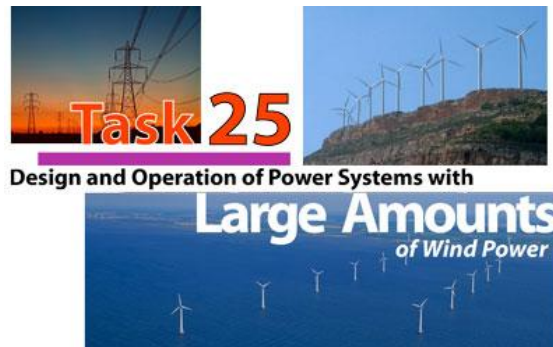VTT TECHNICAL RESEARCH CENTRE OF FINLAND LTD

Wind integration costs – methodologies and shortfalls

Workshop on System integration costs

Wind Europe, 21.3.2018

Hannele Holttinen, Principal Scientist, VTT

Operating Agent, IEAWIND Task 25

IEA Wind Task 25 – What Does It Do ?

- Started in 2006, now 17 countries + WindEurope participate: international forum for exchange of knowledge

- State-of-the-art: review and analyze results so far: latest report June 2016

- Formulate guidelines- Recommended Practices for Integration Studies: Updated to include solar PV in 2018

- Fact sheets and wind power production time series

https://community.ieawind.org/task25/home

IEA Wind Task 25

Design and operation **power systems with** **large amounts of win** **power**

Final summar
Phase three 2

EXPERT GROUP STUDY ON
RECOMMENDED PRACTICES

16. WIND INTEGRATION STUDIES

Wind Integration Issues

Large Amounts *of Wind Power*

Task 25 Fact Sheet

Contents

- Definitions – wind integration studies interest in integration costs
- Evolving methods and experience
- Integration/system costs – other than wind perspective
- Status – what we think today
- Vision: from integration cost of wind power to design and operation of 100% renewable energy systems

07/08/2018

Integration cost, what and why?

- Costs for power system for accommodating wind power
  - Not covered in investment costs by wind power producers
- Information needed for
  - Policymakers to ensure that the benefits of increasing wind energy will not be offset by negative impacts
  - System operators, regulators to ensure fair treatment of all producers: market design and rules, tariffs, allocation of costs

Integration costs include

- things that are paid for in some markets

1. Balancing cost: carrying and using extra operational reserve for extra uncertainty; extra fuel and ramping / cycling for extra variability

   - In some systems wind power plants pay imbalance fees (sometimes higher than costs incurred)

2. Transmission infrastructure cost: reinforcing the grid

   - In some systems wind power plants pay "deep grid connection costs" that will pay for part of this

3. Lower capacity value compared to conventional generation

   - Is this a cost? A reduced benefit? In capacity markets, no compensation for wind.

BALANCING

TSO balancing task – from schedules of the producers/main actors in the market

→ Short term /frequency support reserves,
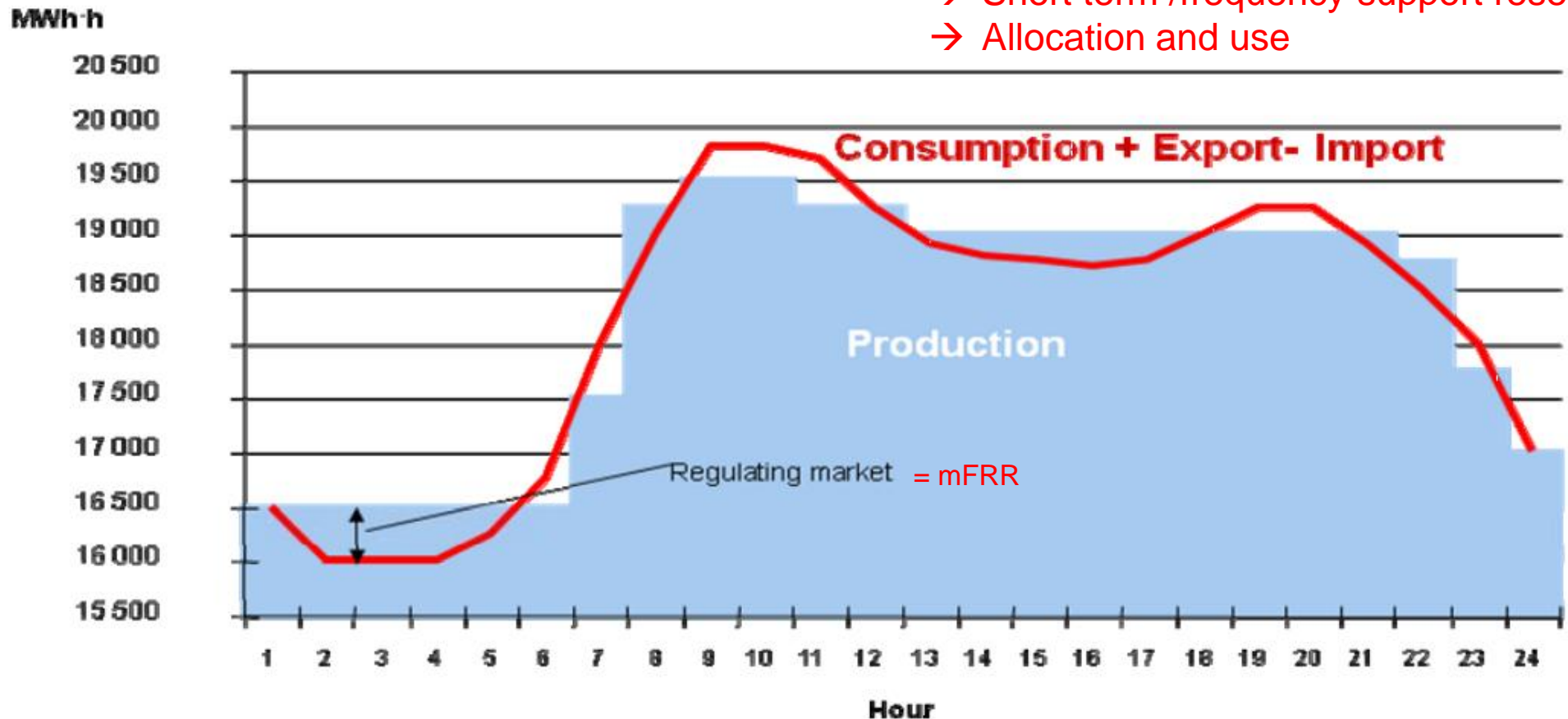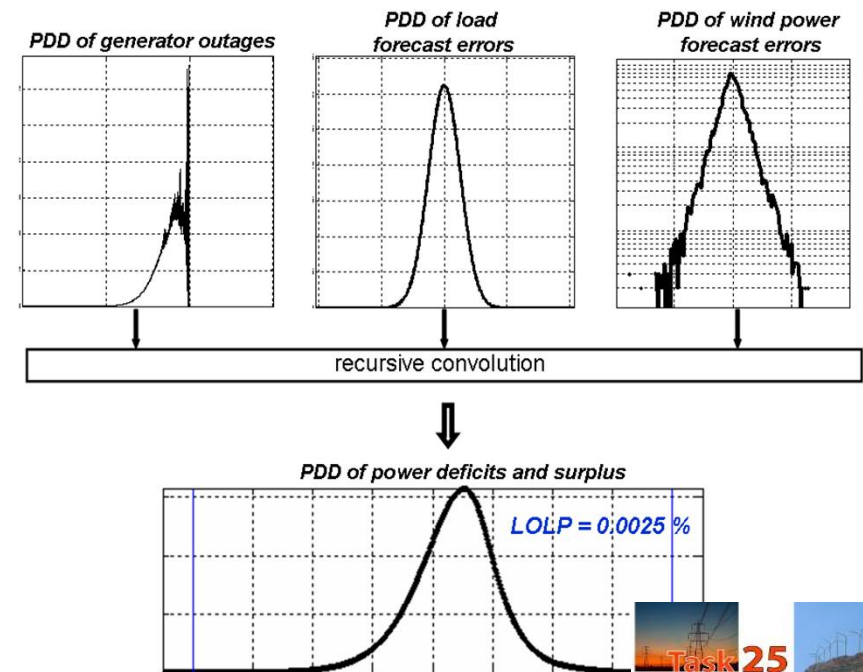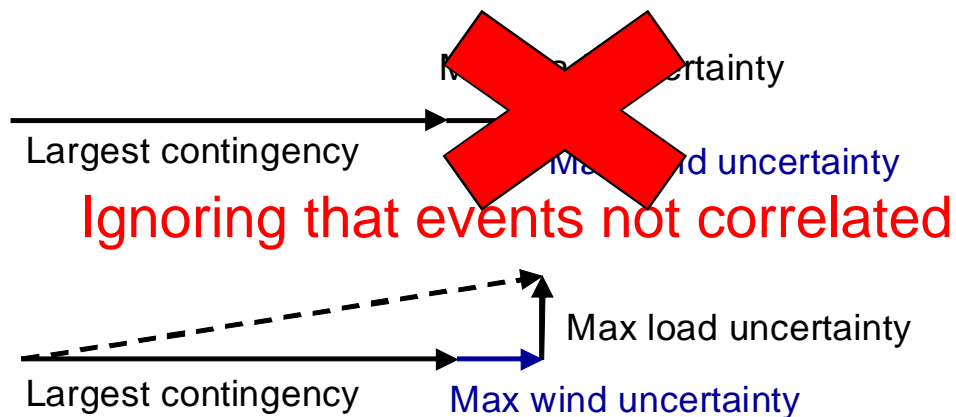→ Allocation and use

FIGURE 1 THE BLUE PRODUCTION GRAPH REPRESENTS THE HOURLY NOTIFICATIONS PLAN. THE TSO MUST MAINTAIN THE MOMENTARY BALANCE BETWEEN PRODUCTION, CONSUMPTION AND EXCHANGE IN THE OPERATIONAL HOUR. THE REGULAT[...] (TERTIARY RESERVE) IS THE TOOL TO ADJUST THE PRODUCTION TO THE ACTUAL CONSUMPTION (NORDIC MOD[...]

Impacts of wind power on short term reserves - methods

- System copes with variability and uncertainty of loads – and sudden failures of large thermal power plants. Combining variability and uncertainty of all sources:

From simple rule of thumb:

To probabilistic analyses:

Max ~~load~~ uncertainty

Largest contingency

Ignoring that events not correlated

Max load uncertainty

Largest contingency

Max wind uncertainty

PDD of generator outages

PDD of load forecast errors

PDD of wind power forecast errors

recursive convolution

PDD of power deficits and surplus

LOLP = 0.0025 %

Results on increase in operating reserves

- Time scale of uncertainty brings large differences in results
- Results for hourly variability similar

Increase in reserve requirement

Legend:
- dena Germany (average; up and down)
- Germany 2010/Day-ahead (pos.)
- Germany 2010/4h-ahead (neg.)
- Germany 2010/1h-ahead (pos.)
- Ireland Tertiary Res.
- Ireland Replacement Res.
- Sweden 1 hour
- Sweden 4 hours
- UK, 2007 distributed wind
- Hydro Quebec
- Minnesota 2006
- US New England ISO
- NL hourly variability
- Finland hourly variability
- Sweden hourly variability
- Denmark hourly variability
- Nordic hourly variability

Y-axis: Increase as % of wind capacity
X-axis: Wind penetration (% of gross demand)

In addition to reserves - balancing costs from cycling of thermal power plants

- How to capture the increase in balancing costs in the big picture of decreasing operational (fuel) costs?

- Also Variable O&M costs go down…

- The part of operational cost that is there when assuming costs should decrease linearly?


West US Operational costs (WWSIS II, NREL)
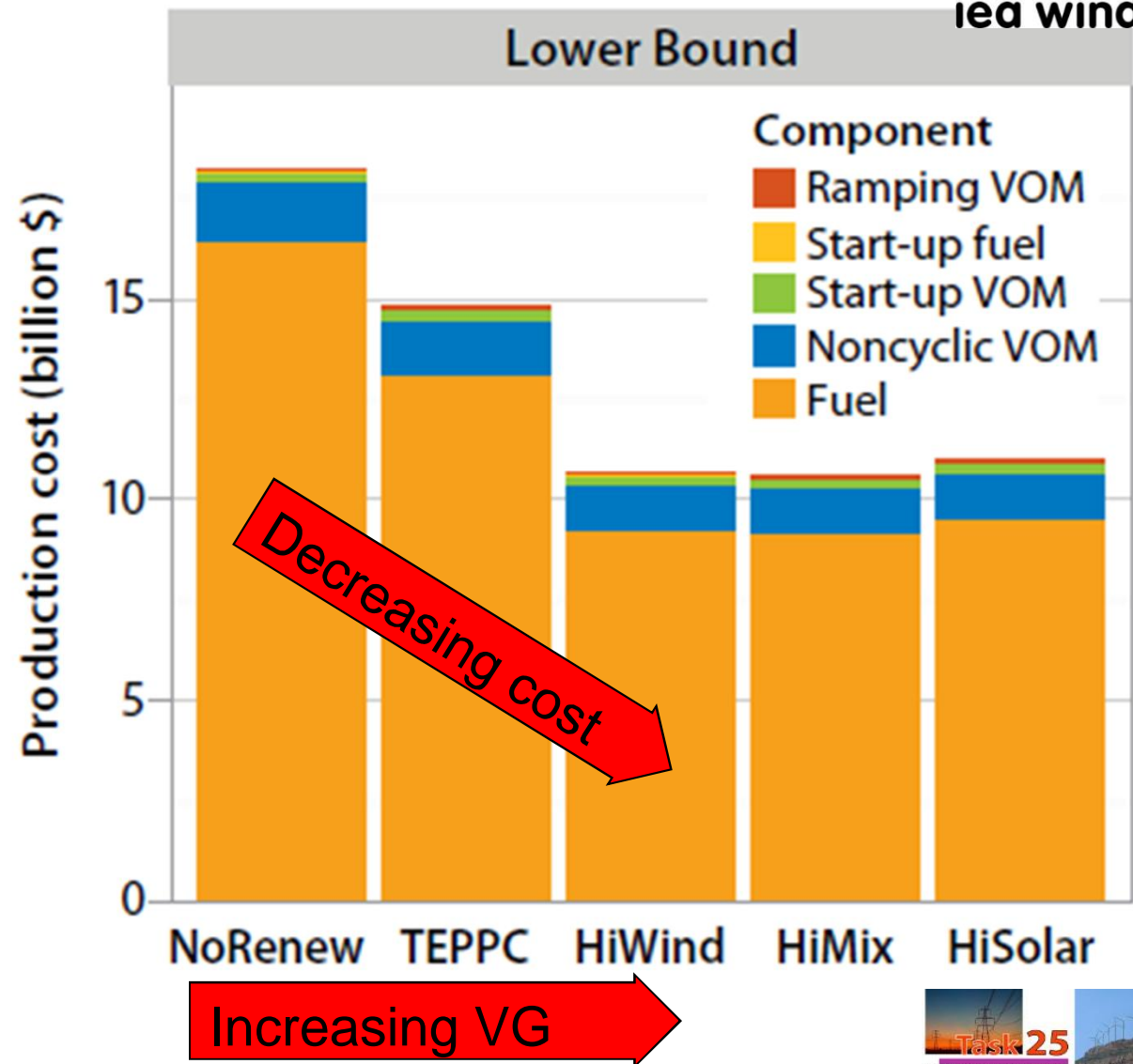
How are balancing costs estimated?

- Compare two (or more) alternative simulations of the power system using production simulation/cost models
  - With wind/solar
  - Without wind/solar
- To provide an energy-equivalent basis, a hypothetical unit is often chosen for the "without wind/solar" case
  - This proxy resource may introduce unintended consequences
- It is natural to ask about integration costs, but extremely difficult, if not impossible, to measure them accurately
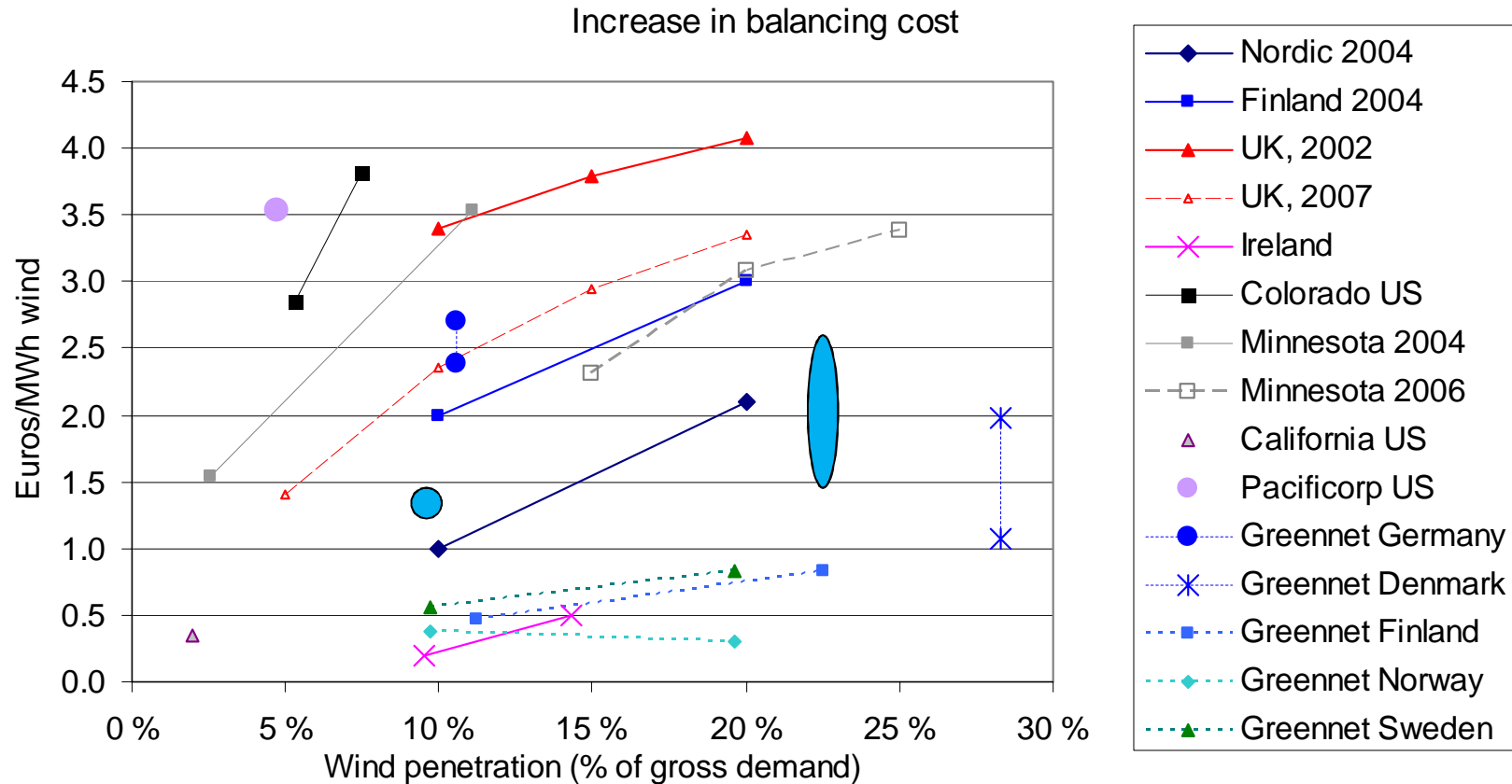
Flat block value - wind value
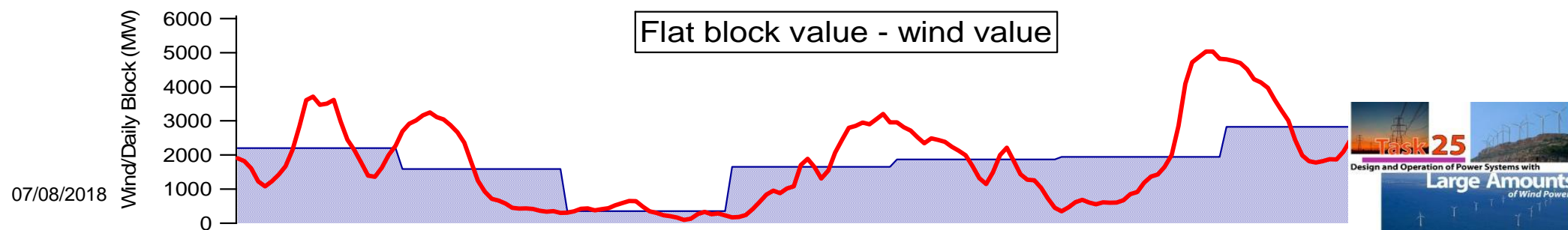
The flat-block proxy resource distorts the value of the energy
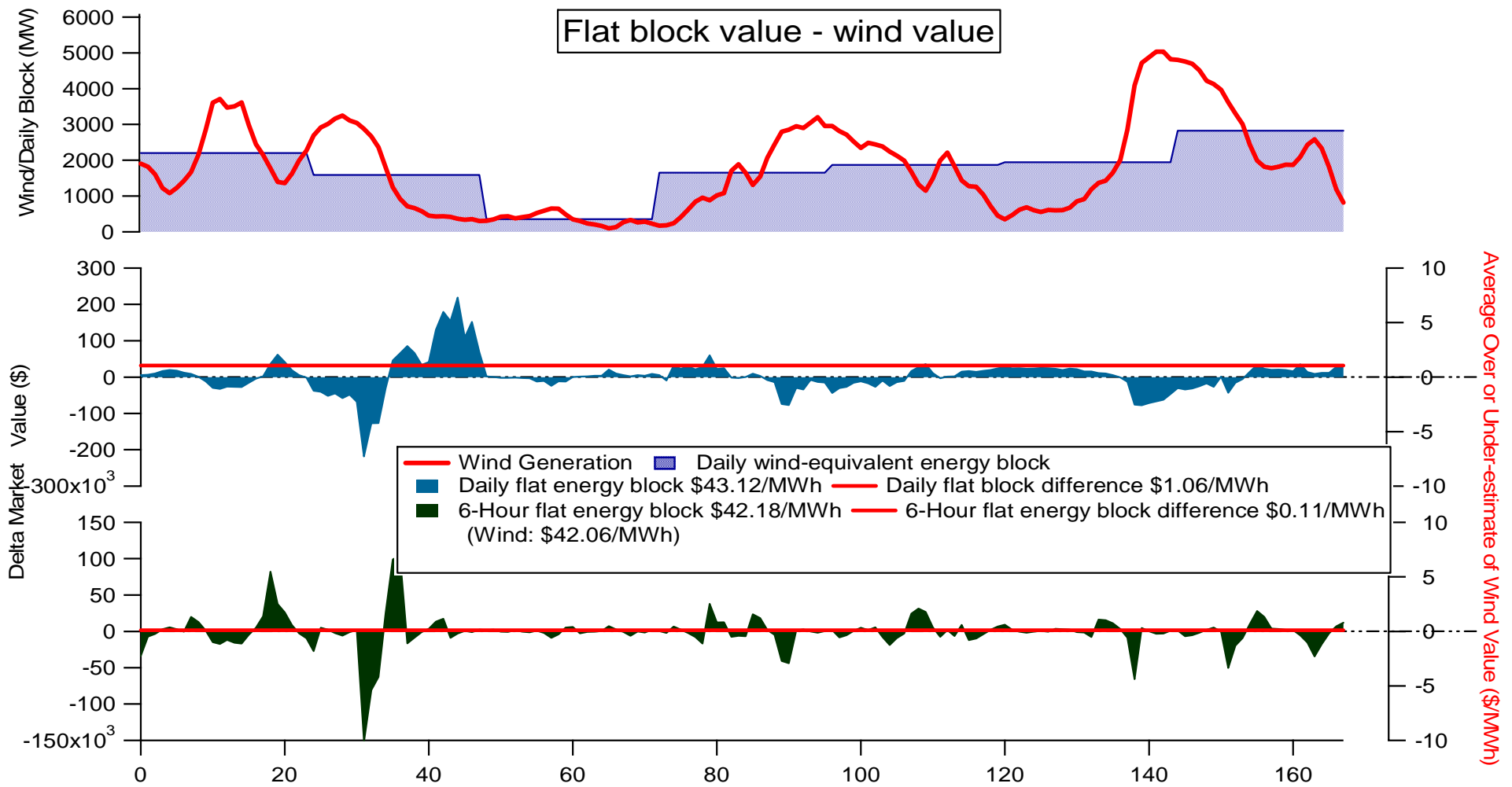
Milligan, M.; Kirby, B. (2009). Calculating Wind Integration Costs: Separating Wind Energy Value from Integration Cost Impacts. 28 pp.; NREL Report No. TP-550-46275.
http://www.nrel.gov/docs/fy09osti/46275.pdf

Summary balancing costs

Increase in balancing cost

Legend:
- Nordic 2004
- Finland 2004
- UK, 2002
- UK, 2007
- Ireland
- Colorado US
- Minnesota 2004
- Minnesota 2006
- California US
- Pacificorp US
- Greennet Germany
- Greennet Denmark
- Greennet Finland
- Greennet Norway
- Greennet Sweden

Y-axis: Euros/MWh wind
X-axis: Wind penetration (% of gross demand)

- Integration costs 0.5 - 4 €/MWh

  - Small compared to production cost /market value of wind power (~ 40-60 €/MWh)

  - Experience from Denmark and Spain, cost of ba[...] from electricity markets

# Balancing costs are lower for large and fast energy markets

Average Total Regulation for 6 Dispatch/Lead Schedules by Aggegation (Dispatch interval - Forecast lead time)
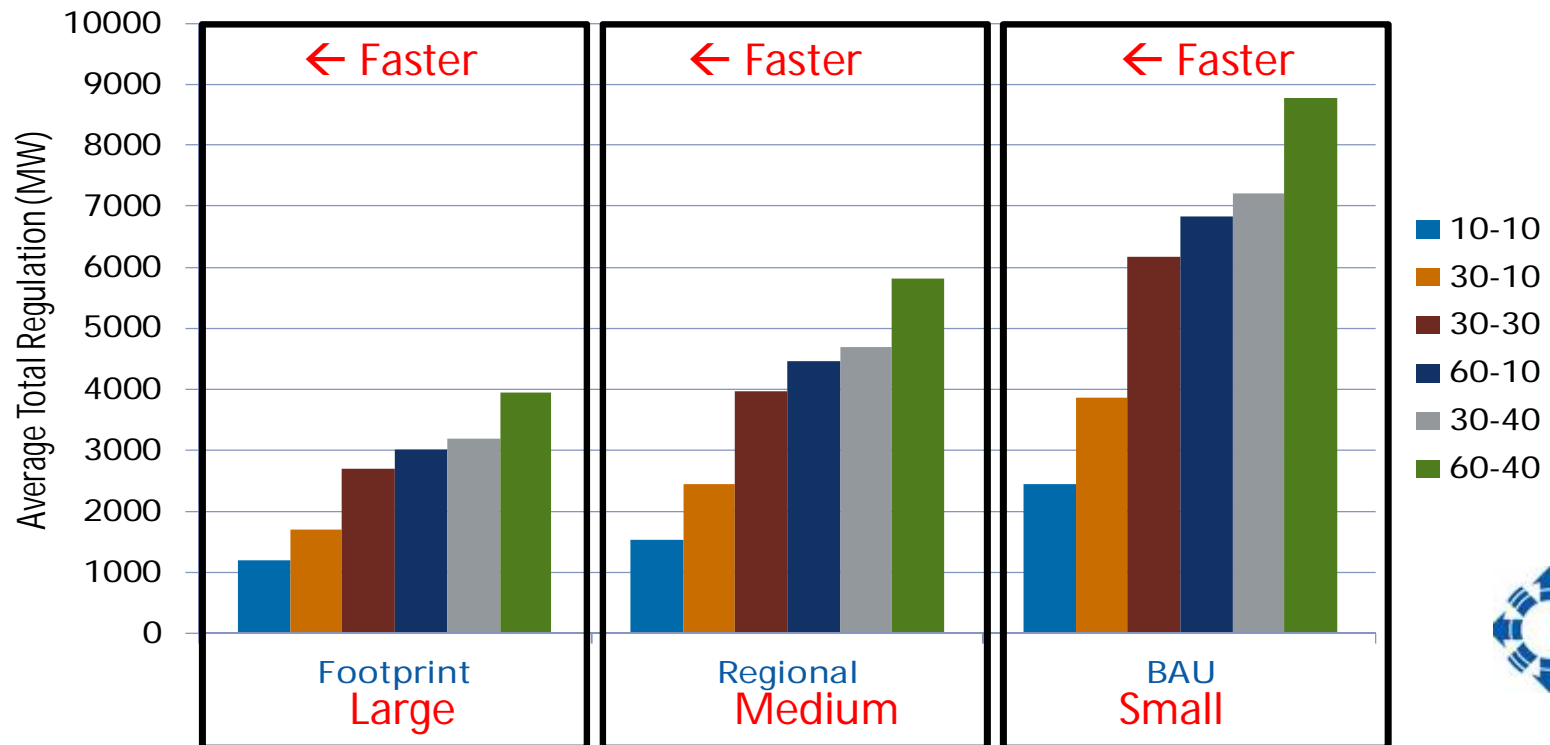
Milligan, Kirby, King, Beuning (2011), The Impact of Alternative Dispatch Intervals on Operat[ing] Reserve Requirements for Variable Generation. Presented at 10th International Workshop o[n Large] Scale Integration of Wind (and Solar) Power into Power Systems, Aarhus, Denmark. Octobe[r]

07/08/2018

Balancing costs - experience

- Italy – increase in operating reserves and frequency control
- Germany - decrease in frequency control reserves, due to sharing of balancing between balancing areas in Germany
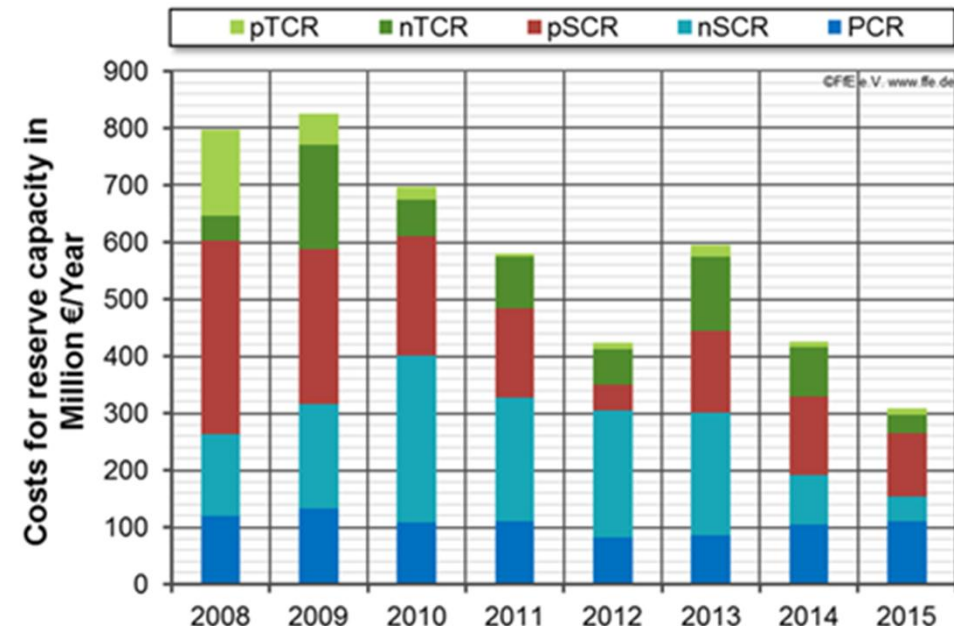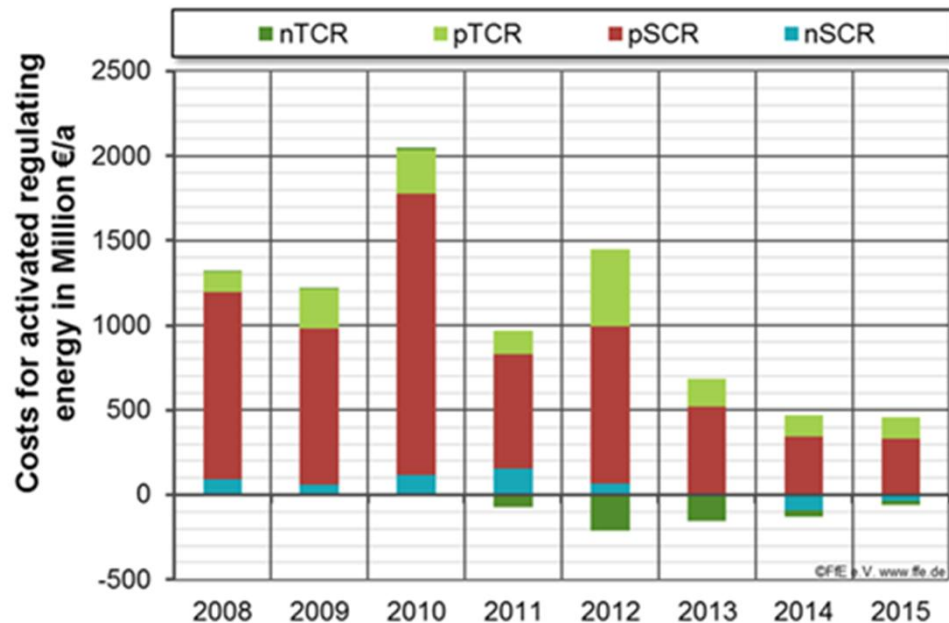
PCR Primary, SCR Secondary and TCR Tertiary control, p for positive and n for negative. Costs for activated energy (left) and reserved capacity (right)
Source Hirth, L., Ziegenhagen, I. Balancing Power and Variable Renewables: Three Links. Renewable & Sustainable Energy Reviews.
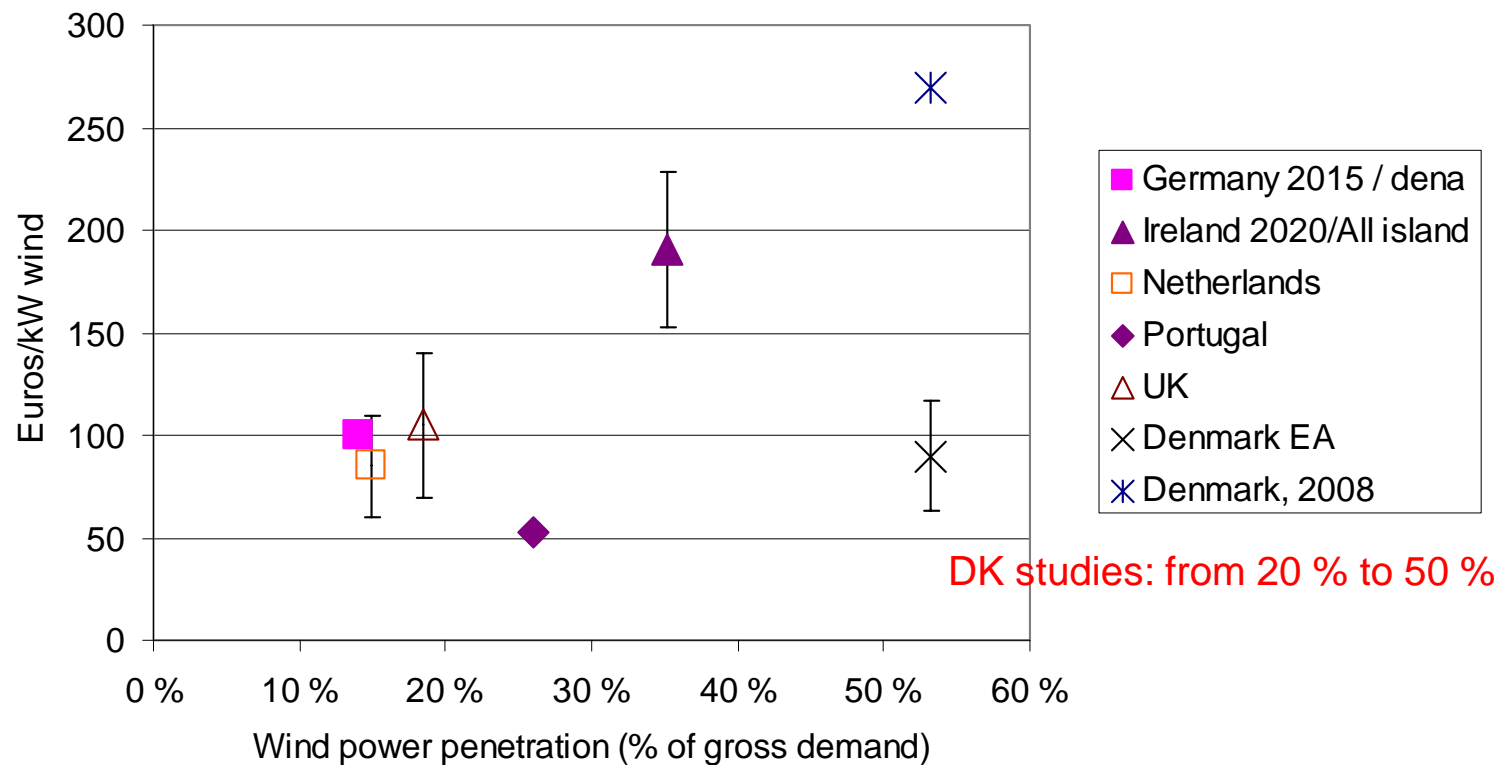
07/08/2018

TRANSMISSION

Grid adequacy

- Depends on wind resource location versus load centres
- Depends on how grid costs are allocated to wind power
  - Often new grid benefits the system in general, and also other reasons for reinforcing
- Building grid for the total wind power amount often significantly more cost effective than upgrading bit by bit
- Grid reinforcement costs are not continuous, there can be single very high cost reinforcements
- Improving the existing network efficiency and utilization can help delay grid reinforcement (DLR, FACTS and phase shift transformers, upgrading degraded components, accepting occasional wind curtailments)

Grid reinforcement costs from studies

- Cannot be compared – existing grid and location of wind resource different, as well as allocation of costs to wind power

Legend:
- ■ Germany 2015 / dena
- ▲ Ireland 2020/All island
- □ Netherlands
- ◆ Portugal
- △ UK
- ✕ Denmark EA
- ✳ Denmark, 2008

DK studies: from 20 % to 50 %

Allocating transmission costs for wind power

- System operators usually do not want to allocate transmission costs to any single technology
    - Meshed grid: reinforcing the grid will benefit all users
    - Benefits to markets and security
    - Usually several reasons for building the grid
- Practically impossible to make an accurate, transparent allocation
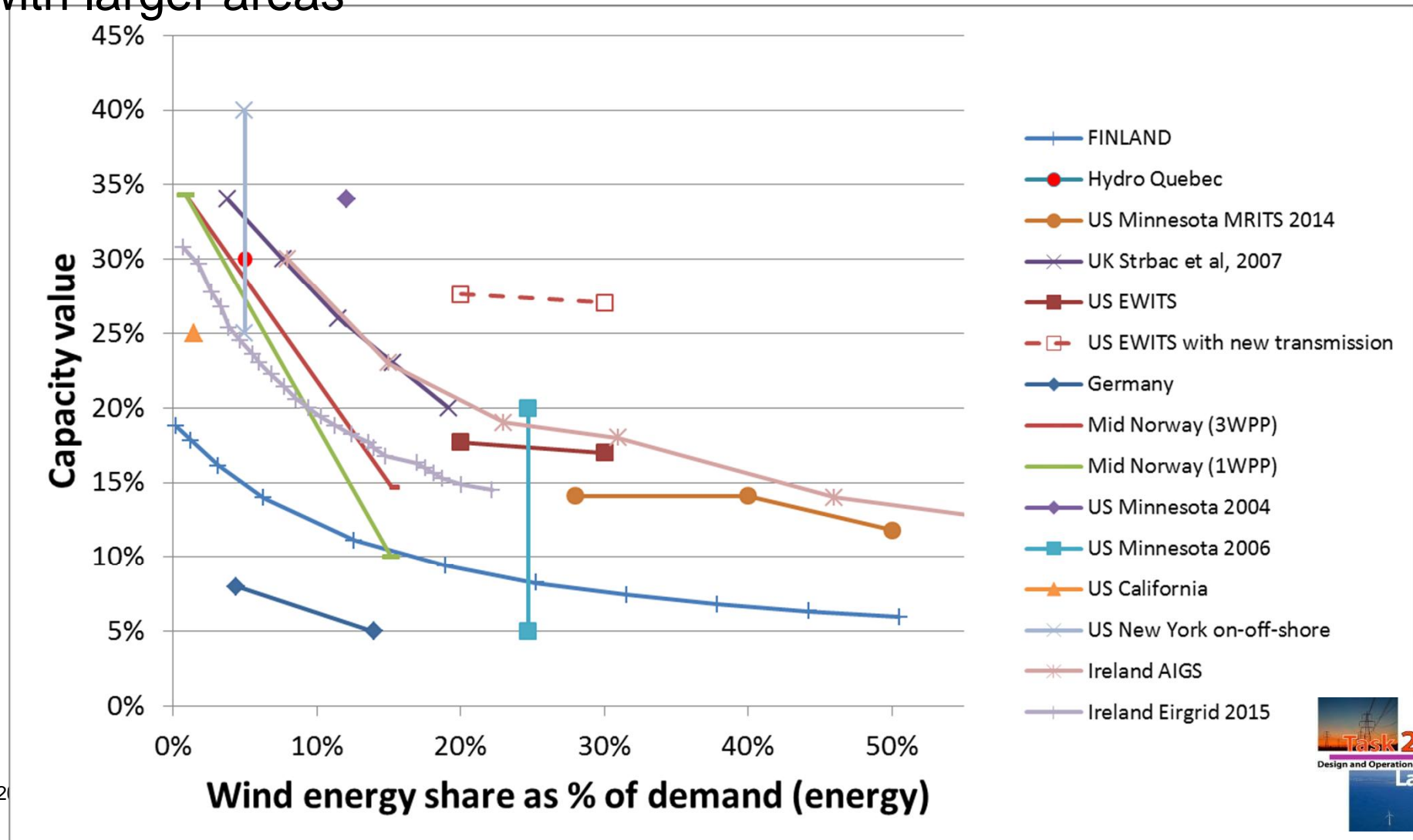
CAPACITY VALUE

Interest in capacity value of wind now starting to be relevant

- High interest in systems starting wind deployment – even if challenge of "no wind at high load" not seen at at low shares of wind

- Wind and solar squeezing fossil plants to low utilisation rates and out of market: how much overcapacity shoul be withdrawn and how much kept for adequacy?
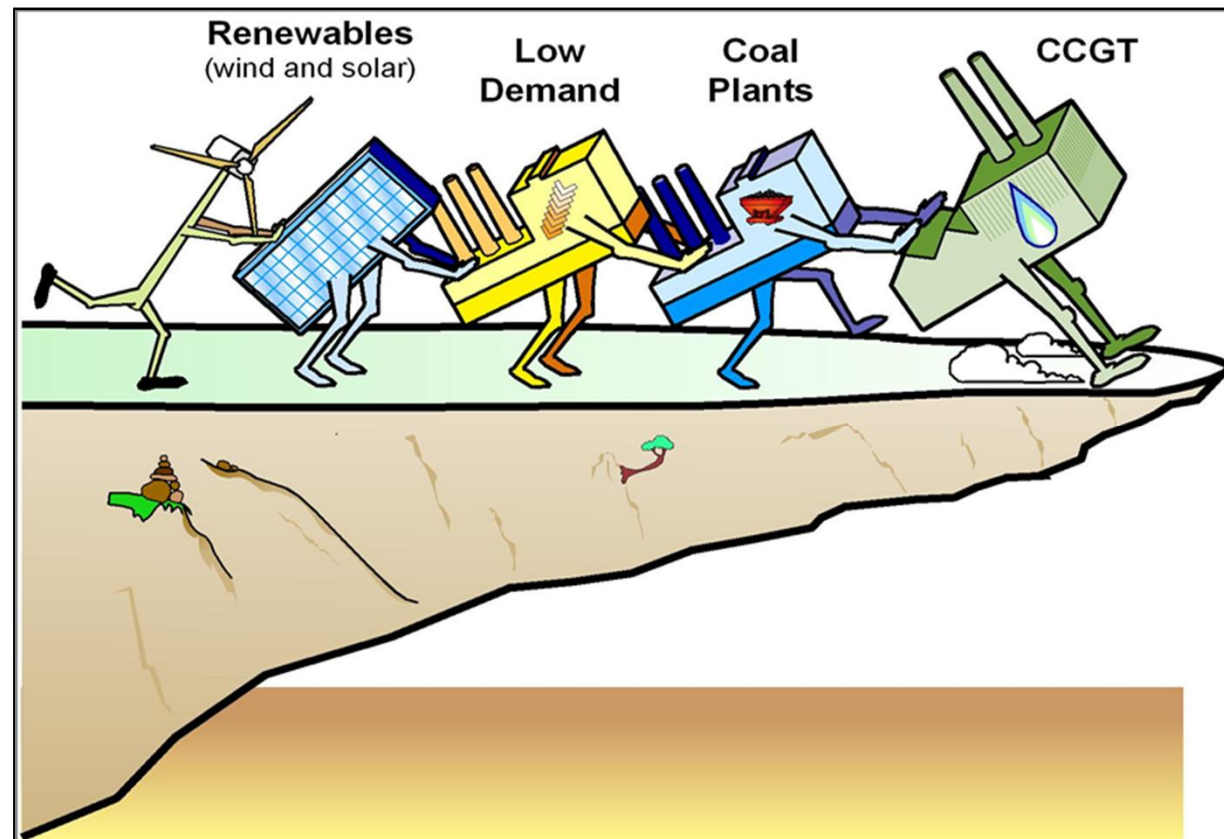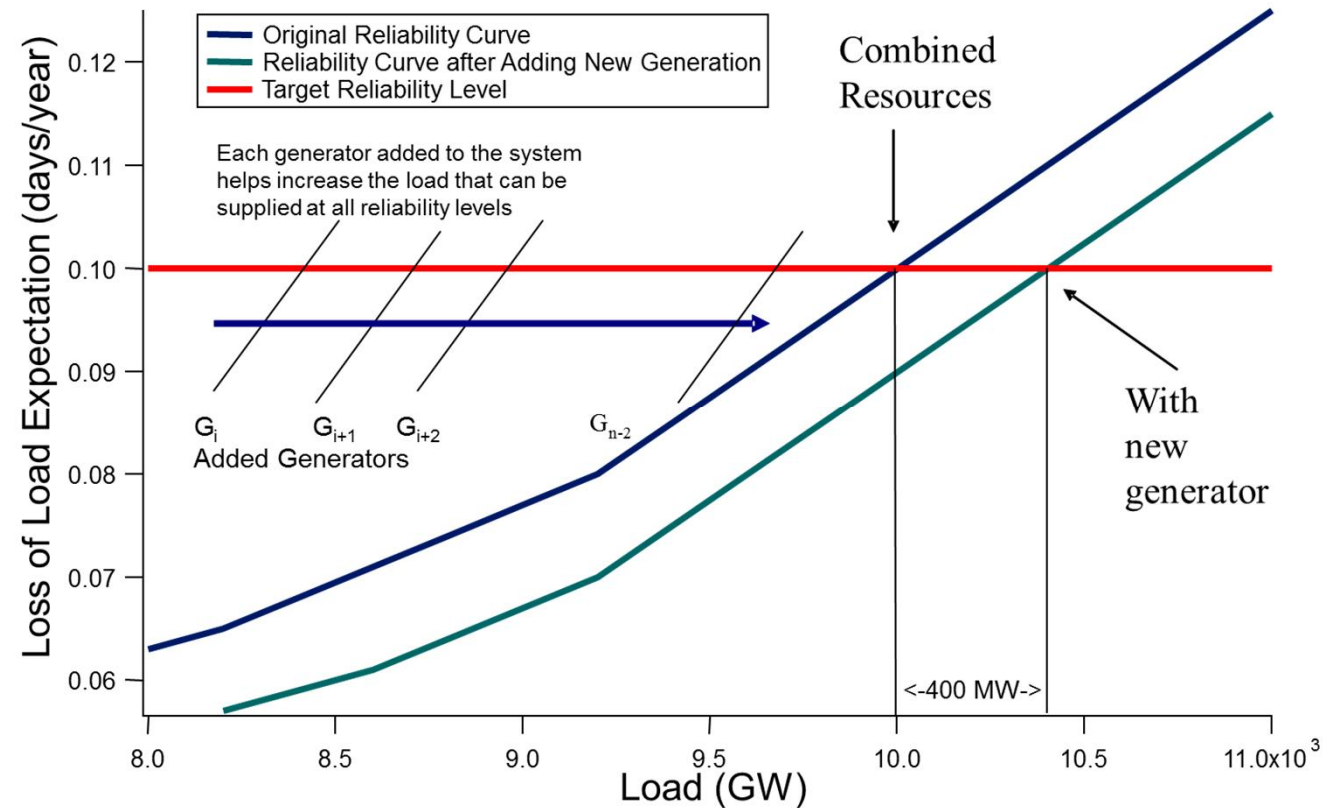
Generation capacity adequacy – capacity value of wind power

- Decreasing capacity value of wind power – reducing more slowly with larger areas

Capacity Value of wind – recommended method

- How much increase in load will bring same reliability/LOLP in the system when adding wind (ELCC method)
- >10 years of data to get robust results
- Neighbouring areas?

Capacity value and capacity cost

- Dedicated back-up is not needed in power systems
  - system with wind / thermal power should have the same risk of capacity deficit – taking into account capacity value of wind
- Deviation between capacity value of wind and thermal power could be denoted "capacity cost"
  - with the same yearly energy production - use correct comparison, not 1 GW gas / 1 GW wind but 0.5 GW gas / 1 GW wind
- Added capacity is only used few hours per year, use low investment cost plants (Open Cycle Gas Turbines).
  - The range of 2-4 Euro/MWh for the wind power produced has been estimated by (Söder & Amelin, 2008)
  - Demand Side Management could cover part of it.
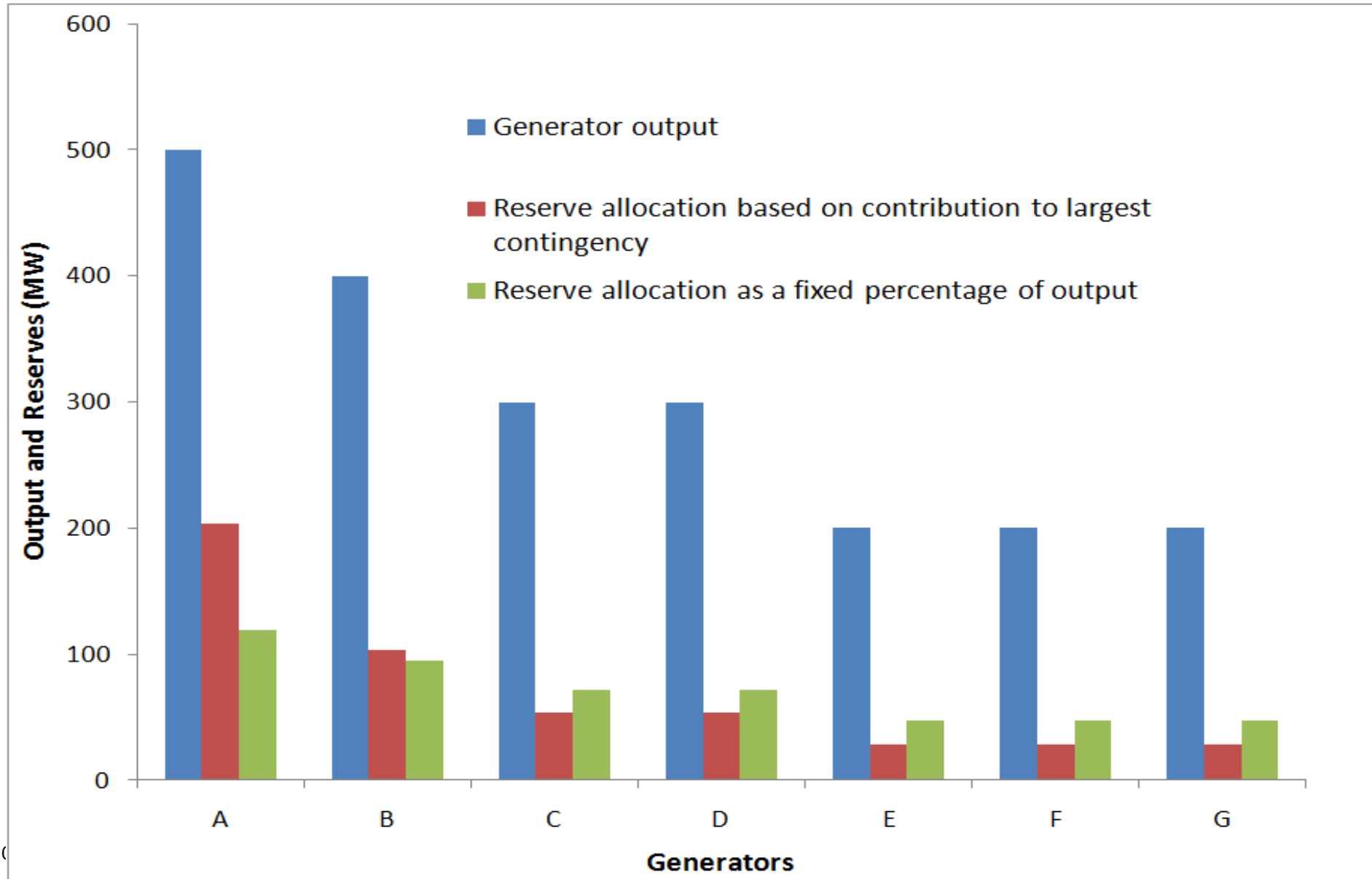- Comparing different future system portfolios gives a better picture

OTHER SOURCES OF SYSTEM COSTS AND ALLOCATION CHALLENGE

Other sources of integration costs?

- Operational practices: hourly block schedules a stress at hour shift

- Contingency reserves, dimensioned by largest unit.

- Individual loads/generators operating with spikes may cause a burden
    - Conventional units not taking part in balancing and frequency support, or performing poorly

- Interaction between generators in the economic dispatch process
    - can result in generator A imposing a cost on generator B, even if both units are "conventional"

Contingency reserve costs could be allocated based on generators' contribution to contingency reserve activation…but this is not done


Legend:
- Generator output
- Reserve allocation based on contribution to largest contingency
- Reserve allocation as a fixed percentage of output

New, low-cost base-load may cause integration costs

1. Coal is operated as base-load unit

2. With new wind generation added, gas and coal cycling increase and capacity factors decline

3. Instead of adding wind, a new, cheap base-load technology is introduced. Coal cycling increases; gas is nearly pushed out. Both coal and gas have lower capacity factors.

Are cycling costs really the cost of competition? Does the economic generator have an obligation to pay the competitor for lost revenues?
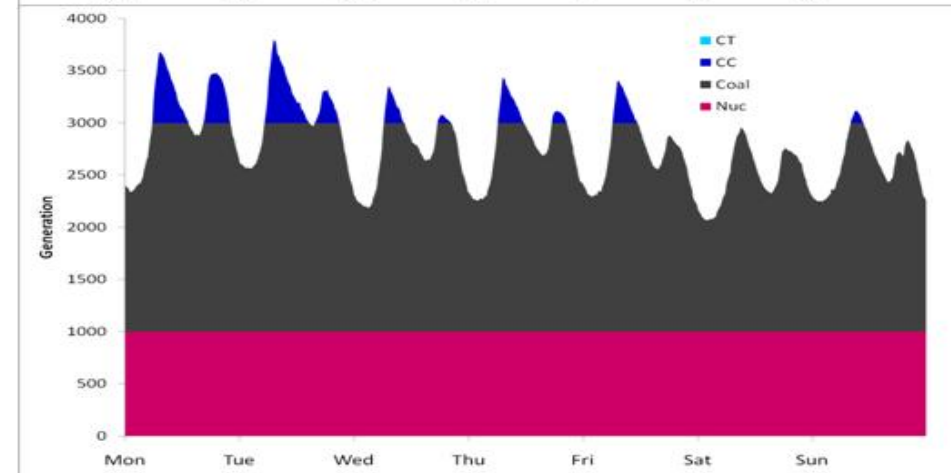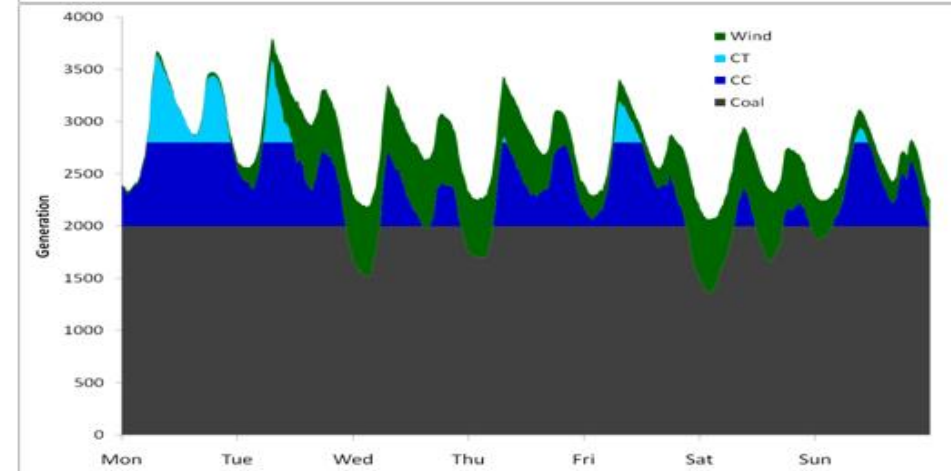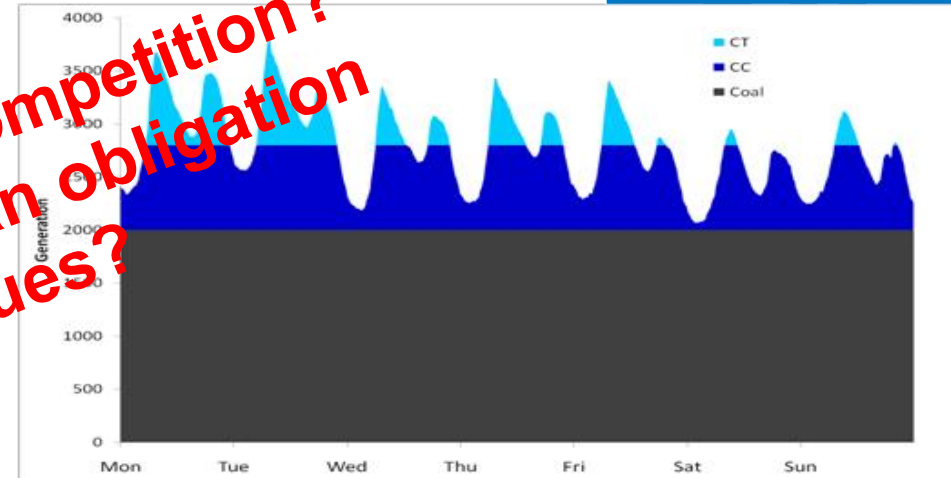
Allocation of nonlinear costs

- Many attributes of the power system have multiple value streams

- Transmission
  - Provides benefit to exporter and importer of power
  - Also provides non-monetized reliability benefits for all on the network
  - How should the benefit (and thus) cost of the transmission line be allocated?

- Ancillary services are required for all loads and generation types – how should the cost be allocated?

The sum of all parts physically cannot exceed the whole

- Methods that separate regulation, load following, uncertainty for the analysis must follow the principle of re-composition.
- → The sum of
    - Regulation
    - Load Following
    - Uncertainty
- Components must combine so that they do not exceed the total variability + uncertainty…
- Sum of all parts of the tariff revenue cannot exceed total costs

Total system costs instead of integration costs

- Integration costs are difficult to extract correctly
- Total operating costs are relatively easy to calculate
- Both of these are sensitive to assumptions about the other parts of the power system
  - What is the mix of conventional generation?
  - What is the transmission build-out (if any)?
  - What are the institutional constraints?
  - Electrical footprint?
  - Do markets allow access to physical capability that exists, or is this access constrained?
  - What will the power system look like in 20xx?

07/08/2018

What is the base case of comparison?

- For larger shares of wind power, the remaining system may adapt with more flexible generation and demand to lower the system costs

Figure ES.1 • Total system cost of a test system at different degrees of system transformation
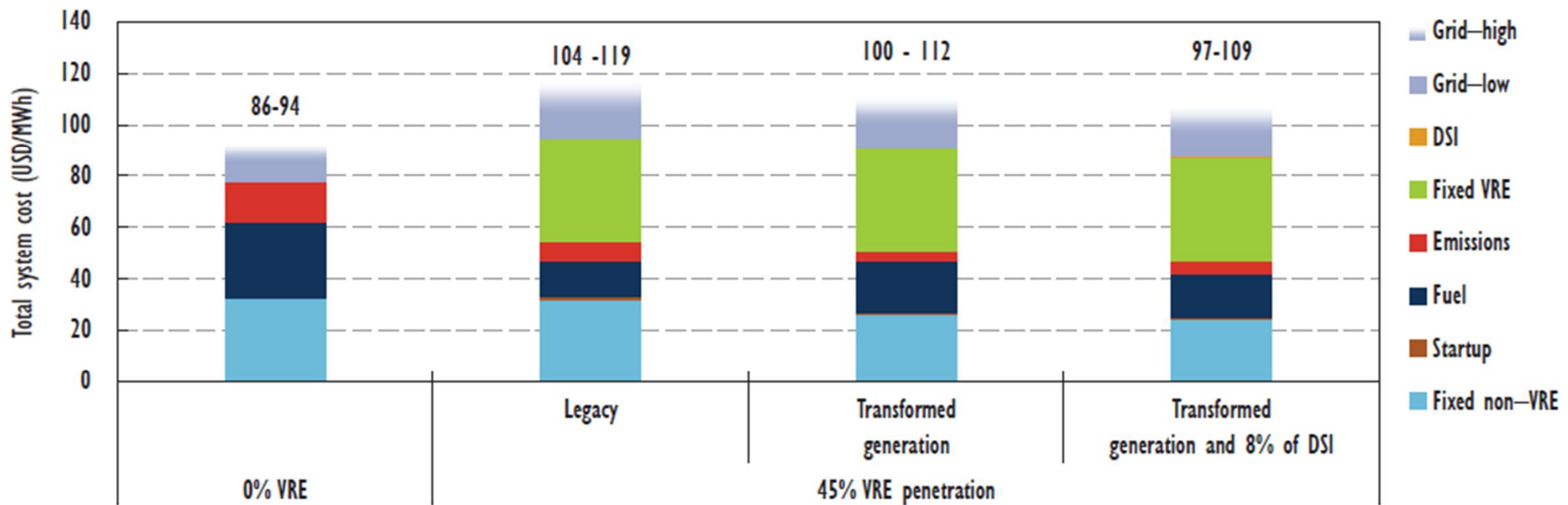
Note: DSI = demand side integration

Source: IEA Power o

Conclusions – where are we now

- There is no universal agreement on integration cost methods, whether these costs are measurable, and how to allocate

- Integration costs are part of normal power systems operation
  - Also conventional units may impose integration costs - f.ex. contingency reserve - calculate integration cost for all, or none
  - Performance-based tariffs are more appropriate than technology-based tariffs, assuming other factors are properly considered

- Total operational cost can be compared for wind and non-wind case
  - Most of the difference comes from reduced fuel costs

Vision: **from integration cost** of wind power **to design and operation** of 100% renewable energy systems – cost of inflexibility

- Curtailments and low market prices → maximising value
- Flexibility, stability
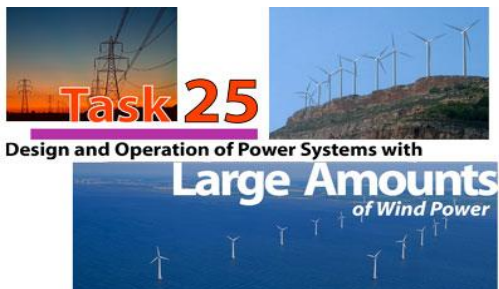- Penetration → share
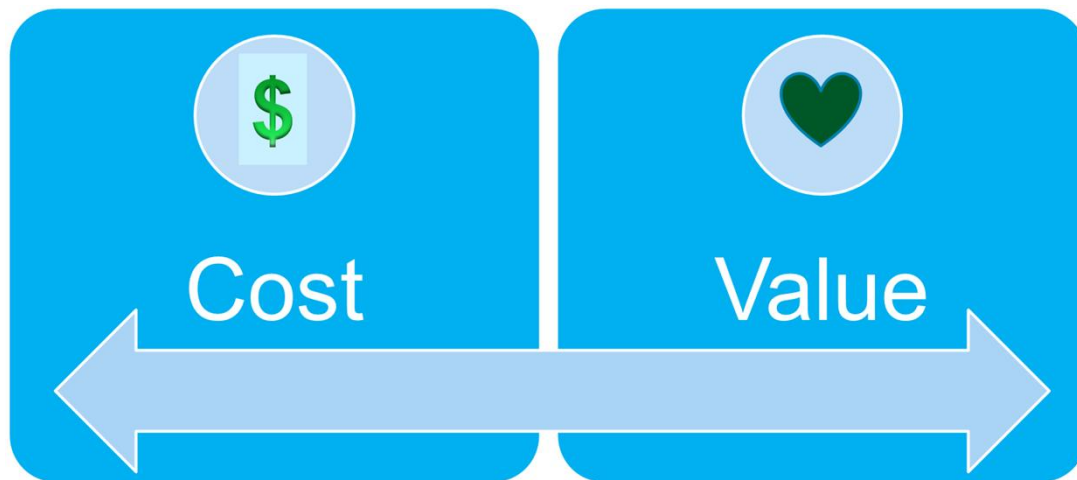
TODAY

FUTURE?

System services

Energy

Capacity

Cost — Value

Task 26
Cost of Wind Energy

IEA WIND Task 25:
Design and operation of power systems with large amounts of wind power

www.ieawind.org

17 countries + Wind Europe participate

	Country	Institution
	Canada	Hydro Quebec (Alain Forcione, Nickie Menemenlis)
	China	SGERI (Wang Yaohua, Liu Jun, Zheng Kuan);
	Denmark	DTU Wind (Nicos Cutululis); TSO Energinet.dk (Antje Orths)
	Finland	VTT (H. Holttinen, J. Kiviluoma) – **Operating Agent**
	France	EdF R&D (V. Silva); TSO RTE (E. Neau); Mines (G. Kariniotakis)
	Germany	Fraunhofer (J.Dobschinski); FfE (S.Roon); TSO Amprion (P. Tran)
	Ireland	EnergyReform (M.O'Malley, J.Dillon), UCD (D.Flynn)
	Italy	TSO Terna Rete Italia (Enrico Maria Carlini)
	Japan	Tokyo Uni (J.Kondoh); Kyoto Uni (Y.Yasuda); CRIEPI (R.Tanabe)
	Mexico	INEEL (Rafael Castellanos Bustamante)
	Norway	SINTEF (J.O.Tande, Til Kristian Vrana); NTNU (Magnus Korpås)
	Netherlands	TSO TenneT (?), TUDelft (?);
	Portugal	LNEG (Ana Estanquiero); INESC-Porto (J. Pecas Lopes);
	South Africa	CSIR (Jarrad Wright, Robbie van Heerden)
	Spain	University of Castilla La Mancha (Emilio Gomez Lazaro)
	Sweden	KTH (Lennart Söder)
	UK	DG&SEE (G. Strbac, Imperial; O. Anaya-Lara, Strathclyde)
	USA	NREL (Bri-Mathias Hodge); UVIG (J.C.Smith); DoE (C. Clark)
	WindEurope	Wind Europe (Daniel Fraile)