iiESI International Institute for Energy Systems Integration

Integration of Variable Renewables on Islands

Energy Systems Integration 101 Course

Irish College, Leuven, Belgium

May 18th 2015

Outline

- Ireland
  - Japan
  - Greek Island
  - Maui

- Dynamics

- Flexibility
  - Storage
  - Spilling wind

- Response to the challenges

Some Irish Data

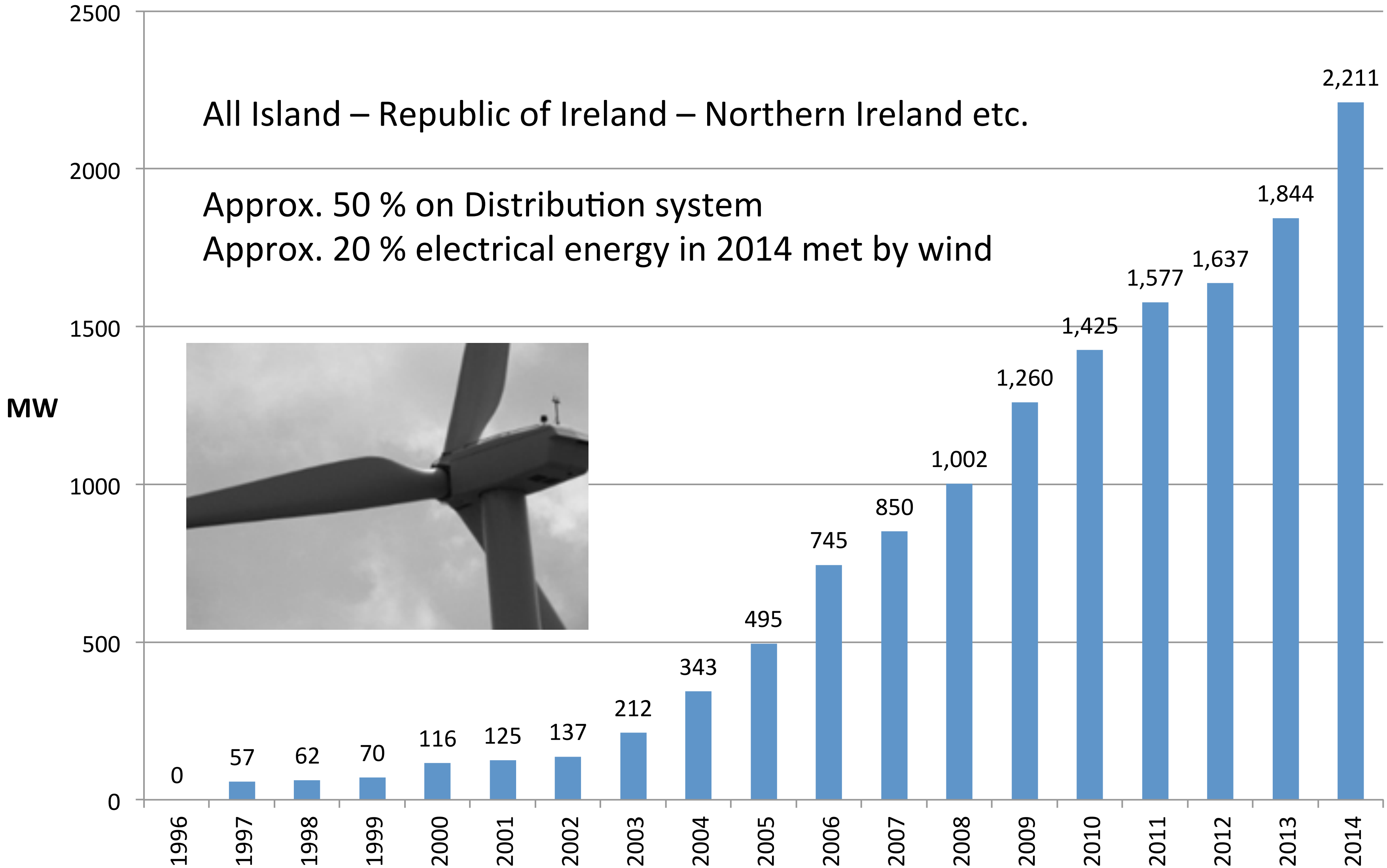
All Island Peak Demand

	2013
Peak System Demand (MW)	*6192*
Time of Peak Demand	*17th Dec 17:30*
Wind Generation at Peak (MW)	*2274*
% Wind of Total Demand	*36*

Wind Installed in Republic of Ireland

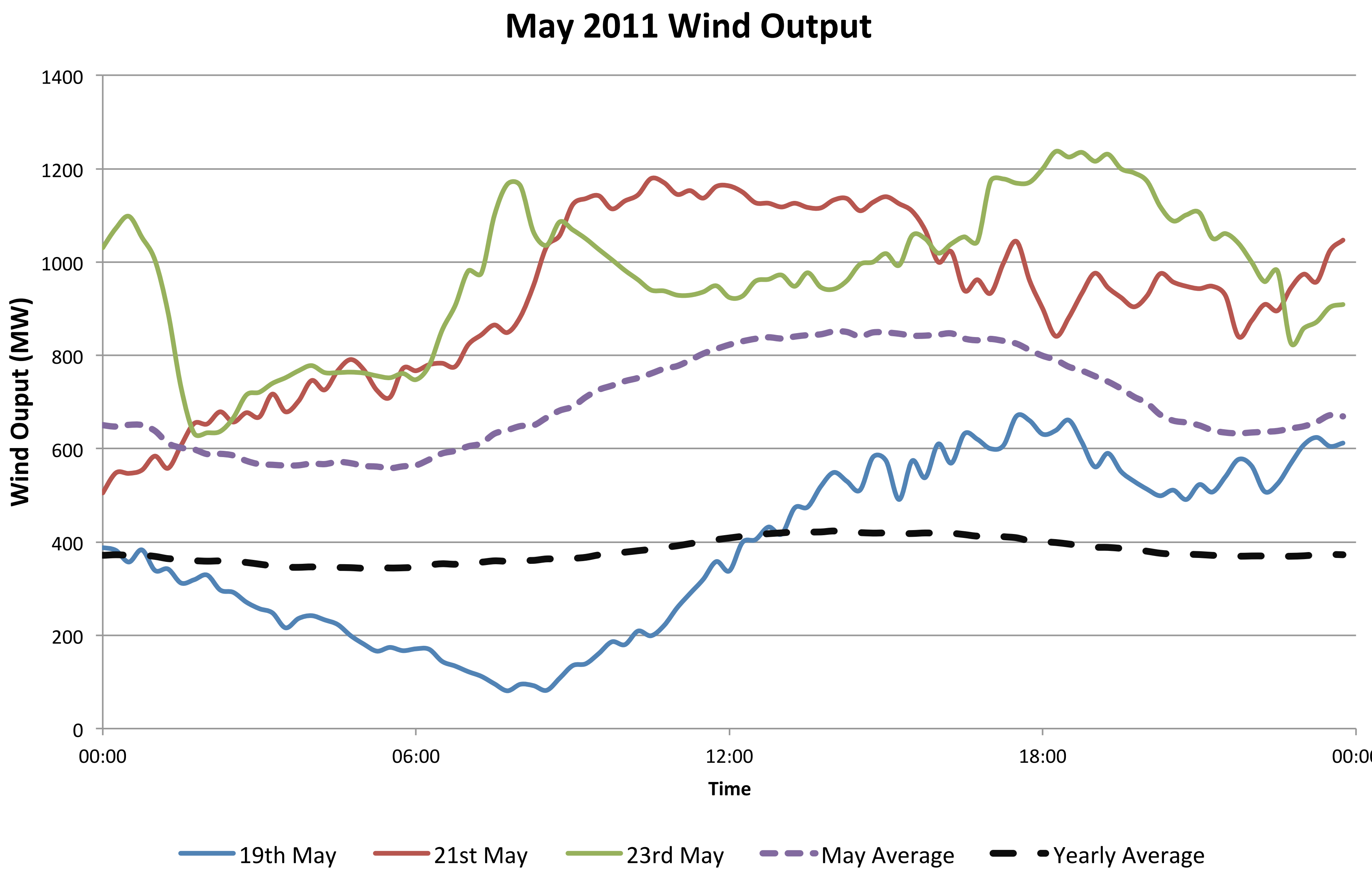
All Island – Republic of Ireland – Northern Ireland etc.

Approx. 50 % on Distribution system
Approx. 20 % electrical energy in 2014 met by wind



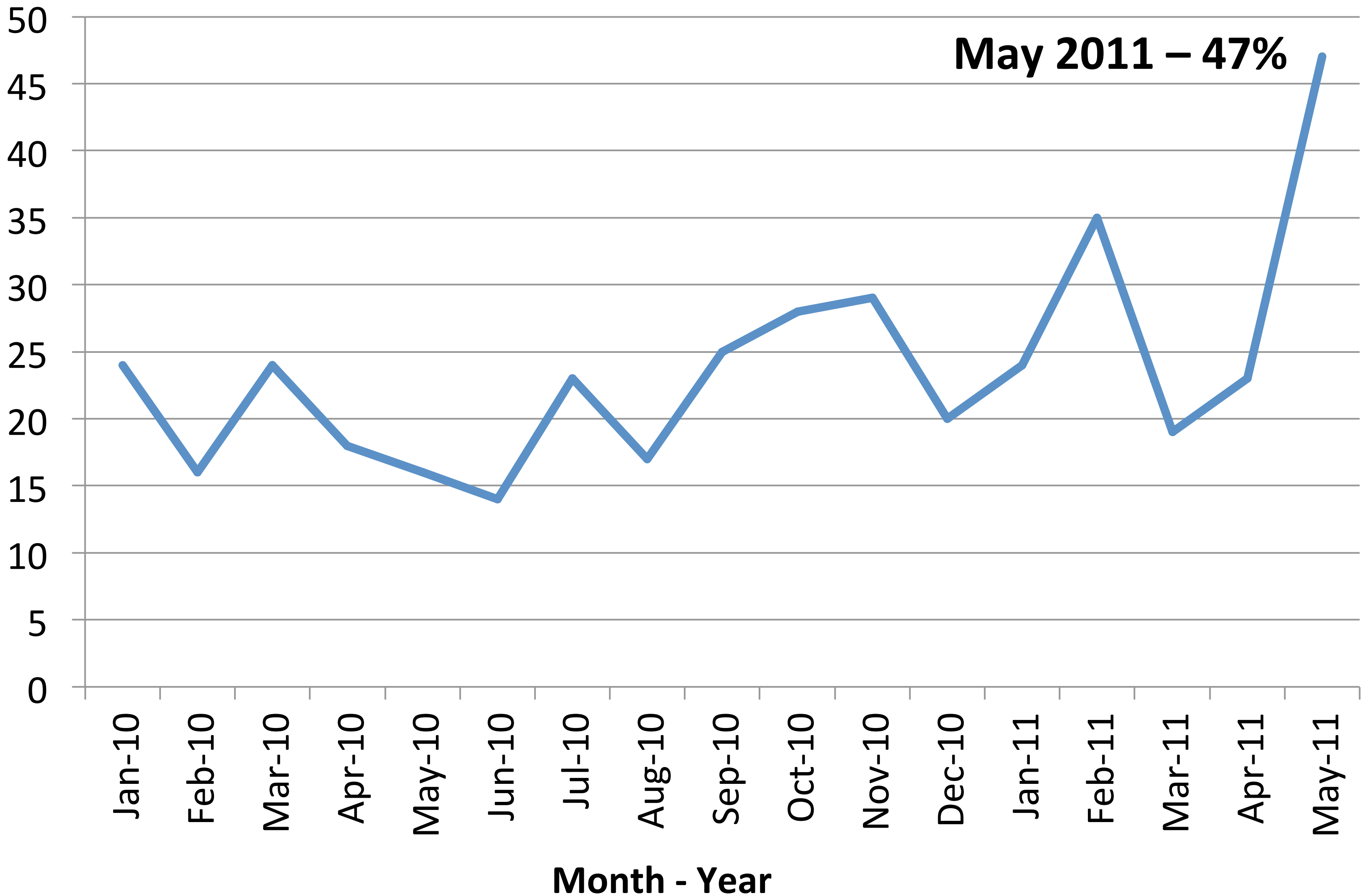
Source: EirGrid http://www.eirgrid.com/operations/systemperformancedata/all-islandwindandfuelmixreport/

Wind Generation Hourly Variability



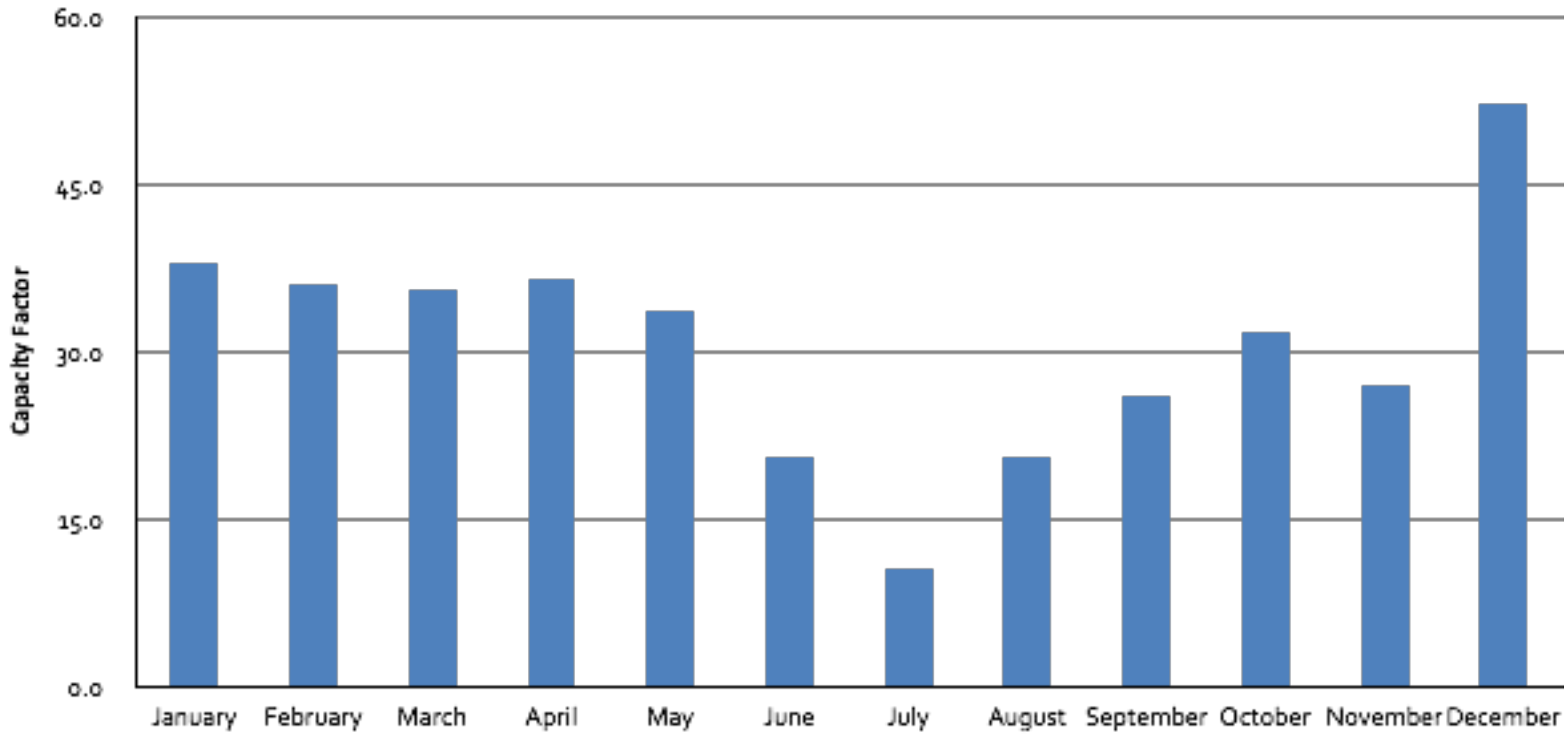
Source: EirGrid

Monthly Variability Capacity Factor – Ireland

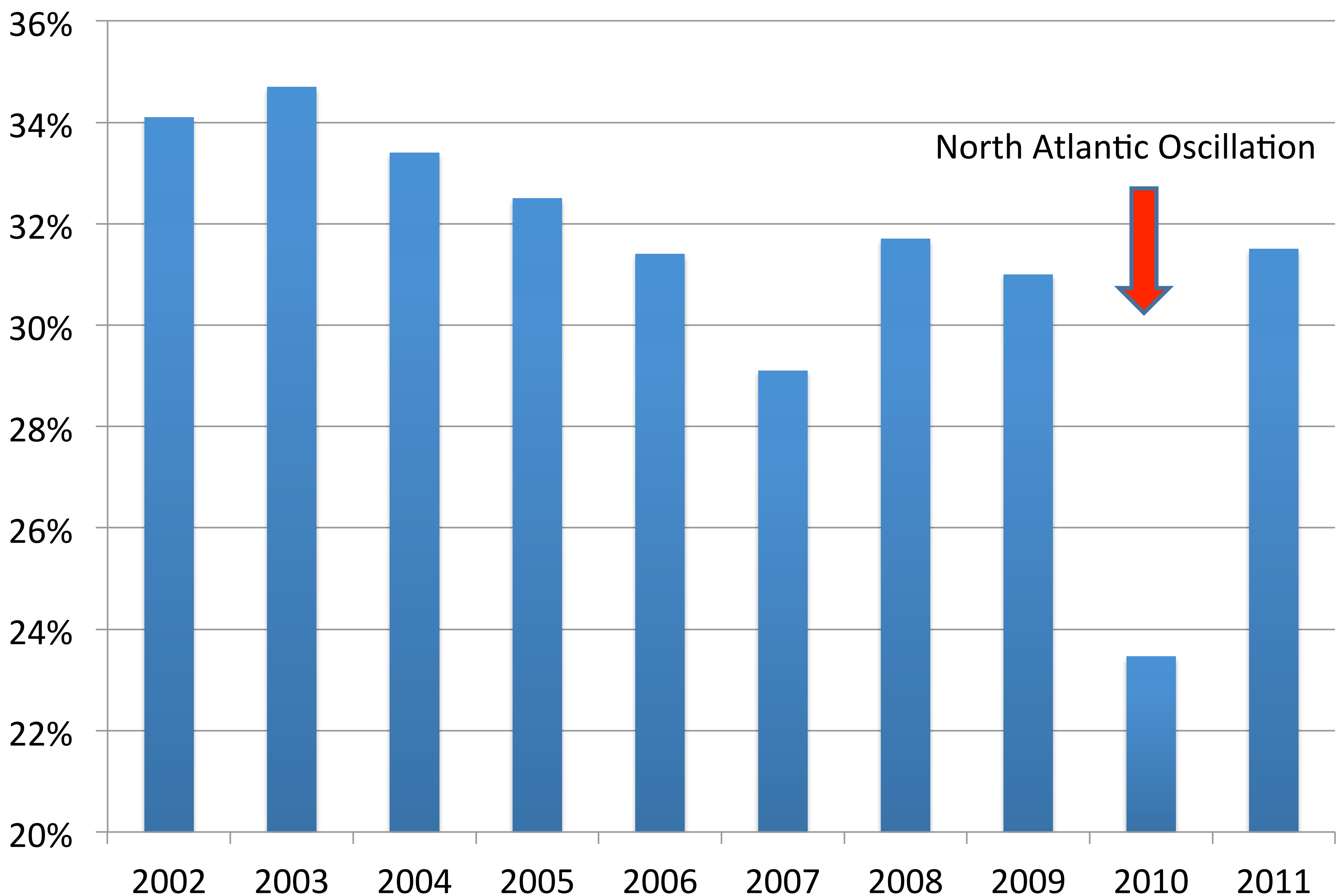


Source: EirGrid

Ireland Wind Capacity Factor 2013

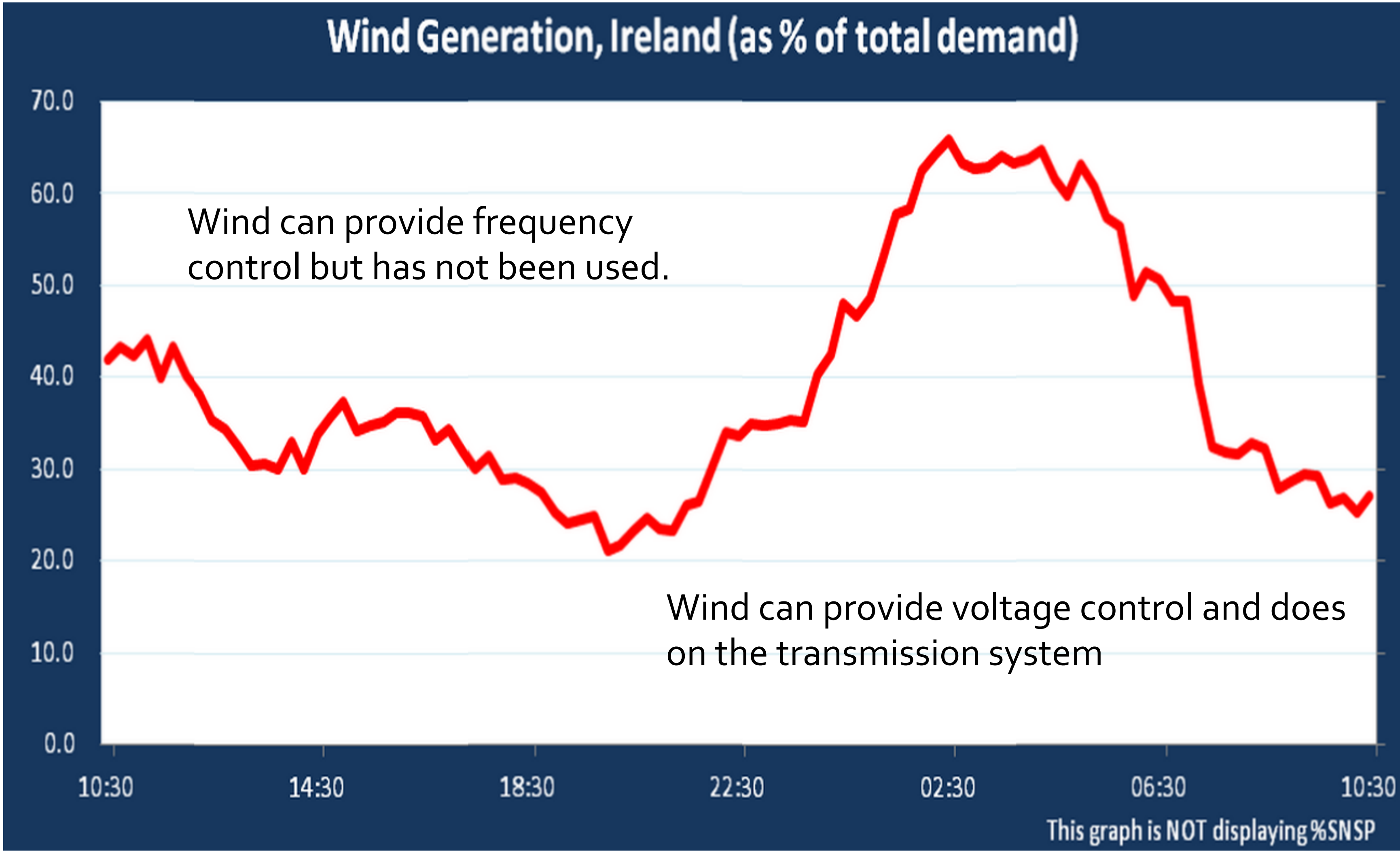


Yearly Variability - Capacity Factor - Ireland

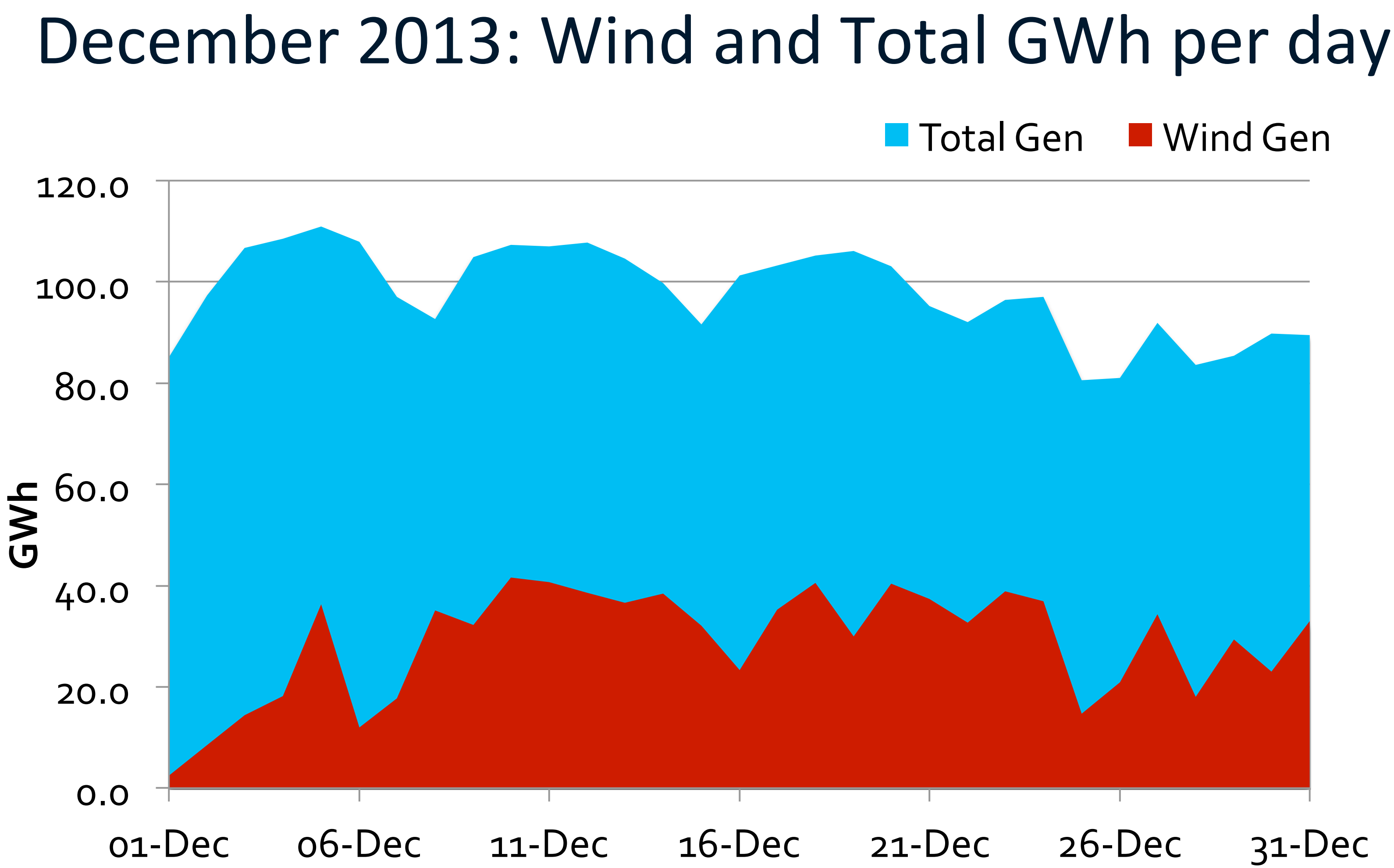


Source: EirGrid

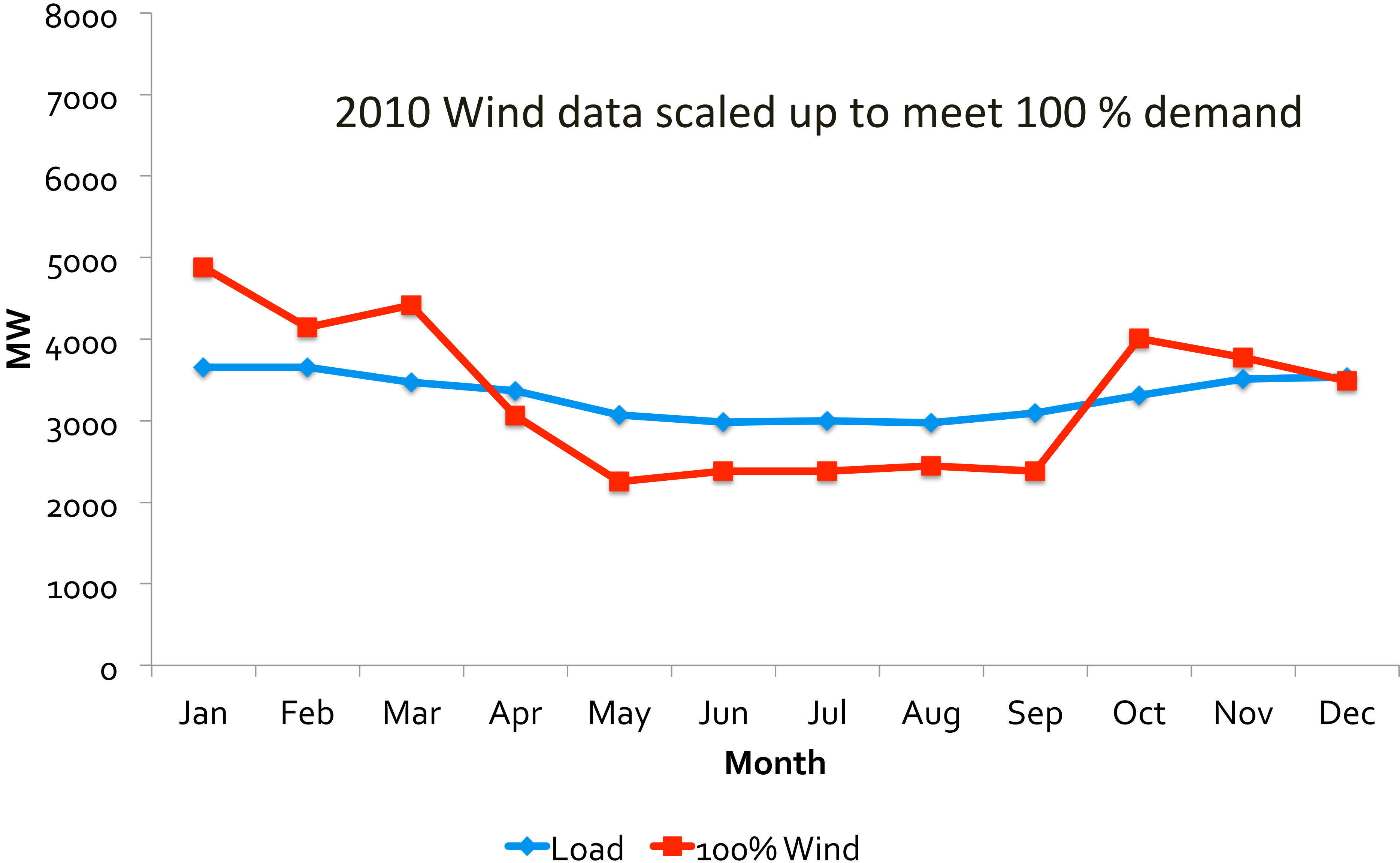
Ireland March 1 & 2, 2015



What is possible

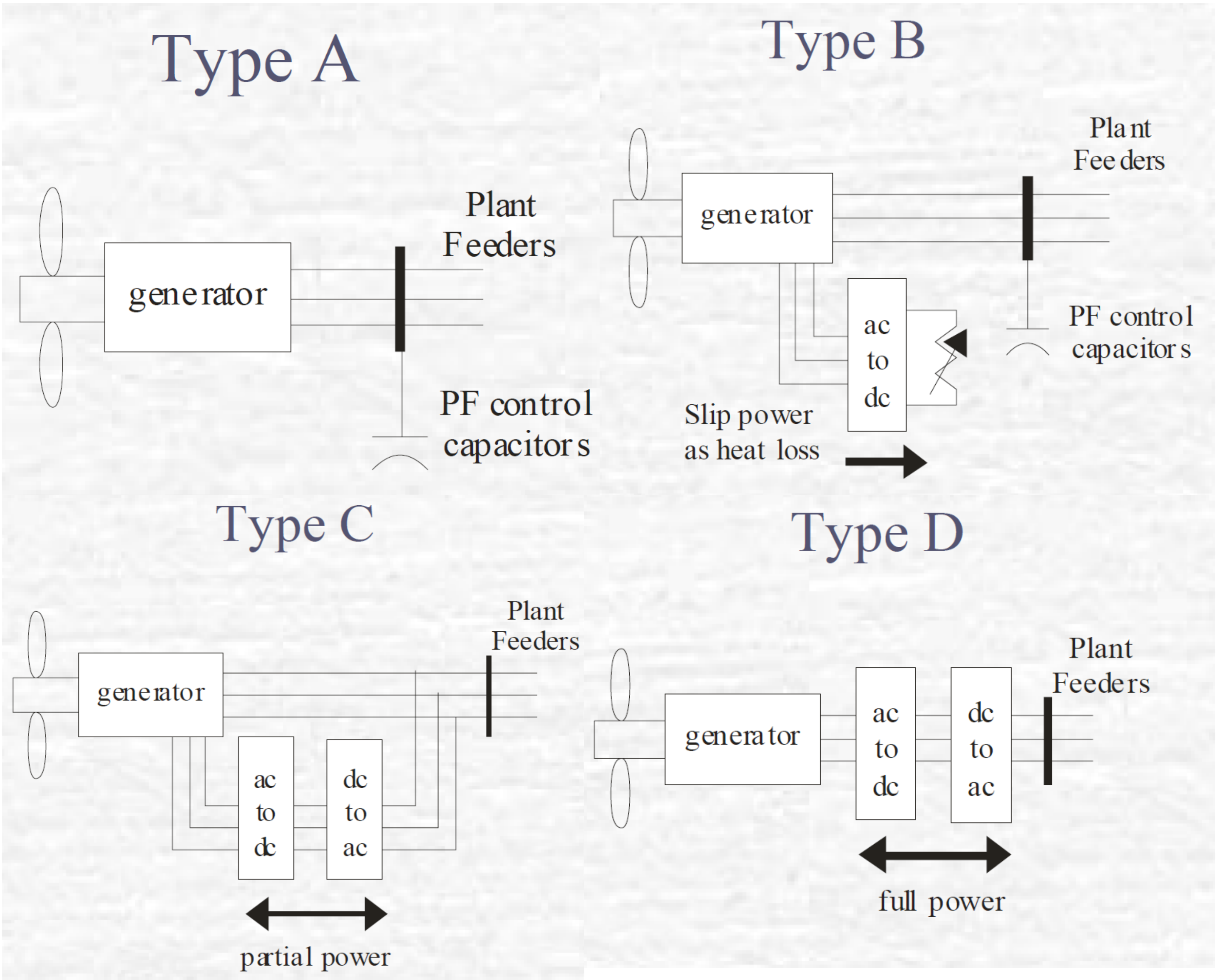


Seasonal Wind – What would we need to be 100 % wind



Dynamics – the hard problem

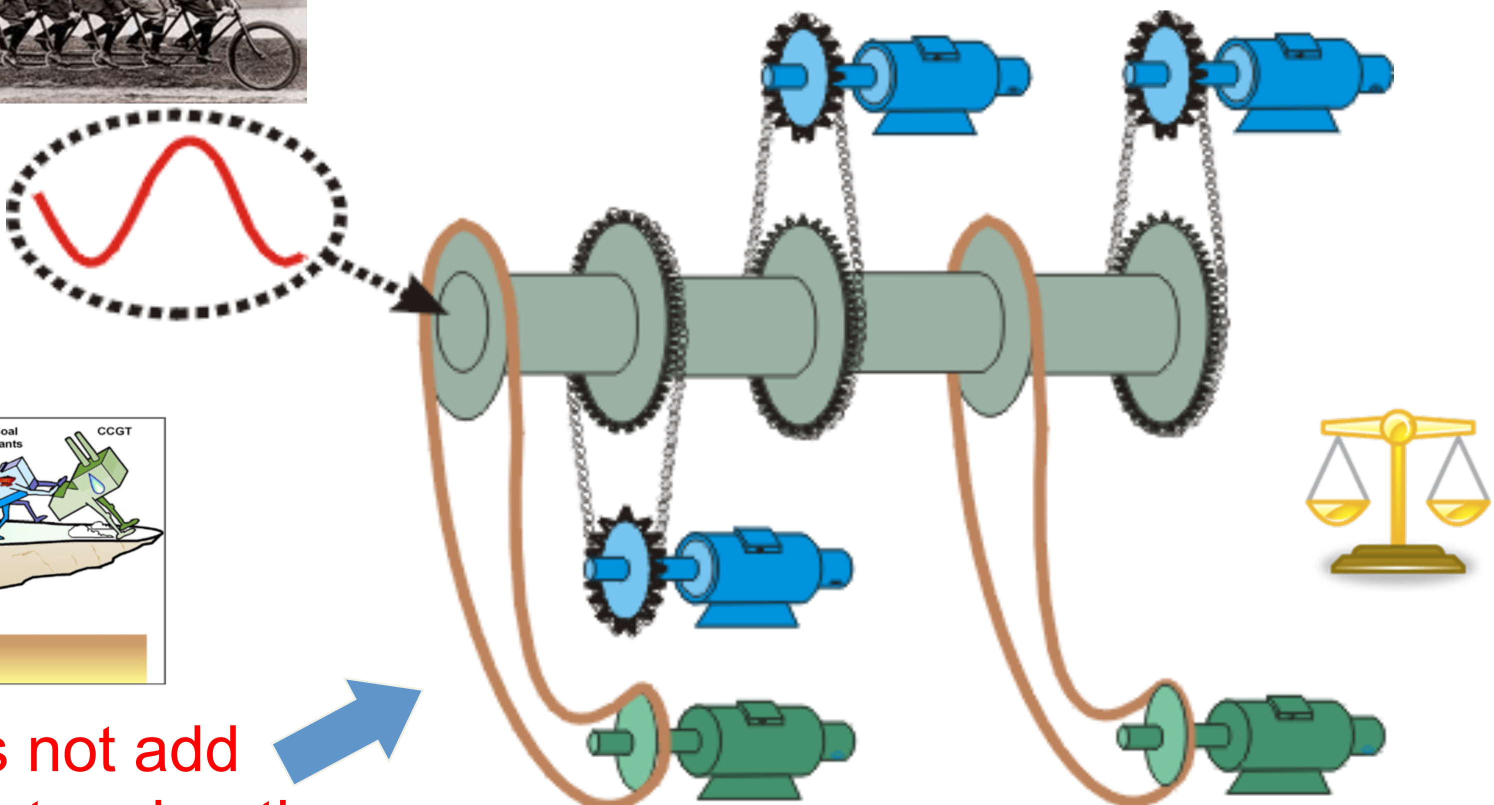
Wind turbine models

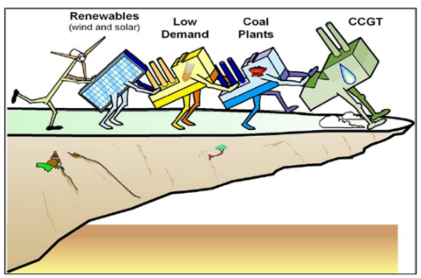


Adding non-synchronous generation

Synchronous generator

50/60 Hz



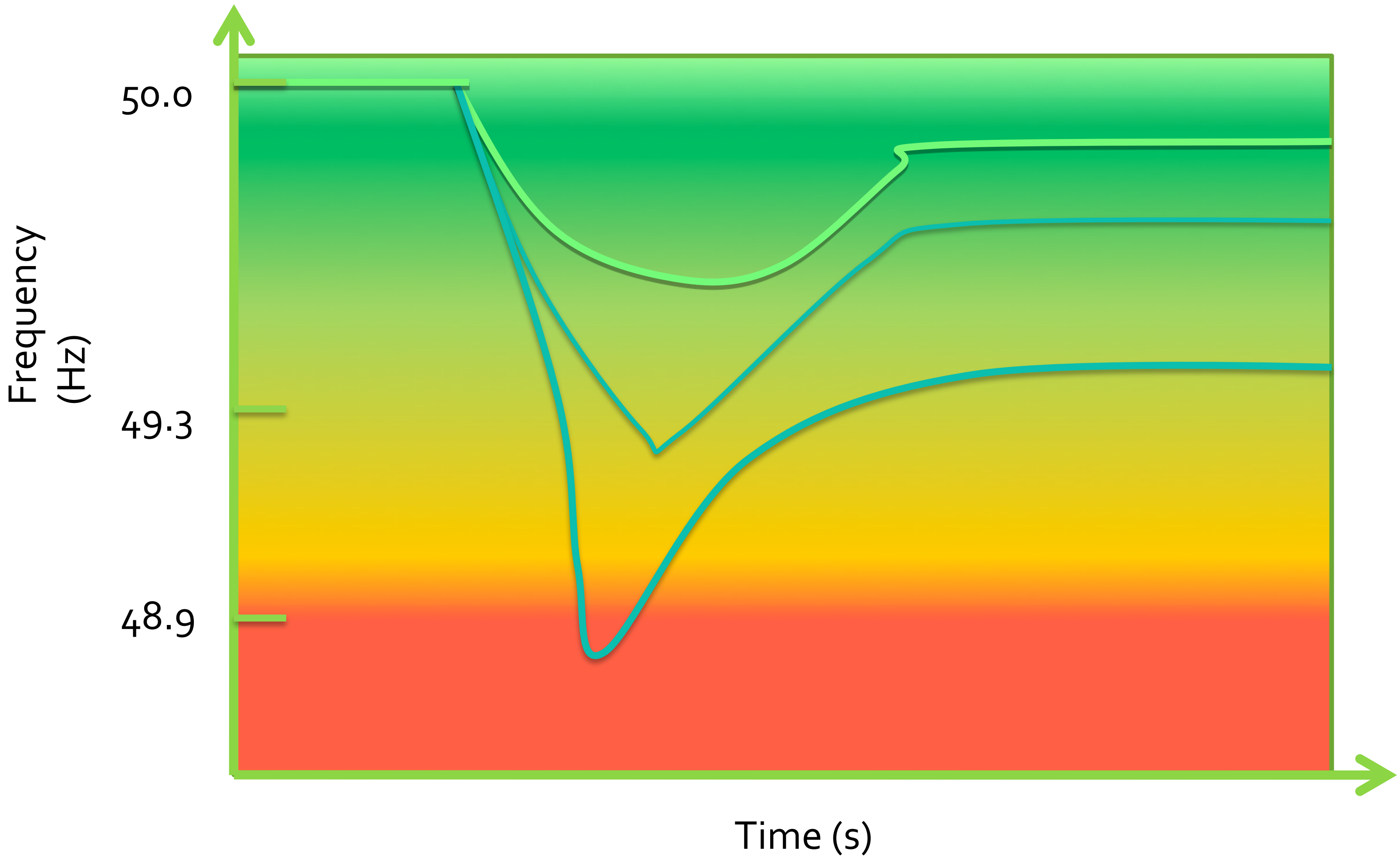


Does not add
to system inertia

Doubly fed induction
generator wind turbine

Fixed speed wind
turbine generator

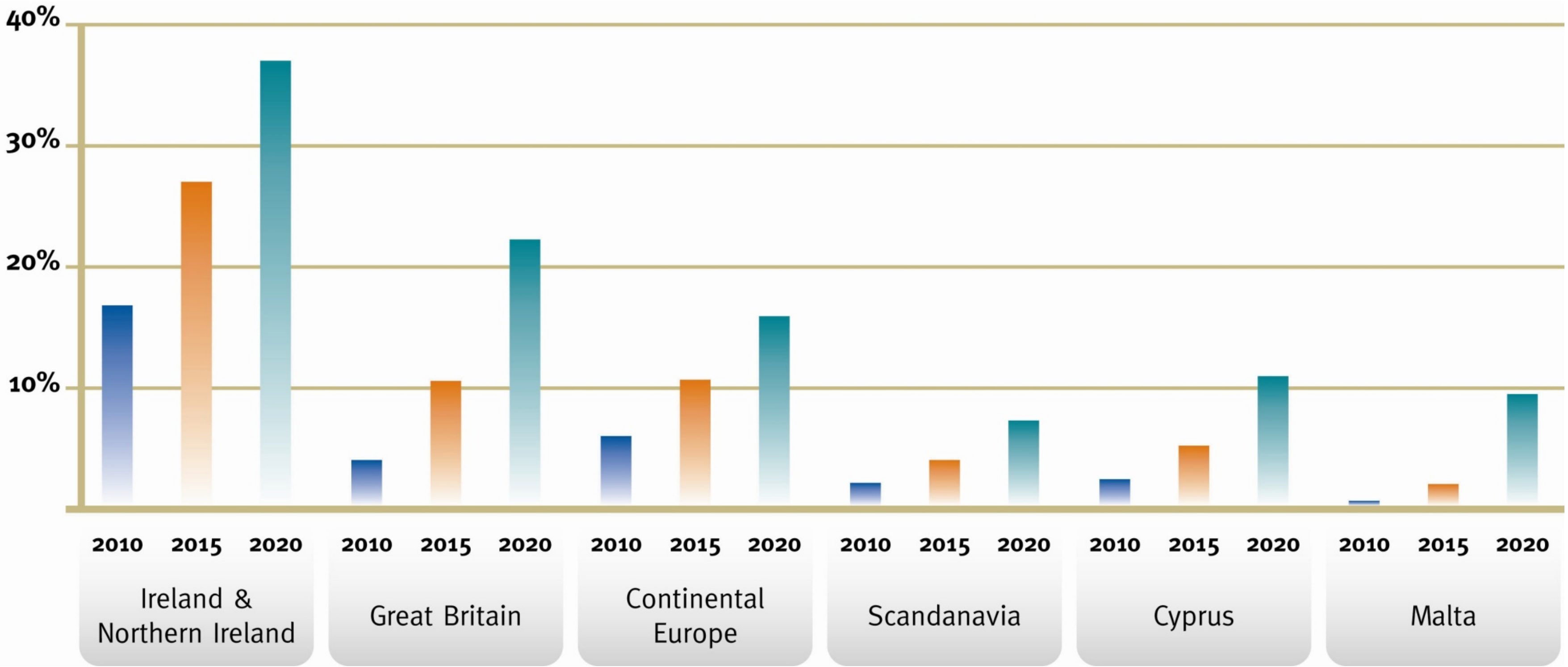
Frequency stability & the nadir



Source: Jonathan O'Sullivan, EirGrid

The Vatican Sept 28th 2003

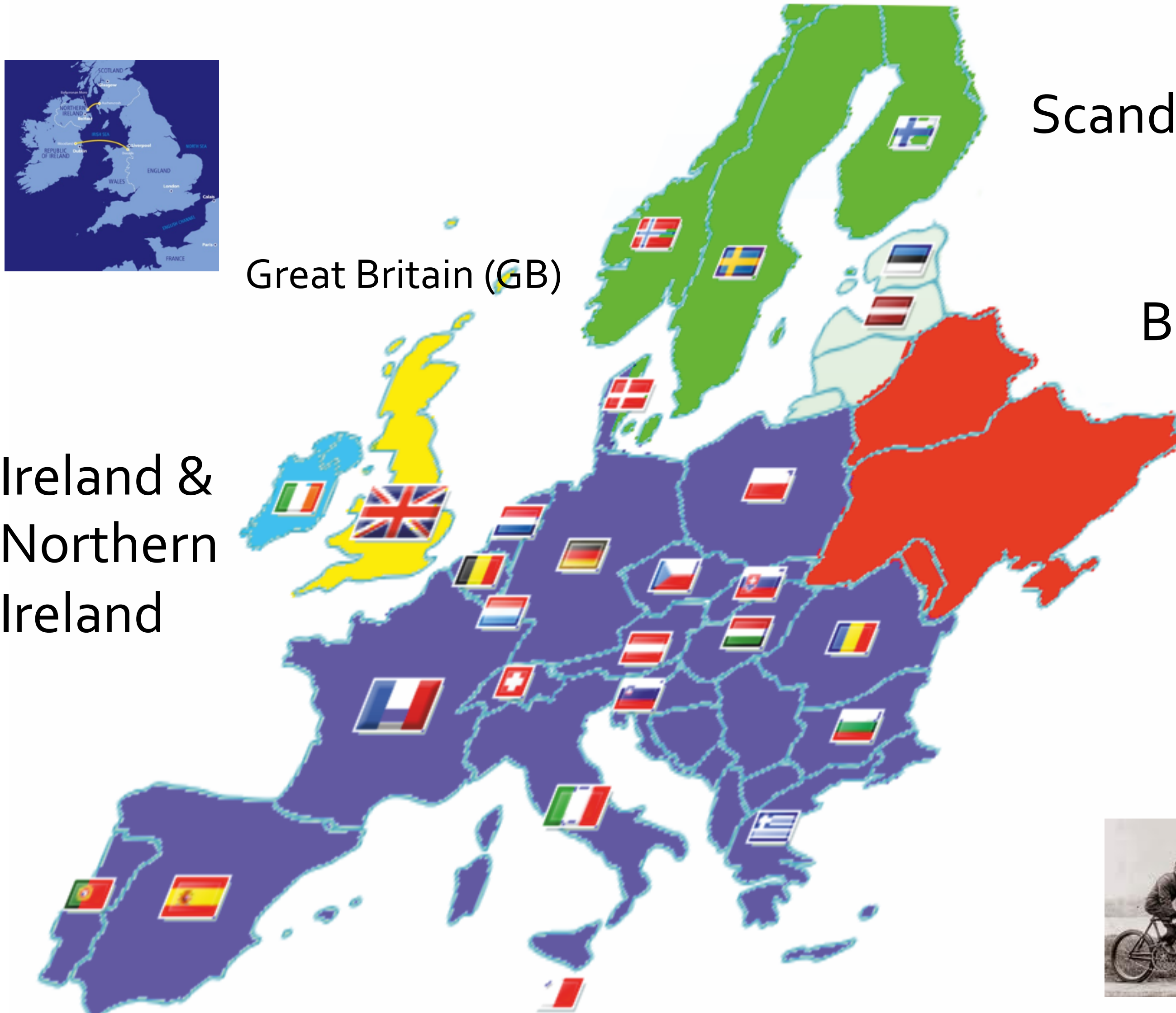
Targets for non-synchronous sources in European Systems



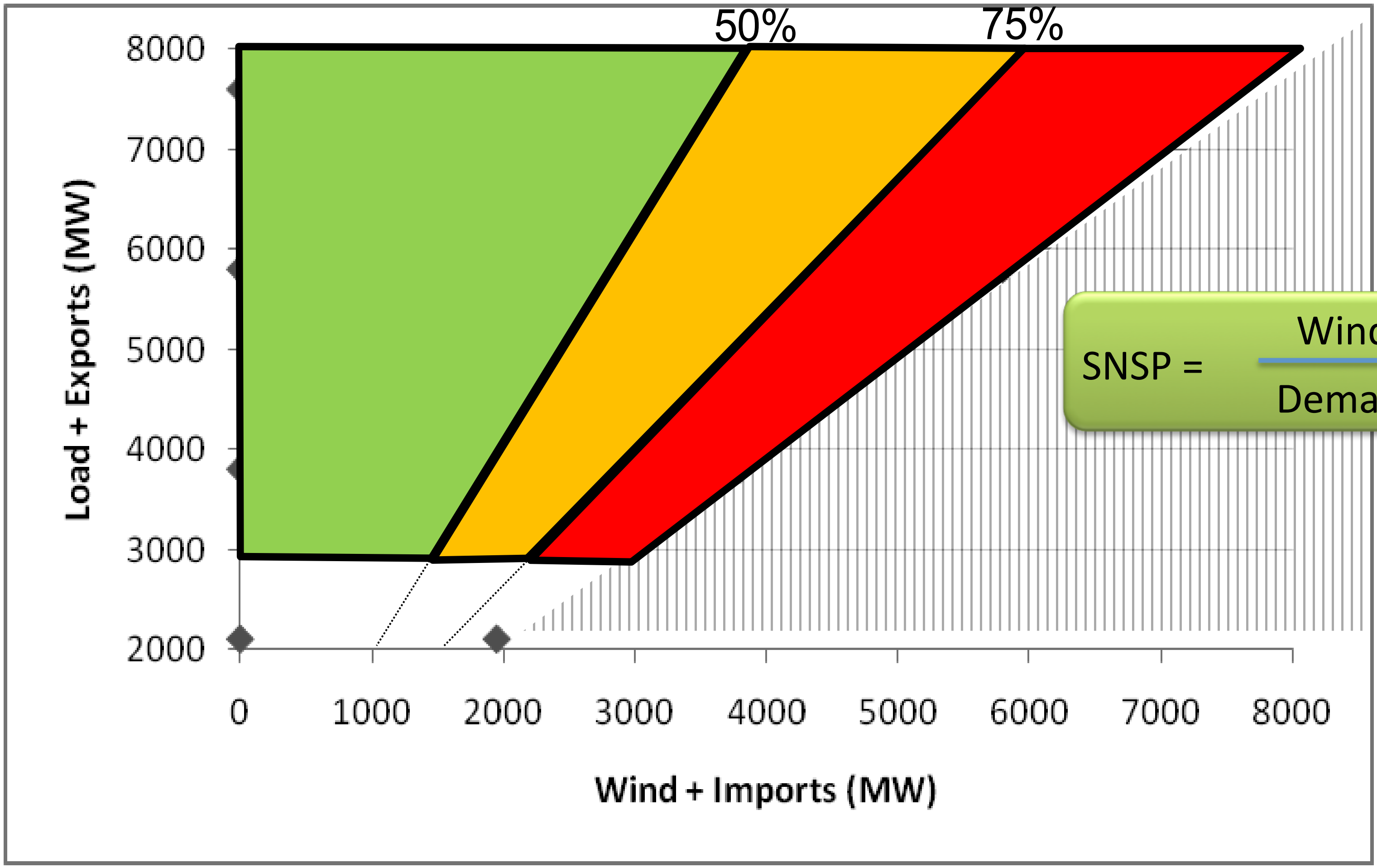
http://www.eirgrid.com/operations/ds3/

* Based on analysis of National Renewable Action Plans (NREAPs) as submitted by Member States

Synchronous systems in Europe



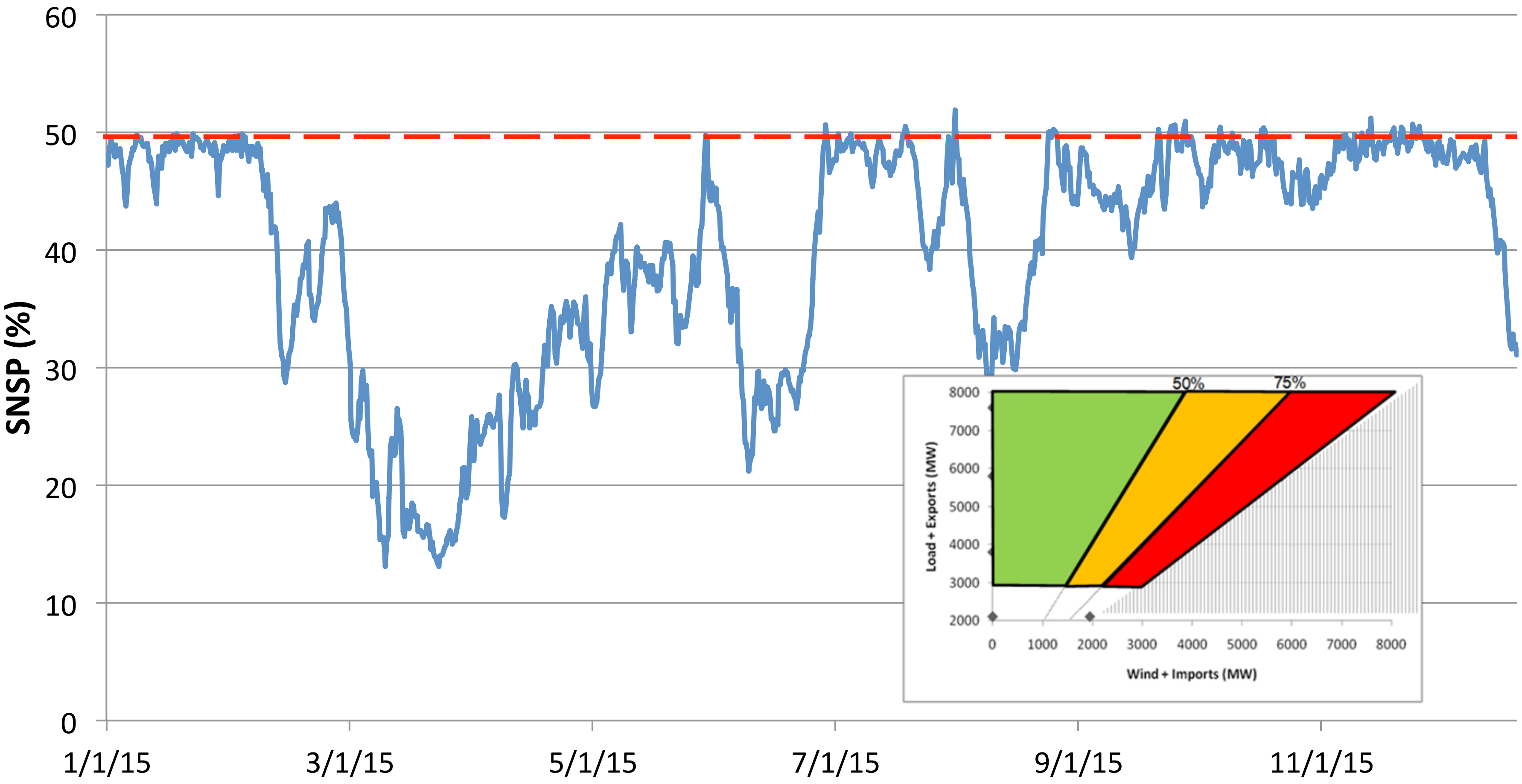
System Non-Synchronous Penetration (SNSP)



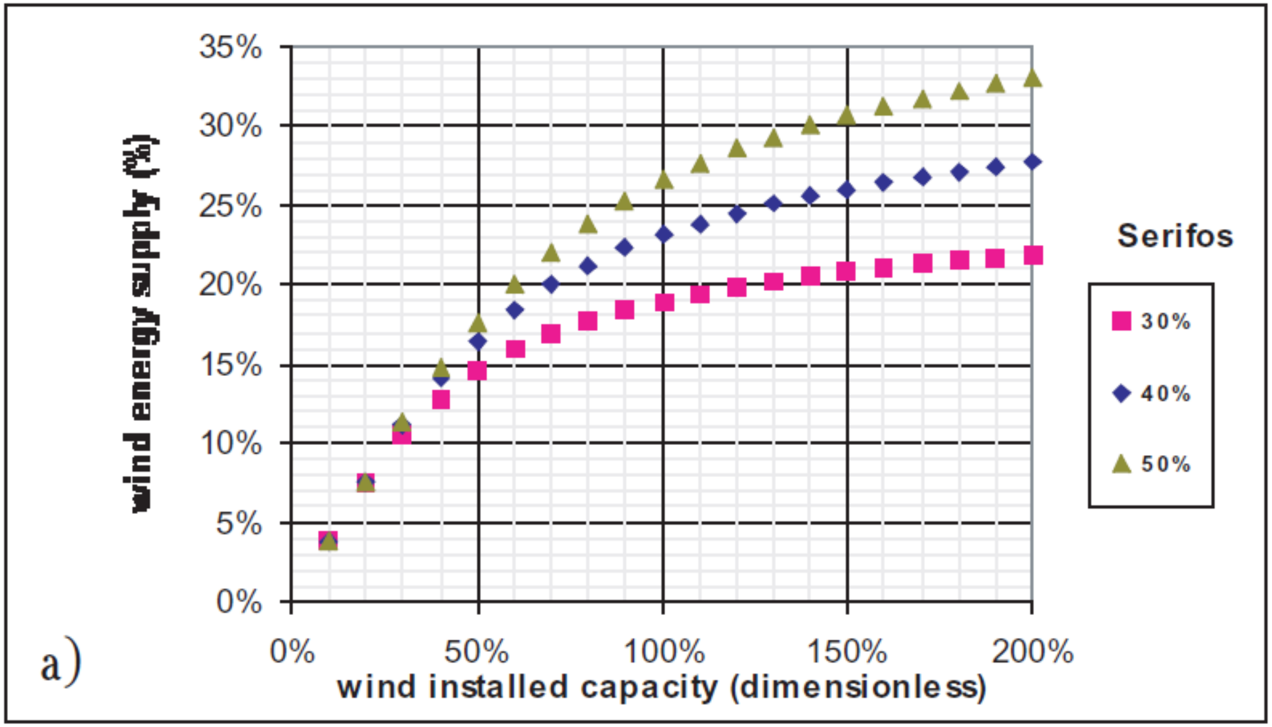
$$\text{SNSP} = \frac{\text{Wind + Imports}}{\text{Demand + Exports}}$$

O'Sullivan, J., Rogers, A., Flynn, D., Smith, P., Mullane, A., and O'Malley, M.J., "Studying the Maximum Instantaneous Non-Synchronous Generation in an Island System – Frequency Stability Challenges in Ireland", *IEEE Transactions on Power Systems*, Vol. 29, pp. 2943 – 2951, 2014.

SNSP – Early 2015



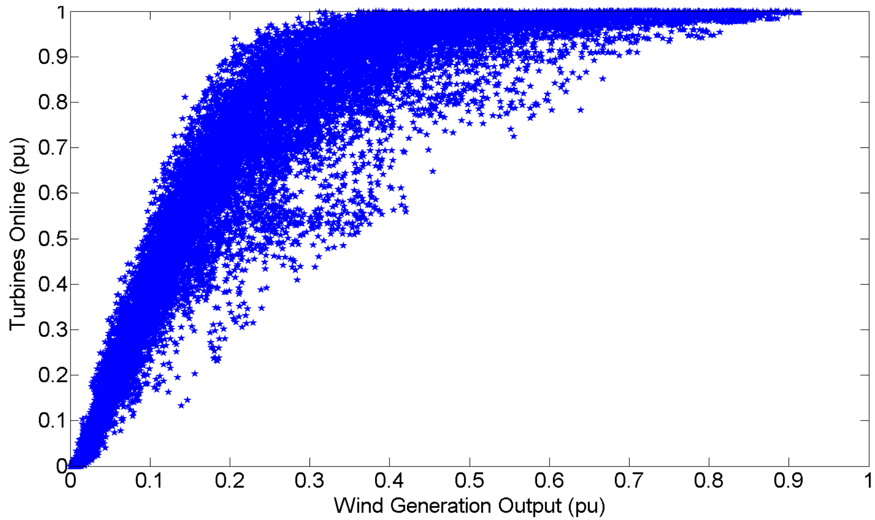
SNSP in Greek Islands



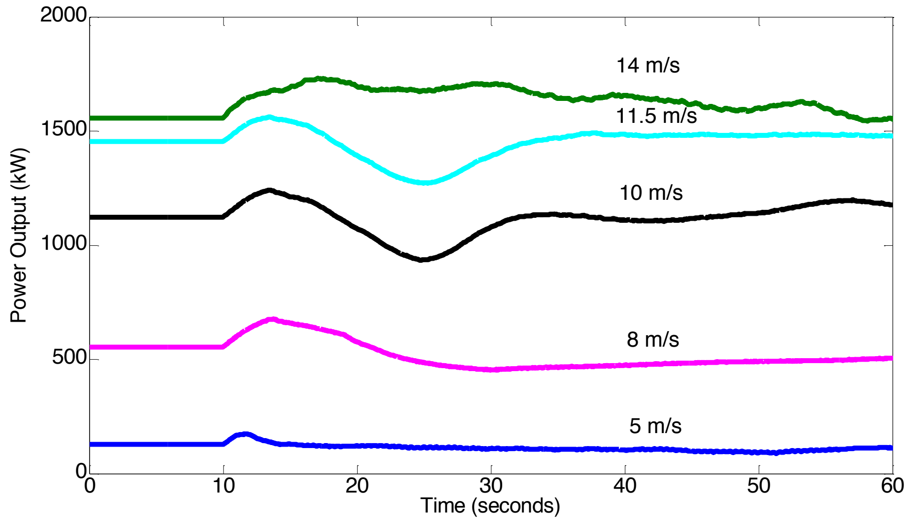
Caralis, G., and A. Zervos (2007a). Analysis of wind power penetration in autonomous Greek islands. *Wind Engineering*, 31(6):487-502.

Aggregate Emulated Inertial Response

- Potential response from wind will be stochastic - dependent on:
  - Number of turbines online
  - Operating level of wind turbines



Number of turbines above minimum speed (from wind farm data, across the island of Ireland)

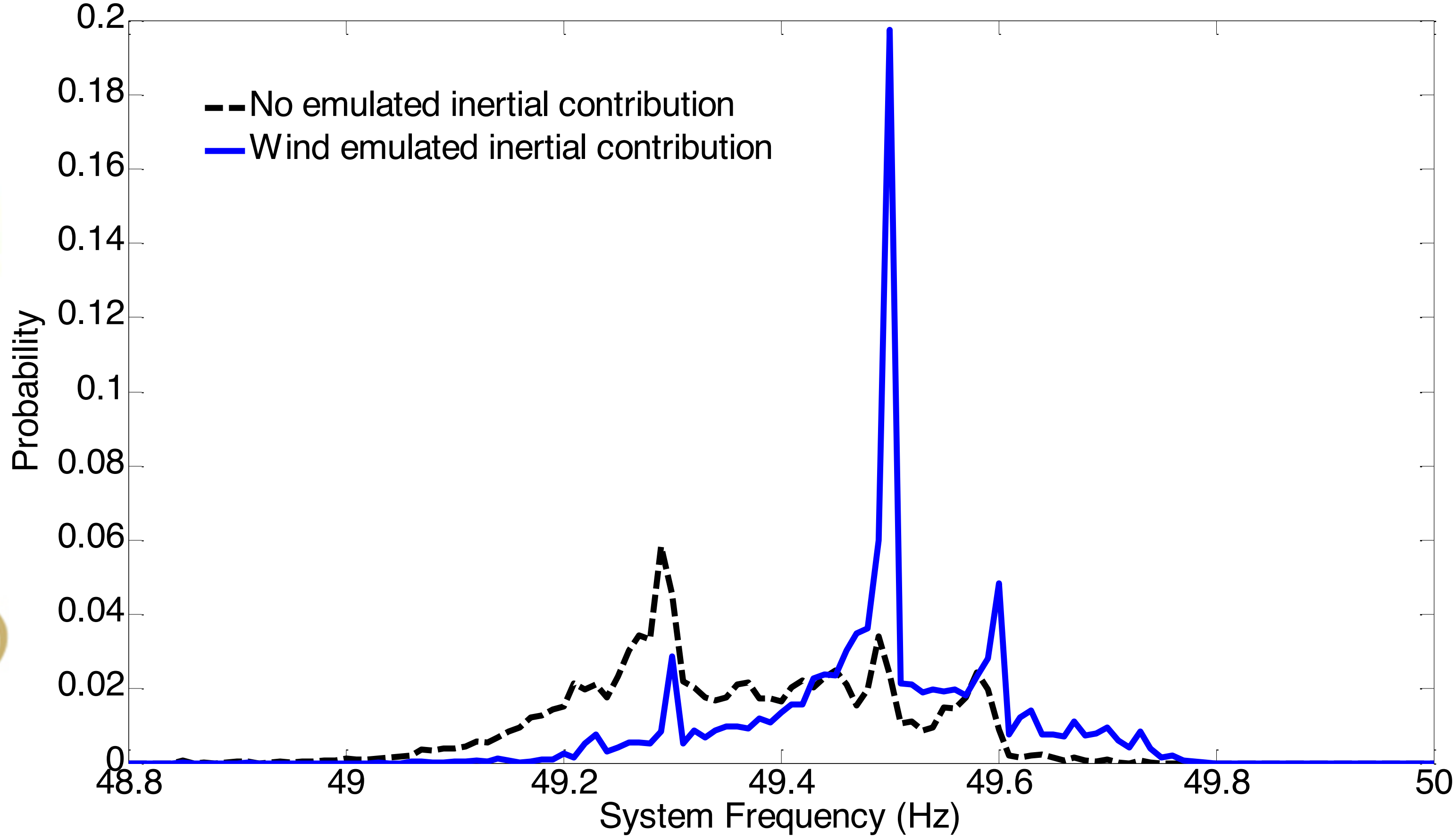


Response at different operating points (GE field tests)

Ruttledge, L.; Miller, N. W.; O'Sullivan, J.; Flynn, D.; , "Frequency Response of Power Systems With Variable Speed Wind Turbines,“ *Sustainable Energy, IEEE Transactions on* , vol.3, no.4, pp.683-691, Oct. 2012
doi: 10.1109/TSTE.2012.2202928 URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6289406&isnumber=6299423

Very High Penetrations "Technical" Flexibility is Key

- Frequency nadir (lowest point) can be improved



(DS3)

- Ruttledge, L.; Miller, N. W.; O'Sullivan, J.; Flynn, D.; , "Frequency Response of Power Systems With Variable Speed Wind Turbines," *Sustainable Energy, IEEE Transactions on* , vol.3, no.4, pp.683-691, Oct. 2012.
- Doherty, R, Mullane, A., Lalor, G., Burke, D., Bryson, A. and O'Malley, M.J. "An Assessment of the Impact of Wind Generation on System Frequency Control", *IEEE Transactions on Power Systems*, Vol. 25, pp. 452 – 460, 2010.

Markets for Inertial Response ?

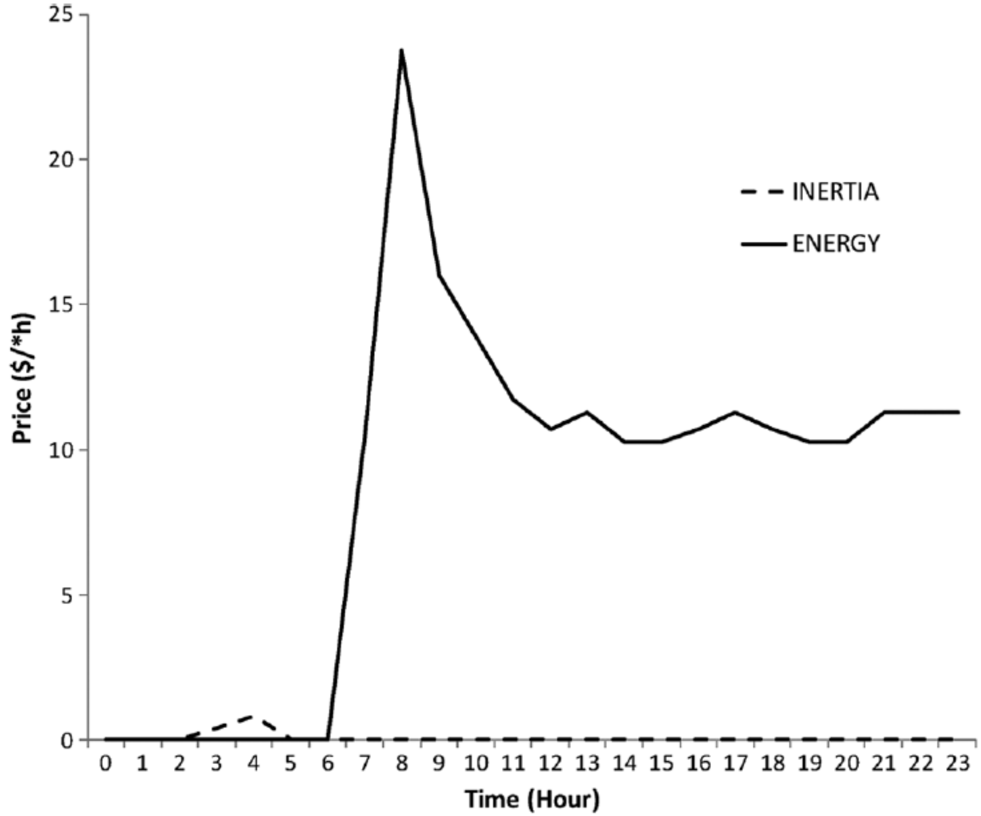


Fig. 10. Prices for energy and synchronous inertia for 50% wind penetration system with all other PFR constraints eliminated. Prices are in ($/MVAs-h) for inertia and ($/MW-h) for energy.

Ela, E., Gevorgian, V, Tuohy, A., Kirby, Milligan, M. and O'Malley, M.J. "Market Designs for the Primary Frequency Response Ancillary Service — Part I: Motivation and Design", IEEE Transactions on Power Systems, Vol. 29, pp.421- 431, 2014.

Ela, E., Gevorgian, V, Tuohy, A., Kirby, Milligan, M. and O'Malley, M.J. "Market Designs for the Primary Frequency Response Ancillary Service — Part II: Case Studies", IEEE Transactions on Power Systems, Vol. 29, pp. 432- 440, 2014.

Mainland Europe & US

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Western Wind and Solar Integration Study Phase 3 – Frequency Response and Transient Stability

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GE Energy Management
Schenectady, New York

NREL Technical Monitor: Kara Clark

Link to Executive Summary

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Subcontract Report
NREL/SR-5D00-62906
December 2014

Contract No. DE-AC36-08GO28308

http://www.nrel.gov/docs/fy15osti/62906.pdf

Pushing the Limits

Europe's New Grid: Innovative Tools to Combat Transmission Bottlenecks and Reduced Inertia

By Wilhelm Winter, Katherine Elkington, Gabriel Bareux, and Jan Kostevc

IN THE FUTURE A GROWING AMOUNT OF POWER electronics will lead to a transition of the power system to a structure with very low synchronous generation. Due to large transit power flows and uncertainties, transmission systems are being operated under increasingly stressed conditions and are close to their stability limits. Together with the integration of large amounts of renewable generation with power electronic interfaces and the addition of high-voltage direct current (HVdc) links into the power system, these challenges will necessitate a review of the operation and control of transmission networks. This article will demonstrate the need for R&D performed by network operators and explain a set of challenges, focusing on three main areas: transmission grid operation in a new power system environment, the need to increase overhead line (OHL) utilization, and the impact of reduced inertia on power system frequency.

Transmission Grid Operation in a New Power System Environment

The tools currently in use by transmission system operators (TSOs) for operational planning and system operation must evolve significantly to work in an environment characterized by large-scale integration of renewable energy sources with low predictability and limited controllability as well as one that is close to its stability limits. The insertion of new equipment such as phase shifters and HVdc lines and the development of an integrated European electricity market with huge power flows over large distances will bring further challenges. These challenges are unprecedented, but fortunately the European Wind Integration Study (EWIS) project, finalized in 2010

Digital Object Identifier 10.1109/MPE.2014.2363534
Date of publication: 7 January 2015

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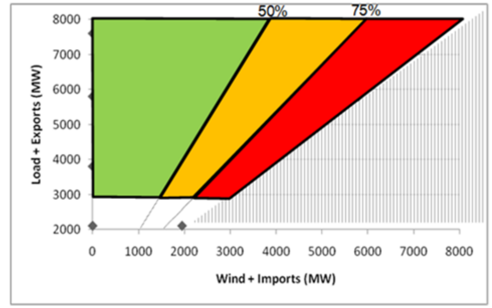
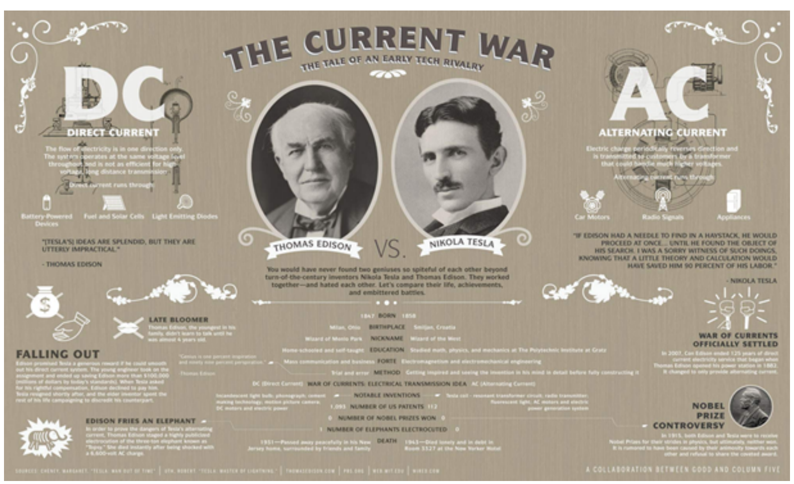
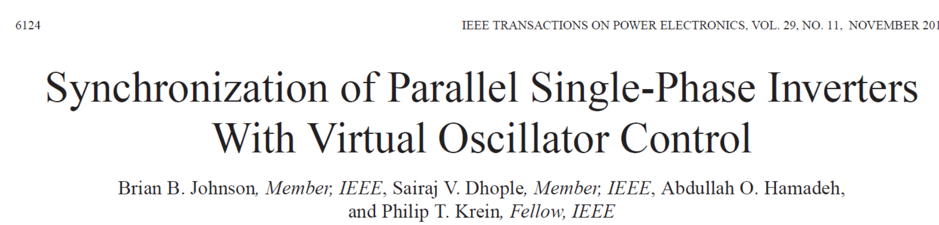
Future > 75 % SNSP



50/60 Hz ?





6124 IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 29, NO. 11, NOVEMBER 2014

Synchronization of Parallel Single-Phase Inverters With Virtual Oscillator Control

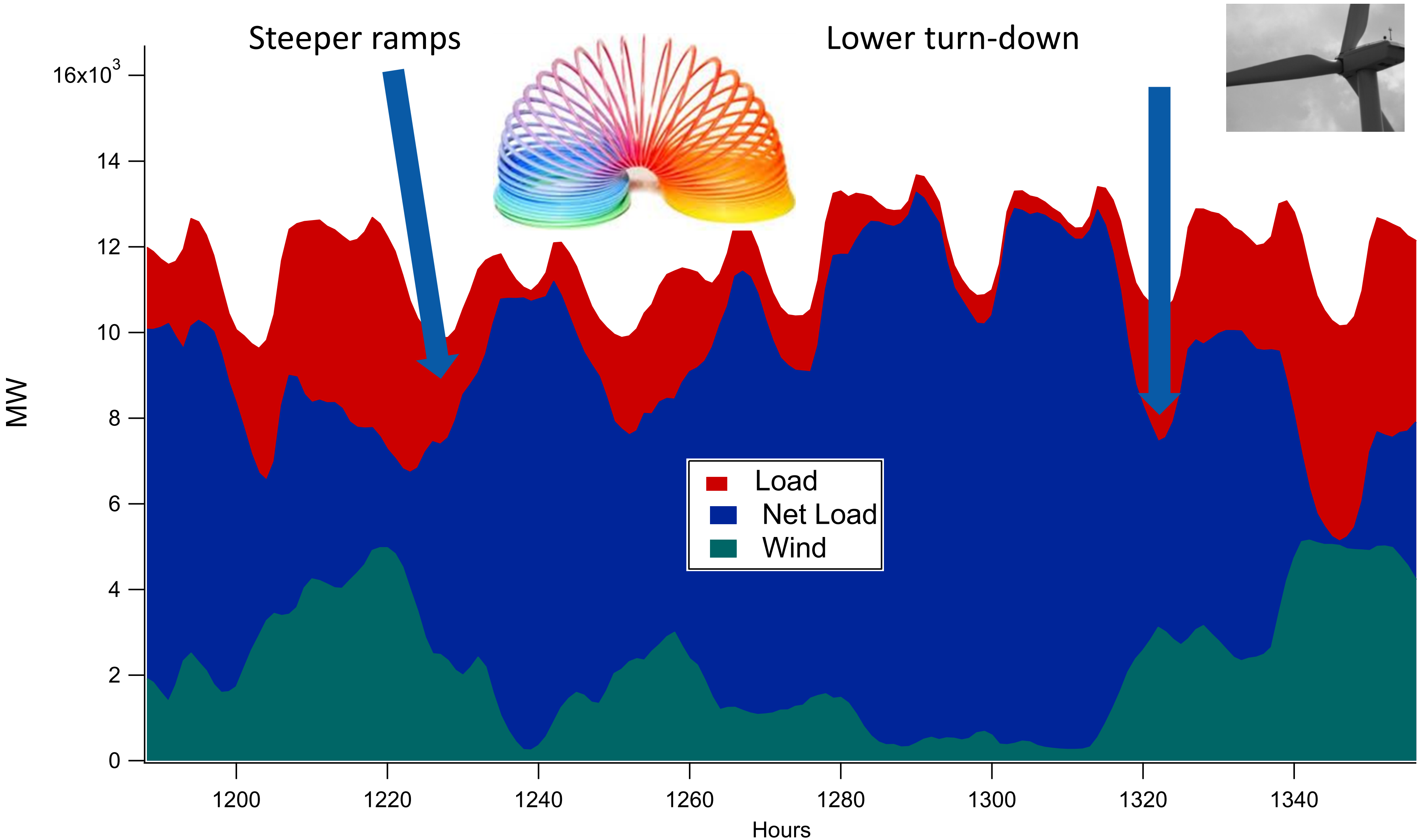
Brian B. Johnson, *Member, IEEE*, Sairaj V. Dhople, *Member, IEEE*, Abdullah O. Hamadeh, and Philip T. Krein, *Fellow, IEEE*

Key Take Away

- The power electronic technology used to integrate wind (and solar photovoltaics) is asynchronous, decoupling the kinetic energy from the system response:
  - Power system dynamics is a limitation
  - We will get to 75 % SNSP soon
  - Going beyond 75 % SNSP – game changing

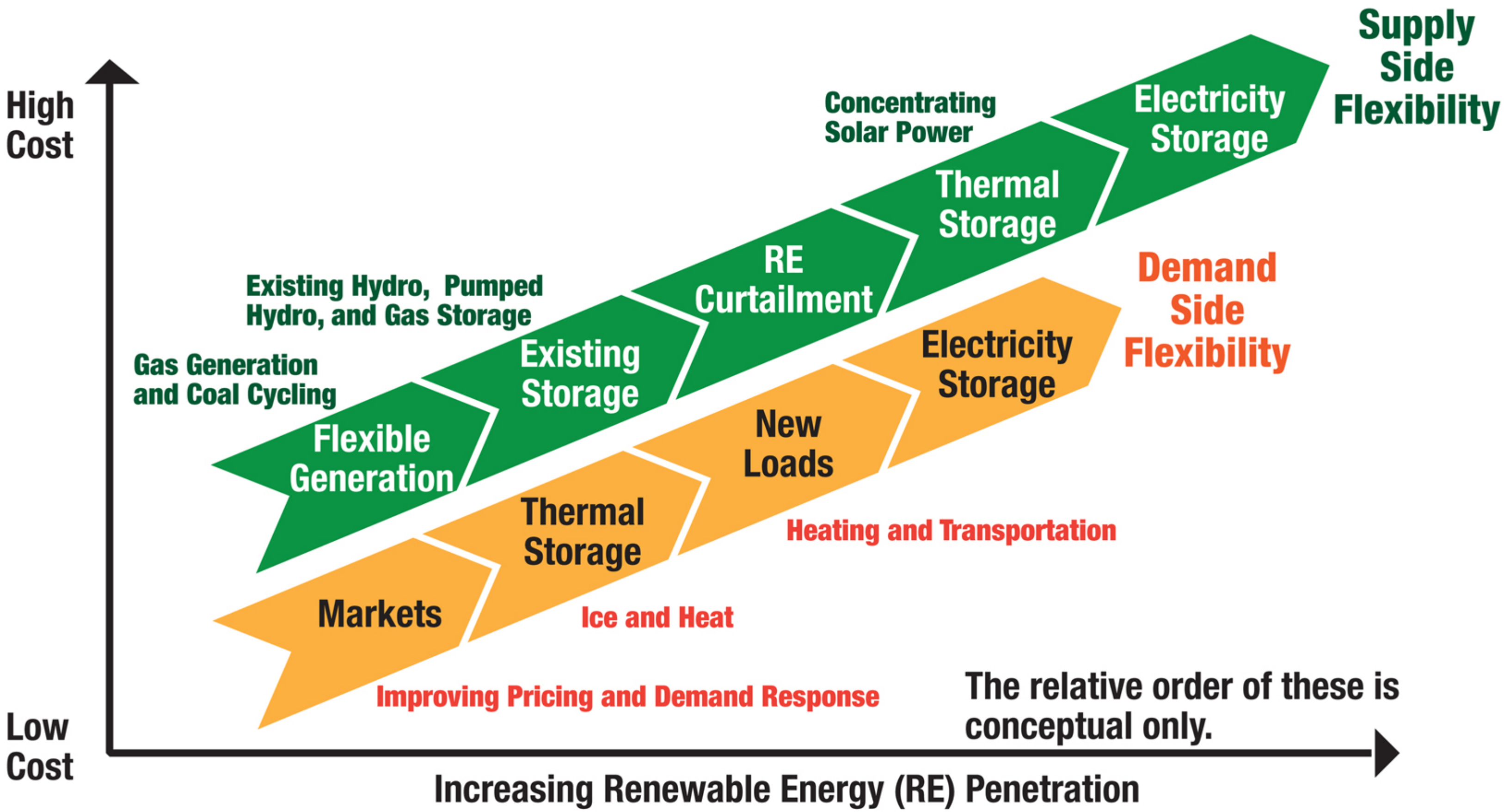
Flexibility

With Variable Renewables More Flexibility is Needed



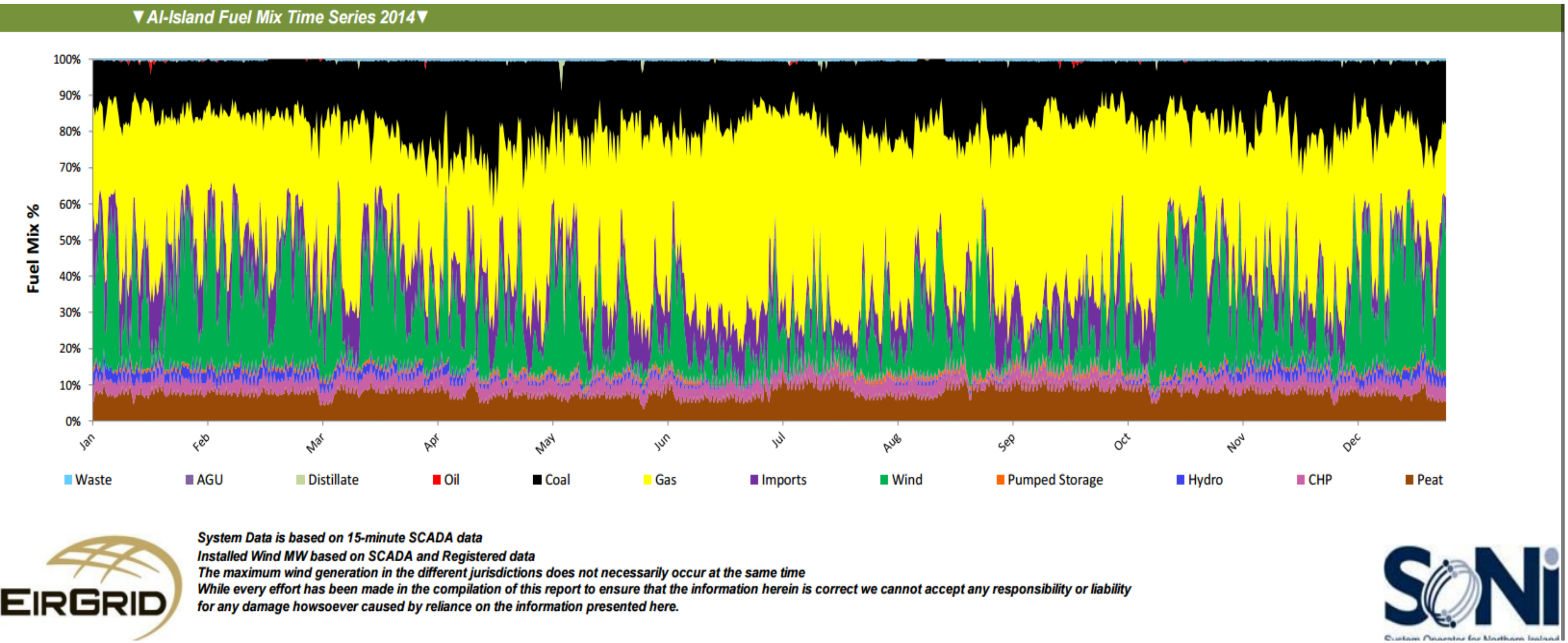
Source: Michael Milligan , NREL

Flexibility Supply Curve



How do we choose the optimum mix of flexibility resources?

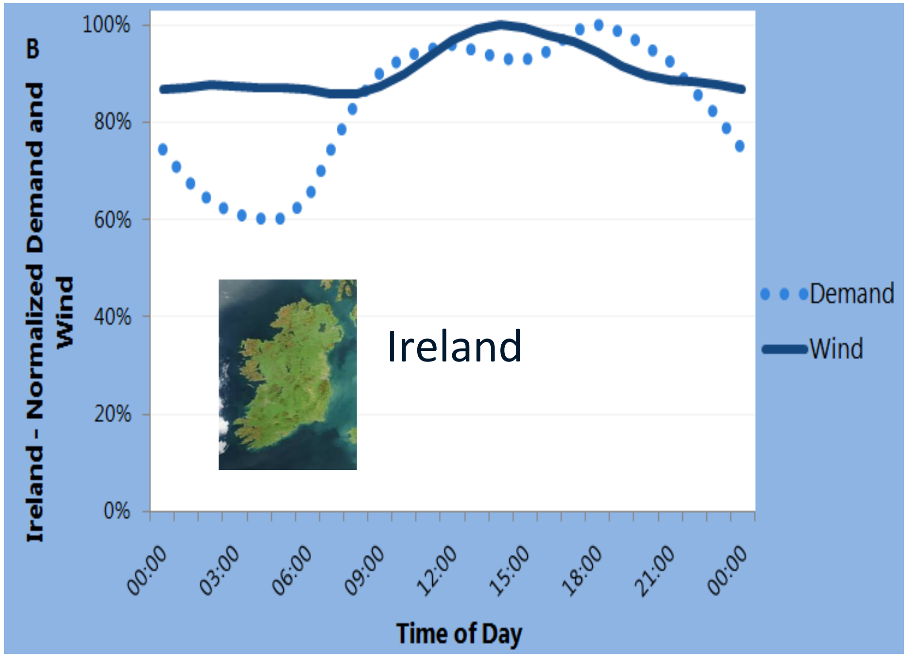
The Role of Gas in Ireland

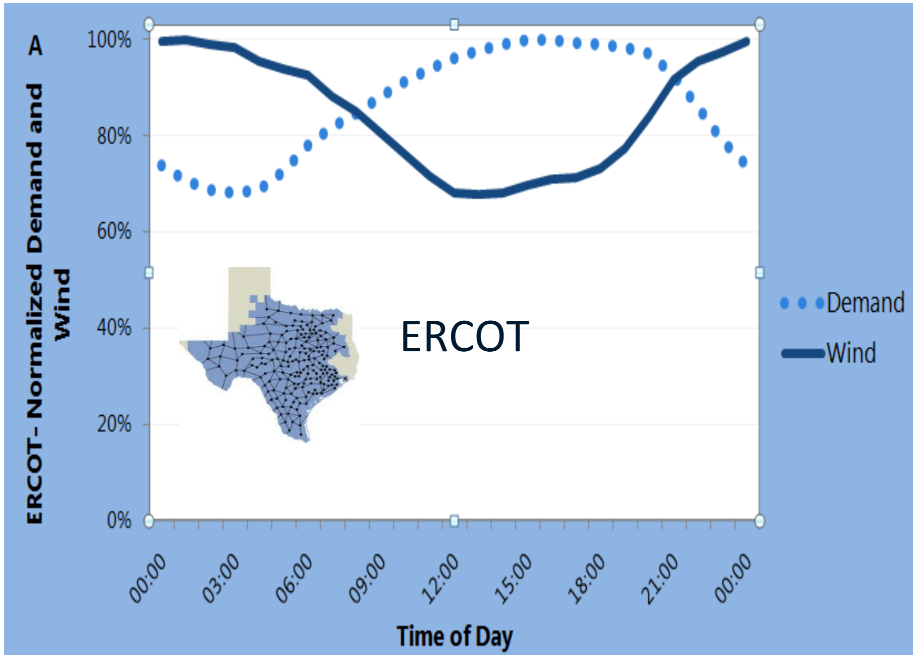


http://www.eirgrid.com/media/All_Island_Wind_and_Fuel_Mix_Summary_2014.pdf

Renewable energy and load characteristics

Dance partners



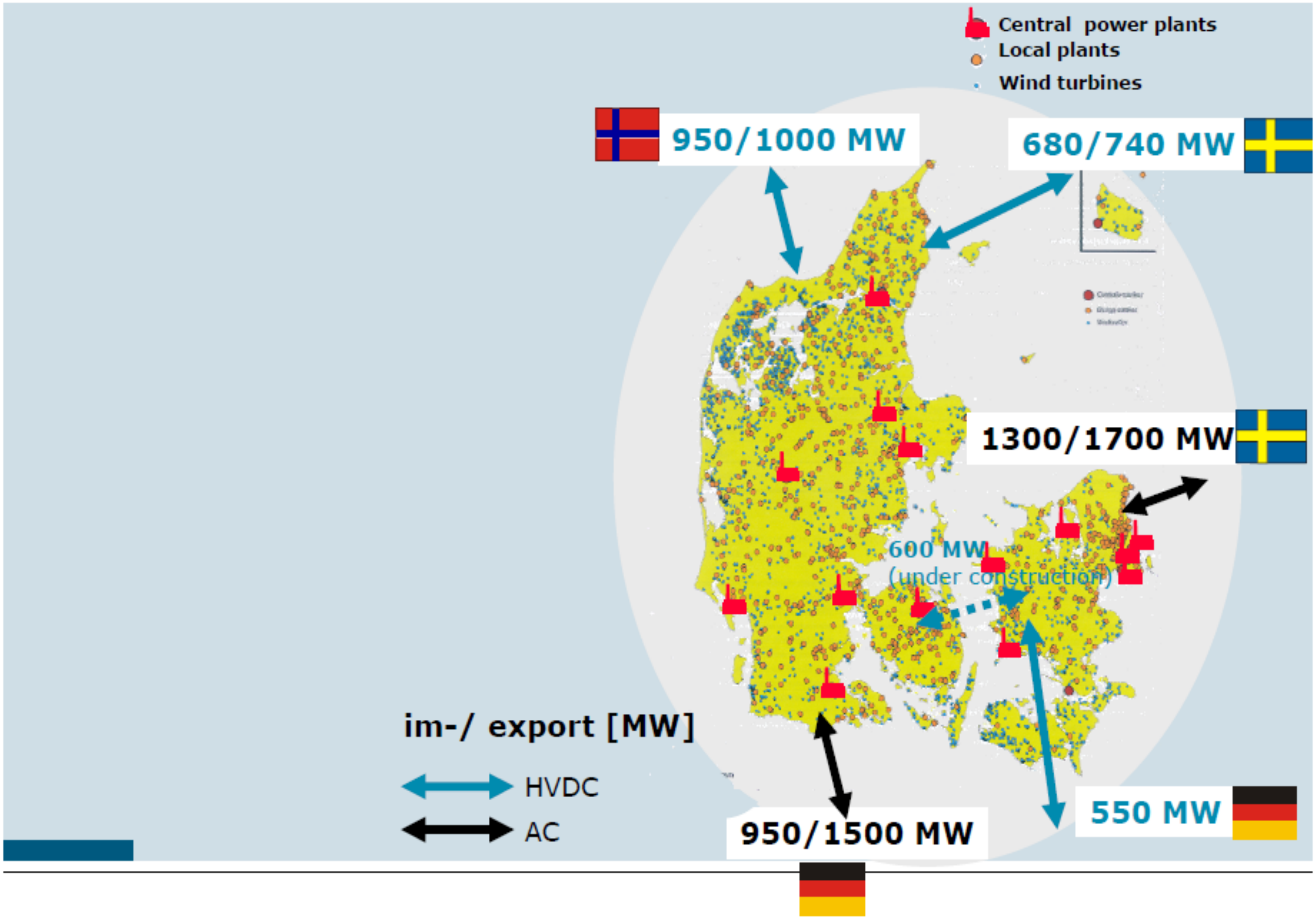


AEMO, Australian Energy Market Operator, "Wind Integration In Electricity Grids: International Practice And Experience" Work Package 1, 2011.
http://www.aemo.com.au/~/media/Files/Other/planning/0400-0049%20pdf.pdf

Top wind integration performance (2011)

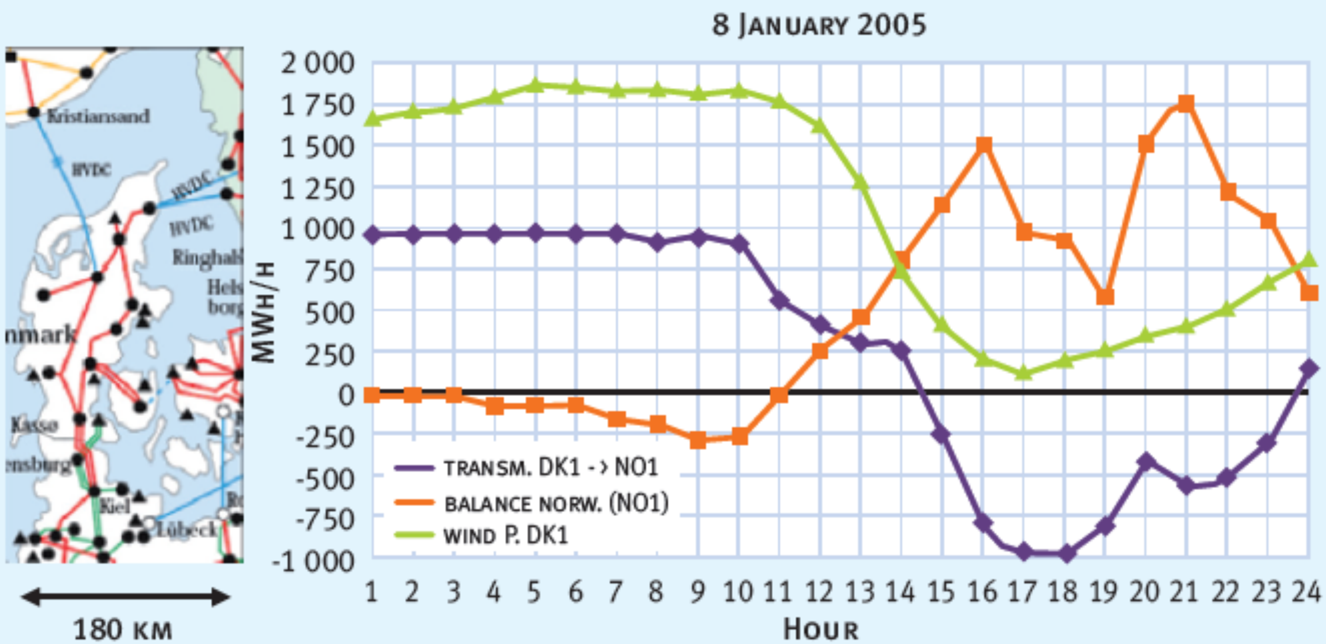
	% Electricity from wind (IEA, 2011)	% Wind Energy Curtailed	Balancing 	Notes
Denmark 	*28.0*	*< 1 %*	*Interconnection, flexible generation (including CHP) & good markets*	*Renewable target (mainly wind) is 50 % by 2020 and 100% by 2050*
Portugal 	*18.0*	*Low*	*Interconnection to Spain, gas, hydro & good market*	*Iberian peninsula: Spain & Portugal all well connected to one another but operate a single market MIEBEL*
Spain 	*16.4*	*< 1 % (but increasing due to excess hydro and low demand)*	*Gas, hydro & good market*	
Ireland 	*15.6*	*2.3 % in 2011* *EirGrid and SONI, 2012; "2011 Curtailment Report"*	*Gas 50 % , good markets, etc.*	*Curtailment reduced in 2012 to 2.1 % and 2.0 % in 2013*

Interconnectors 2009



Denmark’s Wind is Integrated by the Rest of Europe

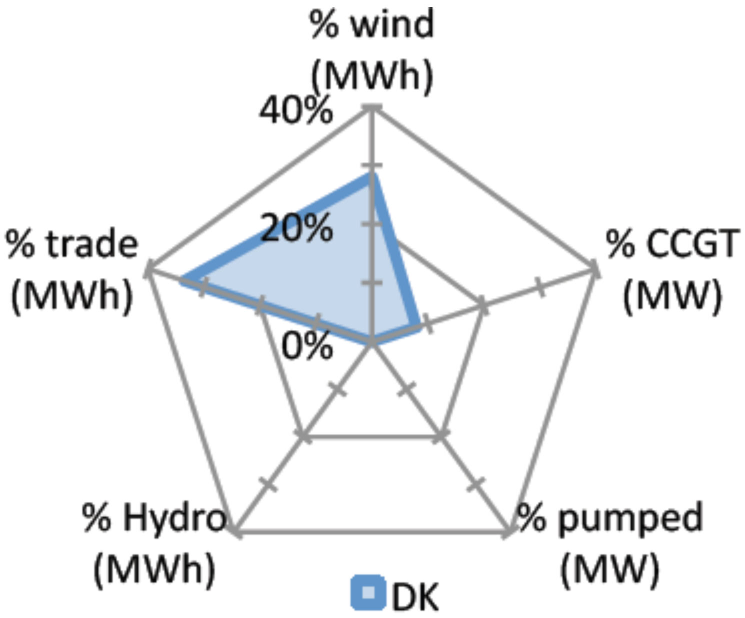
Figure 25: Correlation between a storm hitting the Danish western coast, Danish wind production and the balance of flows between Denmark and Norway



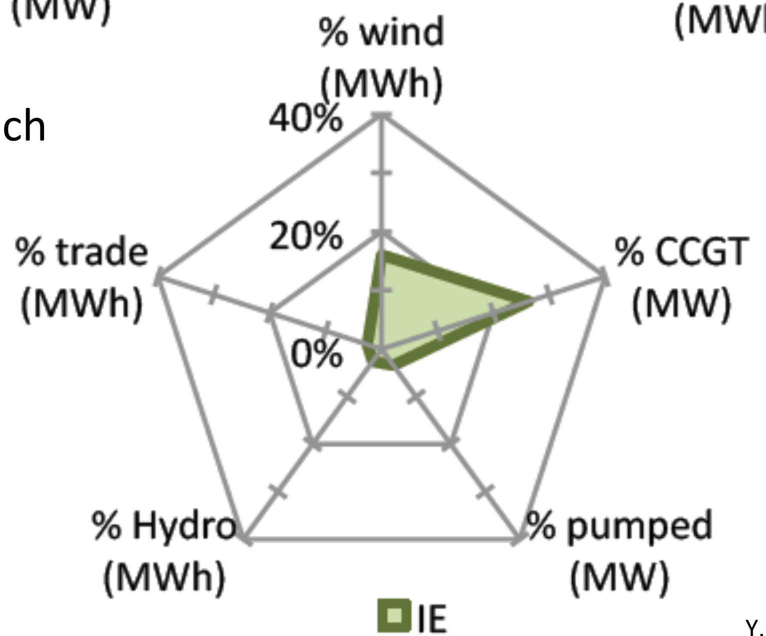
Source: North European Power Perspectives (http://www.nepp.se/organisation.htm)

Eurelectric 2011 “Flexible Generation: Backing up Renewables” Published as part of EURELECTRIC Renewables Action Plan (RESAP)

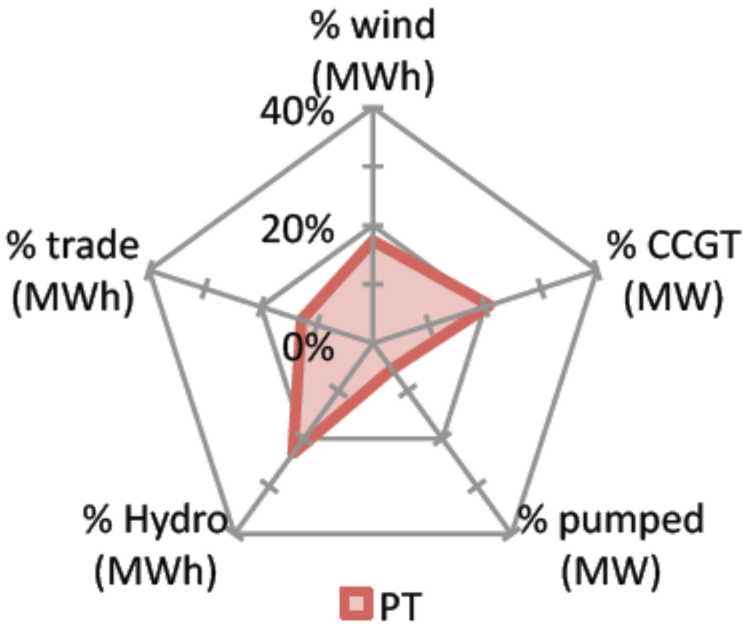
Renewable Integration Solutions; Sources of Flexibility



Denmark: Trading Rich



Ireland: CCGT Rich



Portugal: Hydro Rich

Y. Y asuda et al.: "Flexibility Chart – Evaluation on Diversity of Flexibility in Various Areas", 13th Wind Integration Workshop, WIW13-1029, (2013, 10, London).

Japan is an Island and is facing rapid increase in solar PV

Status after the start of the Feed-in Tariff

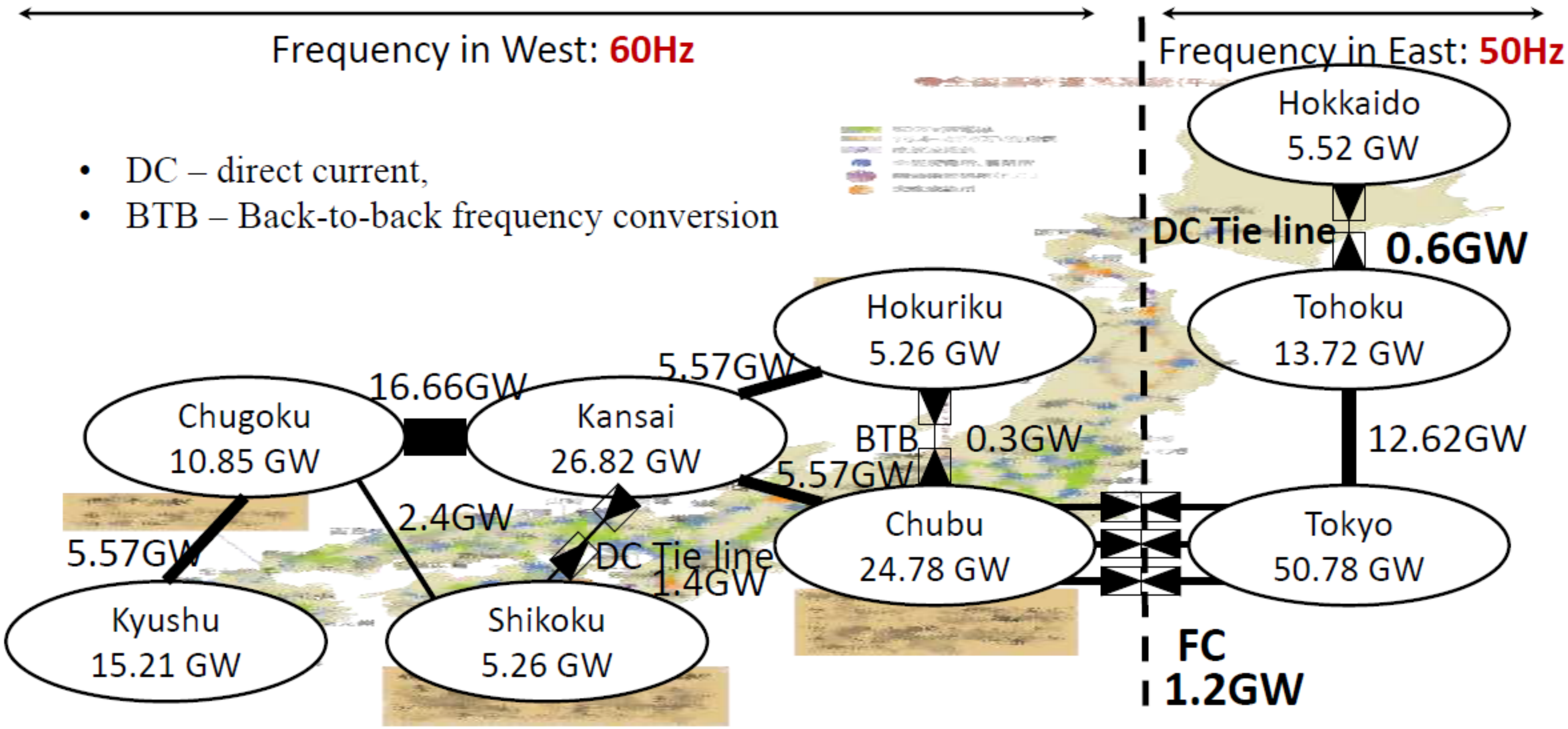
- Since FIT started (July 2012), the capacity of RE increased by 8.95 GWW (45%) as of the end of March 2014, during 21 month.
- Among the Res, PV is the super-highest in the share of deployment and that FIT application

<Deployment of renewable energy (as of the end of March 2014) >

	Accumulated capacity before FIT started	Deployed capacity after FIT started (July 2012)	Certivied capacity in FIT As of March, 2014	Target as of 2030
Solar power (residential)	4.7 GW	2.28 GW	2.69 GW	53.00 GW
Solar power (non-residential)	0.9 GW	6.,44 GW	63.04 GW	
Wind	2.6 GW	0.11 GW	1.04 GW	10.00 GW
Mid- to small-sized hydraulic (Less than 30MW)	9.6 GW	0.01 GW	0.30 GW	5.56 GW
Biomass	2.3 GW	0.12 GW	1.57 GW	-
Geothermal	0.5 GW	0.00 GW	0.01 GW	1.65 GW
Total	20.6 GW	8,95 GW	68.6 GW	

Problem revealed by 3.11

- The Great Earthquake in 2011 revealed negative aspects of regional monopoly system with 10 big and vertically integrated EPCOs:
  1. Lack of interconnections with enough capacity among regions
  2. Little competition and strong price control
  3. Limit in handling the change in energy mix including the increase in renewables



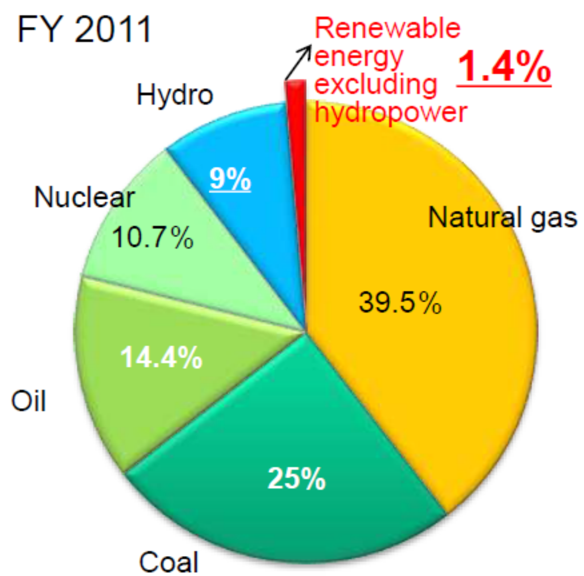
- DC – direct current,
- BTB – Back-to-back frequency conversion

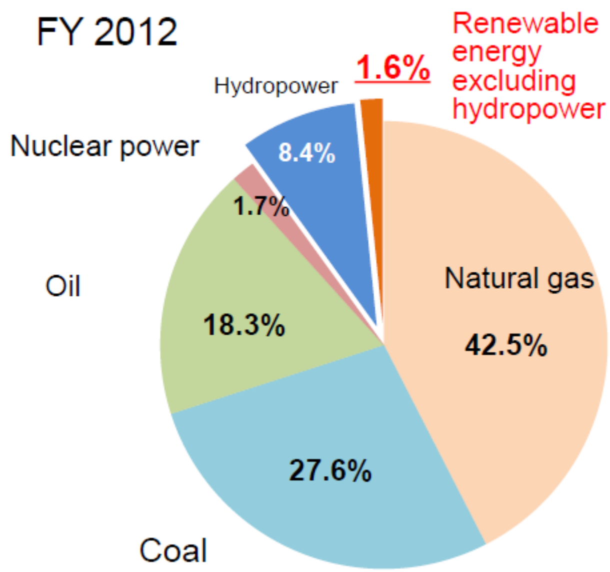
Japan has a flexible generation mix !

Current Composition of Power Sources in Japan

- Among the total electricity generated in fiscal 2012, renewable energy, etc. accounted for approximately 10%; 8.4% of which is hydraulic power generation.
- Renewable energy other than hydro is still cost prohibitive.

Share of RE in the Generation mix of Japan





Note: "Etc." of "Renewable energy, etc." includes the recovery of energy derived from waste, refuse derived fuel (RDF) products, heat supply utilizing waste heat, industrial steam recovery, and industrial electricity recovery.
Source: Prepared based on the Agency for Natural Resources and Energy's "Outline of Electric Power Development in FY 2010"


happytoast

Multiple Balancing Areas – inflexible

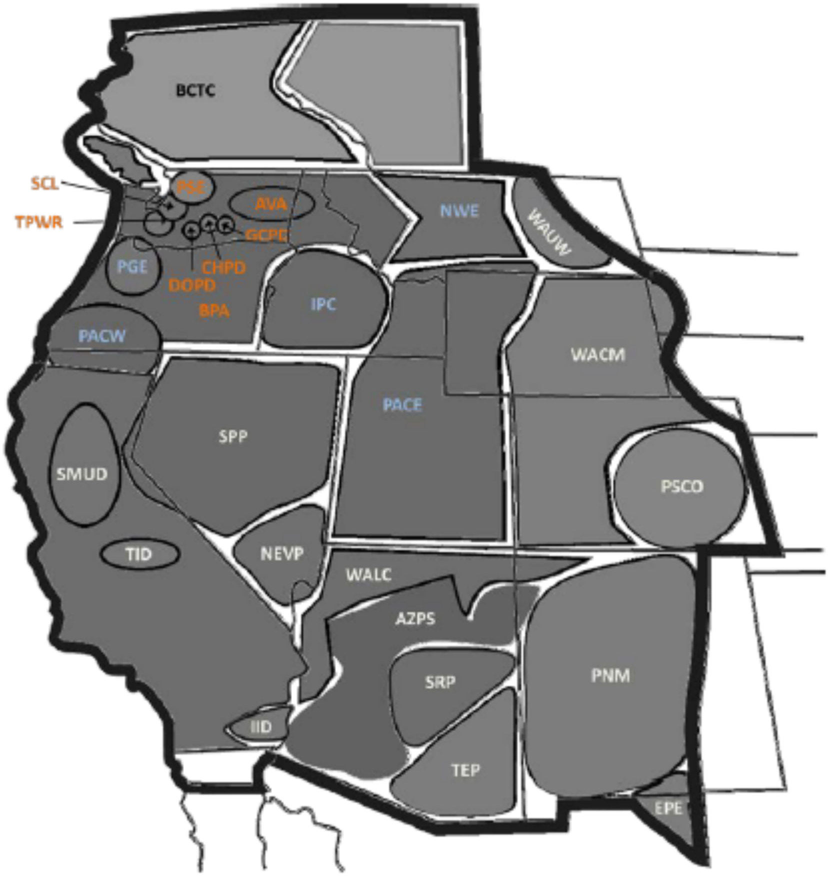
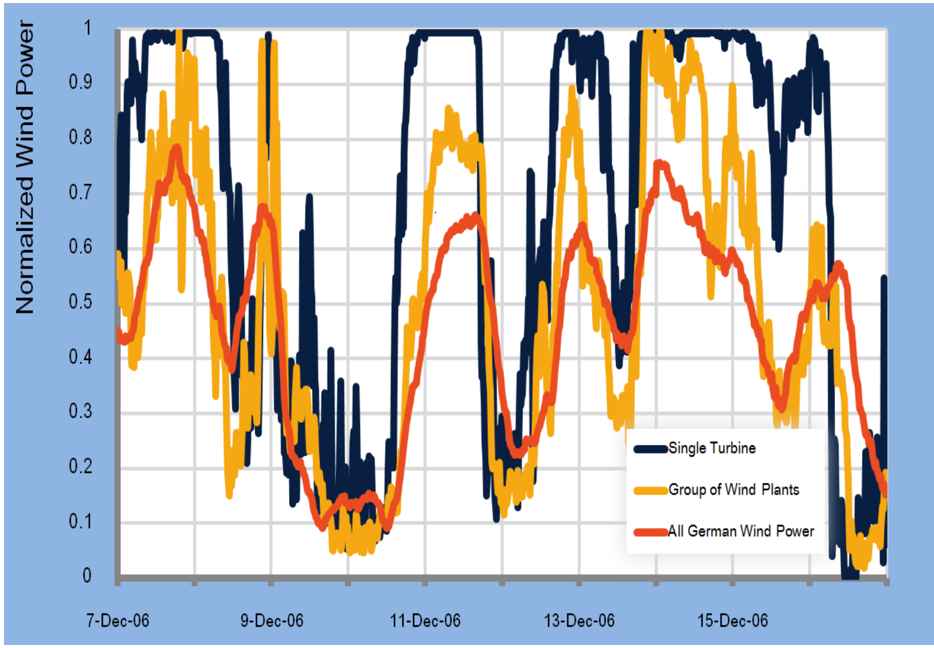
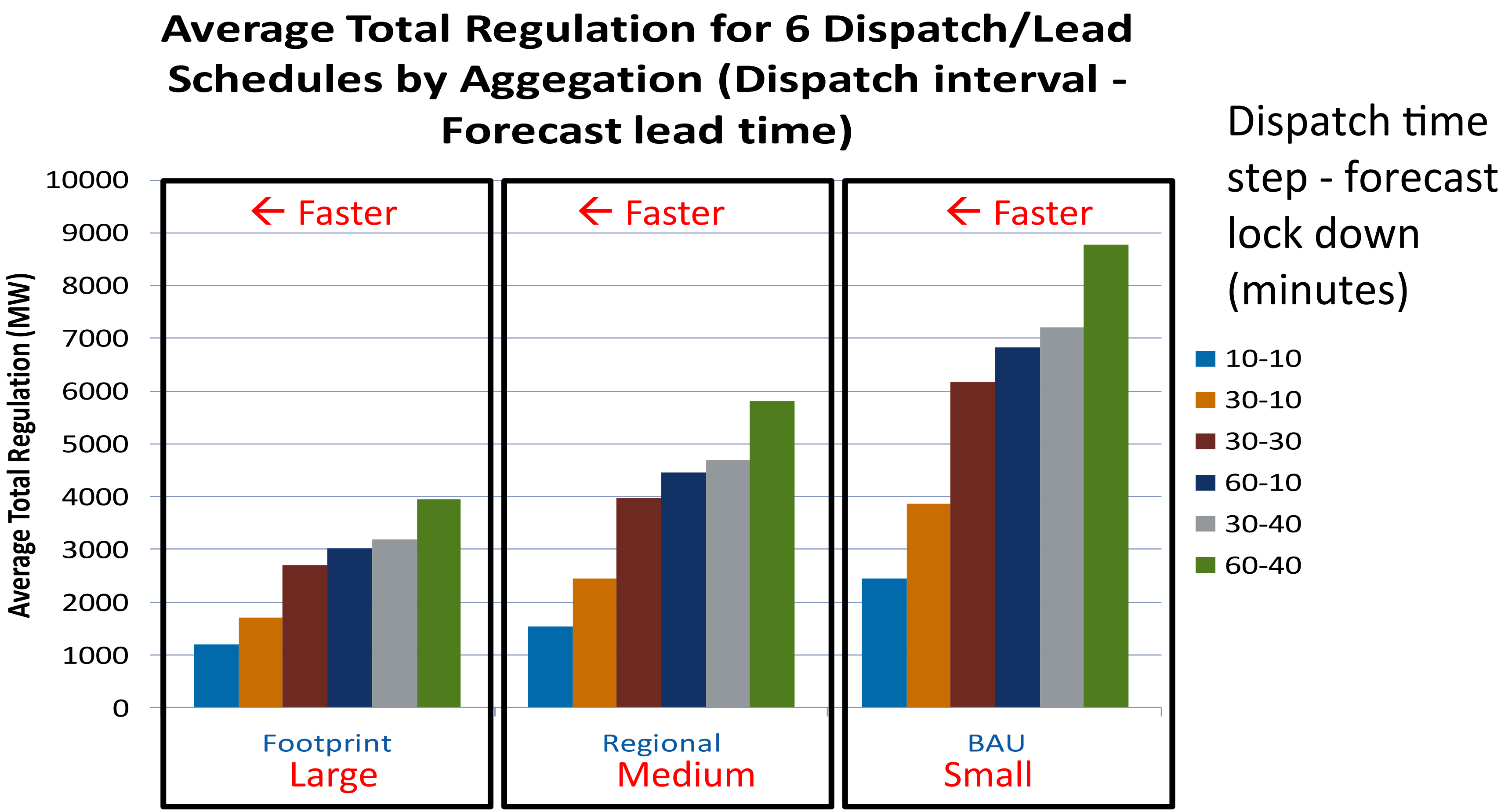


Figure 7. WECC BA map with regional groups



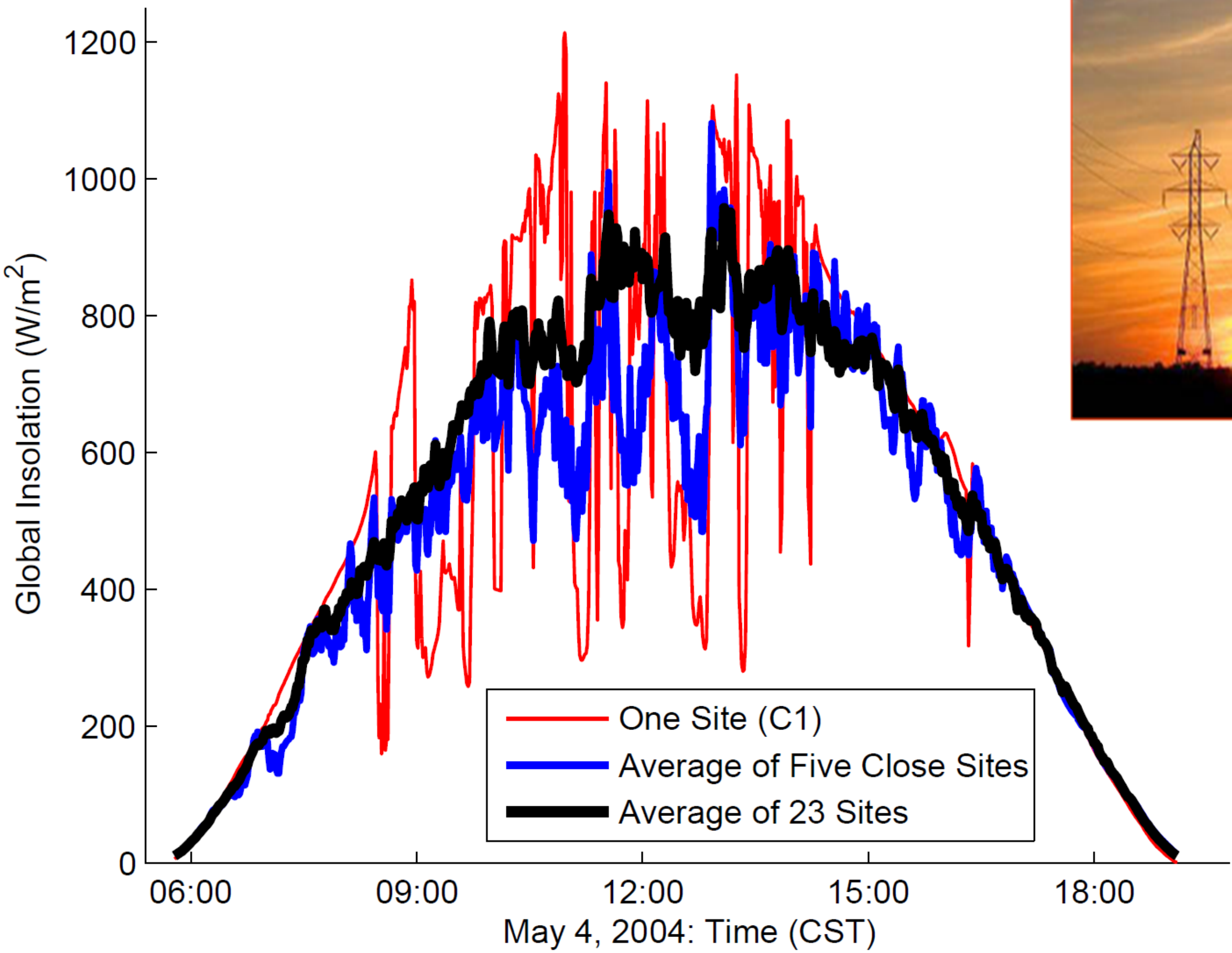
Bigger is better; faster is better



Milligan, Kirby, King, Beuning (2011), The Impact of Alternative Dispatch Intervals on Operating Reserve Requirements for Variable Generation. Presented at 10th International Workshop on Large-Scale Integration of Wind (and Solar) Power into Power Systems, Aarhus, Denmark. October

Source: Michael Milligan, NREL

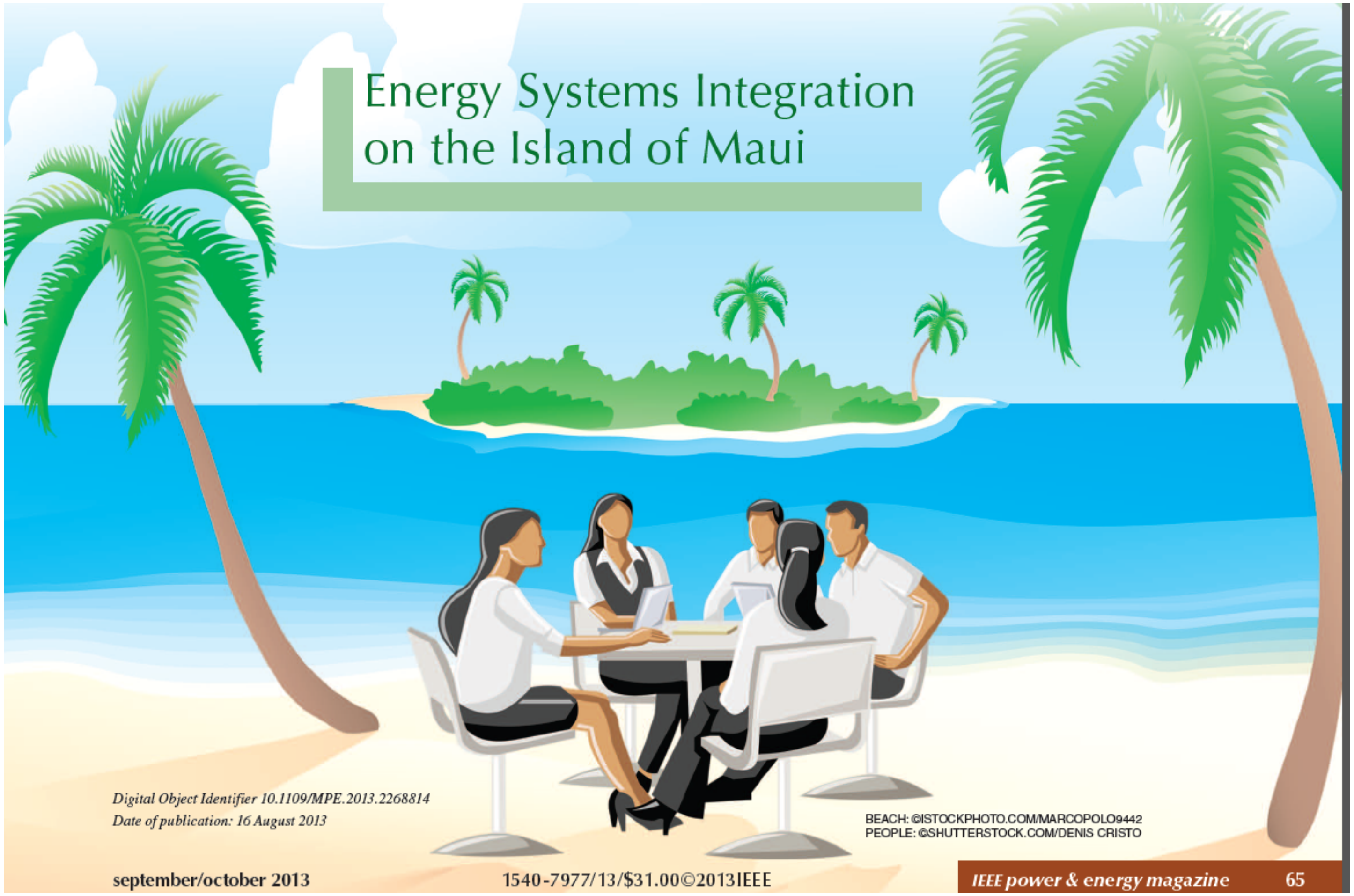
Aggregation of solar



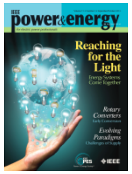
Mills, A. D, and R. H. Wiser. 2011. Implications of geographic diversity for short-term variability and predictability of solar power. In 2011 IEEE Power and Energy Society General Meeting, 1-9. IEEE, July 24. doi:10.1109/PES.2011.6039888.

Source: Andrew Mills, LBL

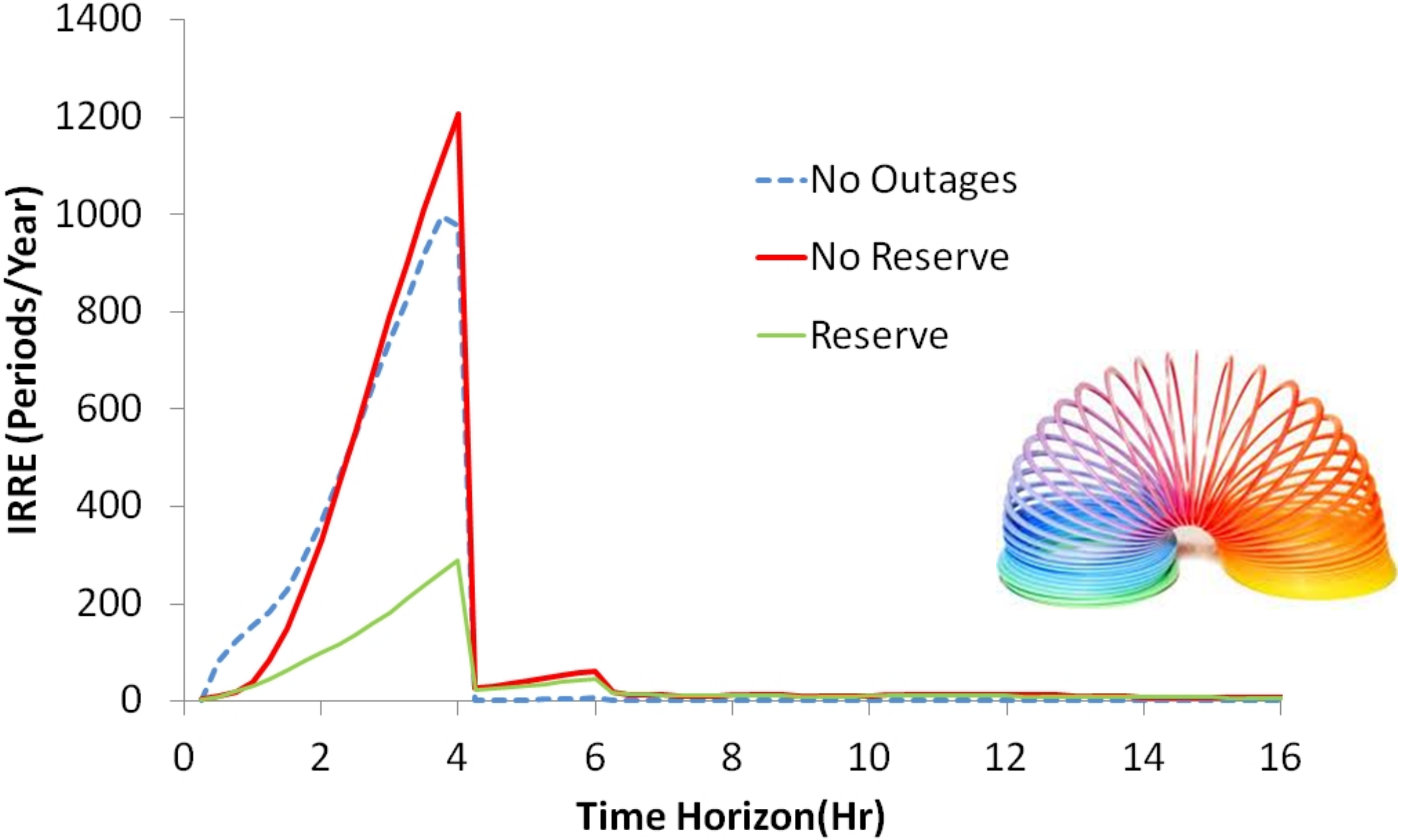
ESI in Maui – Electricity & Transport



Corbus, D.; Kuss, M.; Piwko, D.; Hinkle, G.; Matsuura, M.; McNeff, M.; Roose, L.; Brooks, A., "All Options on the Table: Energy Systems Integration on the Island of Maui," *Power and Energy Magazine, IEEE* , vol.11, no.5, pp.65,74, Sept. 2013.



Flexibility Metric



Lannoye, E., Flynn, D. and O'Malley, M.J. "Transmission, variable generation and power system flexibility", *IEEE Transactions on Power Systems*, Vol. 30, pp. 57 – 64, 2014.

Lannoye, E., Flynn, D., O'Malley, M., "Evaluation of Power System Flexibility" *IEEE Transactions on Power Systems*, Vol. 27, pp. 922 – 931, 2012.

Spilling wind

Spilling wind - Ireland

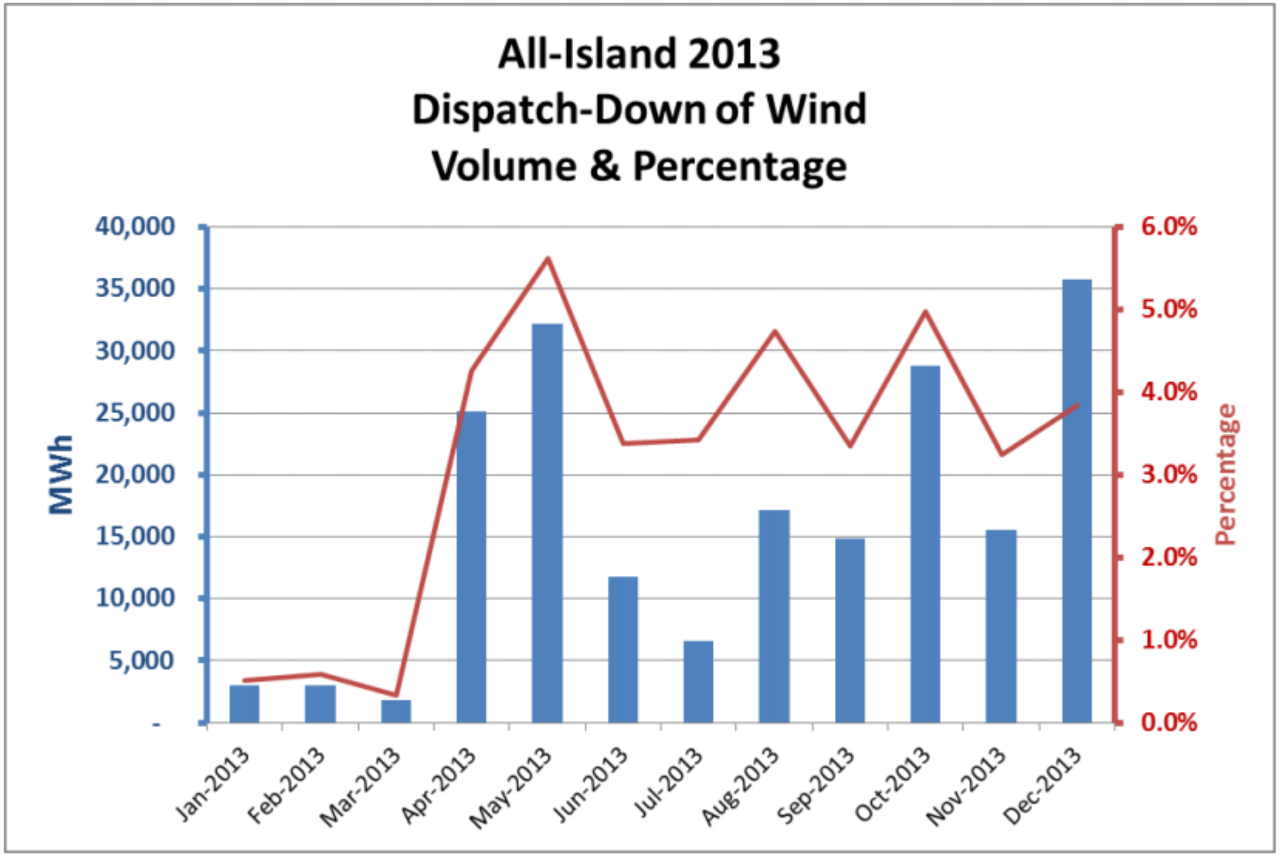


Figure 1: Monthly Variations in Wind Dispatch-Down Levels in 2013

[2] Note that since the percentage figures are presented for centrally dispatched generation (based on SCADA data), they do not account for non-dispatchable embedded renewable generation, which includes biomass, land-fill gas and small-scale hydro.

http://www.eirgrid.com/media/Annual_Wind_Constraint_and_Curtailment_Report_2013.pdf

Different reasons for spilling wind

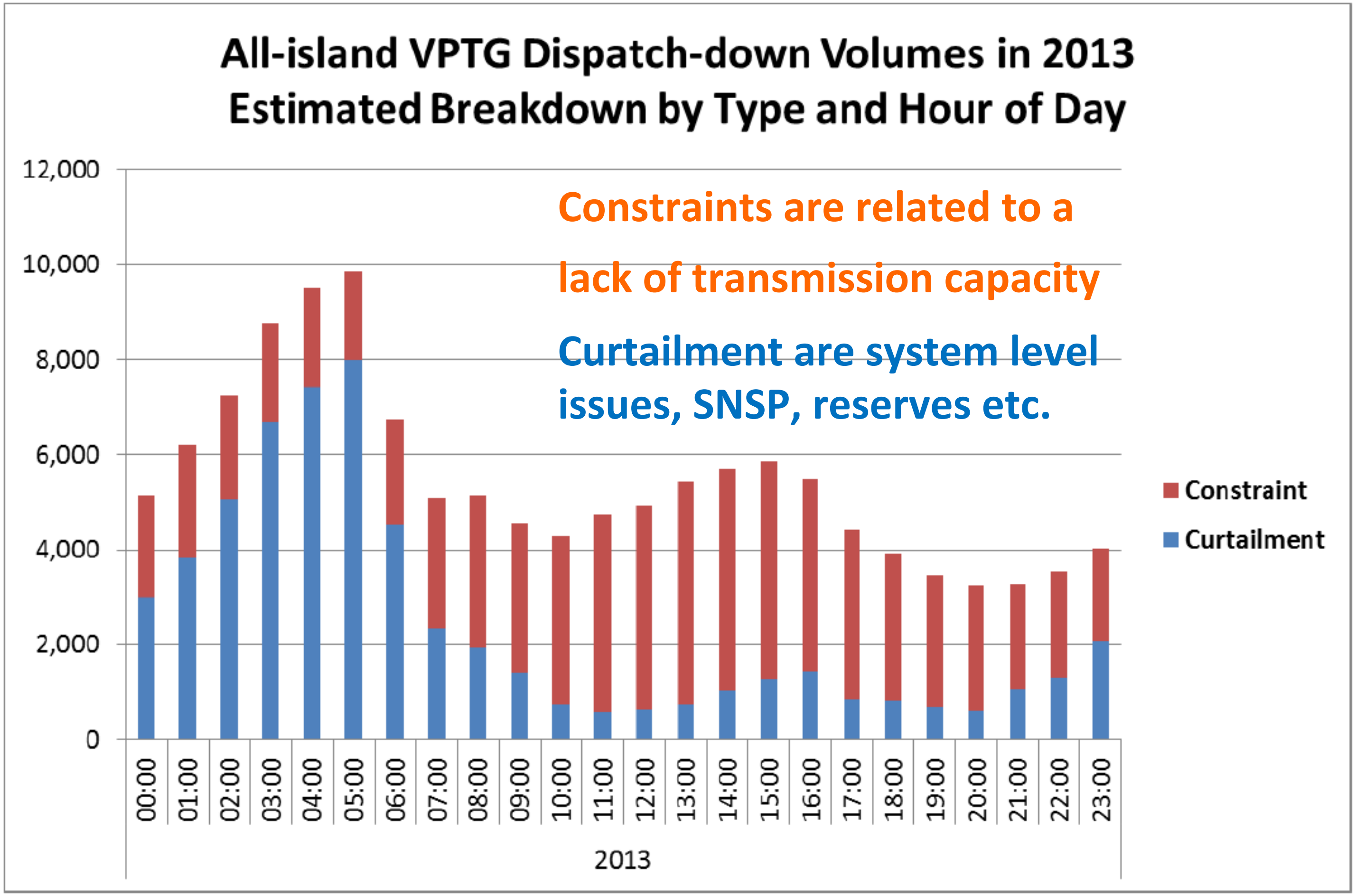


Figure 4: Estimated Breakdown of VPTG Dispatch-down Volumes on the Island in 2013

Mitigation for spilling wind

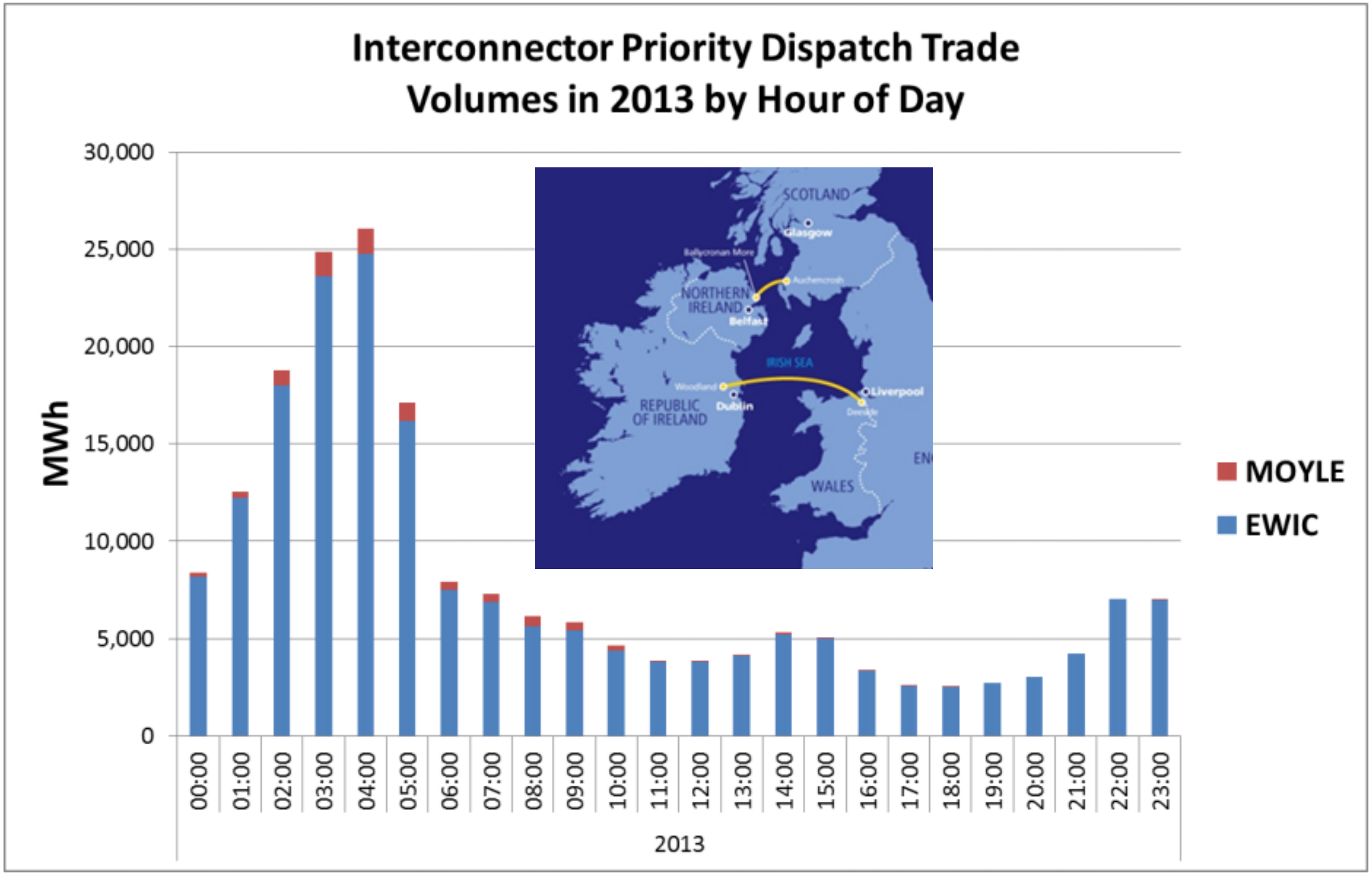


Figure 7: Interconnector Priority Dispatch Trade Volumes in 2013 by Hour of Day

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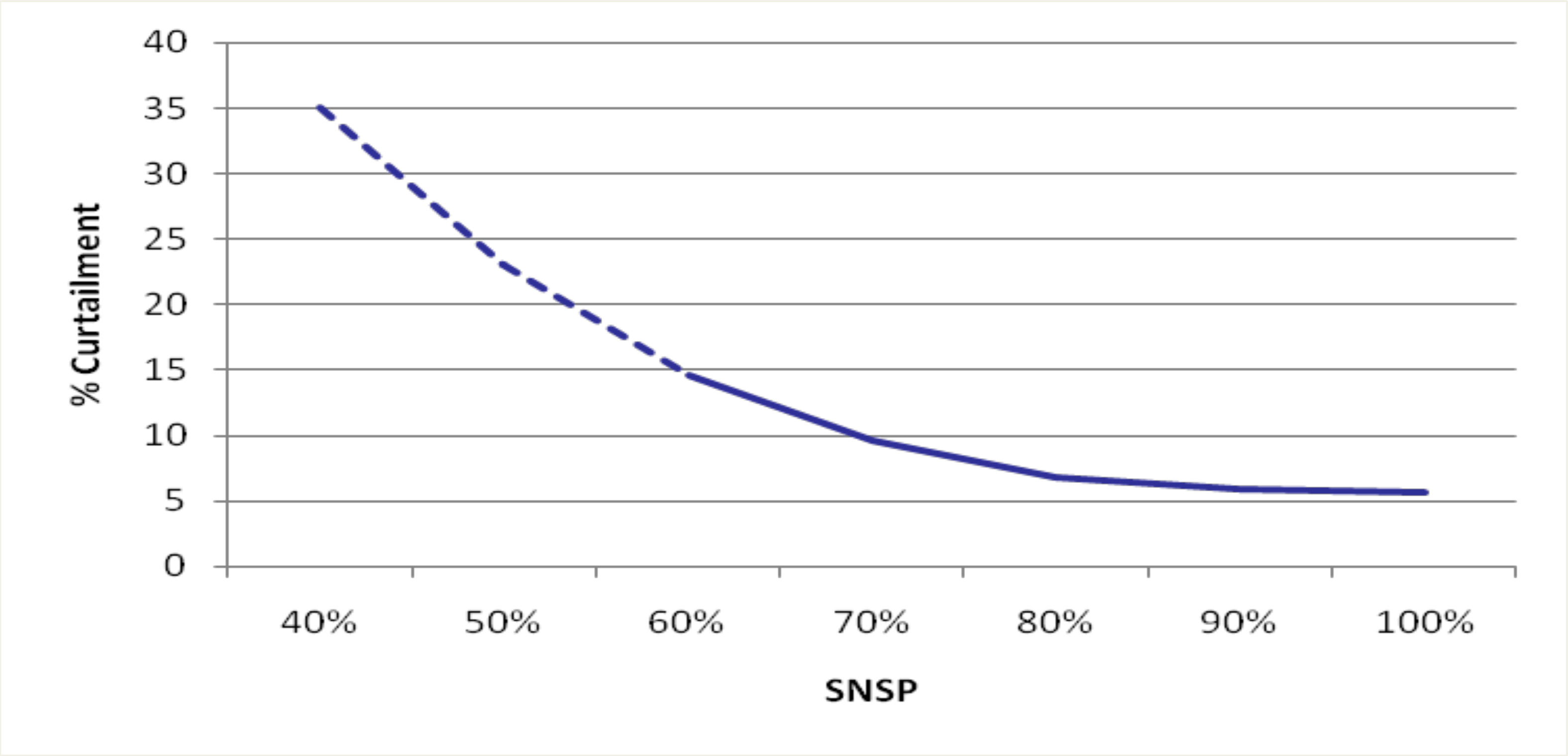
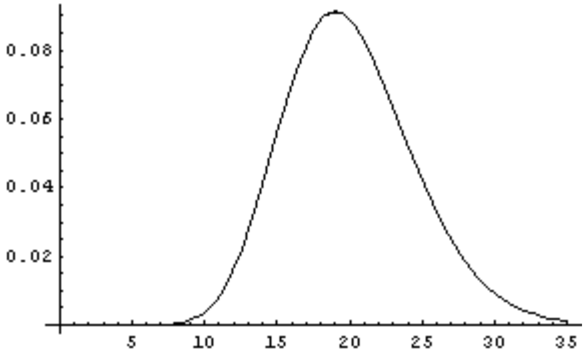
9 http://www.eirgrid.com/media/Information%20Note%20on%20SOInterconnectorCountertrading12July2013.pdf

Impact of SNSP on Wind Curtailment



Curtailment – what is healthy

- Wind curtailment in Texas was 8 % in 2010 and 17 % in 2009 mainly due to lack of transmission (Wiser and Bollinger, 2011). It was this type of high levels of curtailment in the early part of the century that spurred Texas to initiate a proactive scheme to alleviate this problem.



- Competitive Renewable Energy Zone (CREZ) – curtailment in 2012 – 3.7 %

Wiser and Bollinger (2011), "Wind Technologies Market Report" US DOE Energy Efficiency and Renewable Energy
http://www1.eere.energy.gov/wind/pdfs/2011_wind_technologies_market_report.pdf

Lack of transmission results in spilling wind

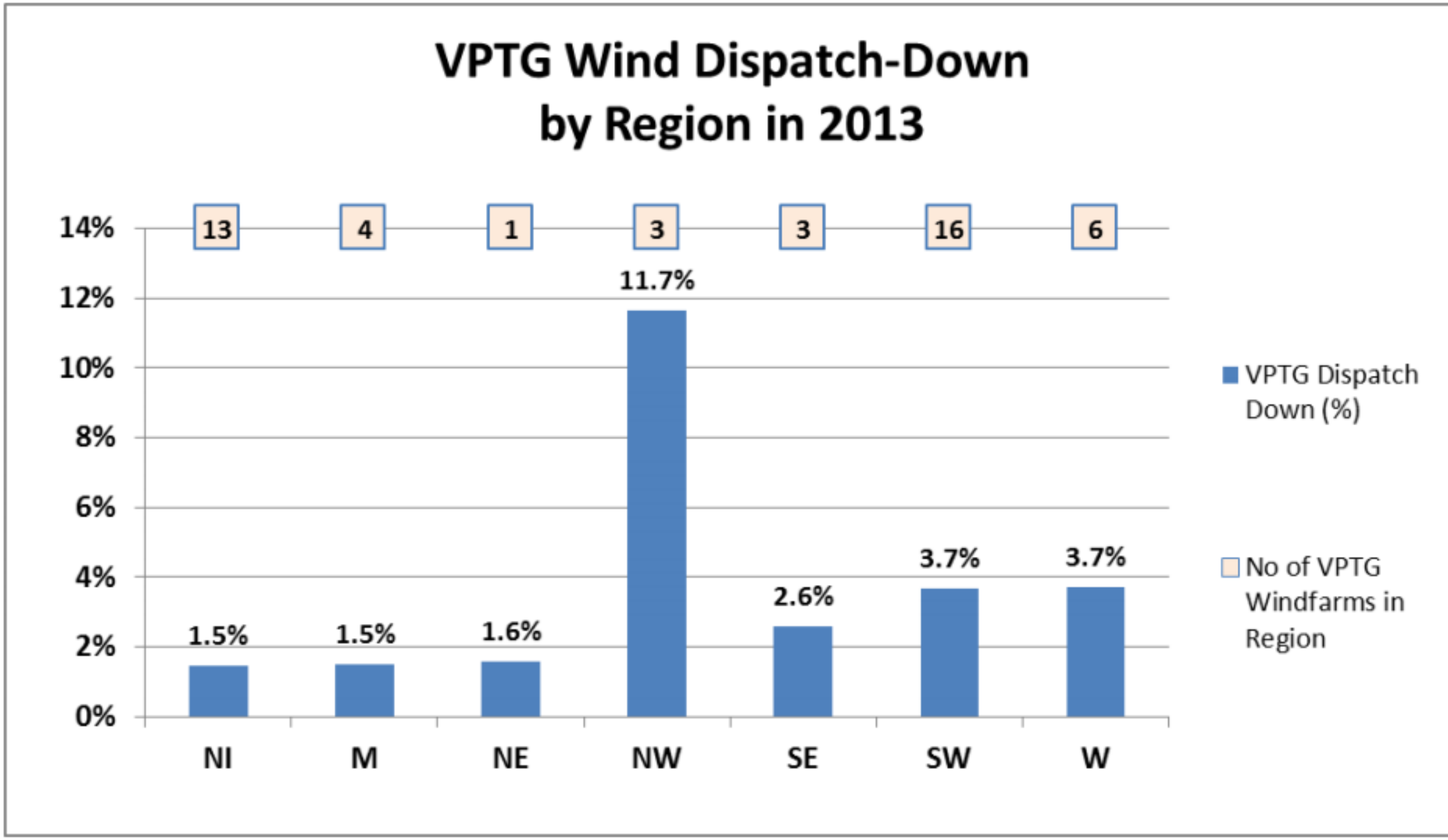
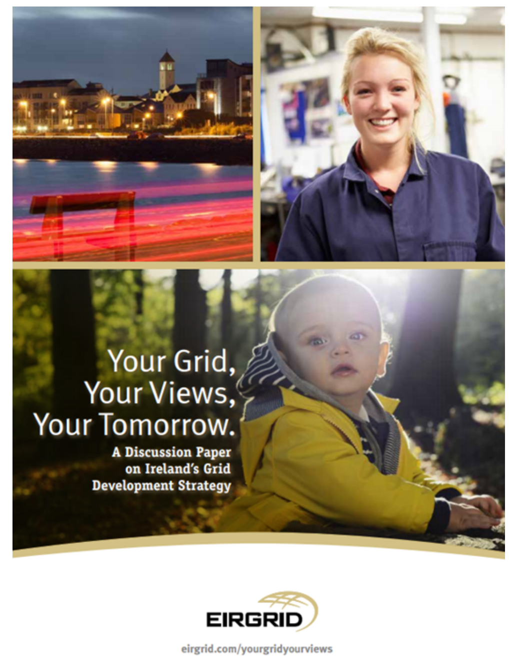


Figure 6: VPTG Wind Dispatch-Down by Region in 2013

http://www.eirgrid.com/media/Annual_Wind_Constraint_and_Curtailment_Report_2013.pdf

If you love wind/ solar you have to at least like Transmission

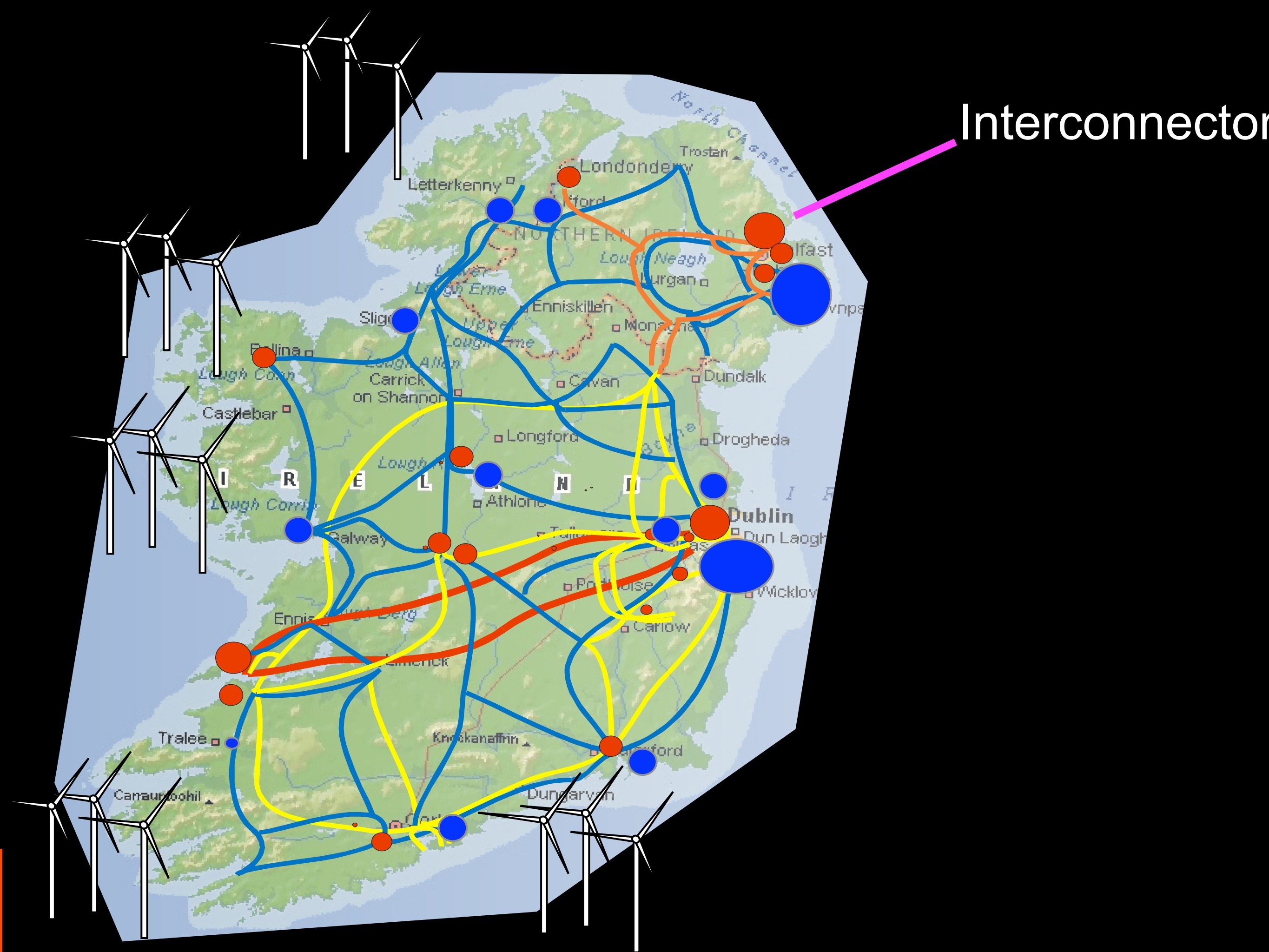


http://www.eirgrid.com/media/EirGridsDraftGridDevelopmentStrategy.pdf

The Network Challenge

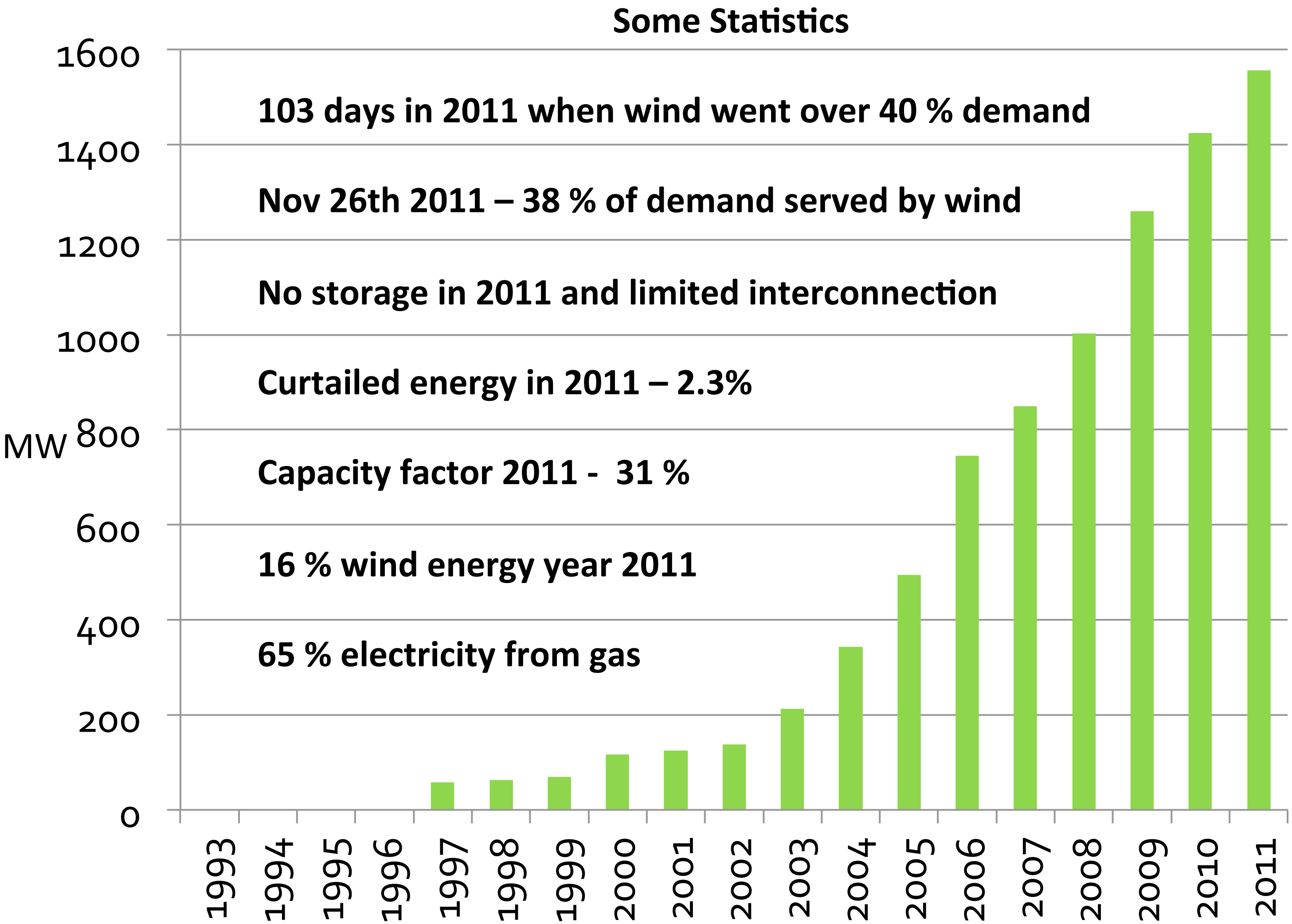
Generators
Demand

110kV
220kV
275kV
400kV



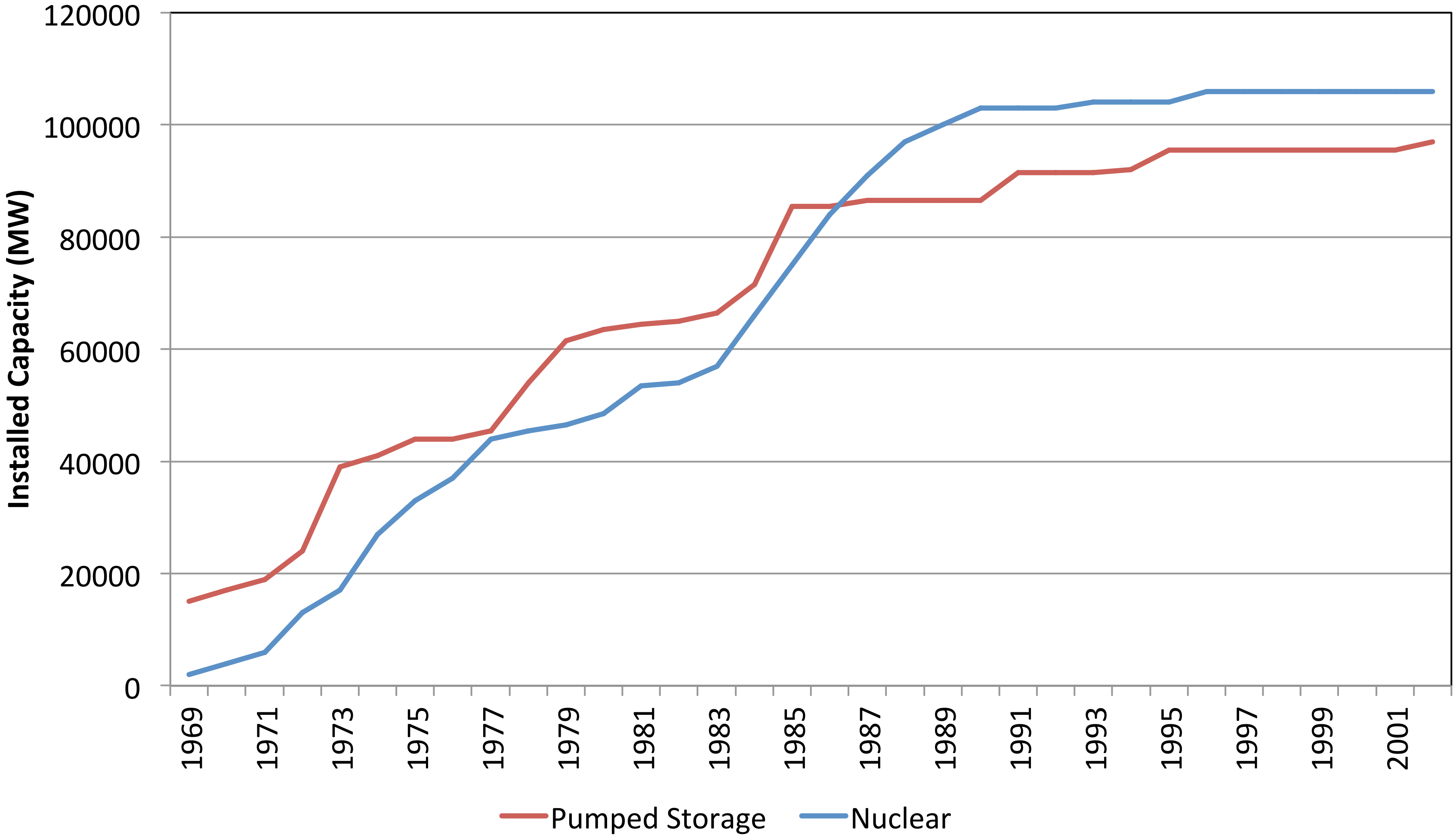
Storage

Wind Power in Ireland 2011



Source: EirGrid

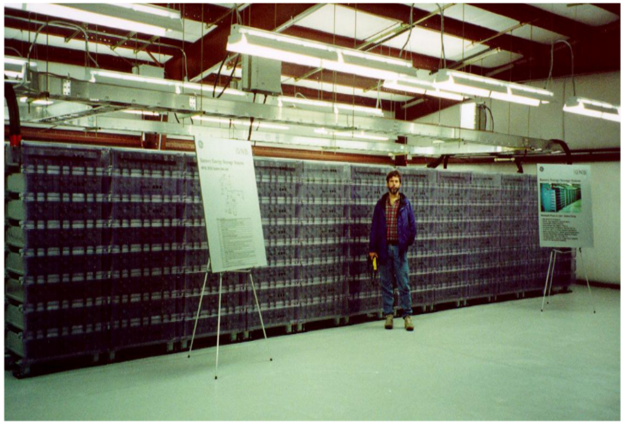
Historical Storage Drivers



Data From OECD Countries only

Repeal of fuel use act in US: http://www.eia.gov/oil_gas/natural_gas/analysis_publications/ngmajorleg/repeal.html

Energy Storage on Islands



Manz, D.;Piwko, R; Miller, N , “Look Before You Leap: The Role of Energy Storage in the Grid”, IEEE Power and Energy Magazine, pp. 75-84, July/August, 2012.

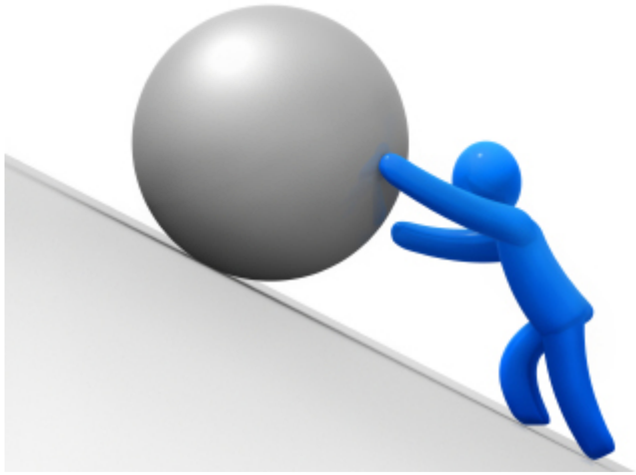
Storage Applications & Competitors

Elzinga, D., Dillon, J., O'Malley, M.J., Lampreia, J., "The role electricity storage in providing electricity system flexibility", in Electricity in a climate constrained world. International Energy Agency, Paris, 2012.

Key Take Away

- Flexibility is the key characteristic to integration variable renewable energy
  - Transmission is the critical element
  - Some curtailment is healthy
  - Flexibility is not just physical
  - Very difficult to quantify

- Spilling wind
  - sometimes the best thing to do
  - Transmission is very important
  - Sometimes “institutional” issues cause the spilling of wind
- Storage
  - Is expensive
  - has lots of competitors



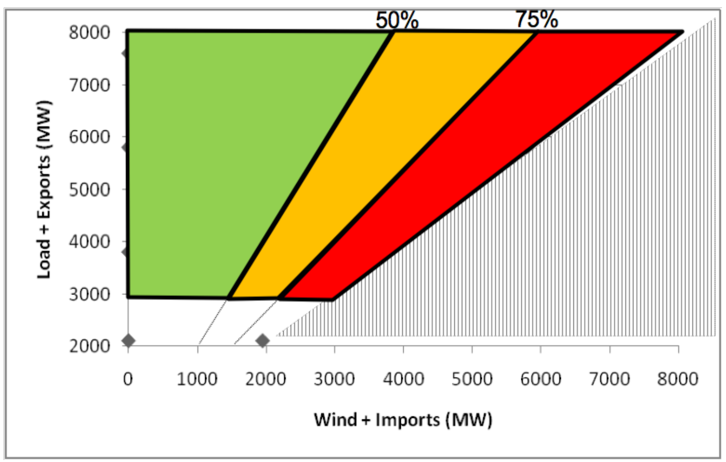
Response to the challenges

Challenges & Response

Facilitating up to 75% Renewables in real-time requires change

Challenges

- System Stability
- Resource Variability
- Complexity
- New connections
- Changed power flows



- Network Infrastructure
- Interconnection/Offshore Grids
- Network Access
- Smart Grid Programme/DS3

EIRGRID semo SONI

DS3 Programme (Delivering a Secure Sustainable Electricity System (**DS3**))

Grid Code

Performance Monitoring

DSM

System Services

ROCOF

Frequency

Voltage

Renewable Data

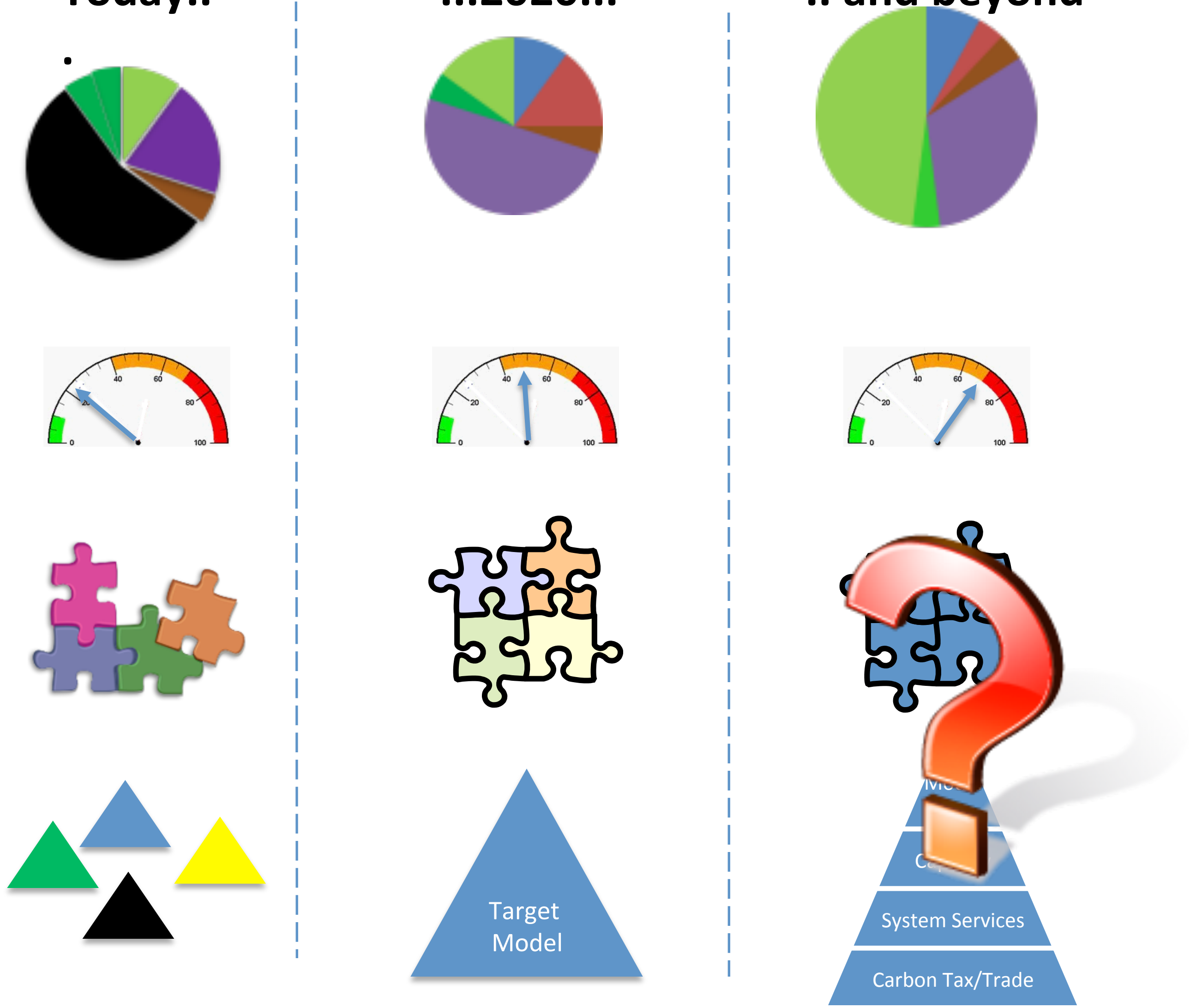
WSAT

Control Centre Tools

Model Dev. & Studies

The System Needs Holistic Thinking

	Today..	...2020...	.. and beyond
Renewable Levels in Electricity			
Operational Complexity			
Supports			
Market Design			



The ingredients of success – today 20 % wind

	INSTITUTIONAL
POLICY ENVIRONMENT	Supportive
MARKETS AND SCHEDULING	Supportive
FORECASTING	Supportive
ANCILLARY SERVICES	Some
REGULATION, GRID CODES	Supportive but challenging
PLANNING	Supportive but challenging
VARIABLE RENEWABLE CURTAILMENT	Negligible

	PHYSICAL
TRANSMISSION & INTERCONNECTION	Supportive
THERMAL PLANT FLEXIBILITY	Supportive but challenging
RESOURCE CHARACTERISTICS	Supportive
RENEWABLE ENERGY GENERATOR CAPABILITIES	Supportive but challenging
STORAGE	Some
DEMAND SIDE	Negligible
NEW TECHNOLOGIES: FACTS, ETC	Negligible

- Supportive
- Supportive but challenging
- Some
- Negligible

Work remaining for 40 %

	INSTITUTIONAL
POLICY ENVIRONMENT	Supportive
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Supportive

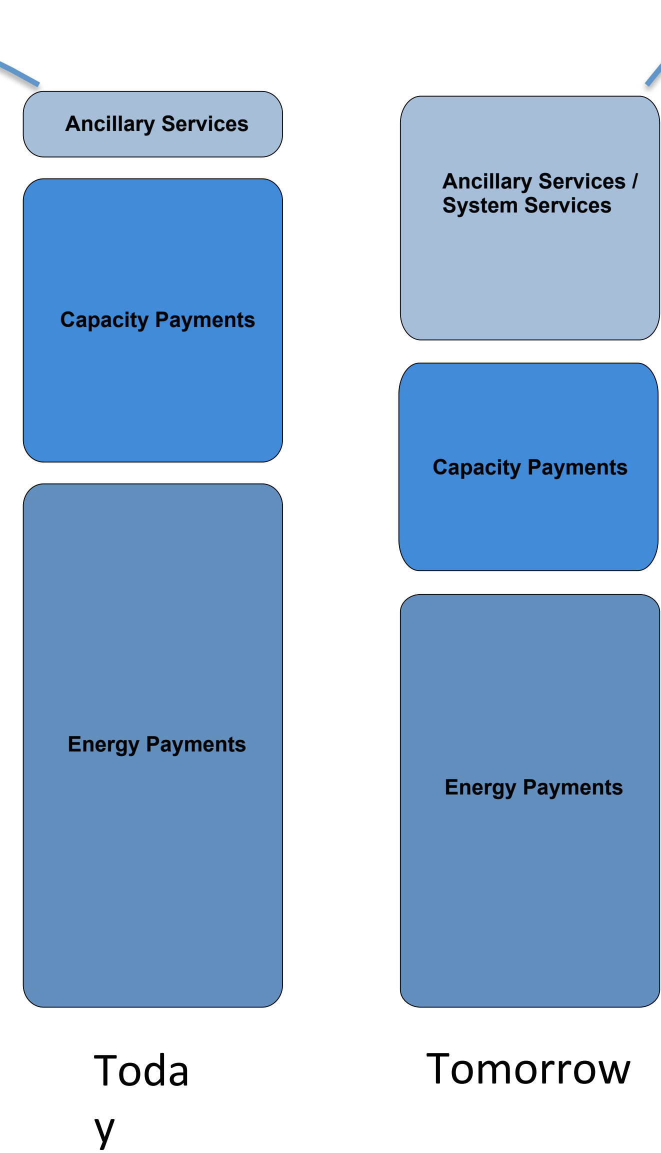
Supportive but challenging

Some

Negligible

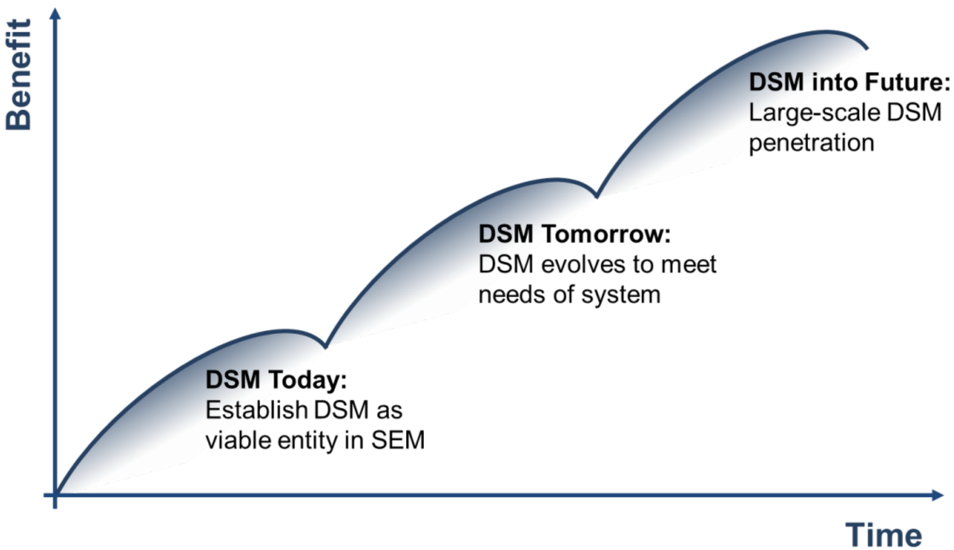
System services: Incentivising the Portfolio

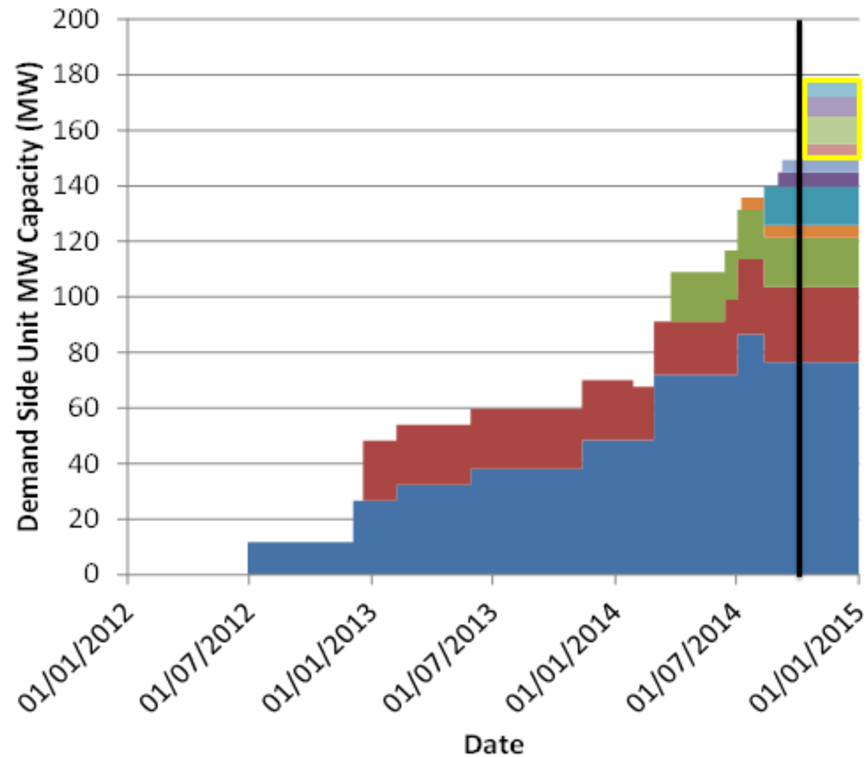
- 60 €m
- 7 Services



- 235 €m
- 14 Services

DSM – A New Service Provider…





Key take aways

- Get organized – coordination
- Whole system thinking is required
- Electricity market design is key

Acknowledgements

- My colleagues for many of the slides – NREL, EirGrid, UVIG, DTU etc.