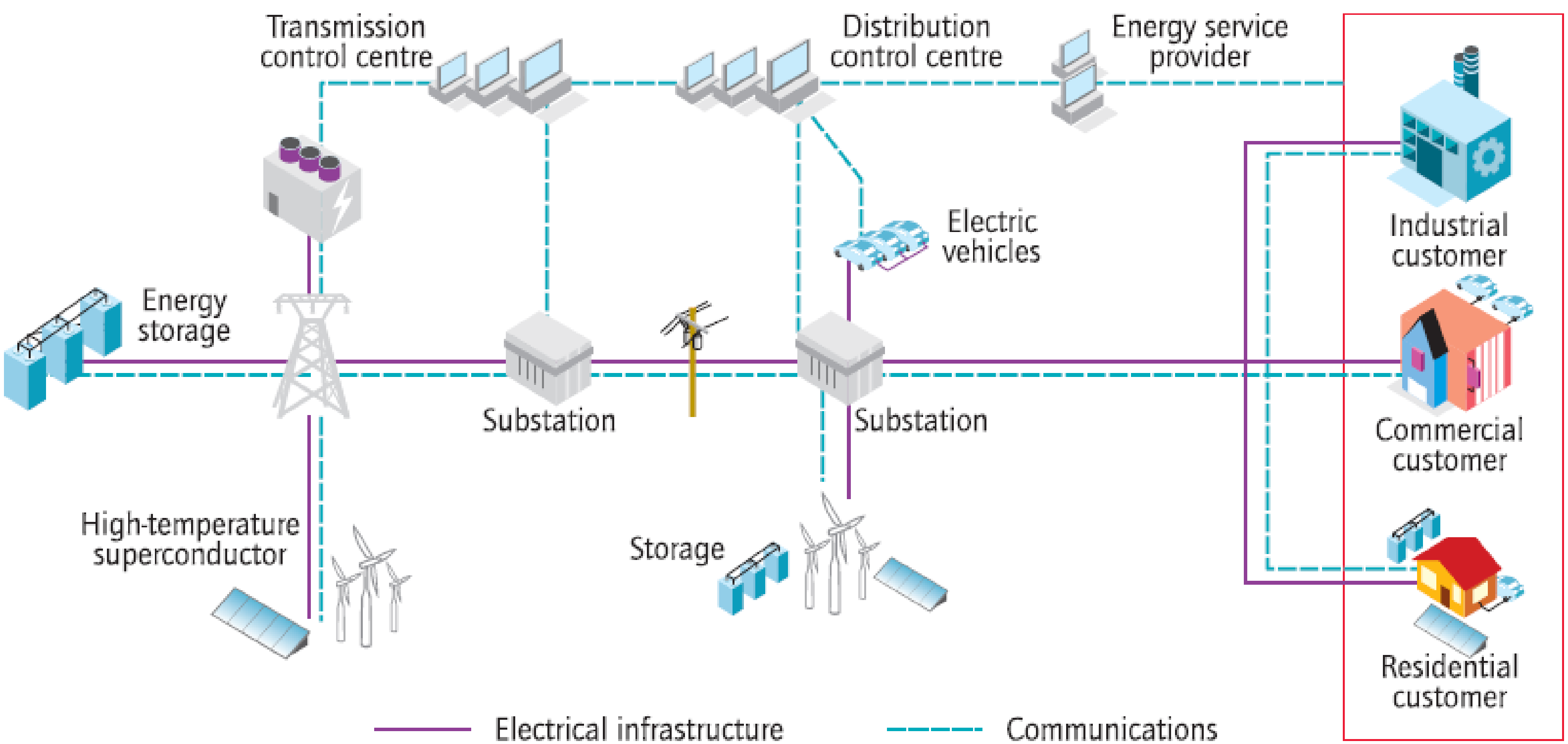
- Pumped hydro, compressed air energy storage



# Flexible demand

- Two types: managed and responsive

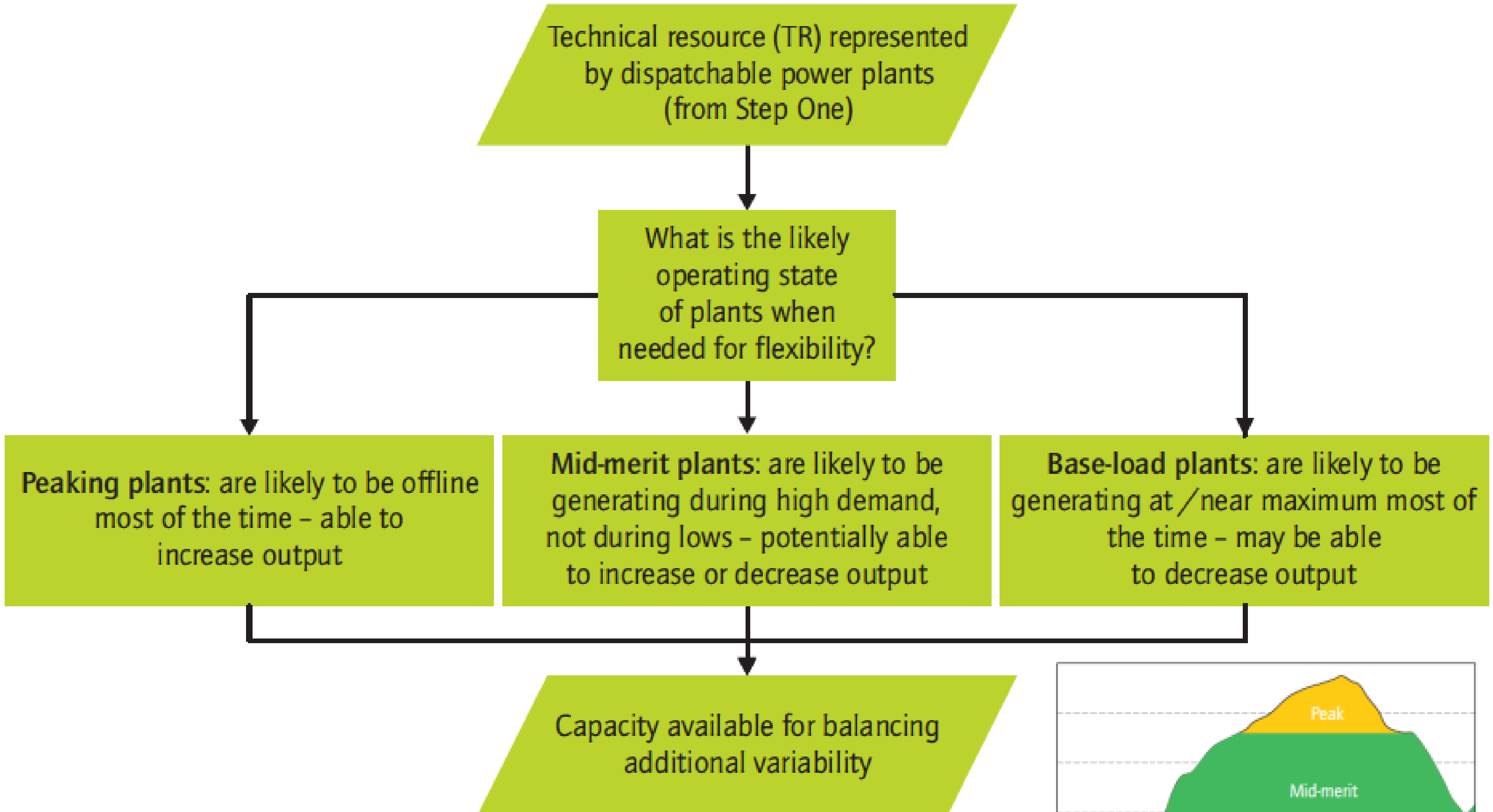


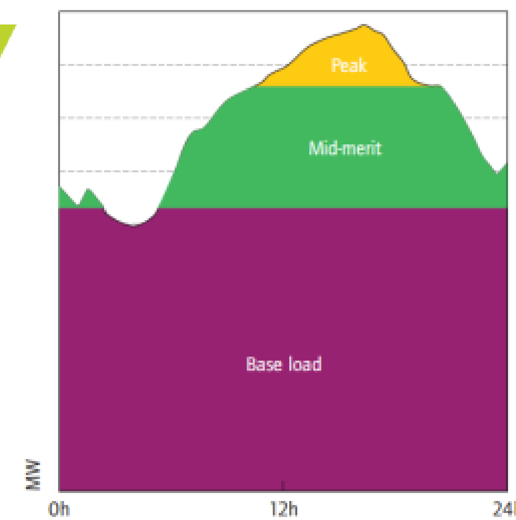
# Interconnections

- Connections between distinct markets
  - Access to flexible resources in those areas
  - Major driver smoothing of VRE

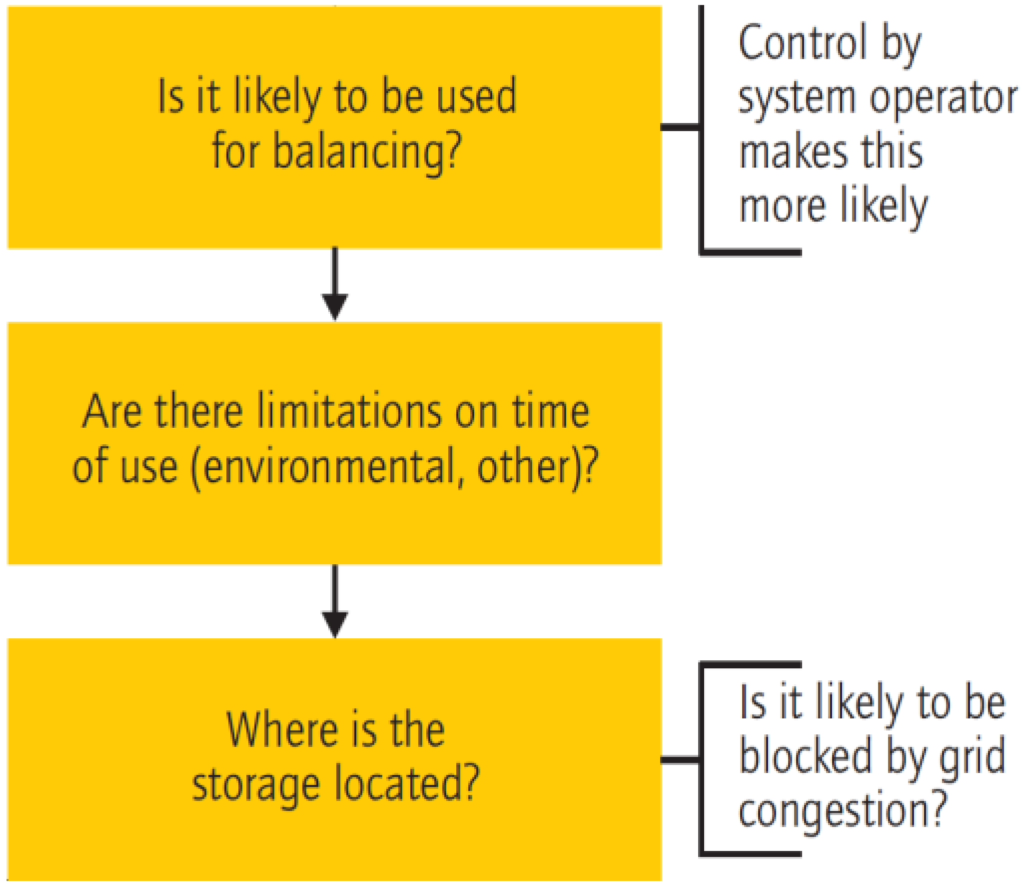
# But are those flexible resources available when they are needed?

# *Can* dispatchable plants respond?



# *Can* storage plants respond?



# *Can* the demand-side respond?

Managed resources

What capacity is contracted in advance by the system operator (managed part of the resource)?

↓

Is this strictly for contingencies or is it available for balancing?

---

Responsive resources

What capacity is likely to be responsive to a real time price signal?

↓

Is real time price available to the consumer (through *e.g.* smart grid)?

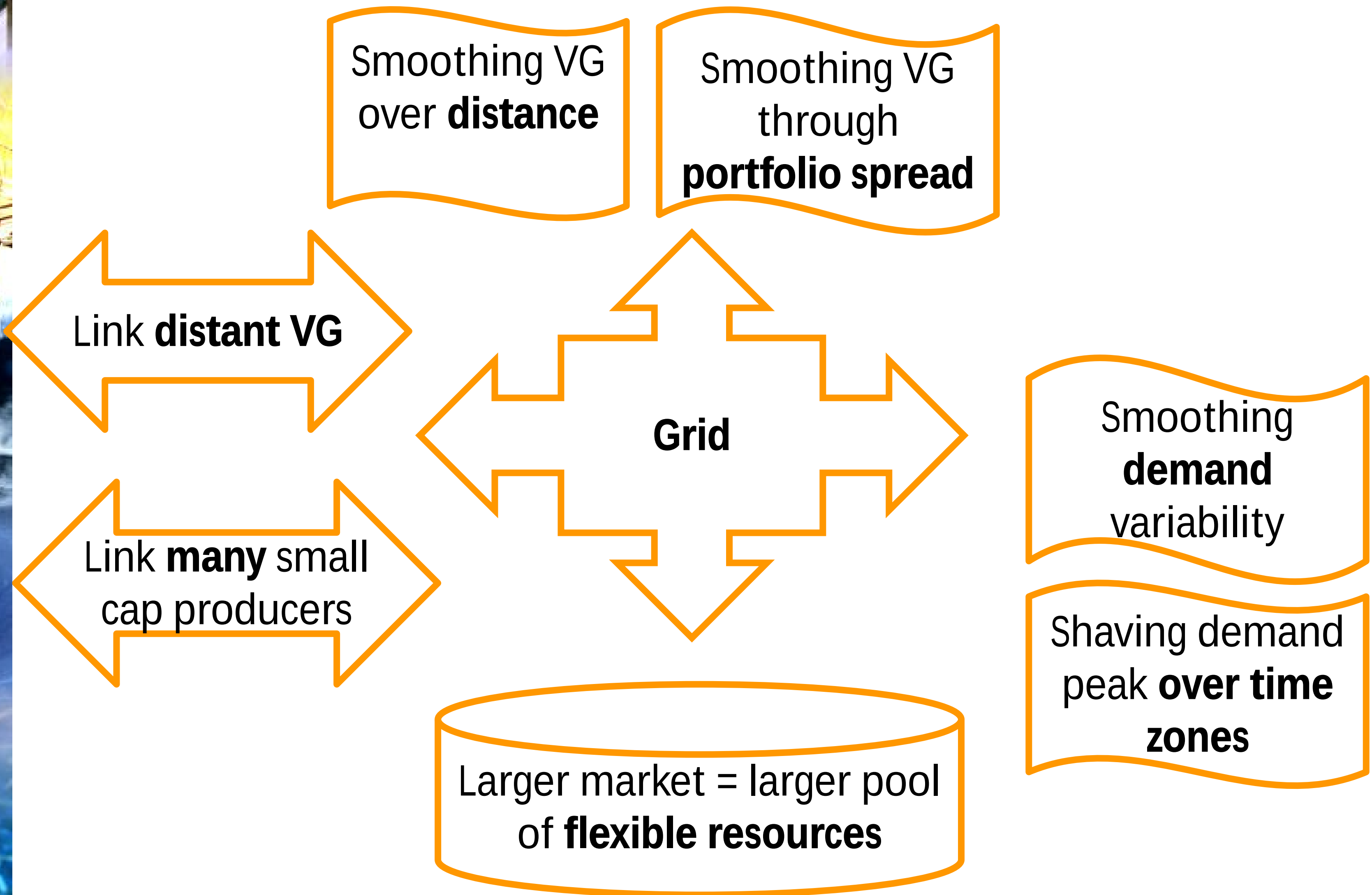
↓

Are small (*i.e.* residential) consumers aggregated into larger block(s)?

# *Can* trade happen when it is needed?

# Wider constraints on flexibility

# The grid is fundamental



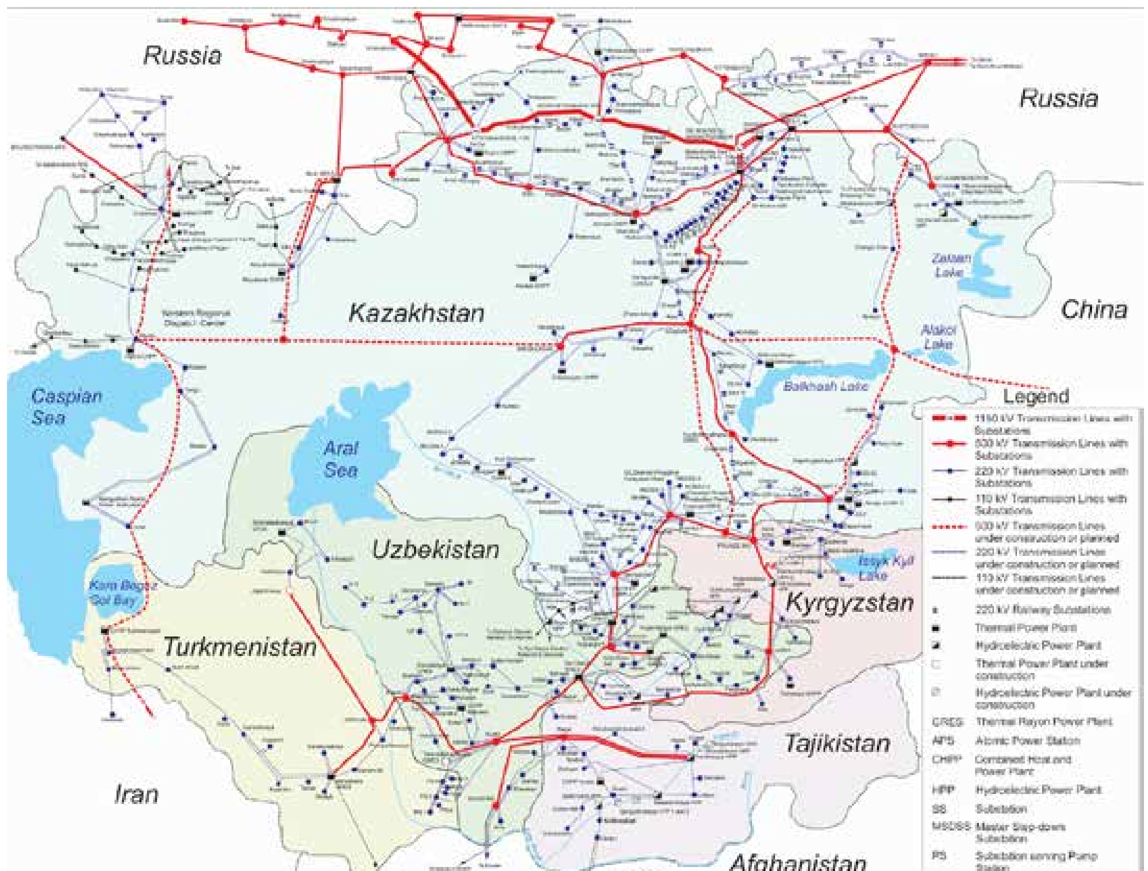
# ...but works on different scales

- At small scale

Source: EPRI

# ...but works on different scales

- At international scale



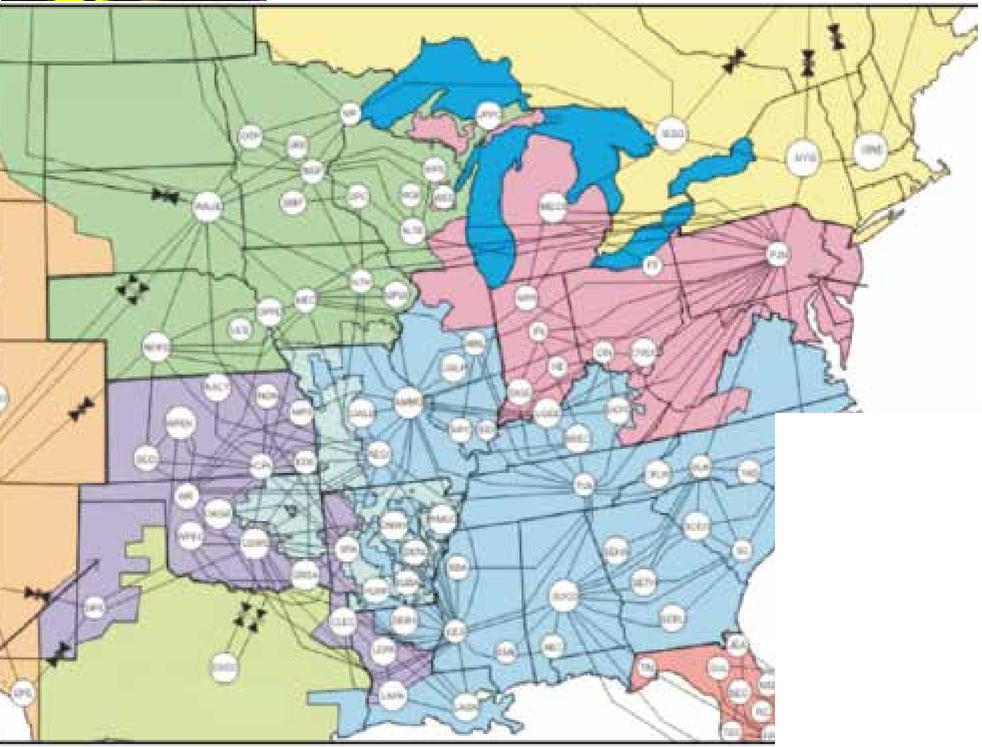
# ...but works on different scales

- At continental scale

# Building the grid

- Transmission and distribution account for **42% of all power sector investment** in IEA scenarios (to 2035)
- **USD 7.1 trillion investment needed** to 2035 (NPS)
  - 2/3 of that is in non-OECD countries
  - Where 2/3 of spend is on **expansion**
    - Compared to only 40% in OECD (majority is refurbishment)
- About USD 190 bn in 2009
  - 33% in China
- Poor maintenance during 1990s likely to mean greater spend in the long term
- **Only 3% of T&D investment specifically to integrate renewables** USD (220 bn)

# In the past, control areas were separate



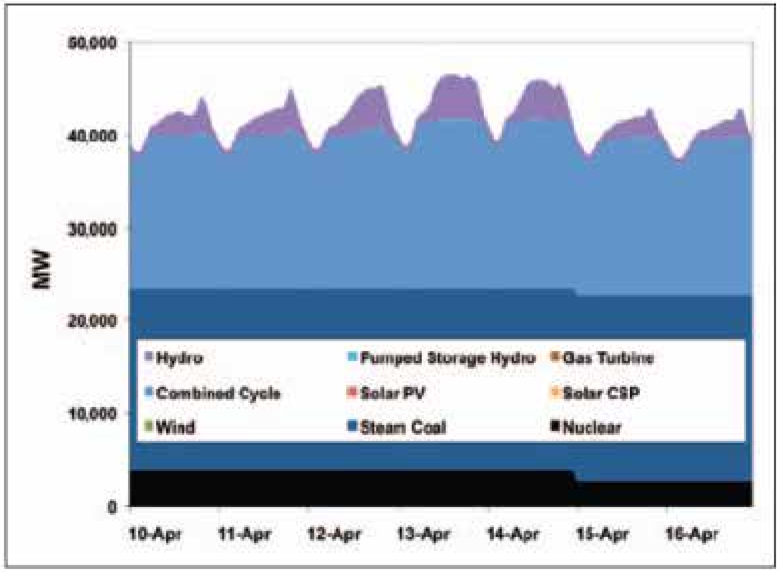
**Today**

Multiple balancing areas in 6 power markets

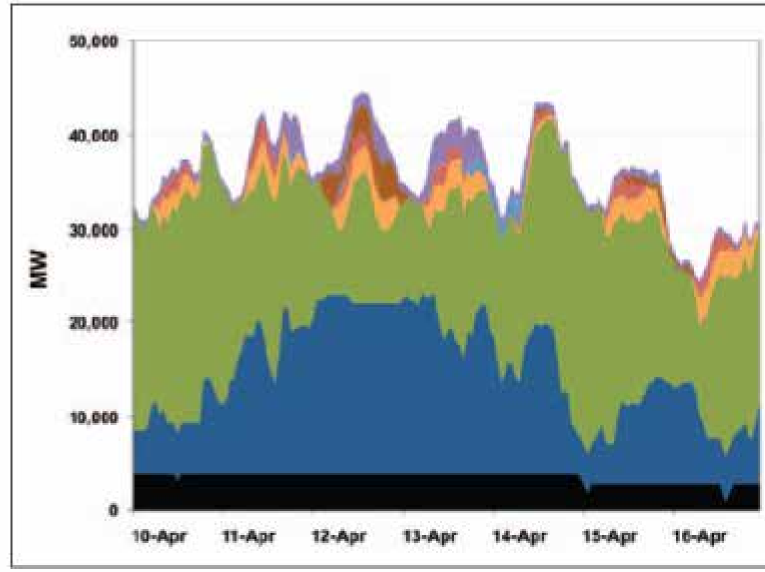
# System and power market operation

# Are existing plants still profitable?

**Without** wind and solar




**A** windy, sunny week




Source: Western Wind and Solar Integration Study, GE Energy for NREL (2010)

- Coal plants are working hard
  - Can they afford to?
- Capacity mechanisms are under discussion…
  - But speed of response is as important as extent

# Conventional markets were inflexible

**INFLEXIBLE** → **FLEXIBLE**

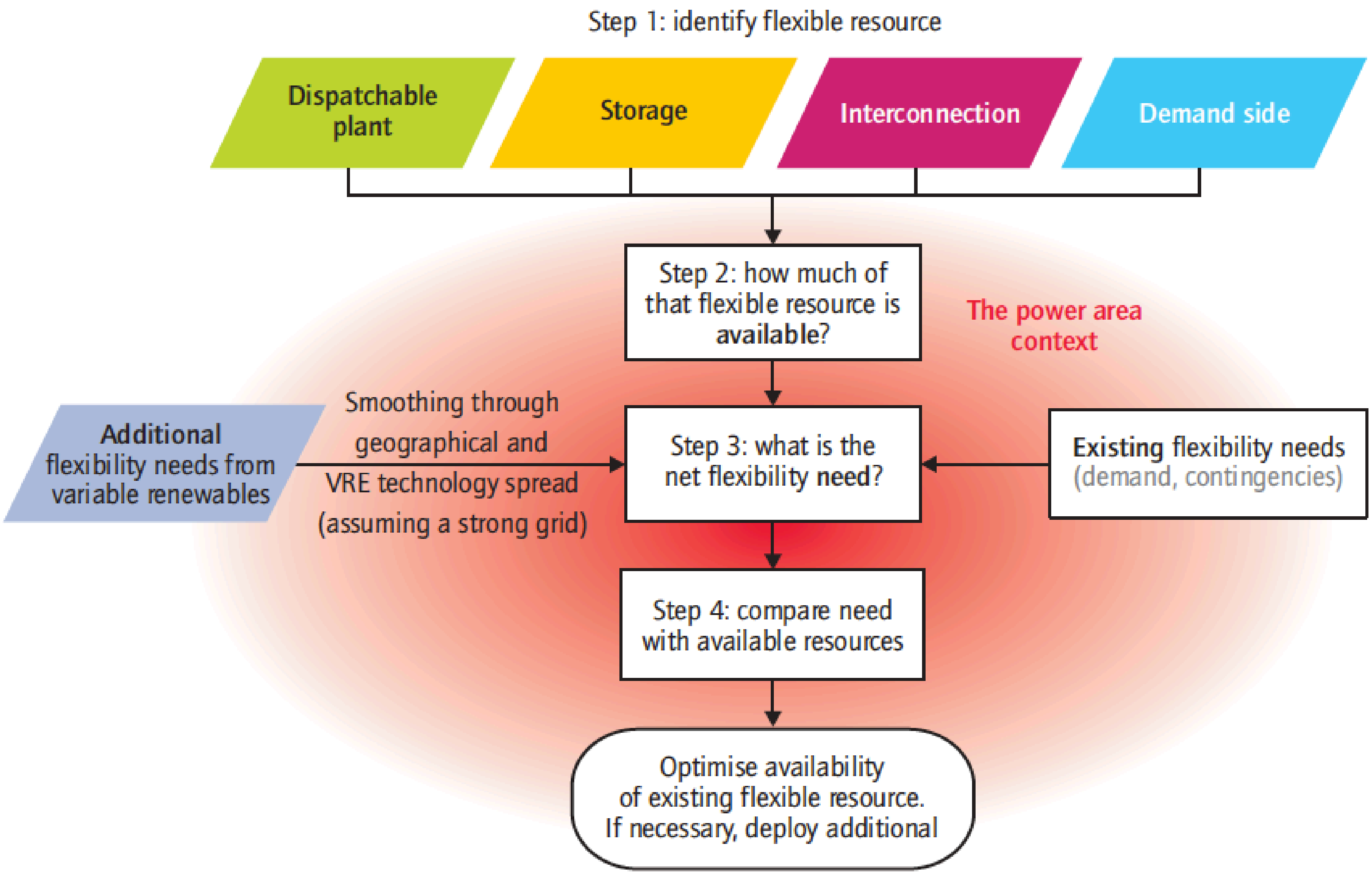
| INFLEXIBLE | FLEXIBLE |
| --- | --- |
| • OTC trading | • Exchange trading |
| • Fixed contracts for reserves | • Trade with neighbours |
| • Days to months ahead | • Balancing, ancillary markets |
| • Low liquidity | • Flexibility incentive |
| • Isolated | • Trading close to real-time |
| | • Advanced forecasting |
| **Shallow pool of flexible resources** | **Deep pool of flexible resources** |

# Key messages

- **Balancing high shares** of VRE is manageable
- **Flexibility** is the essential complement to variability
- Flexibility **assessment** should inform RE target setting
- **More flexible resources exist** than commonly thought
    1. Assess what you already have
    2. Make more of that *available*
    3. Only then, consider additional resources
- A strong, intelligent **grid** is critical
- Large, liquid **markets** using forecasts are better
    - Balancing costs are likely to be lower
- But **lost revenue** may drive off key flexible plants
    - So **compensation** based on provision of flexibility may be necessary

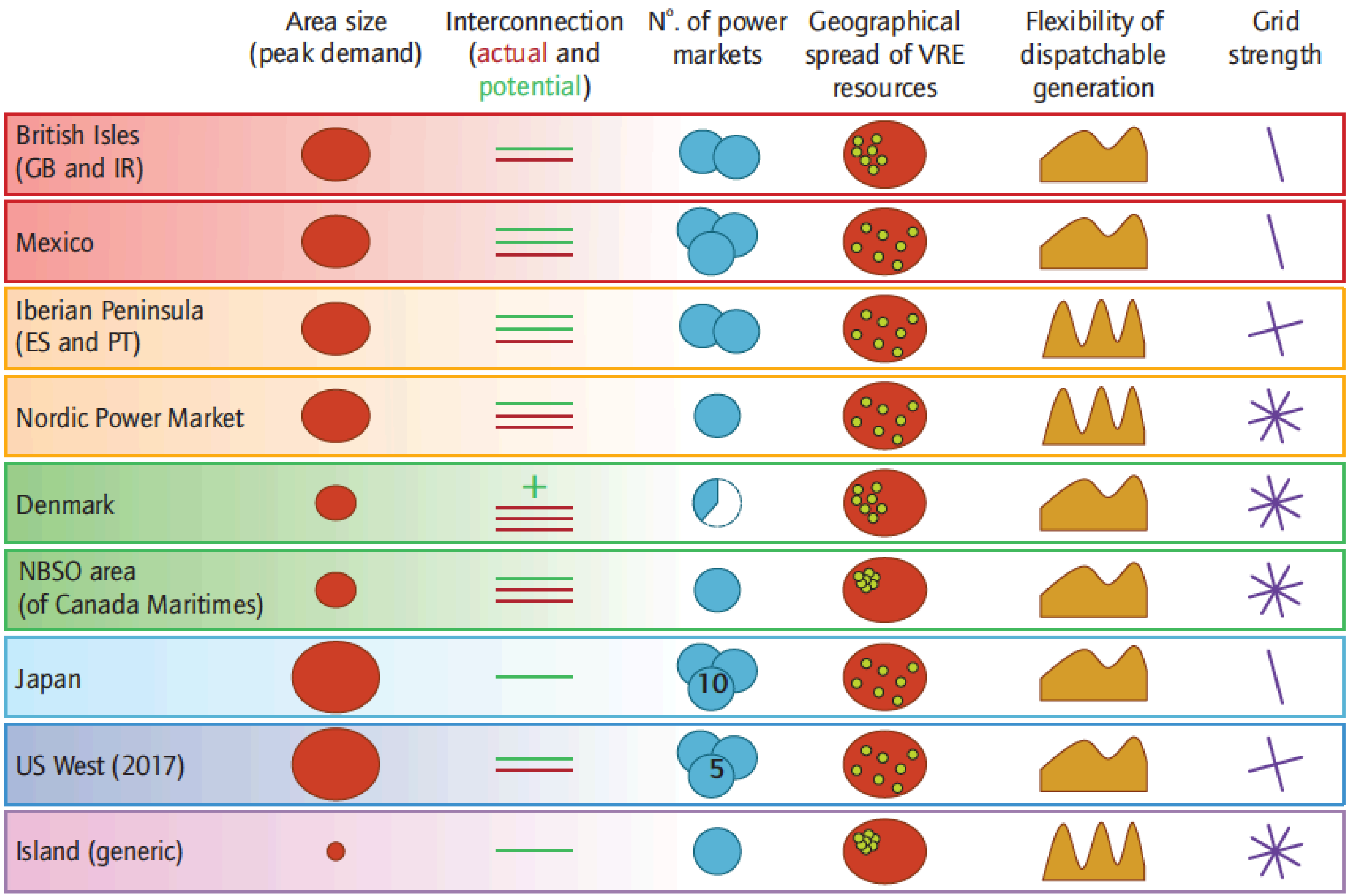
# Assessing flexibility

# FAST Method

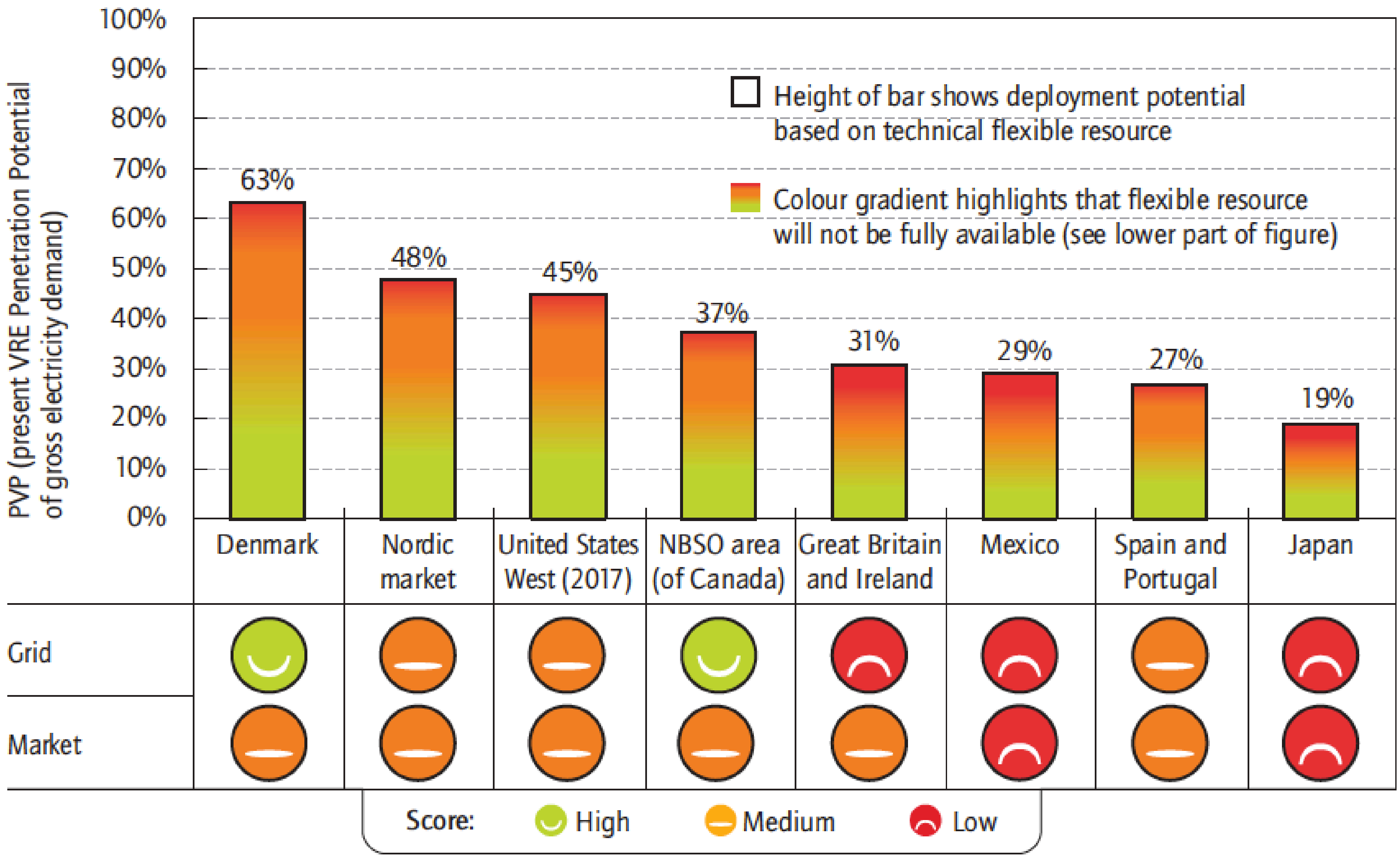


Step 1: identify flexible resource
Dispatchable plant
Storage
Interconnection
Demand side
Step 2: how much of that flexible resource is available?
The power area context
Additional flexibility needs from variable renewables
Smoothing through geographical and VRE technology spread (assuming a strong grid)
Step 3: what is the net flexibility need?
Existing flexibility needs (demand, contingencies)
Step 4: compare need with available resources
Optimise availability of existing flexible resource. If necessary, deploy additional

# Each case is different



# FAST results



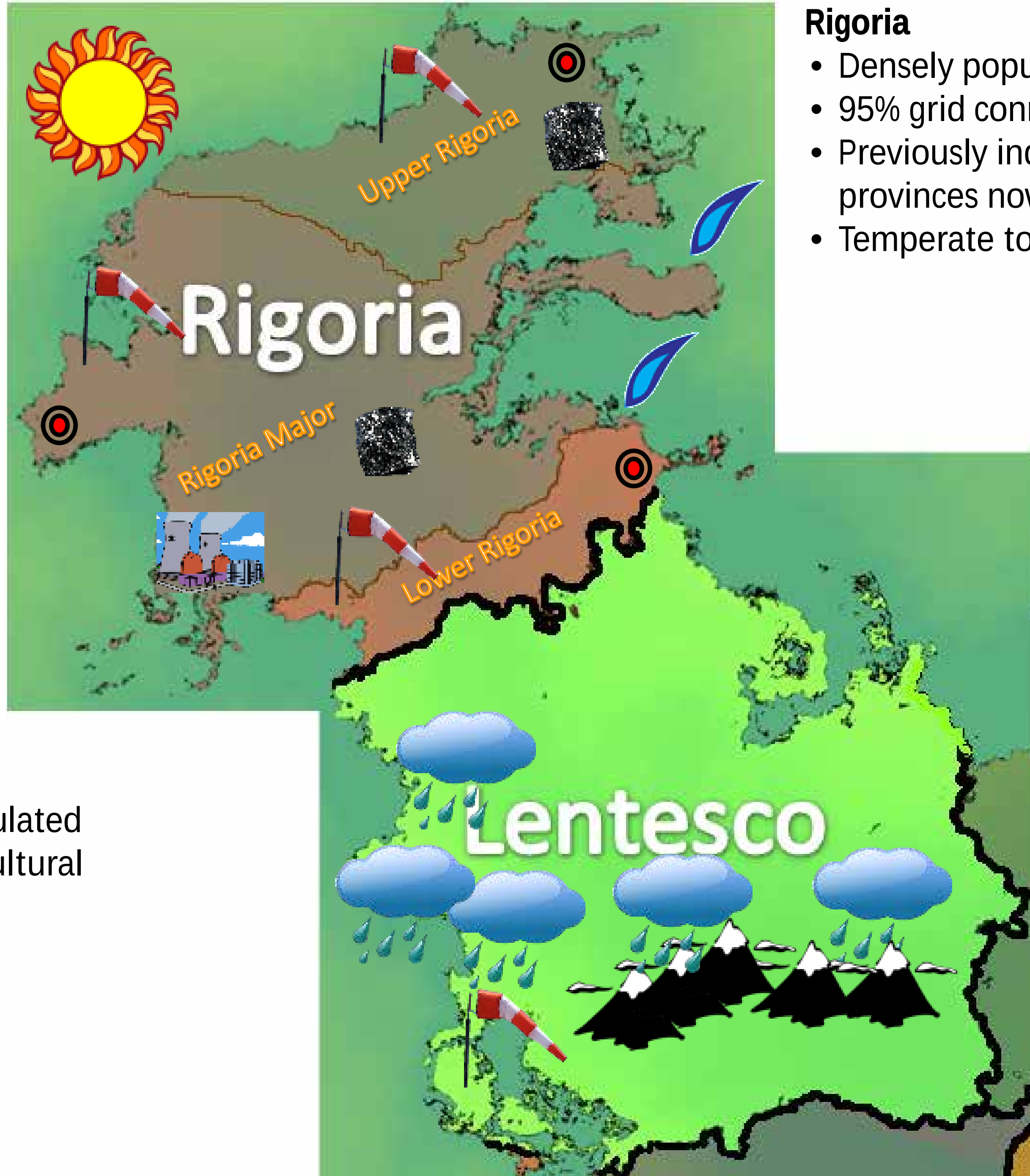
# Example for discussion

## The fictional countries of Rigoria and Lentesco

city

500 km

Prevailing wind




**Rigoria**
- Densely populated
- 95% grid connected
- Previously independent provinces now federated
- Temperate to arid

**Lentesco**
- Sparsely populated
- Heavily agricultural

# Worst Case

1. Let’s imagine an INFLEXIBLE system
   - Minimal presence of flexible resources
   - Minimal availability for balancing VRE

2. Now we introduce VRE plants in such a way that output variability and uncertainty are likely to be high
   - (i.e. we do it in the wrong way)

# Best Case

1. Now imagine a FLEXIBLE system
   - Maximal presence of flexible resources
   - Maximal availability for balancing
2. And introduce VRE plants in a way that will bring minimum additional variability and uncertainty to the existing system

# System Integration of Renewables 2

## Best Practice and Key Policy Steps

**Hugo Chandler, M.Sc. D.I.C.**

# Wind and PV penetration in Germany


**Average for DE: 8%**

**Wind: 6%**

**PV: 2%**

| | 50Hertz | Amprion | EnBW TNG | TenneT | Germany |
|---|---|---|---|---|---|
| Date & time | 01/01/11 06:00 | 07/09/11 14:00 | 25/04/11 13:00 | 08/05/11 13:00 | 08/05/11 13:00 |
| *Wind* | 6 383 | 2 404 | 54 | 5 034 | 8 070 |
| *PV* | 0 | 1 517 | 1 793 | 5 987 | 12 627 |
| Load (MW) | 5 145 | 11 082 | 4 617 | 6 876 | 34 435 |

# Integration Success Factors

1. Get the infrastructure right
2. Encourage system operation to evolve
3. Open up the power market

# Getting the infrastructure right

# Holistic infrastructure planning

- DE: 2010 Energy Concept: system-wide planning
  - Wind energy no longer viewed in isolation
    - All grid needs
    - Conventional and renewable plants
    - Additional flexibility
- DK: Energy Strategy 2050
- EU: 10 year Network Development Plan of all European TSOs
  - Advance warning of weaknesses

# Statutory grid development

- 2009 Power Grid Expansion Act (EnLAG)
  - HV electricity highways to manage congestion
- 2011 Grid Expansion Acceleration Law (NABEG)
  - Reduced planning and permitting delays
    - Present 10 years to 4 years max
- Plan to develop Federal Requirement Plan for Transmission Networks
  - Informed by EU Ten Year plan
  - May be legally binding

# Statutory unbundling

- Until 2010, the German "big four" utilities (E.On, EnBW, RWE and Vattenfall) owned both the grid and the majority of generation capacity
  - Vattenfall sold to Elia and IFC Infrastructure
  - E.On sold assets to Tennet
  - RWE sold 75% of Amprion to a pension fund consortium managed by Commerz Real
- Only EnBW remains bundled
  - Owned by state of Baden-Württemberg

# Public support for transmission

- German population environmentally aware, relatively wealthy
  - But who really wants new transmission pylons?
- Public support campaign in Energy Concept
  - To Build understanding that more VRE = more grid.
- New website launched by TSOs
  - Range of new-build scenarios

  à Presentation of first grid development plan in June
- Compensation for new-build hosts?

# Innovative transmission technology

- Flexible line management based on line temperature monitoring
  - Coincidence of need for carrying capacity and wind output
- High temperature aluminium conductors
  - More capacity on the same pylon size
- Cables instead of overhead lines
  - Danish Cable Action Plan 2009
    - Undergrounding of entire 132kV – 150kV grid by 2030
    - All new 400 kV (highest voltage) lines
    - Probably all distribution network too

# Evolved system operation

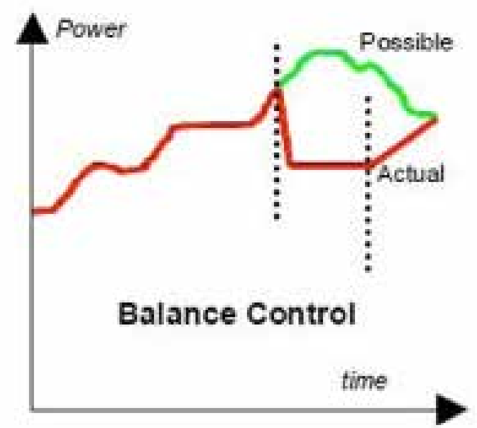
# Effective system management

- Single grid entity
  - Merger of ELTRA and ELKRAFT
  - East and west recently connected
- 100% state-owned
  - Controlled by Ministry of Climate and Energy
    - Key driver towards government target of 50% wind by 2020
  - No conflict of interest
    - Extension / reinforcement delays minimal
- Energinet has responsibility for market operation (with other Nordic TSOs)
  - Can develop market to reflect needs of VRE
  - Can address congestion signaled by the market

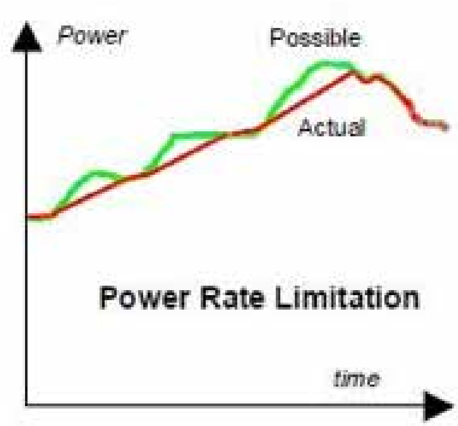
# Supportive RE power plants

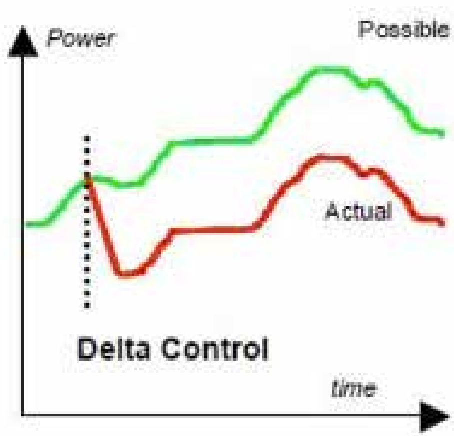
- Distribution (low voltage) grids are usually not actively managed… But more and more plant is installed at this level
  - DE 2011: remote curtailment ceiling lowered from 100 kW to 30 kW – mainly due to PV proliferation
- From village orphan… to pillar of the community
  - New German wind and PV plants are required to support the grid; Incentives to refurbish older plants too
  - In Denmark since 1999 on HV grid

# Supportive RE power plants 2


- Offshore wind farms in Denmark may have to curtail in a number of ways
- If given advance notice, they will not be compensated






Source: EWEA 2005


# Sufficient flexible resources

- German fund encourages new-build fossil plants to use most flexible available technology
  - New generation of super flexible gas plants – GE Siemens, Alstom
  - To be more complementary with VRE output
- CHP plants
  - Larger heat storage – to decouple heat and power production
  - Electric heaters can take advantage of surplus cheap electricity
    - Danish tax on electricity use in CHP reduced in 2008

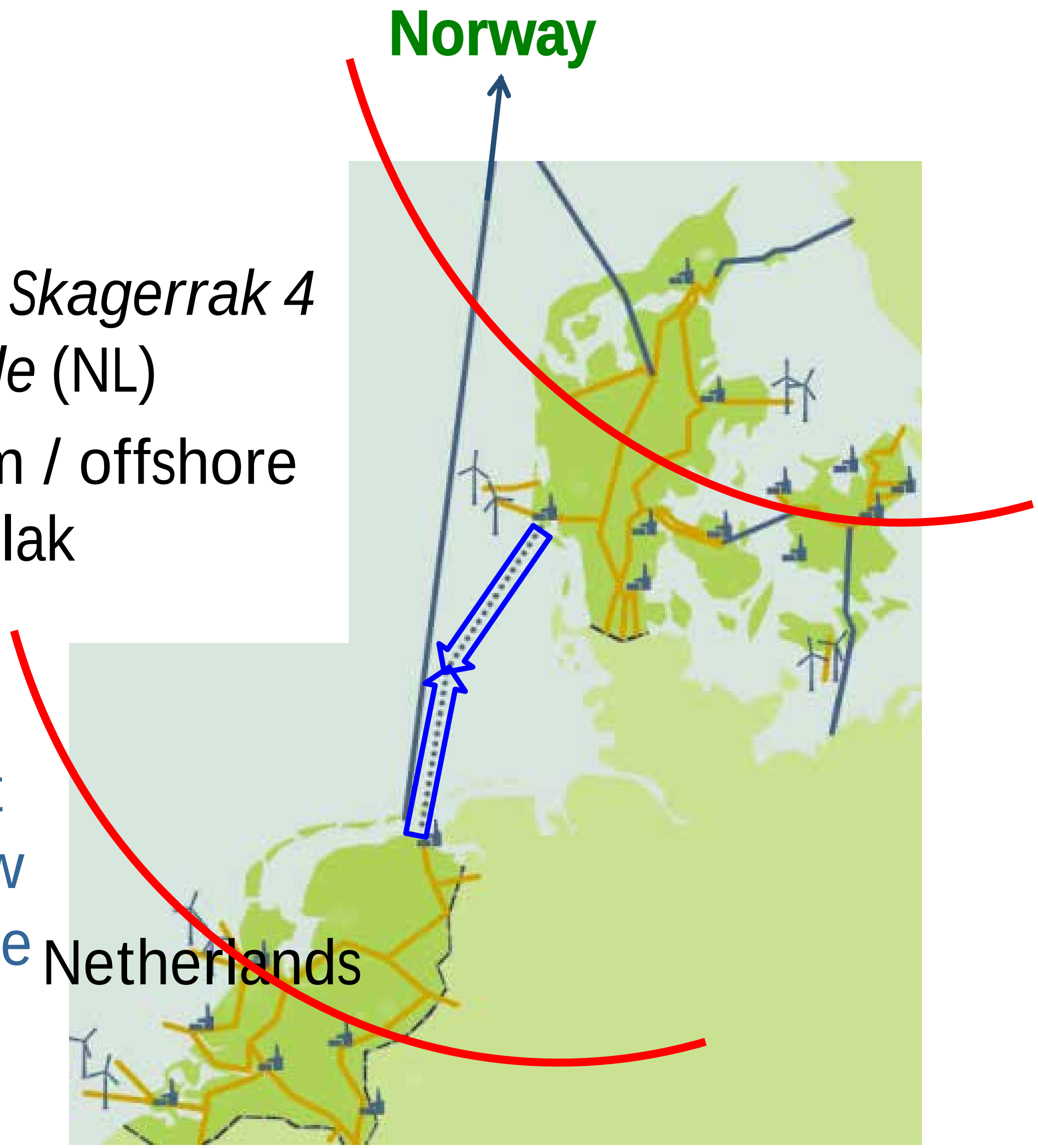
# Smarter network management

- EUR 30 million to support EV charging stations
- All meter installations after 2015 to be smart meters
- Bornholm: 50% wind

# Opening up the power market

# Where feasible, trade

- Future Danish interconnectors: *Skagerrak 4* (NO), *COBRAcable* (NL)
- Shared wind farm / offshore grid at Kriegers Flak




As weather front moves south, flow along COBRA cable reverses

# Market coupling

- Buying electricity is only the first step
  - Electricity is consumed as it is produced – after the buy / sell transaction
- It has to be able to flow to where it has been bought
  - This used to mean explicit auctions of transmission capacity
  - In a coupling, these one-off flows are managed as a whole by the TSOs
  - Removing need for explicit auctions

à Faster and more efficient – a facilitator

à Cheap electricity flows more easily to higher price areas

# European market couplings

Nordic market splitting

Central and West European Market Coupling


Interim Tight Volume Market Coupling

# Flexible power market

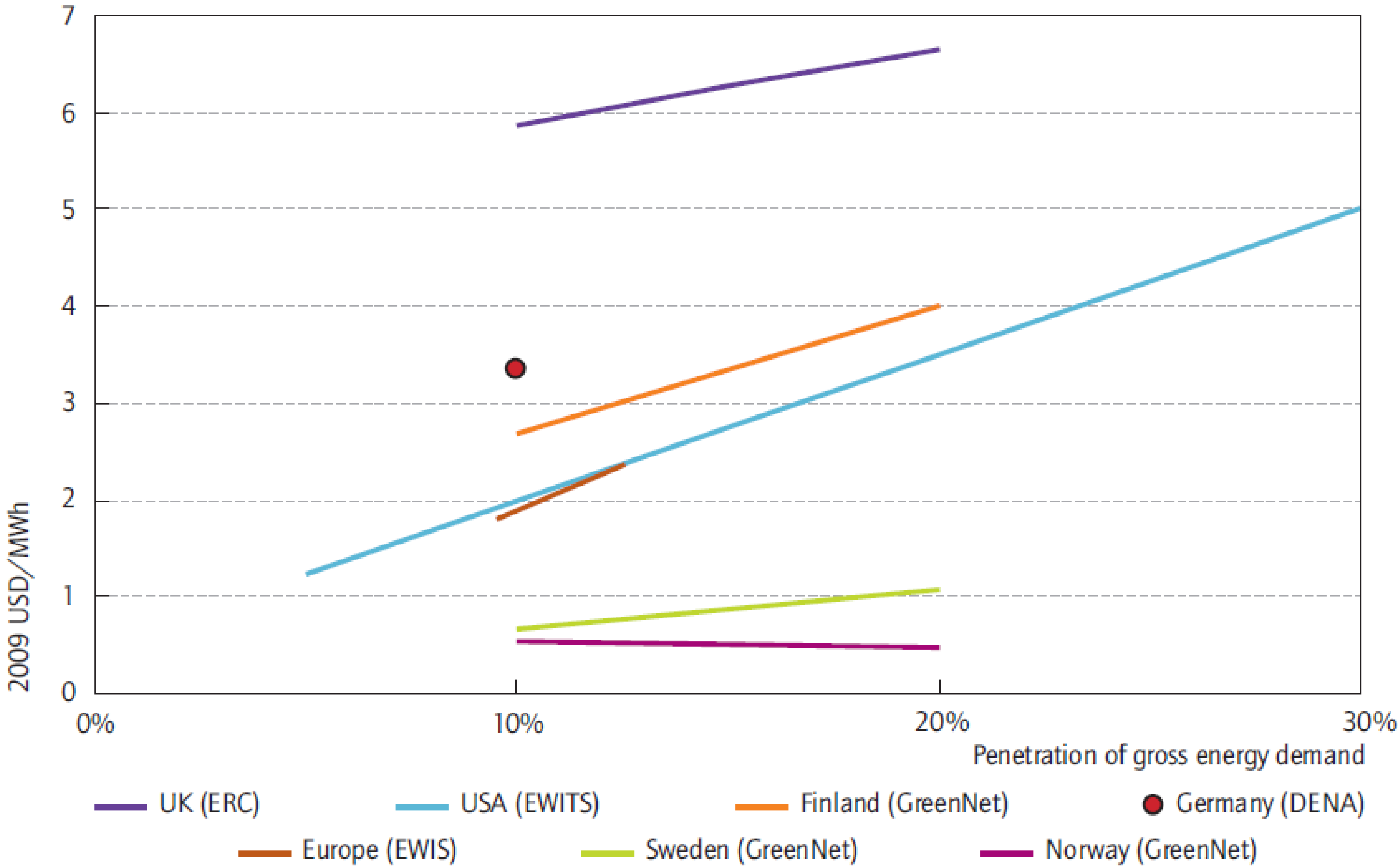
- EPEX (FR,DE,AT,CH): 33% of European power
  - 25% of German power
  - Intra-day trading grew 500% in the three years to 2010.
  - Needs resulting from wind forecast uncertainty to be traded on the intra-day since 2011
  - Gate closure times reduced to 45 minutes ahead in both day ahead and intra-day markets
- Balancing market (after EPEX closes)
  - Now all tenders disclosed through online platform
  - Secondary reserves common across all 4 areas

# Flexible power market 2

- 75% of Scandinavian electricity traded through Nord Pool (45% in 2006)
  - Day ahead and intra-day
- Negative prices (20 – 100 hours pa)
  - Permitted since 2009, replacing floor at zero
  - Producers reduce or pay to generate
  - Large consumer incentive to consume accordingly
- Nordic Operational Information System
  - (Outside Nord Pool market)
  - Immediately needed flexibility (up to 15 minutes ahead) can be traded over the whole Nordic area
  - Offers are managed by the TSOs

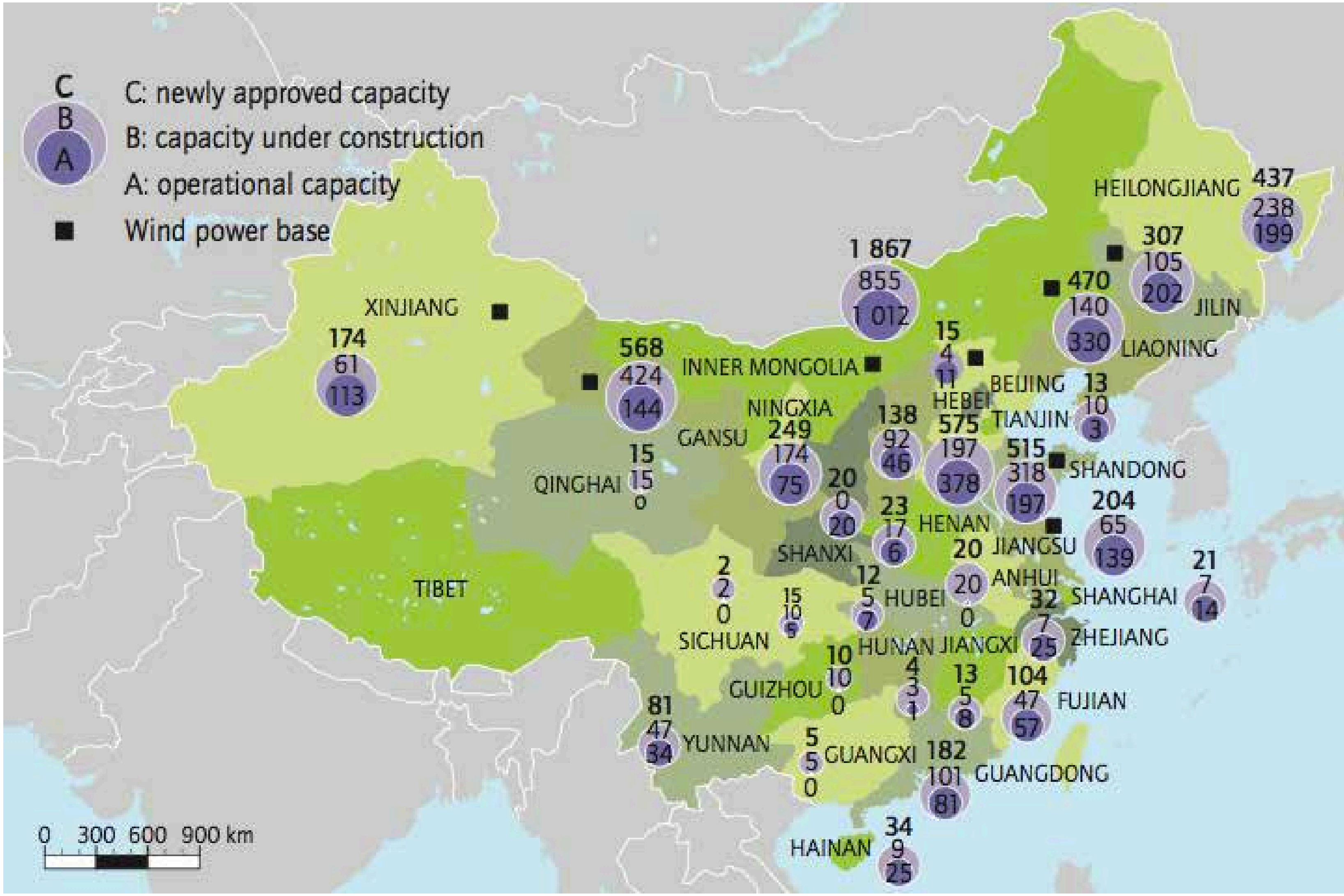
# Integration economics

# Balancing costs

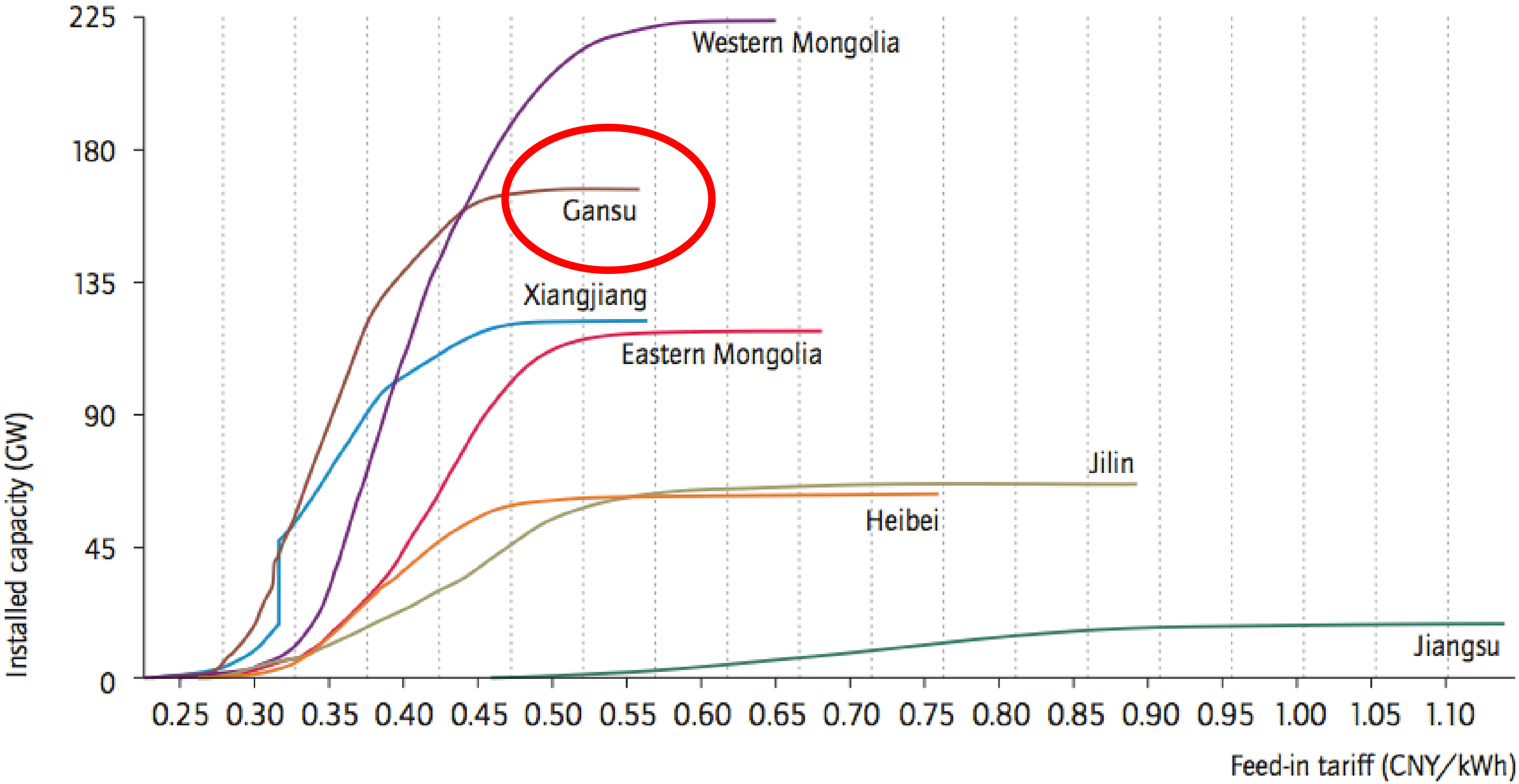



Differences: conventional portfolio, geospread, interconnection, storage, market design, system operation…

# Transmission costs in China

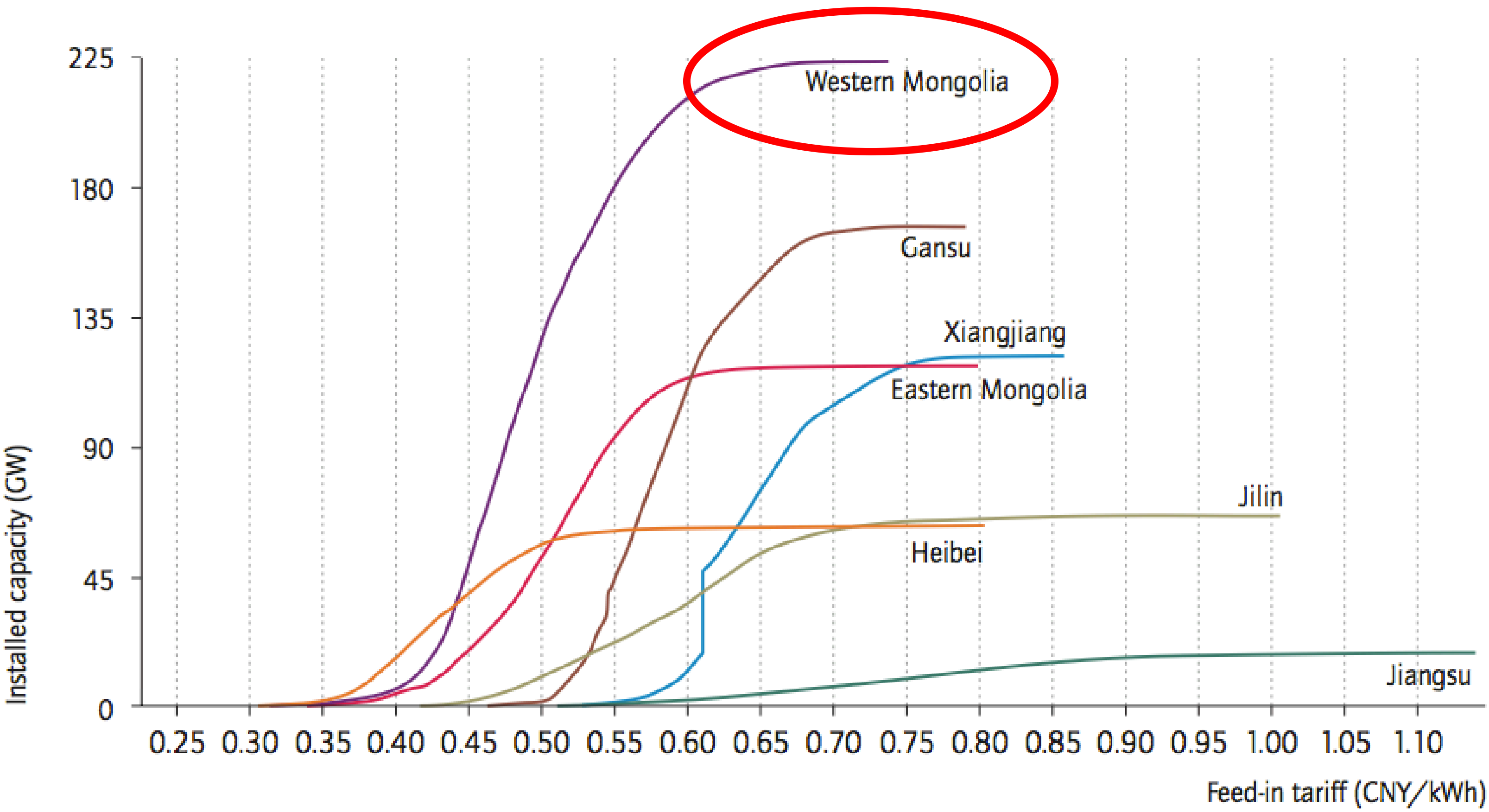


# Wind cost without transmission




The gradient of the curve reflects where the cheapest wind is

# ... and with transmission

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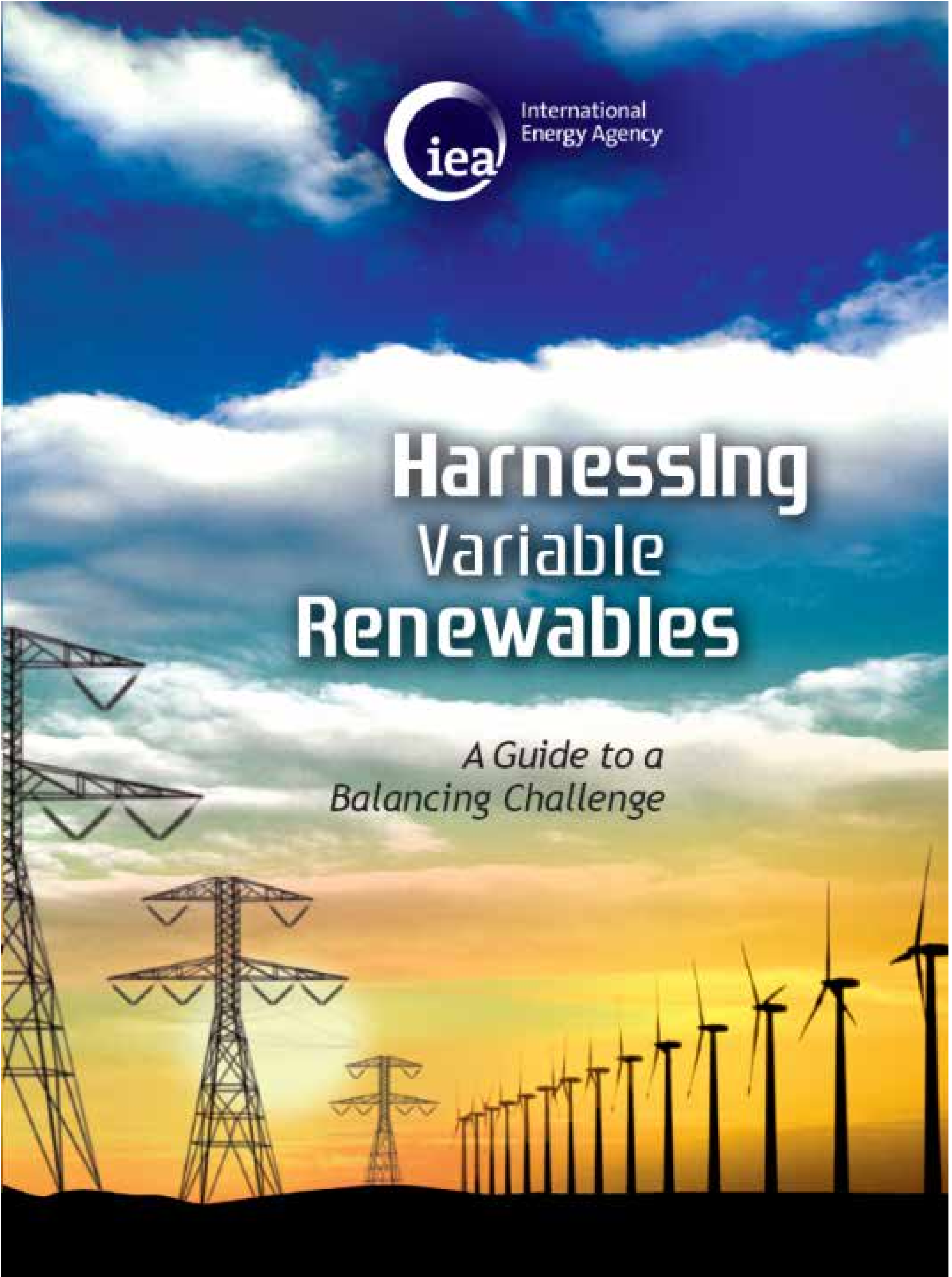


## Follow-up?

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