



Design and Operation of Power Systems with Large Amounts of Wind Power, first results of IEA collaboration

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Background

- τ Wind power penetration increasing: system integration costs is becoming an issue for many countries
- τ Ongoing work in many countries and organisations. Difficult to compare the results
- τ Integration costs – extra costs for power system for accommodating wind power, not included in investment costs
- τ Task 25 for IEA WIND Implementing Agreement:
“Design and operation of power systems with large amounts of wind power“
was started in 2006: 3 years, 2006-2008
Participation as of 1.9.2006: Denmark, EWEA, Finland, Germany, Ireland, Norway, Netherlands, Portugal, Spain (unconfirmed), Sweden, UK, USA

<http://www.ieawind.org/>



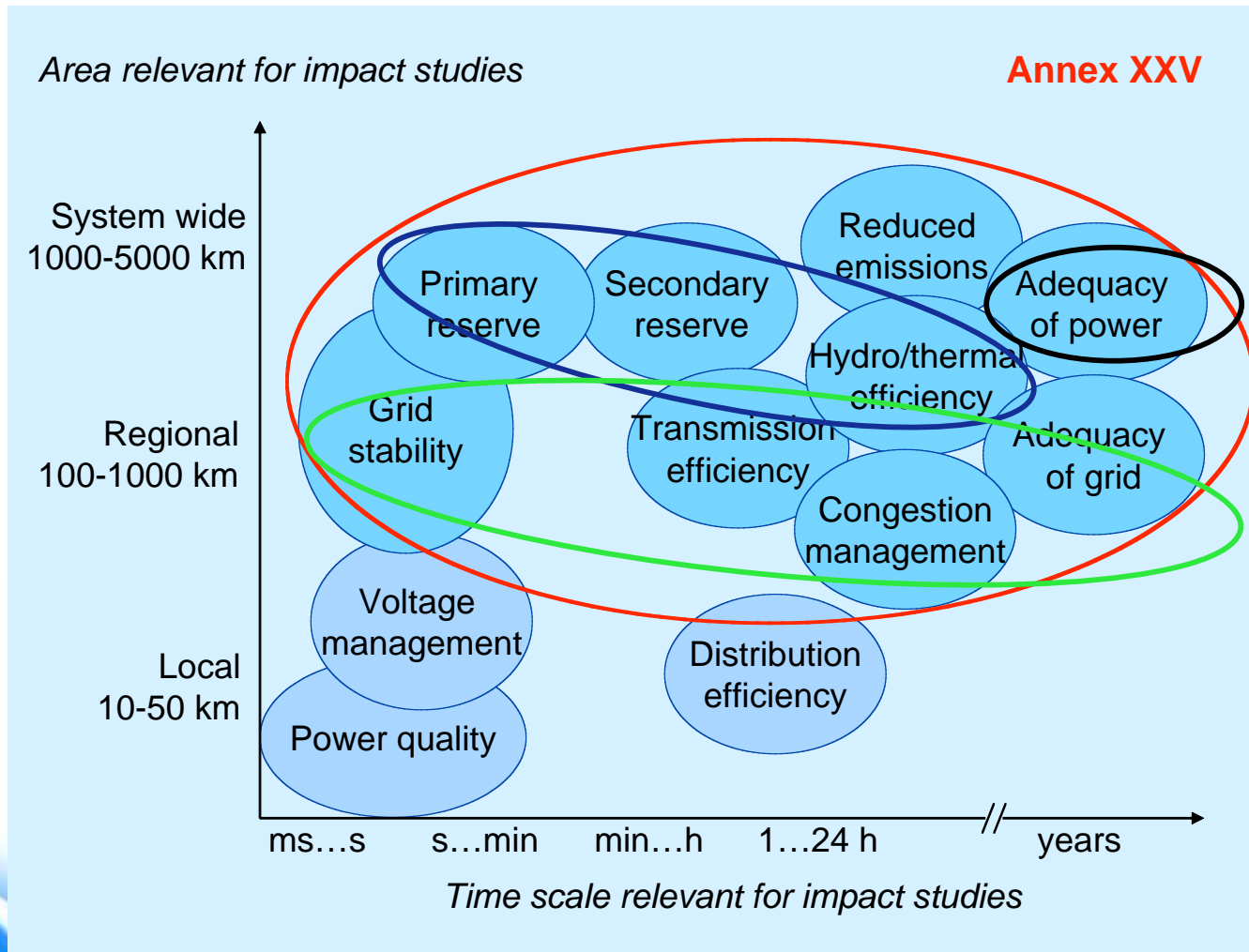


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Possible impacts of wind power on the power system: impacts on reliability and efficiency



Balancing

Adequacy

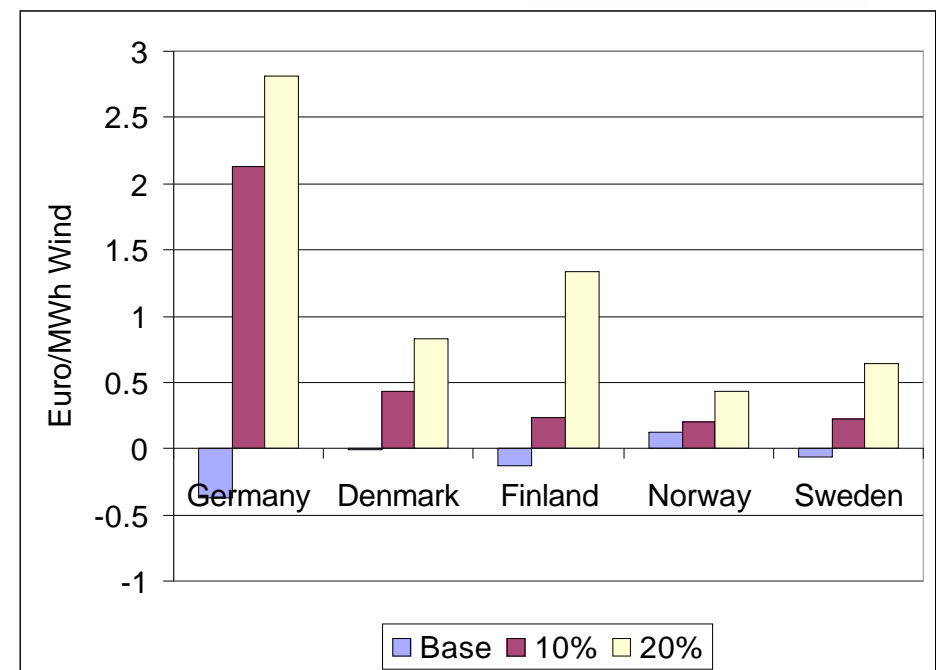
Grid





Denmark

- τ Greennet Eu27 study using WILMAR model – increase in operating costs due to wind
- τ EnergyPLAN and Balmorel models – heat pumps and electric boilers to increase the flexibility of a power system when wind penetration >20 % of gross demand
- τ SIVAEL model – 100 % wind study, new markets for surplus energy, demand-side important





Finland /Nordic study

- τ EMPS model - Nordic electricity market, 46 TWh/a wind (12 % of gross demand)
 - The losses due to increased bypass of water through the hydro power plants correspond to about 1 % of the wind power production.
 - Nordpool spot market prices lowered by about 2 €/MWh per 10 TWh/a if wind added as extra production
- τ Balance requirements: analysis of time series of wind and load
 - Nordic 4 countries together: 1 €/MWh for 10 % (energy) penetration and 2 €/MWh for 20 % penetration
 - Finland only: 2 €/MWh for 10 % (energy) penetration and 3 €/MWh for 20 % penetration
 - Hourly variability only. Investment costs for new reserve capacity allocated to wind power





Germany

- τ Dena study: wind power from 14 600 MW (2003) to 36 000 MW (2015)
 - Grid reinforcement until 2015: 850 km new 380-kV lines + 390 km reinforcement. new components for active power flow control and reactive power compensation
 - Capacity credit: 6 - 8 % for 14.5 GW and 5 - 6 % for 36 GW wind
 - Balancing:
 - For upregulation: additional max 7000 MW, average 3200 MW has to be contracted “day ahead” (9 % of wind power capacity). In 2003: 2000 MW max and 1200 MW ave
 - For downregulation: additional max 5500 MW, average 2800 MW has to be contracted “day ahead” (8 % of wind power capacity). In 2003: 1900 MW max and 800 MW ave
 - Stability: modification of Grid Code of wind farms in the high voltage grid (fault-ride-through and grid voltage maintenance respective voltage control)





Ireland

- τ “Operating Reserve Requirements as Wind Power Penetration Increases in the Irish Electricity System”, 2004:
 - small increase in operating reserve costs: 0.2 €/MWh for 1300 MW wind and 0.5 €/MWh for 1950 MW of wind
- τ “Renewable Energy Resources for Ireland 2010 & 2020”, 2004:
 - limits on wind penetration 1000MW in 2010 and 1250MW in 2020
 - If replacement for conventional plant retired in 2016 aeroderivative OCGT rather than CCGT the 2020 limit became 3500MW
- τ “Renewable Energy in the New Irish Electricity Market”, 2004:
 - costs of ramping & start-ups were reasonable for 1500 MW wind
- τ All Island Grid Study on the way in 2006



Netherlands

- τ Effects of 6000 MW offshore wind on the Dutch grid
 - for the relatively short distances between wind farms and substation, AC connections are to be preferred
 - Investment costs to grid were estimated to 344-660 M€, depending on location/scenario (about 4% of est. total investment for 6 GW wind).



Norway

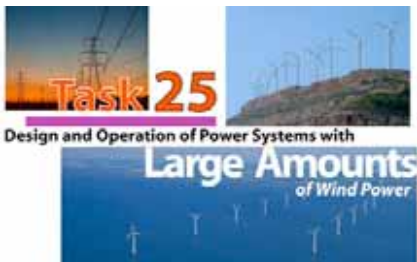
- τ "Impact of integrating wind power in the Norwegian power system", 2006:
 - 20 TWh/a wind generation a realistic goal for 2020
 - Market based balancing tackles large magnitudes of wind power and local control enables operation of a large wind farm on a fairly weak regional grid
 - Combining wind and hydro provides for a more stable annual energy supply than hydro alone
 - Sufficient transmission capacity a key for efficient operation in future
- τ Wind/Hydro integration
 - accepting temporary grid congestions and utilizing the control possibilities of modern wind farms large amounts of wind power can be integrated without costly grid reinforcements
- τ Capacity credit for a region:
 - 30 % at low wind energy penetration and 14- 15 % high penetration. Smoothing effect due to geographical distribution has significant impact on capacity value at high penetration





Portugal

- τ ambitious wind energy plans up to 15% of gross demand in 2013
- τ Grid reinforcement need and costs:
 - In the overall period 2005 – 2010, the investment directly attributable to renewables, mostly for wind parks, will total 200 Million €.
- τ Grid stability:
 - grid codes with fault ride through required at certain parts of the grid, possibility to use FACTs is under study.



Sweden

τ Balancing:

- additional regulating/reserve requirement is small, for the 1 hour horizon
- power systems with large consumption variations, like (Sweden), require lower additional reserves than those with lower consumption variations (like Finland)

τ Wind/Hydro integration:

- coordination decreases wind curtailments and leads to more efficient utilization of transmission lines, without negative economical impact on hydro power producer
- decrease of efficiency in the hydro power system due to forecast errors of wind power equivalent to 1 % of the wind power production at a wind power penetration of 4 % of the yearly gross demand

Installed wind power MW	Penetration level %	1 hour stand. dev. MW (%)	4 hours stand. dev. MW (%)	Day-ahead Max. positive MW (%)	Day-ahead Max. negative MW (%)
4000	6.6	20 (0.5)	195 (5.0)	690 (17.2)	590 (14.8)
6000	9.9	45 (0.75)	-	1350 (22.5)	1030 (17.2)
8000	13.2	80 (1.0)	-	1570 (19.6)	1220 (15.2)





UK

- τ **Balancing:**
 - £2.38/MWh of wind produced at 10% wind penetration and £2.85/MWh at 20% of gross demand.
- τ **Grid reinforcement:**
 - £275m - £615m to accommodate 8 GW of wind (£35-77/kW)
- τ **Capacity credit:**
 - 35% at low penetration, 20 % at penetration of 20 % of gross demand
- τ **Stability:**
 - Wind turbine types providing damping and transient stability
 - Value of Fault-Ride-Through of wind turbines for the power system



USA (1)

- τ Minnesota: 1500 MW of wind in 10 GW peak load system (15 %)
 - Balancing: Regulation (< minute) increase by 8 MW, intra-hour load following burden increase by 1-2 MW/min. Hourly to daily wind variation and forecasting error impacts the largest cost items: \$4.37/MWh. A total integration cost of \$4.60/MWh
 - Capacity credit of 26%-34%
- τ New York: 3300 MW of wind in 33 GW peak load system (10 %)
 - Balancing: increased needs can be met by existing resources and market processes. Regulation increase by 36 MW, intra-hour load following burden increase by 1-2 MW/ 5 min. Hourly ramp increased from 858 MW to 910 MW. Value of wind forecasting \$10.70/MWh
 - Stability improved by modern wind turbines
 - Only limited grid reinforcement needs
 - Capacity credit 10 % for onshore and 36 % offshore wind





USA (2)

- τ Colorado 700 and 1050 MW in 7 GW peak load system (10/15 %)
 - Balancing: Regulation cost \$0.20/MWh and hourly reserve cost range of \$2.20-\$3.30/MWh. Impact of variability and uncertainty on dispatch of gas system \$1.25-\$1.45/MWh the 10% and 15% cases
- τ California: existing wind power, 4 % of peak load
 - Balancing: Regulation cost for wind \$0.46/MWh, load following minimal
 - Capacity credit: 23-25%



Other organisations: EWEA, UCTE, ETSO

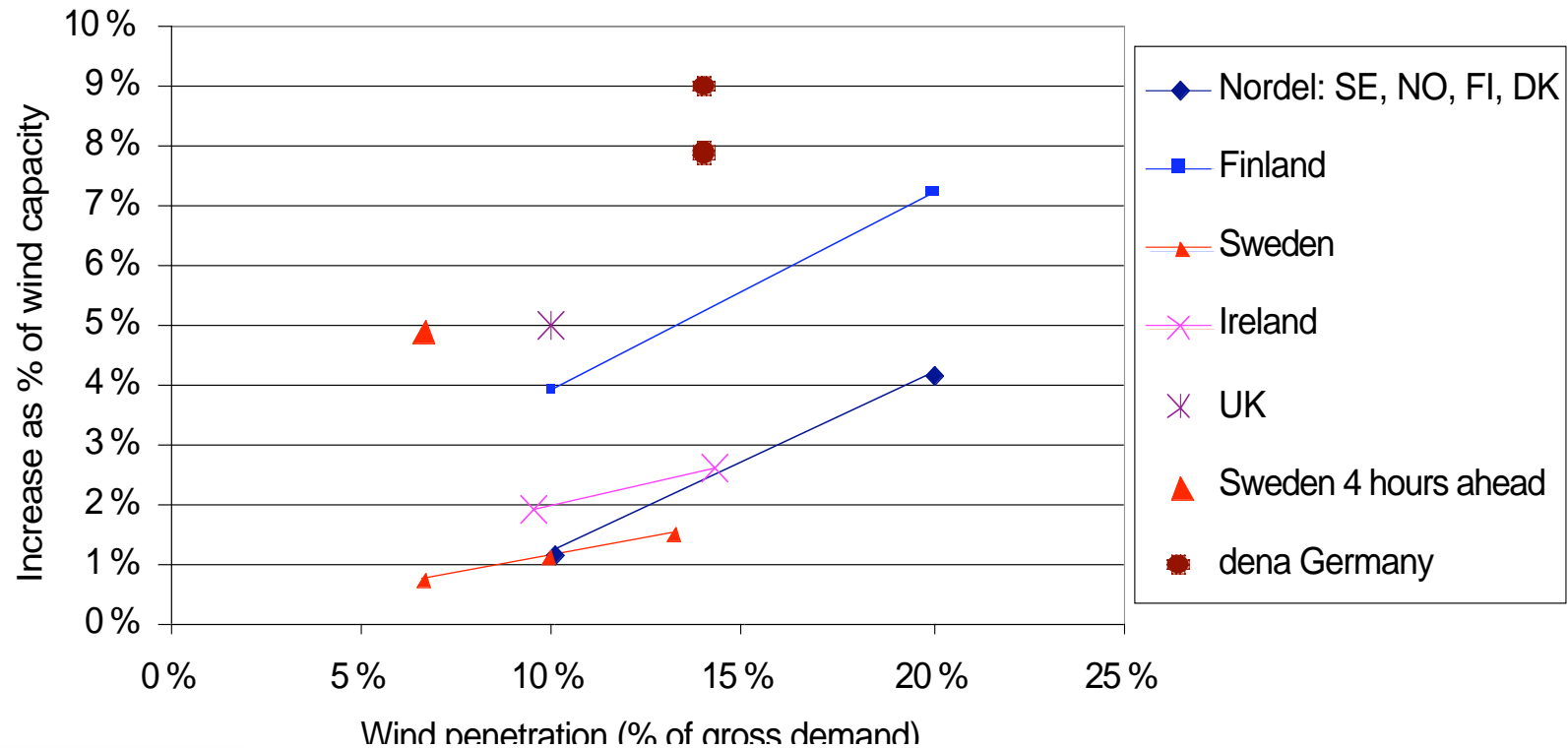
- τ EWEA Grid report 2005
 - feasible to integrate the targeted wind power capacity of 300 GW in 2030
 - regulatory, institutional and market modifications should be dealt with in the broader European power market context
- τ UCTE (synchronous interconnected network of continental Europe)
 - harmonized approach for studies for accommodation new RES
 - European promotion scheme for RES taking account of the conditions of the transmission infrastructure
 - compatible market arrangements for safe and stable power supply
 - synchronization of grid planning and RES expansion
 - procedures expediting process of new transmission lines and grid reinforcements
- τ ETSO European Wind Integration Study (EWIS)
 - grid codes and regulatory and market-related requirements impacting the integration of wind energy





Summary balancing requirements

Increase in reserve requirement

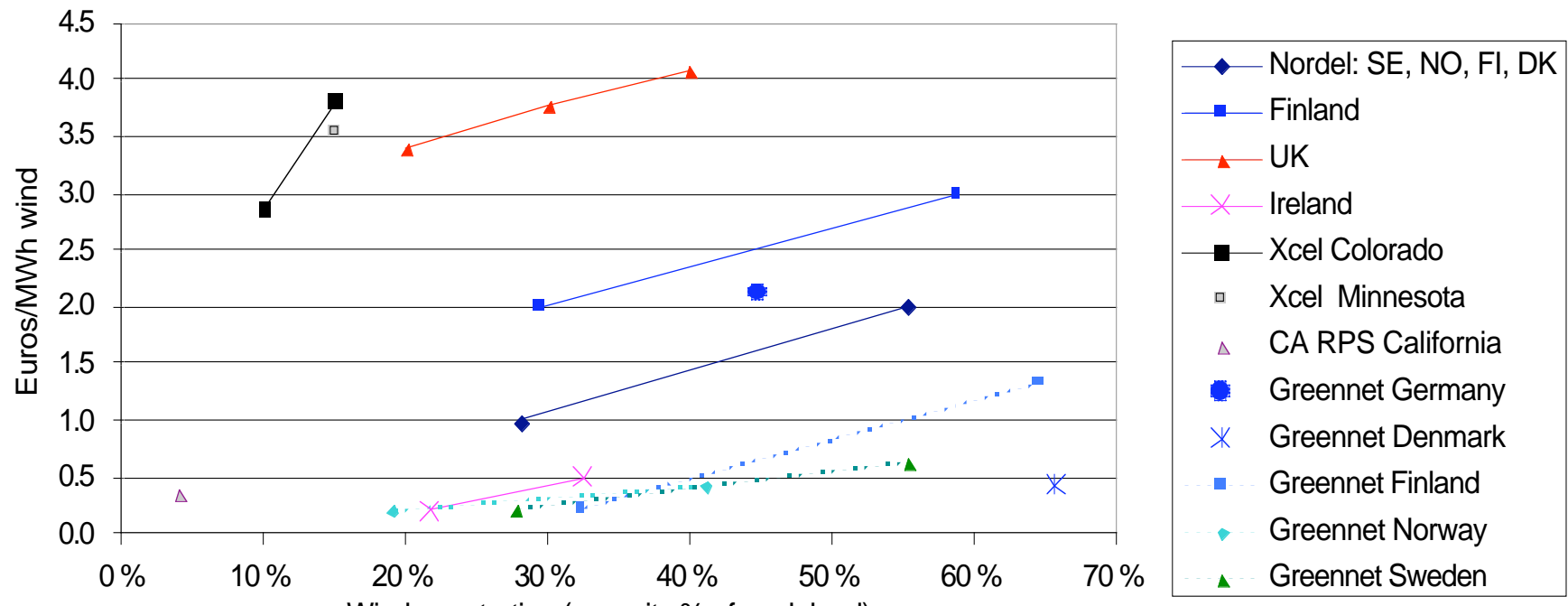


- different time scales for estimating the reserve requirement: Germany day-ahead, UK up to four hours ahead, others in-hour
- different methodology used



Summary balancing costs

Increase in balancing cost



- Not directly comparable due to: different time scales; allocating investment for new reserve or only use of reserves; method for calculating costs based on assumptions on thermal power; possibilities for power exchange to neighbouring countries etc



Summary grid reinforcements

- τ UK : £50-100 / kW (70-140 €/kW).
- τ Netherlands : 60-110 €/kW for 6000 MW offshore
- τ Portugal : 53 €/kW
- τ The German dena study: 100 €/kW

- τ The grid reinforcement costs are not continuous, there can be single very high cost reinforcements



Experience with large wind power penetration NWPC conference paper results

- τ Gotland, Sweden: 90 MW wind power, 160 MW peak load (19 % of energy)
 - Maximal wind power penetration 40 % ($\text{max wind} / (\text{min load} + \text{transmission})$)
 - Balancing solved outside region: control enhanced to enable around 0 MW operation of HVDC link to mainland
- τ West Denmark: 2380 MW wind power, 3700 peak load (24 % of energy)
 - Maximal wind power penetration 58 % ($\text{max wind} / (\text{min load} + \text{transmission})$)
 - Balancing solved both inside and outside region. Wind power regulation has been used in rare occasions.
- τ North Germany: 2275 MW wind power, 2000 peak load (33 % of energy)
 - Maximal wind power penetration 18 % ($\text{max wind} / (\text{min load} + \text{transmission})$)
 - Balancing solved both inside and outside region. Wind power regulation has been used since 2003 in occasions with high wind and congested transmission. Fault-ride-through needed to avoid wind power becoming a dimensioning fault (> 3000 MW tripping off)





Conclusions

- τ Integration costs 0.5-4 €/MWh for balancing
 - Small compared to production cost of wind power (30-50 €/MWh) or with avoided fuel costs (20-30 €/MWh with 2001 price level)
 - In some countries wind power producers already pay imbalance payments that are greater than the actual extra cost incurred to the power system
- τ Integration costs 50-100 €/MWh for grid reinforcements
 - depending on wind resource location versus load centres
- τ Recommended practise so far
 - Capture the smoothed out variability of wind power production time series for the geographic diversity assumed: actual data from several wind farms and met towers or synchronized weather simulation. Wind forecasting best practice for the uncertainty of wind power production.
 - Examine wind variation in combination with load variations
 - Capture system response through operational simulations
 - Examine actual costs independent of tariff design structure





Further work of the IEA Task 25: Objective:

to analyse and further develop the methodology to assess the impact of wind on power systems

GOALS:

- τ Provide an international forum for exchange of knowledge
- τ State-of-the-art: review and analyse the studies and results so far
 - methodologies and input data, system operation practices, planning methodologies and modifications that have been necessary with high penetration, concepts and technologies enabling enhanced penetration
- τ Formulate guidelines:
 - recommended methodologies and input data when estimating impacts and costs of wind power integration
- τ Quantify the impacts of WP on power systems
 - range of impacts/costs; rules of thumb

