Integrated Energy Systems

the importance of

technology, markets & policy

Mark O'Malley

IEEE DLP Lecture

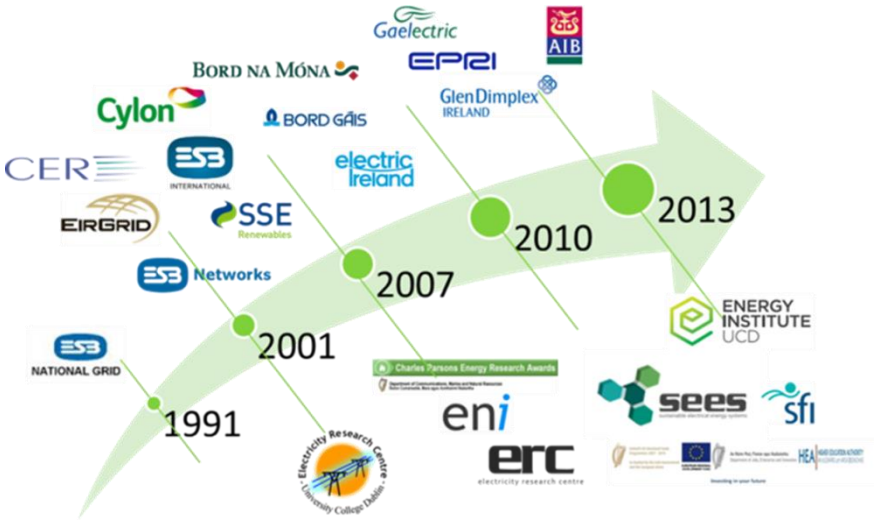
NTNU, Trondheim, March 4th 2016

Outline

- Background
  - About UCD, ERC and Energy Institute
- Integrated Energy Systems
  - Technology
  - Markets
  - Policy
- International activities
- Conclusion

University College Dublin

- 28,000 students
- Founded in 1854
- Has educated half of Ireland's prime ministers (Taoiseach)
- Largest urban campus in Europe (350 acres)
- Unique capability in electrical energy research at global level



erc electricity research centre

ENERGY INSTITUTE UCD

Institute Overview

UCD Energy Institute, http://energyinstitute.ucd.ie, launched in 2013 by Taoiseach Enda Kenny, Institute Board Chairman Dave O'Reilly.

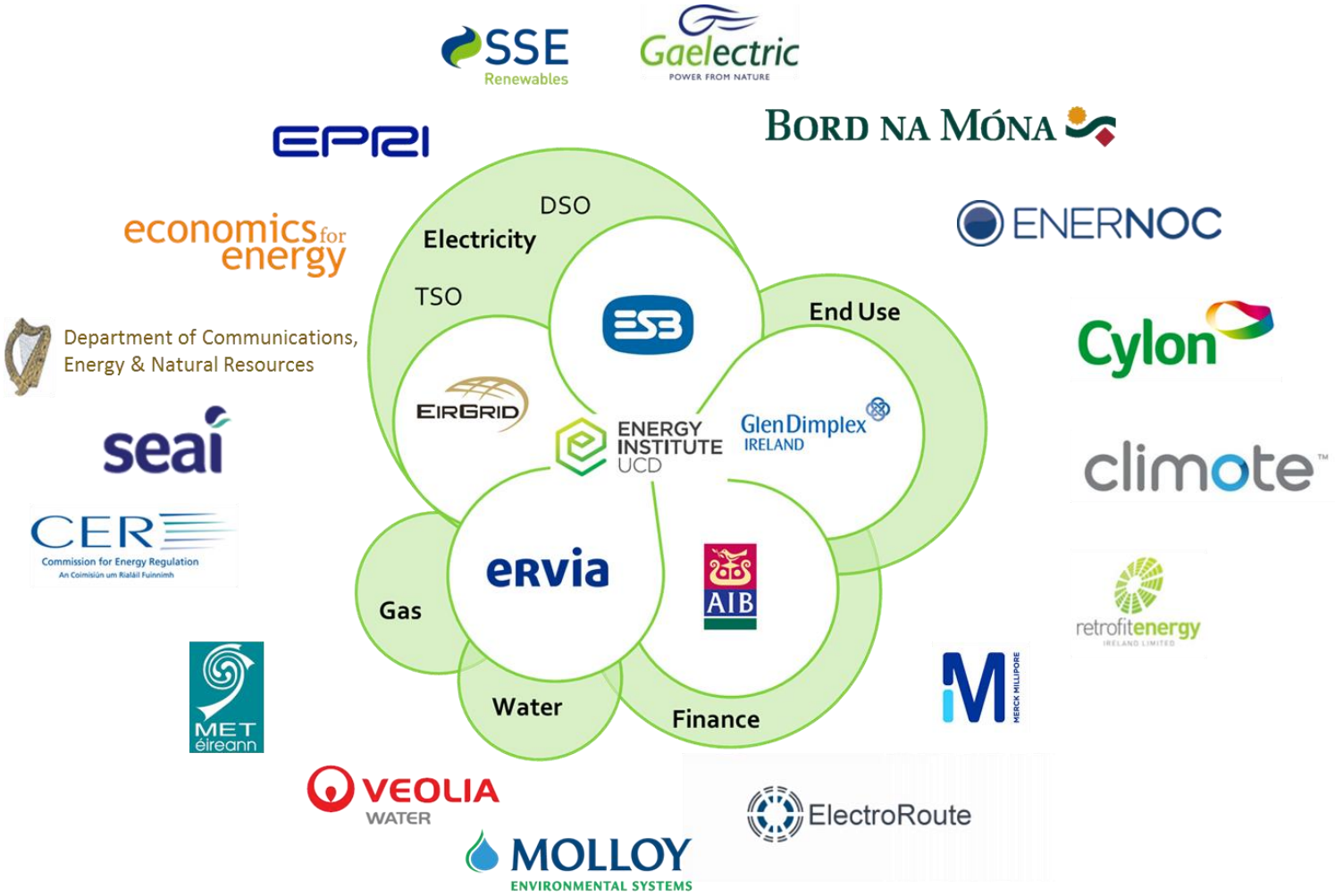
Led by Prof. Mark O'Malley, and building on the foundation of the Electricity Research Centre http://erc.ucd.ie, founded in 1991.

Based in UCD; partnered with 6 Irish universities and 22 industry collaborators, and internationally networked

Vision: A leading partner in major global energy systems research & innovation initiatives.

Mission: Doing energy systems research that impacts and serves society, nationally & internationally, by being rigorous, strategic and objective

Industry Collaboration



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What is an Integrated Energy System ?

What is Energy Systems Integration (ESI) ?

Energy System Integration (ESI) is the process of coordinating the operation and planning of energy systems across multiple pathways and geographical scales in order to deliver reliable, cost effective energy services with less impact on the environment.

Energy Systems Integration (ESI)

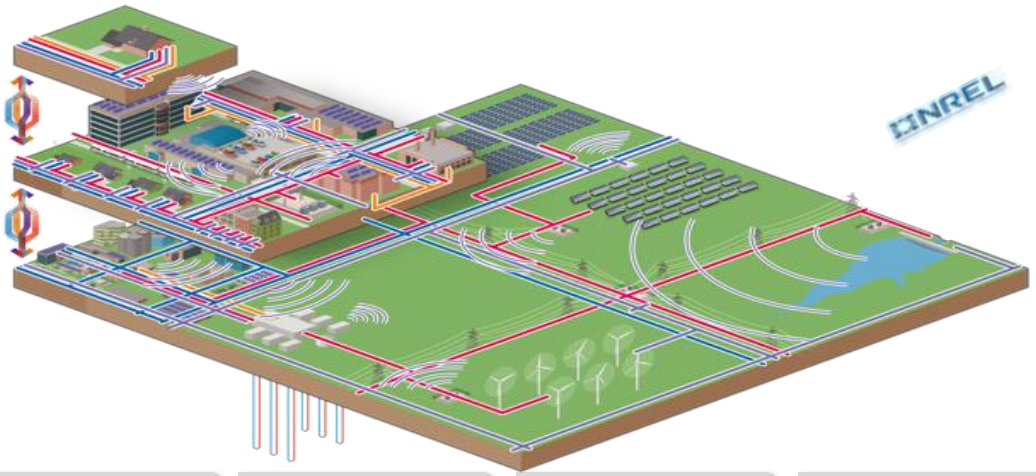
Energy Source

Fossil | Nuclear | Renewable

Single Technologies and Locations

Campus, City Community

Regional, National, Continental



Electricity

Thermal

Fuels

Data

Water

Residential | Commercial | Industry | Mobility

Energy Use Sector

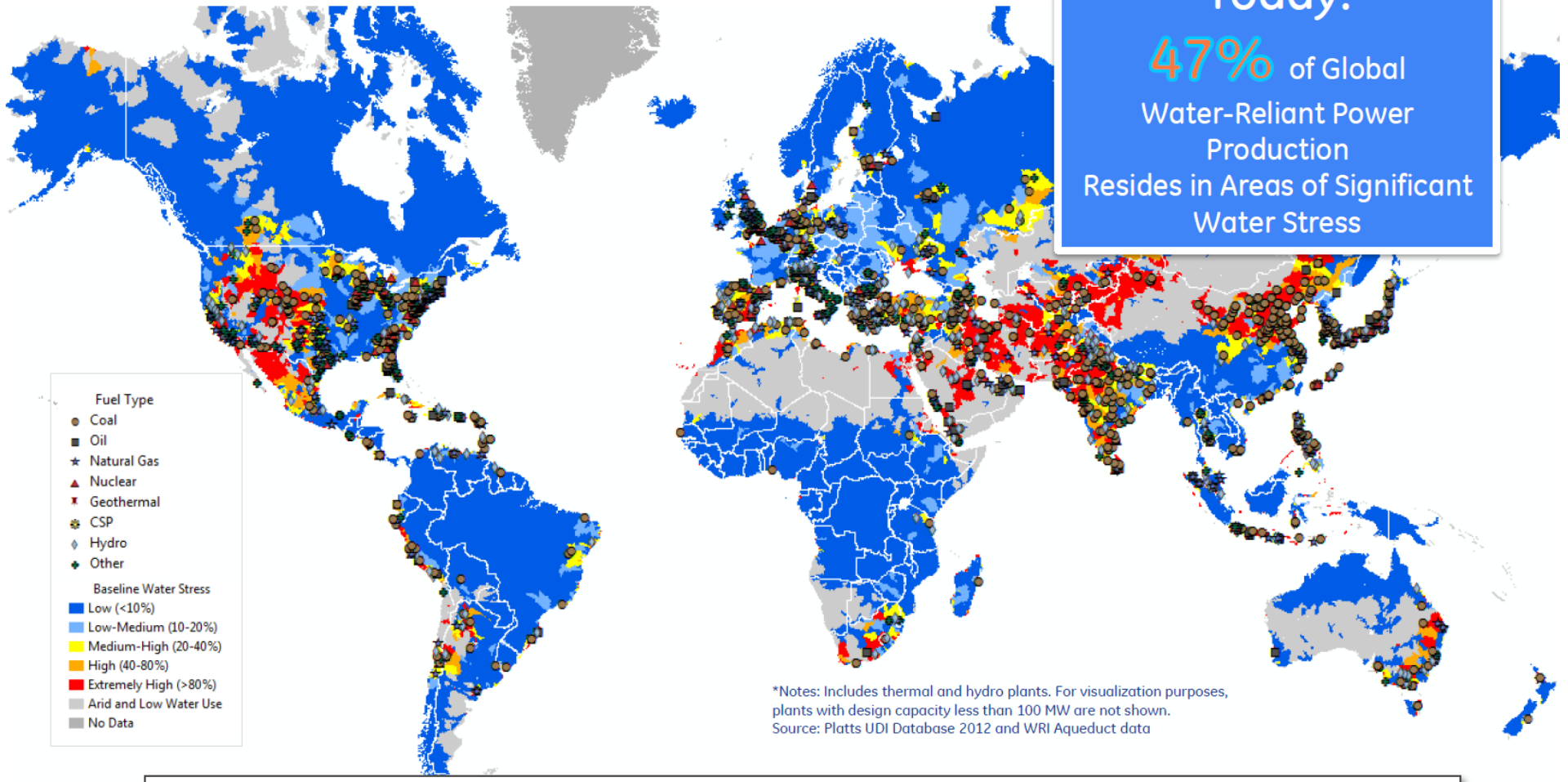
- **optimization** of energy systems across multiple pathways and scales
- increase reliability and performance, and minimise **cost and environmental impacts**
- most valuable at **the interfaces where the coupling** and interactions are strong and represent a challenge and an opportunity
- control variables are **technical economic and regulatory**

Global generation units with water stress*

Medium to extremely-high stress

Today:

47% of Global Water-Reliant Power Production Resides in Areas of Significant Water Stress



*Notes: Includes thermal and hydro plants. For visualization purposes, plants with design capacity less than 100 MW are not shown.
Source: Platts UDI Database 2012 and WRI Aqueduct data

Over 26,000 units are in areas of medium to extremely-high water stress

ENERGY INSTITUTE UCD

Multidisciplinary

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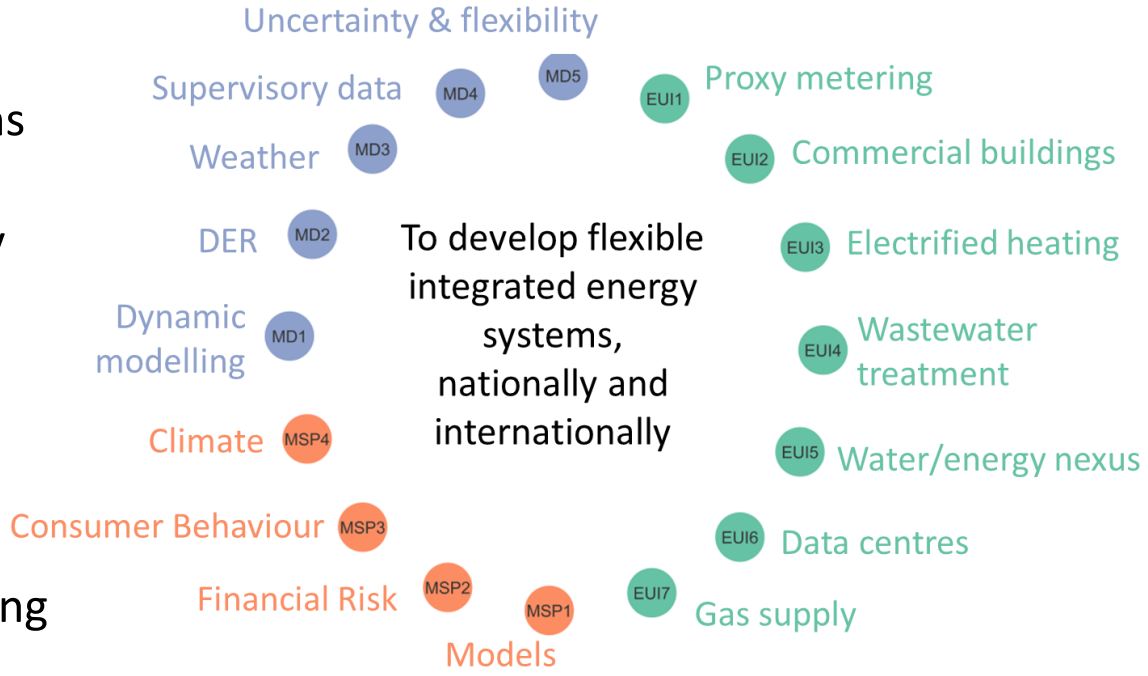
ESIPP

- Energy Systems Integration Partnership Programme (ESIPP)
- 23 academics from 7 institutions
- 5 Industry Partners, 17 Industry Collaborators
- Three strands:
  - Modelling & Data
  - End Use
  - Markets & Strategic Planning
- Funding €11.0M (SFI, philanthropic donation & industry funding)
- Officially launched, 24th November 2015



Examples of Integrated Energy System

RealValue

HORIZON 2020

RealValue

HORIZON 2020
CALL FOR COMPETITIVE
LOW CARBON ENERGY

REALISING VALUE

FROM ELECTRICITY MARKETS
WITH LOCAL SMART ELECTRIC
THERMAL STORAGE
TECHNOLOGY

LCE-08-2014

LOCAL SMALL-SCALE STORAGE

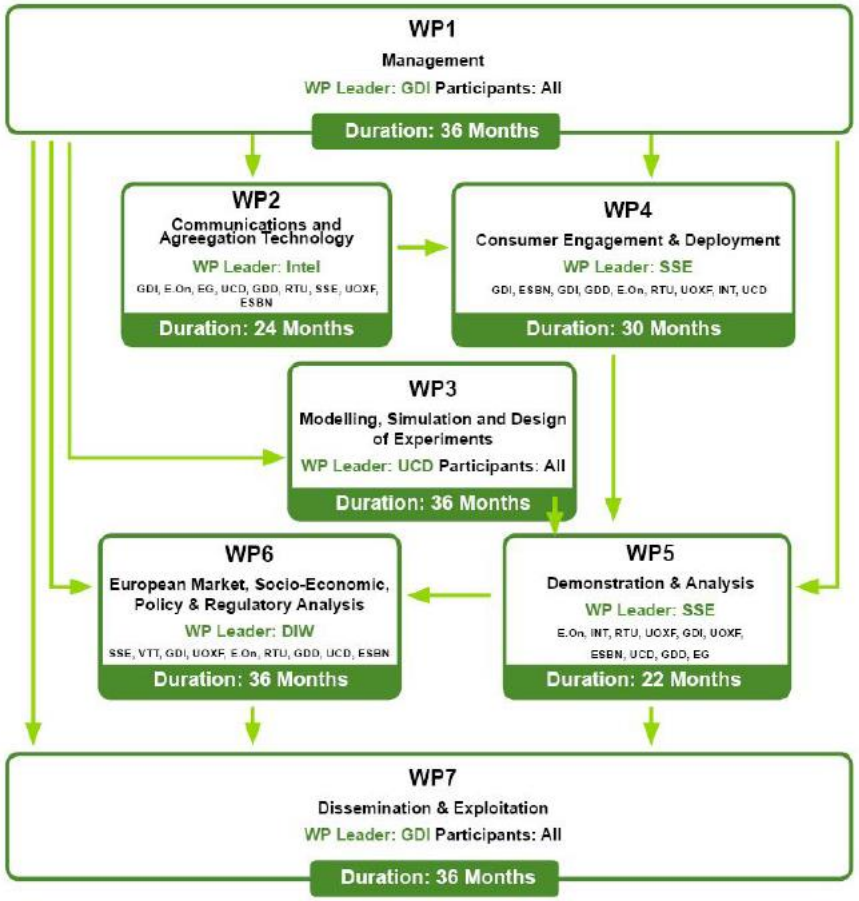
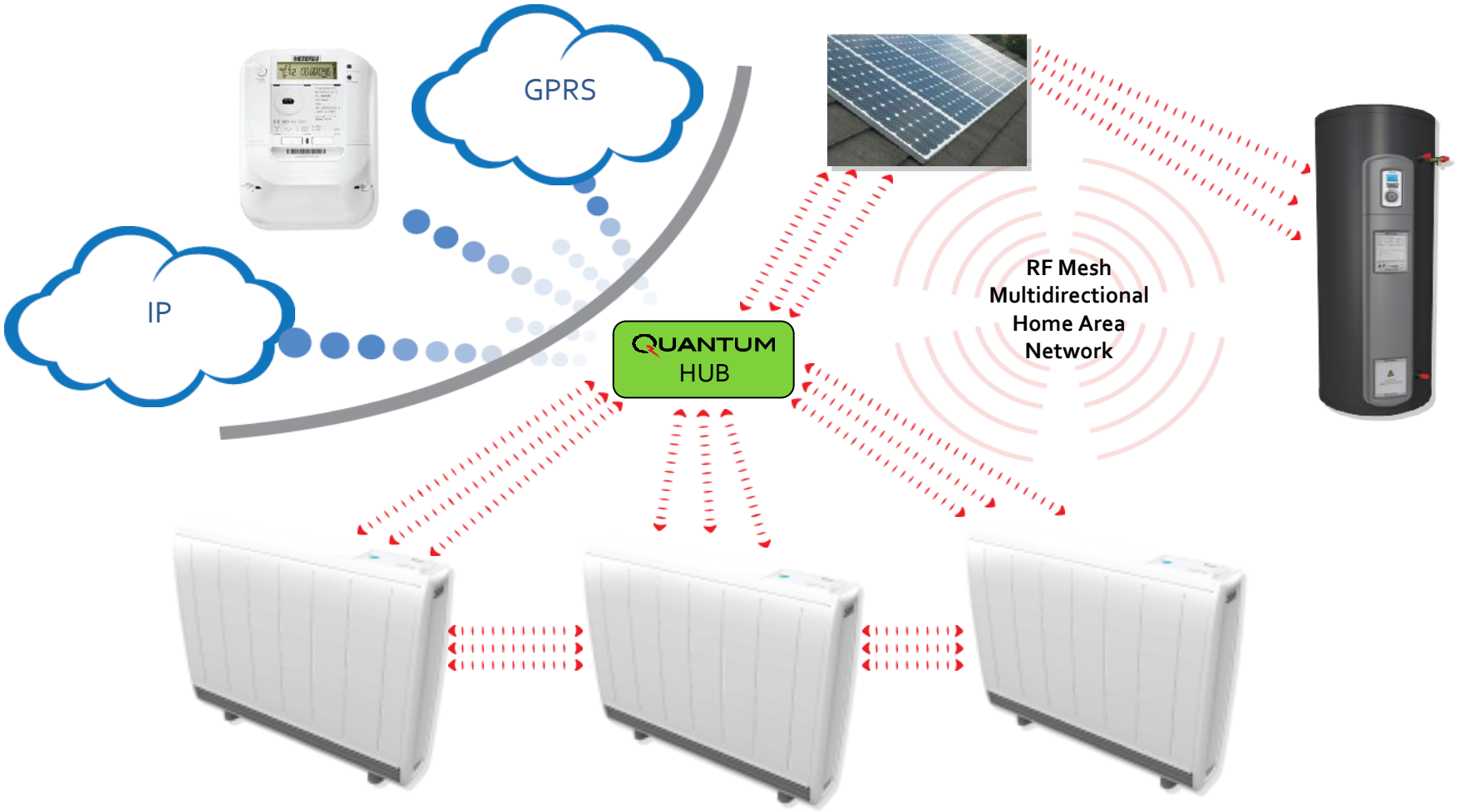


Figure 3: Interaction between Work Packages

GlenDimplex

Electric Heat Demand is Flexible



Smart Thermal Electric Storage Heaters as a Load Shifting Resource

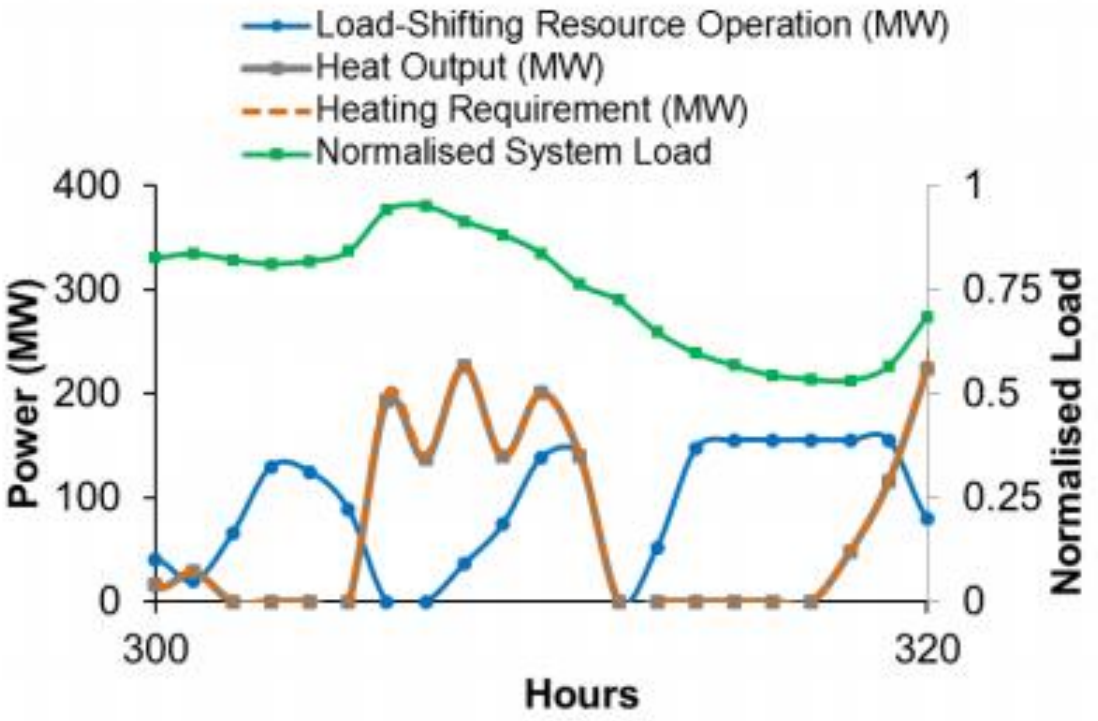


Fig. 5. Operation of the load-shifting resource, heat output and heating requirements with full-time occupants and with resource reserve capability. Normalized system load highlights when the system peak hours occur.

Smart Thermal Electric Storage Heaters as a Load Shifting Resource

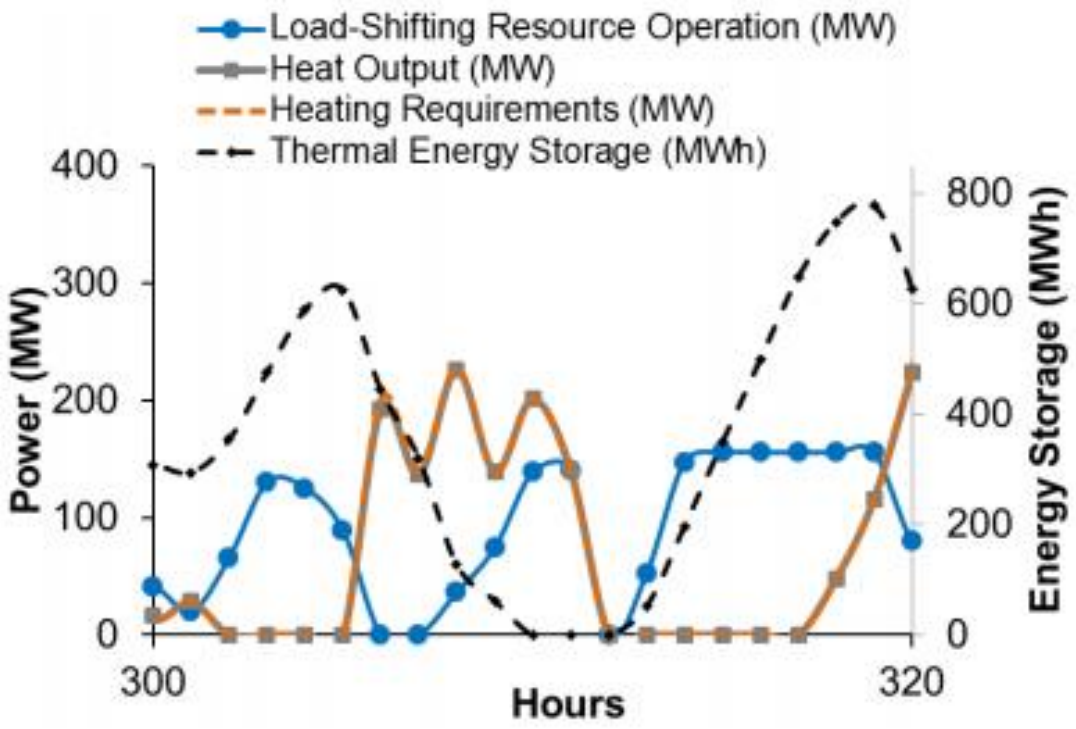
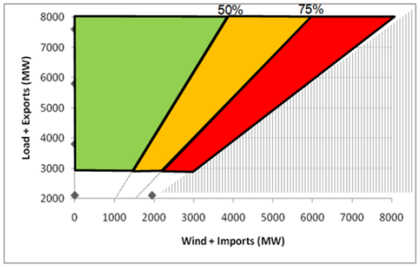
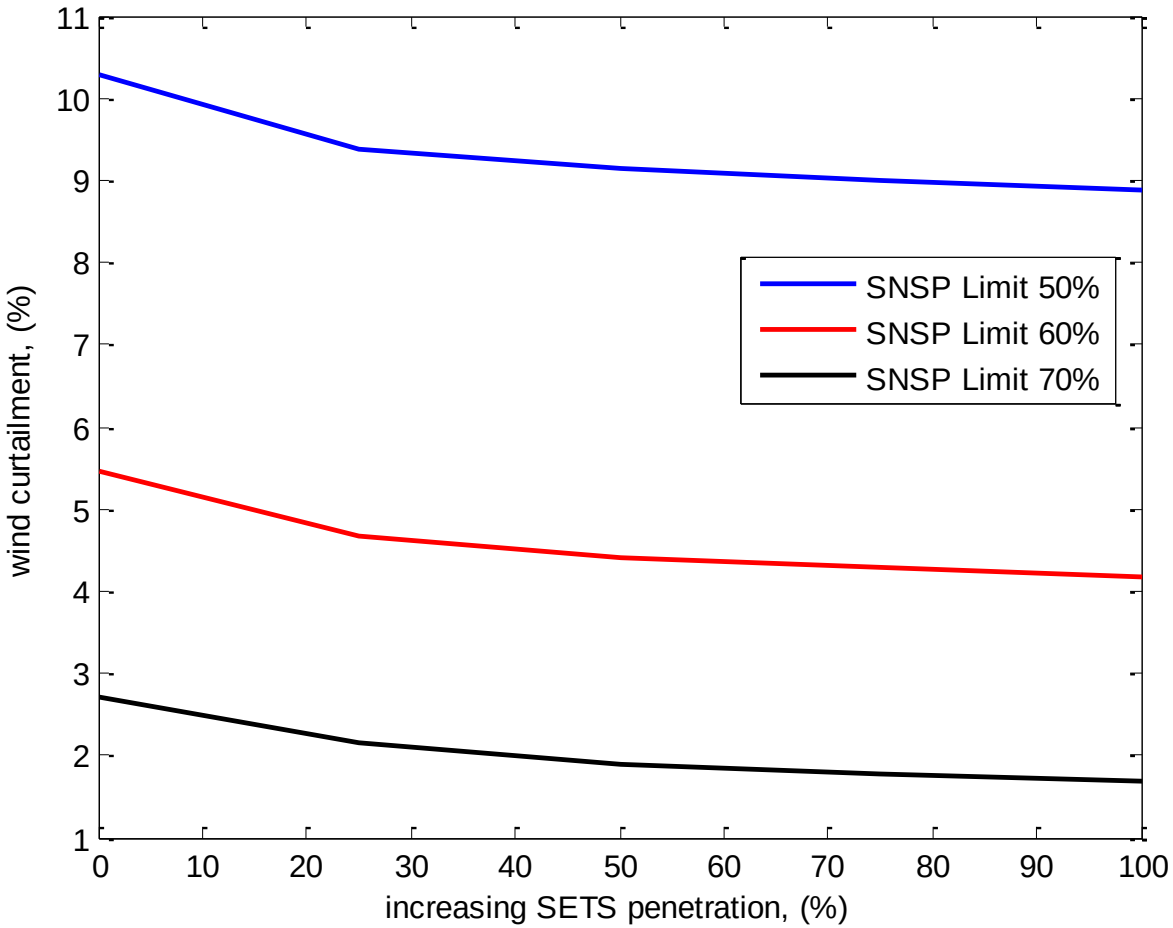


Fig. 6. Operation of the load-shifting resource, heat output, heating demand and the energy storage component for the case with full-time occupants and with load-shifting resource reserve capability.

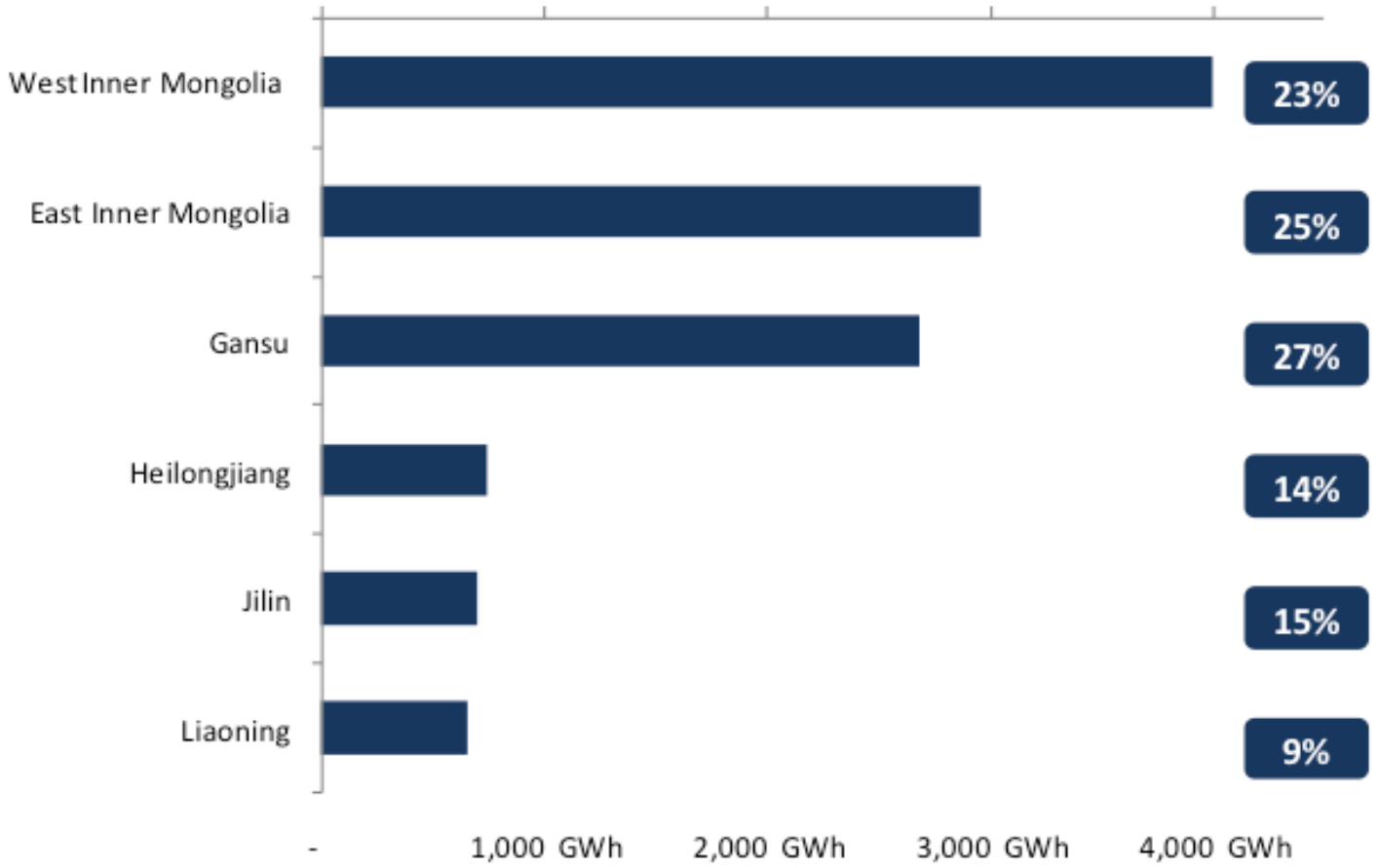
SNSP Limit & Curtailment





Modest ability of Smart Electric Heat Demand (SETS) to reduce wind curtailment is consistent across the SNSP limit constraint sensitivities

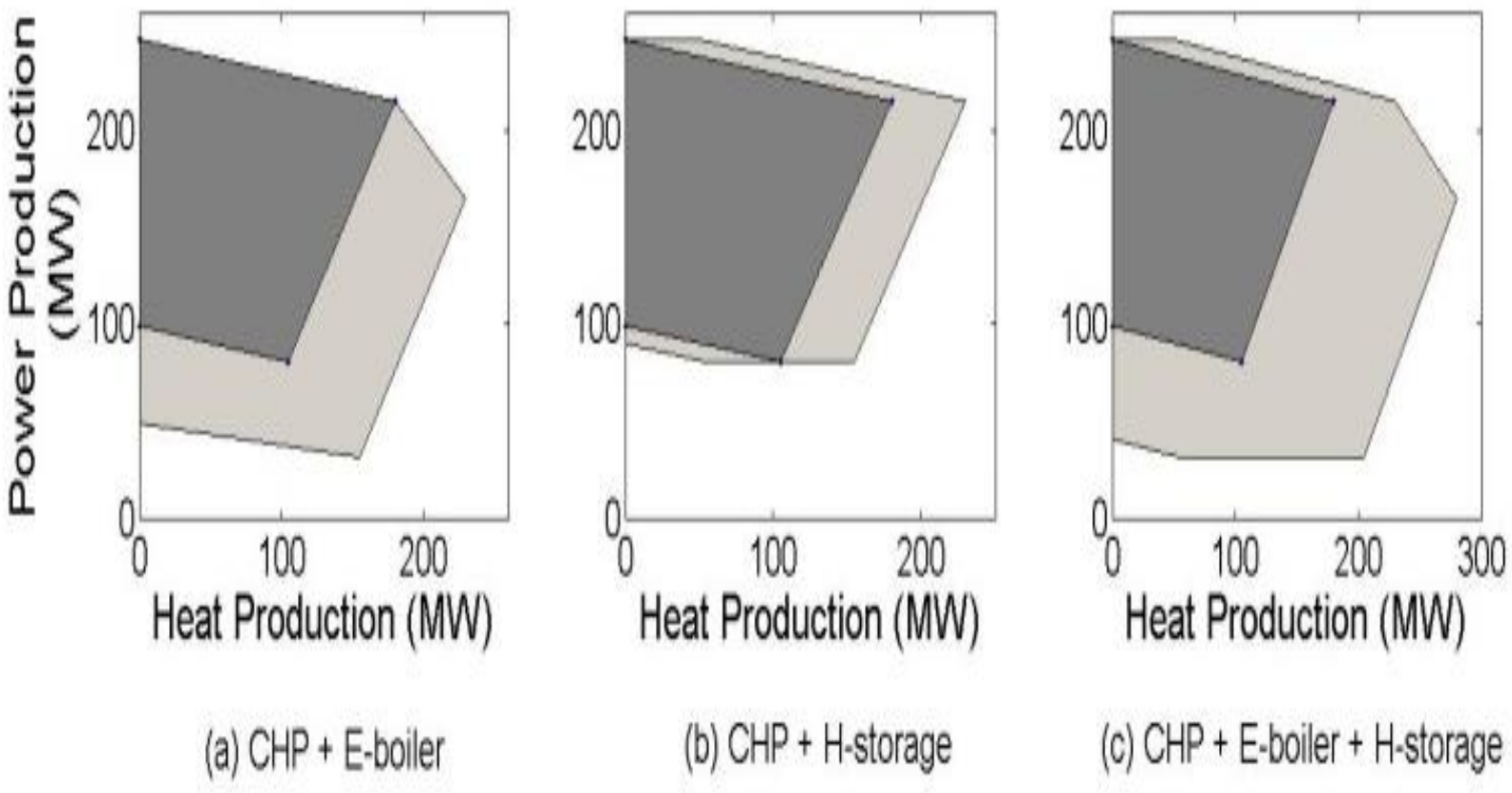
Wind curtailment in China



- **In 2011 wind curtailment in China was 16.9 % that is of the wind that is connected to the grid i.e. approx. 75 % of the 80 GW installed.**
- **May well be just a legacy issue i.e. in China as the load grows the new thermal plant can be made more flexible and system will be designed around the needs.**

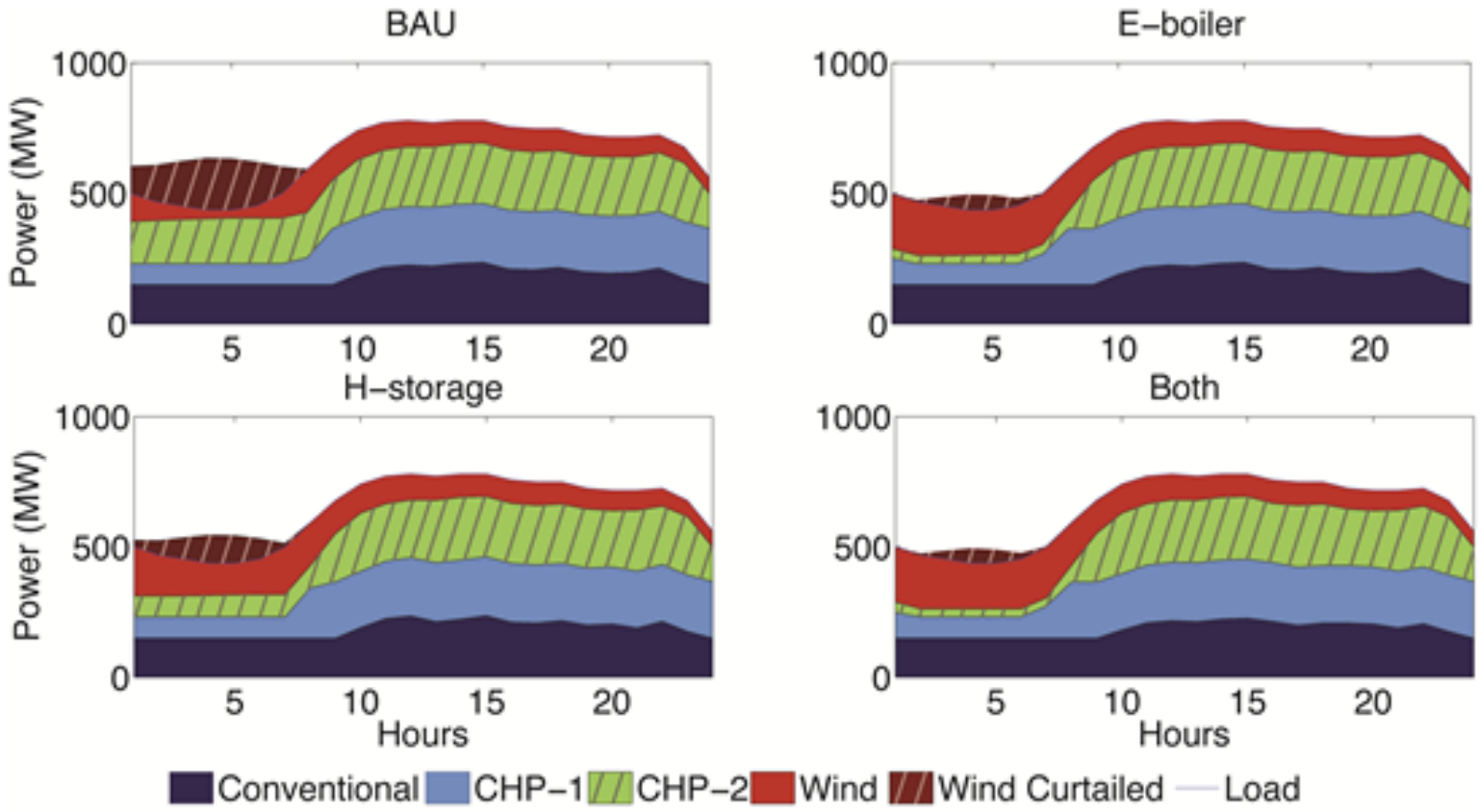
http://www.greentechmedia.com/articles/read/Chinas-Wind-Market-Growing-but-Challenged-by-Grid-Real

Combined heat and power (CHP) can be made flexible



Chen, X., Kang, C., O'Malley, M.J., Xia, Q., Bai, J., Liu, C., Sun, R., Wang, W. and Hui, L., "Increasing the Flexibility of Combined Heat and Power for Wind Power Integration in China: Modeling and Implications", IEEE Transactions on Power Systems, Vol. 30, pp.1848-1857, 2015.

Flexible CHP can reduce wind curtailment



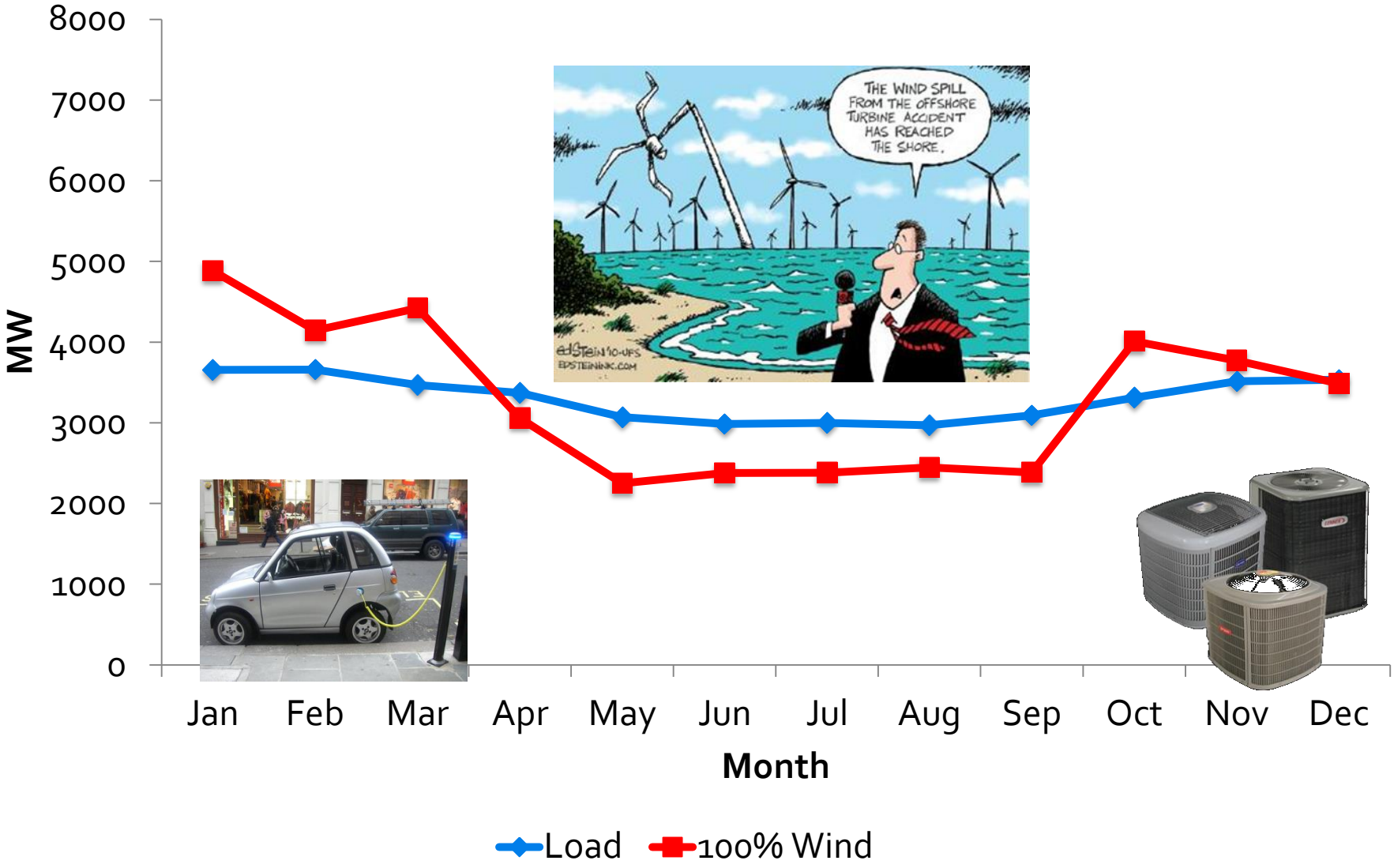
Chen, X., Kang, C., O'Malley, M.J., Xia, Q., Bai, J., Liu, C., Sun, R., Wang, W. and Hui, L., "Increasing the Flexibility of Combined Heat and Power for Wind Power Integration in China: Modeling and Implications", IEEE Transactions on Power Systems, Vol. 30, pp.1848-1857, 2015.

Demonstration projects

- Established in Inner Mongolia, 2014, with 20 electric boilers
- 500,000 m^2 heat supply
- 75 GWh wind power annually, equivalent to 19,000t coal
- Decrease CO2 emission by 68,000t

Source: Chongqing Kang, Tsinghua University

100 % Wind we will have to change how we live



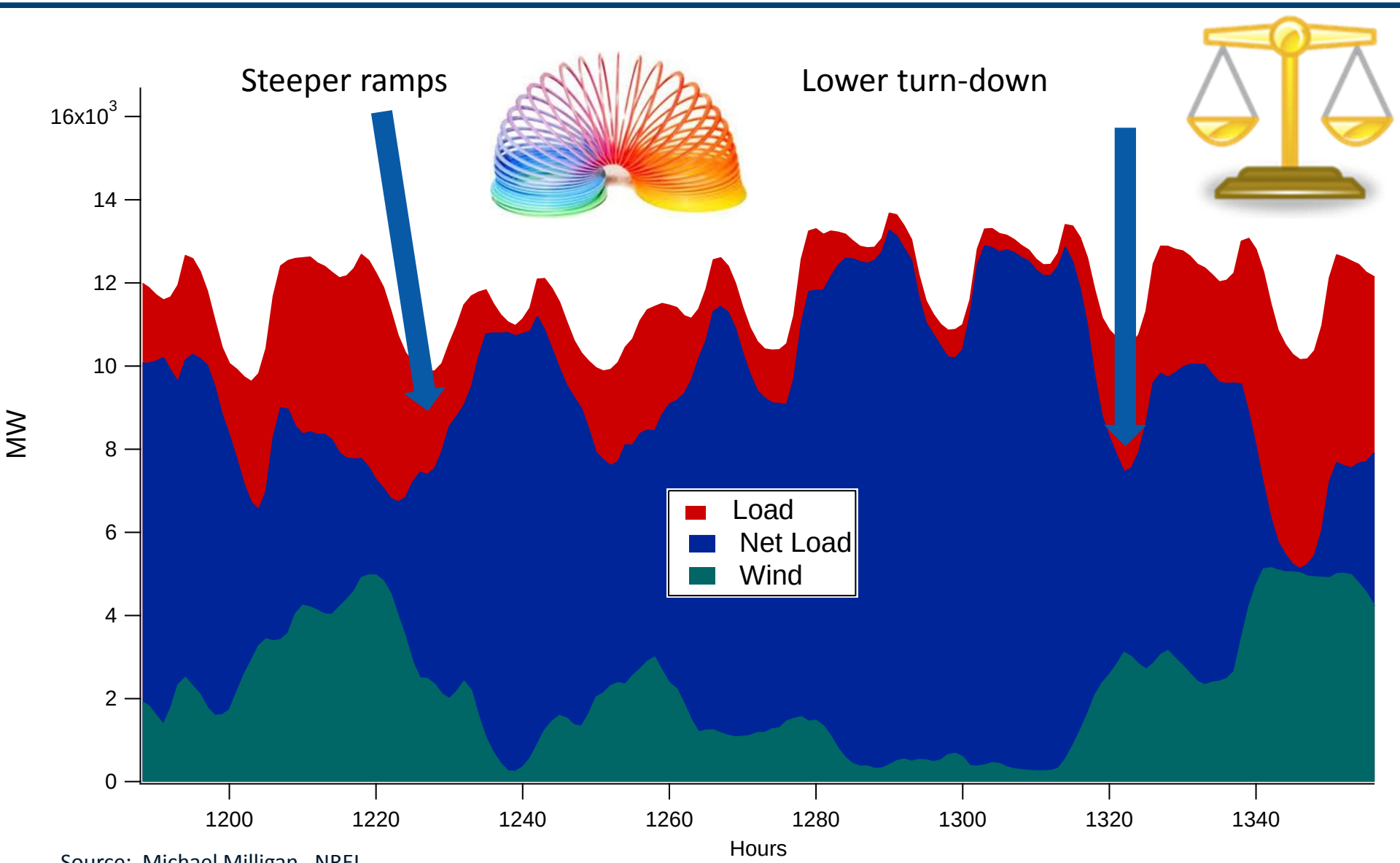
Key Take Away

- Coupling electricity and heat (and other vectors) across scales can help integrate variable renewable energy

- To make a real impact it probably requires changes at the planning stage

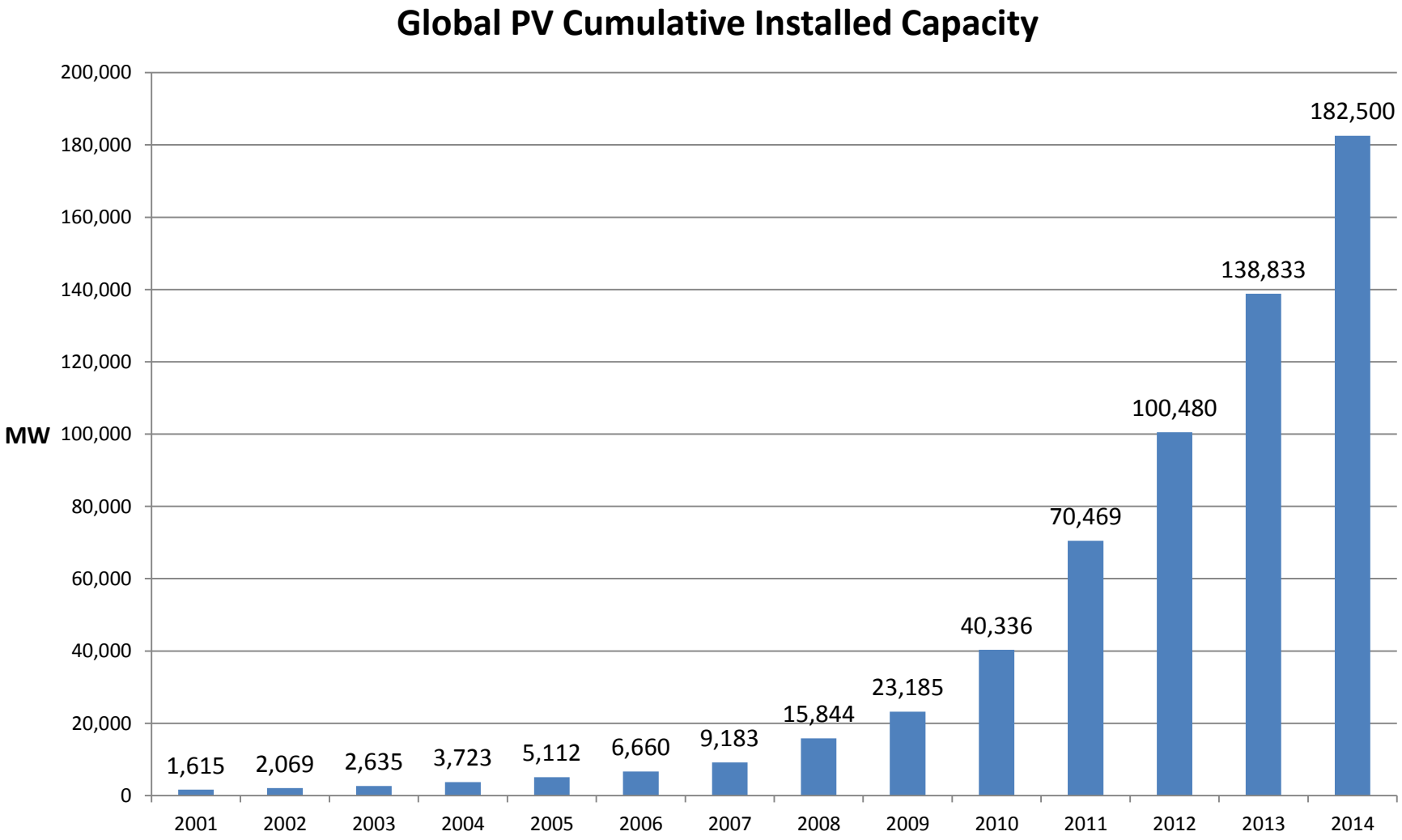
Grid Flexibility

With Variable Renewables More Flexibility is Needed



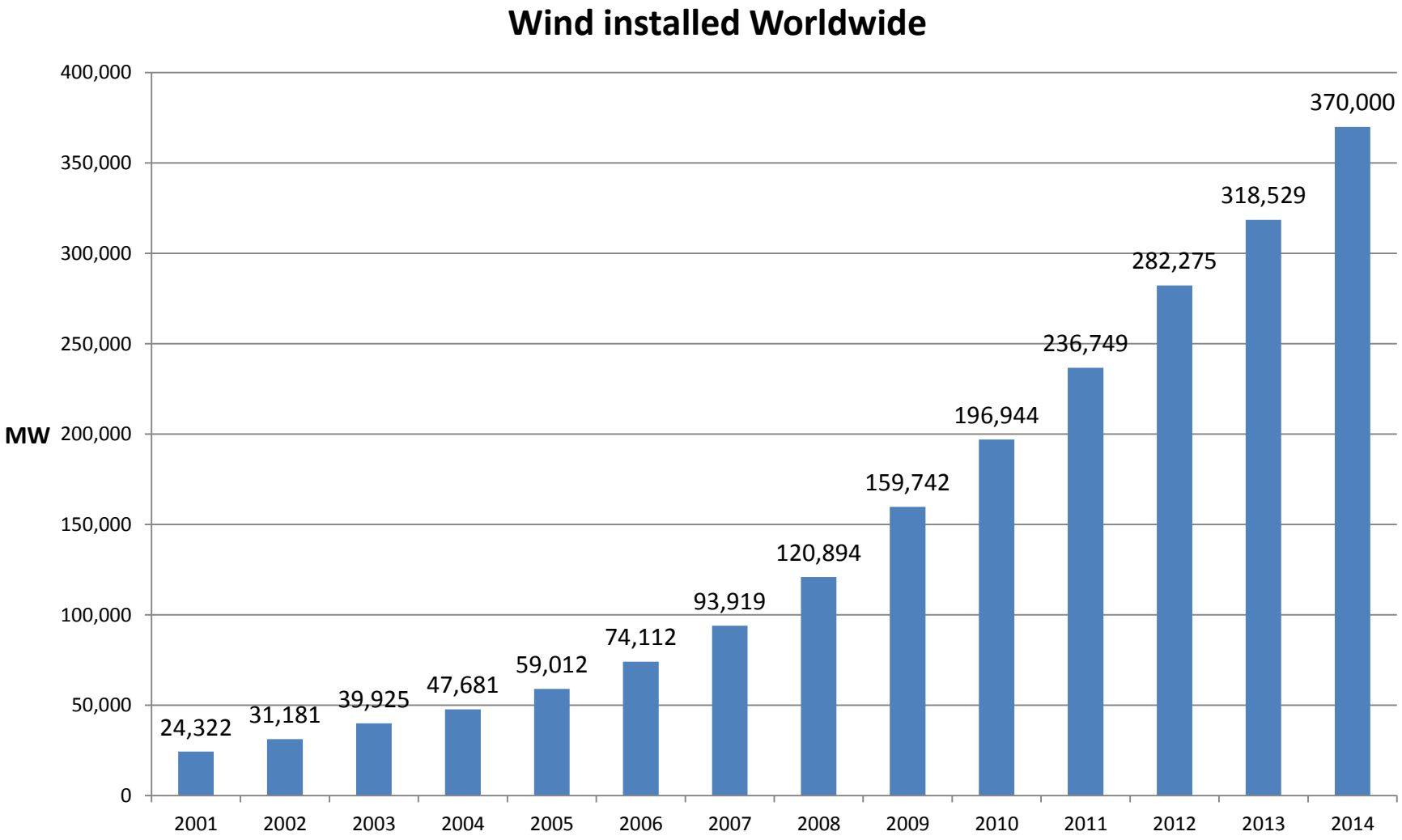
Source: Michael Milligan , NREL

PV Installed Worldwide



Sources: European Photovoltaic Industry Association (EPIA), International Energy Agency (IEA), IHS Technology (2014 figure)

Wind Installed Worldwide



Data from http://www.wwindea.org/home/index.php

Electric Vehicles & Role in integration of wind

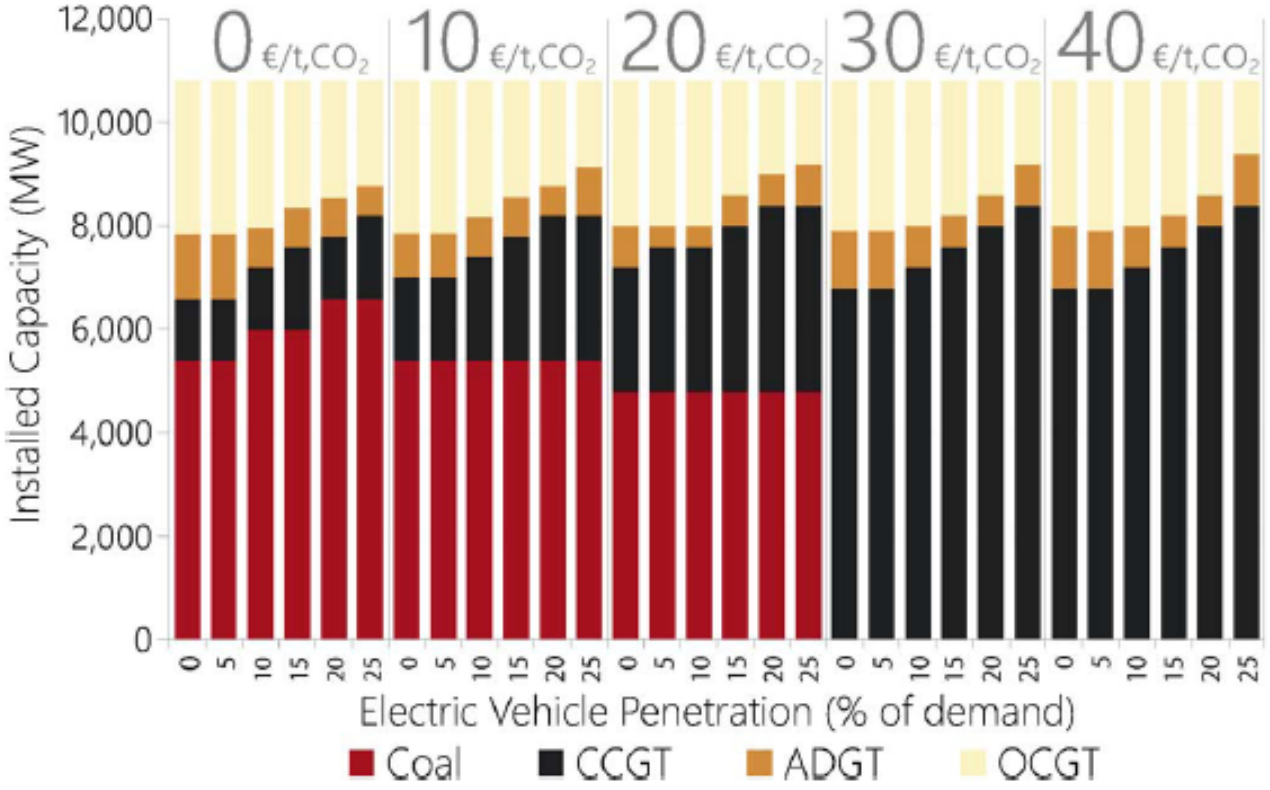
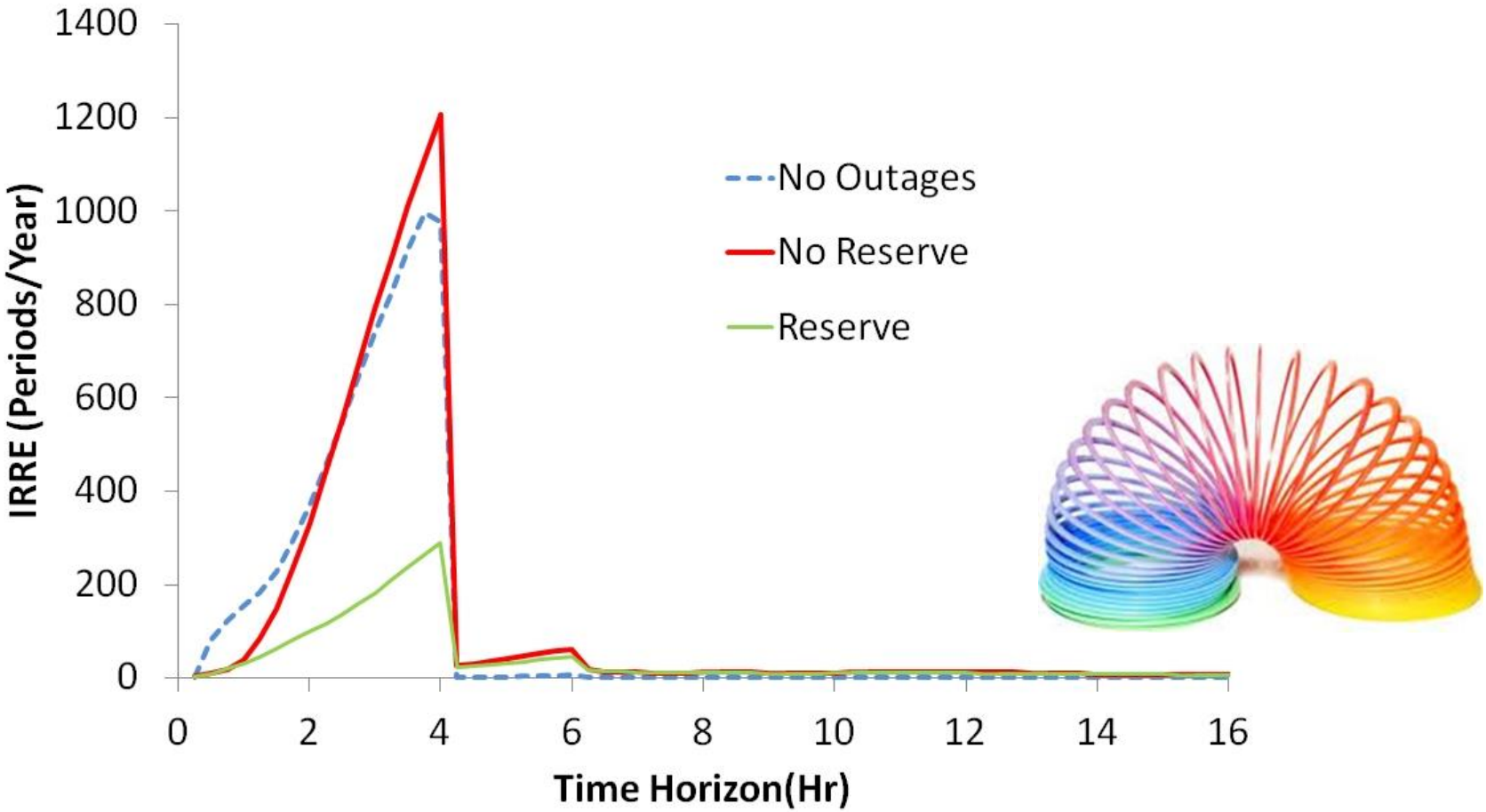


Fig. 20. Final installed capacities for selected CO_2 cost levels and electric vehicle penetrations (Ireland, 10% wind).

Increasing EVs bring flexibility but also encourage more base load efficient plant so reducing flexibility

Shortt, A. and O'Malley, M.J., "Quantifying Long-Term Impact of Electric Vehicles on the Generation Portfolio", IEEE Trans. on Smart Grid, Vol. 5, pp. 71-83, 2014.

Flexibility Metric

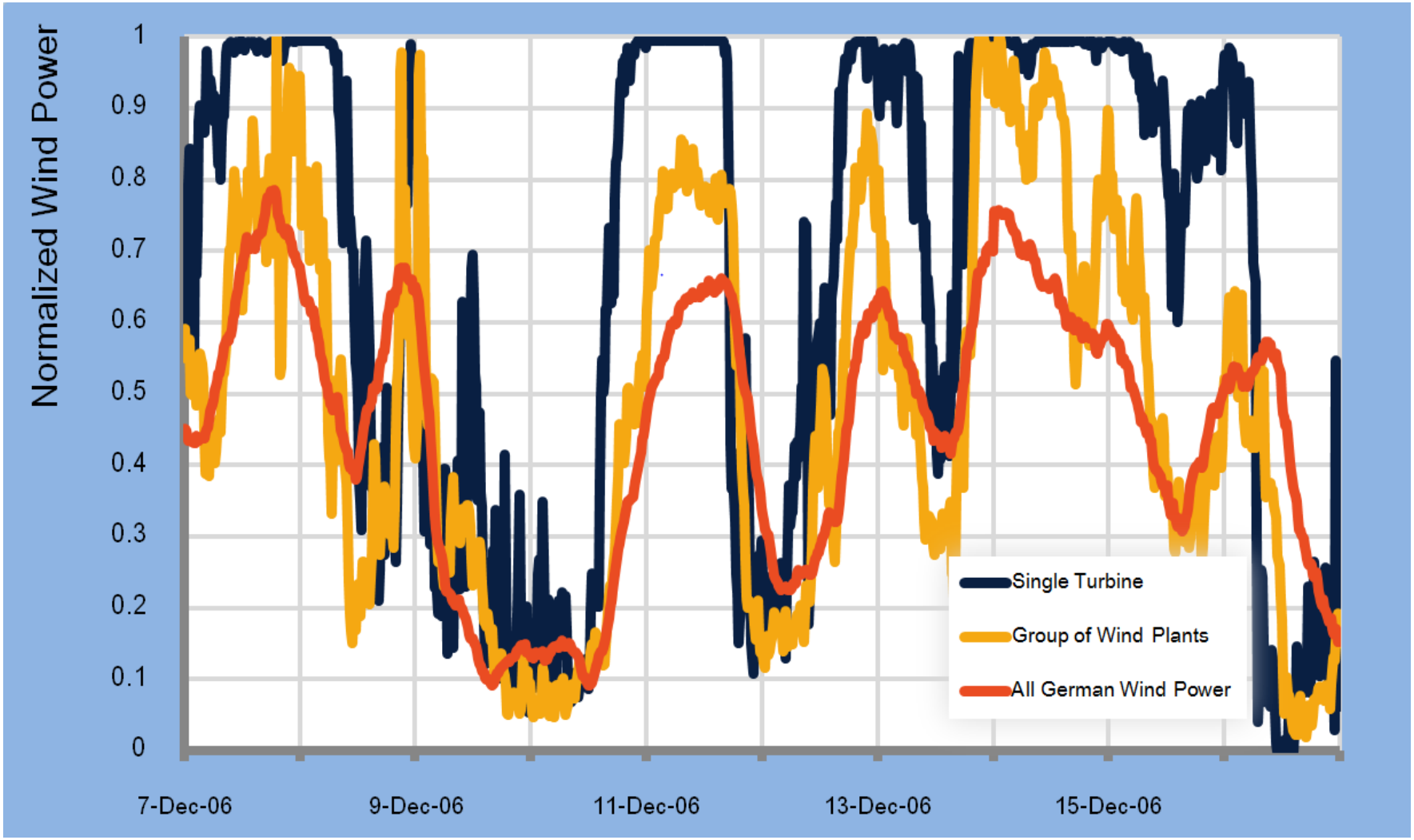


Lannoye, E., Flynn, D. and O'Malley, M.J. "Transmission, variable generation and power system flexibility", *IEEE Transactions on Power Systems*, Vol. 30, pp. 57 – 64, 2014.

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

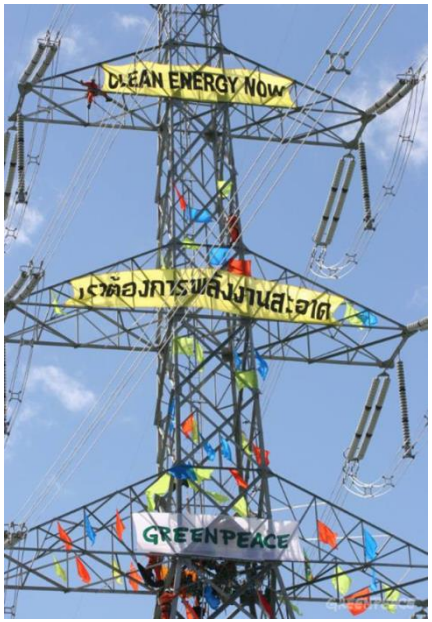
If you love wind/solar you have to at least like Transmission

Aggregation of wind with transmission



Krewitt, W. et al. Integration of Renewable Energy into Present and Future Energy Systems. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2011.

Enter the “consumer”



‘Engineers and economists are ignoring people and miscasting decision making and action’, *Sovacool, B.K. (2014) Nature 511, 529-530*


DIETER TELEMANS/PANOS

Masai women from Kenya take a course on solar energy in India.

Energy studies need social science

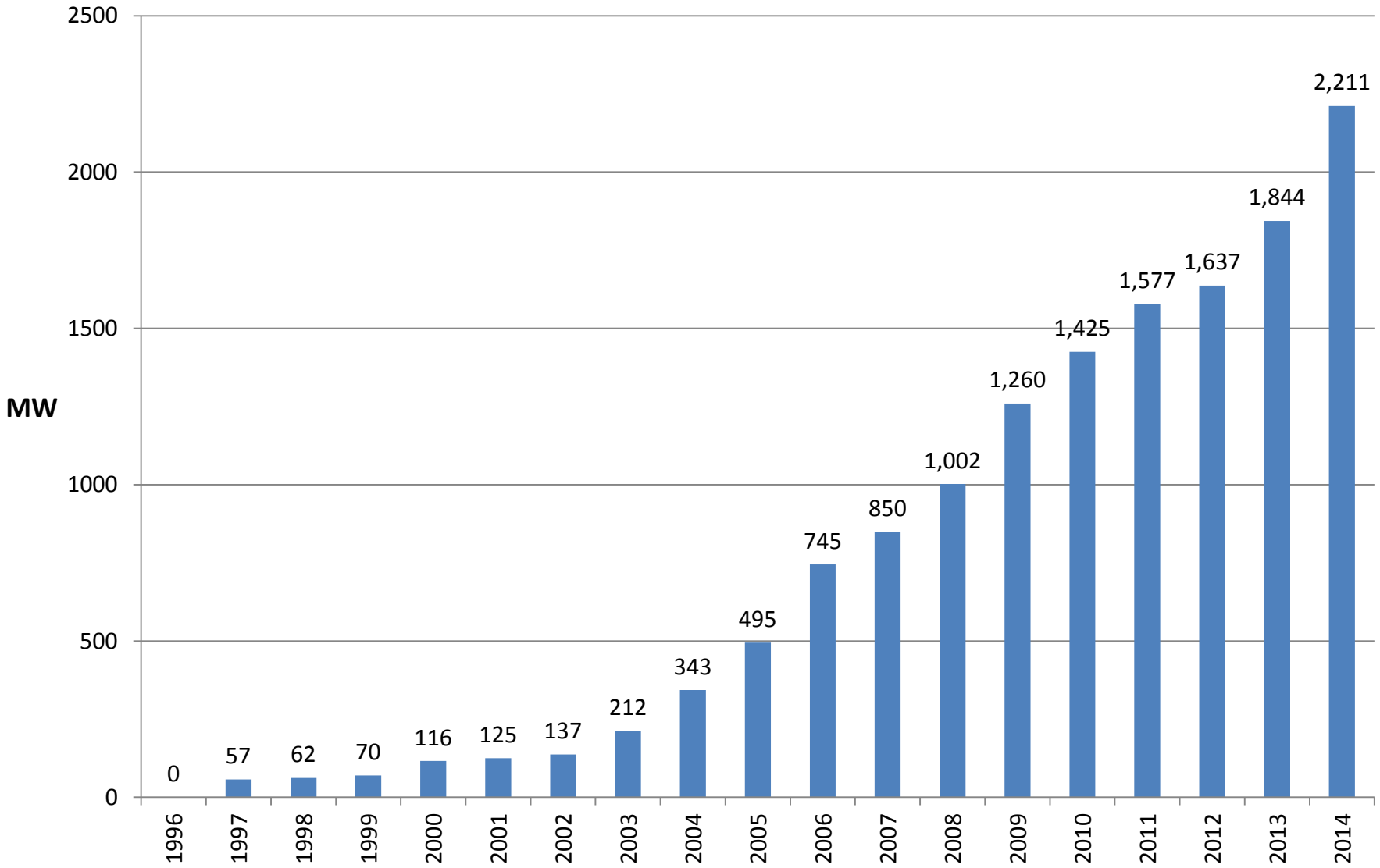
Trilemma plus the “consumer”

Key Take Away

- Society impacts on the integrated energy system are very significant
- Policy and markets very important

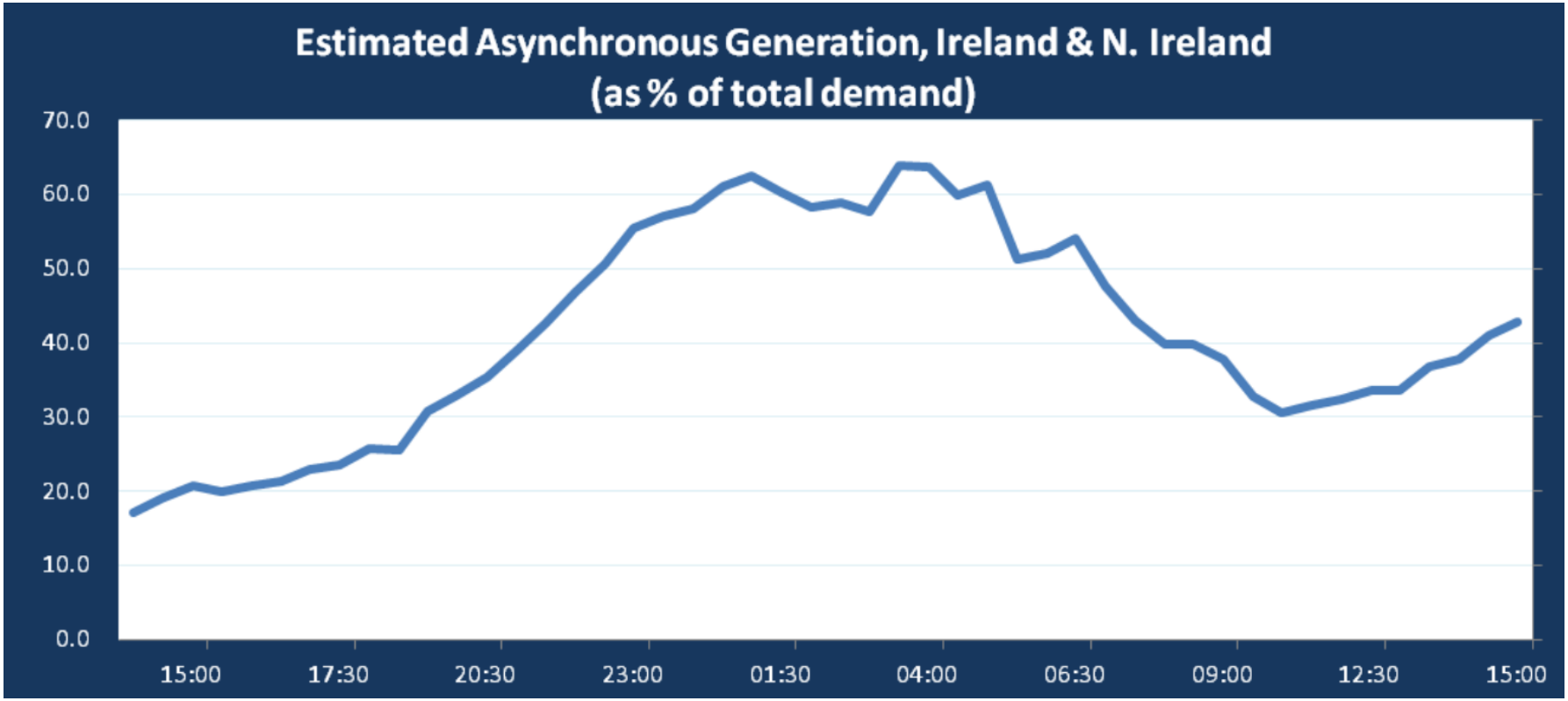
Markets and policy

Wind Installed in Republic of Ireland



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

28th & 29th January (Ireland)



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

Grid Code

Performance Monitoring

DSM

System Services

ROCOF

Frequency

Voltage

Renewable Data

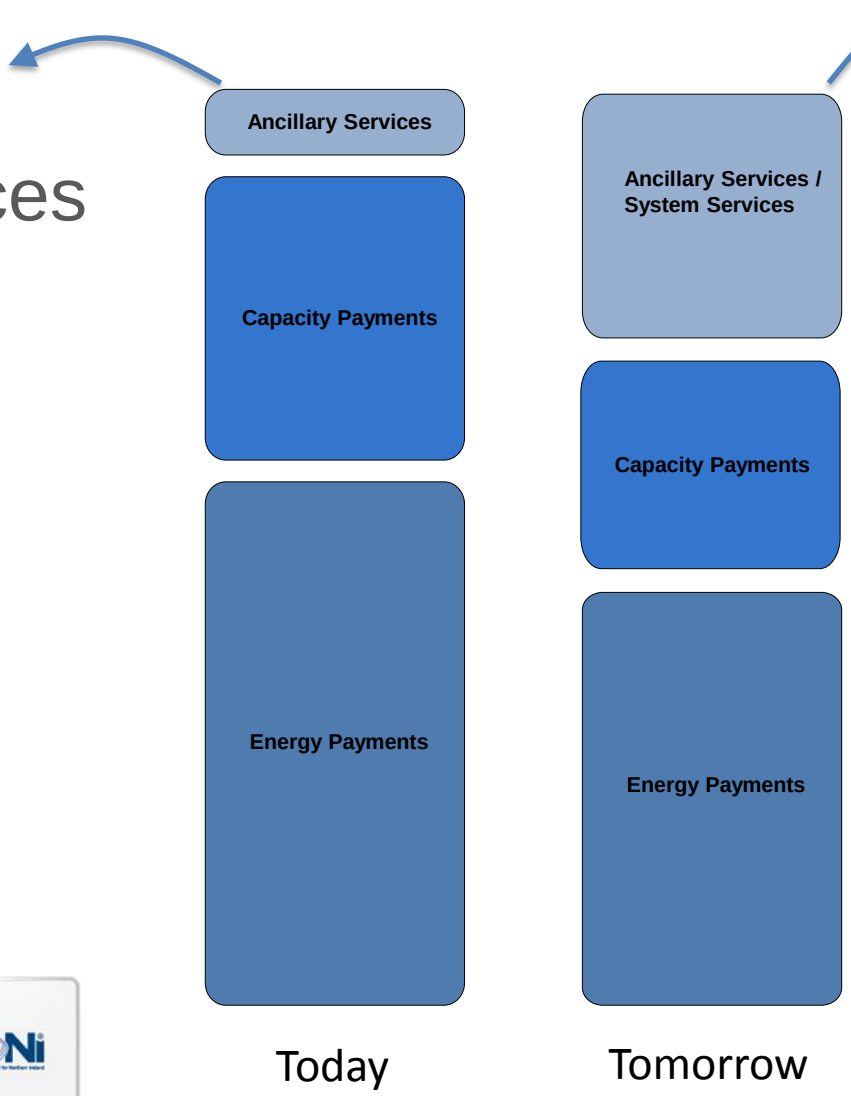
WSAT

Control Centre Tools

Model Dev. & Studies

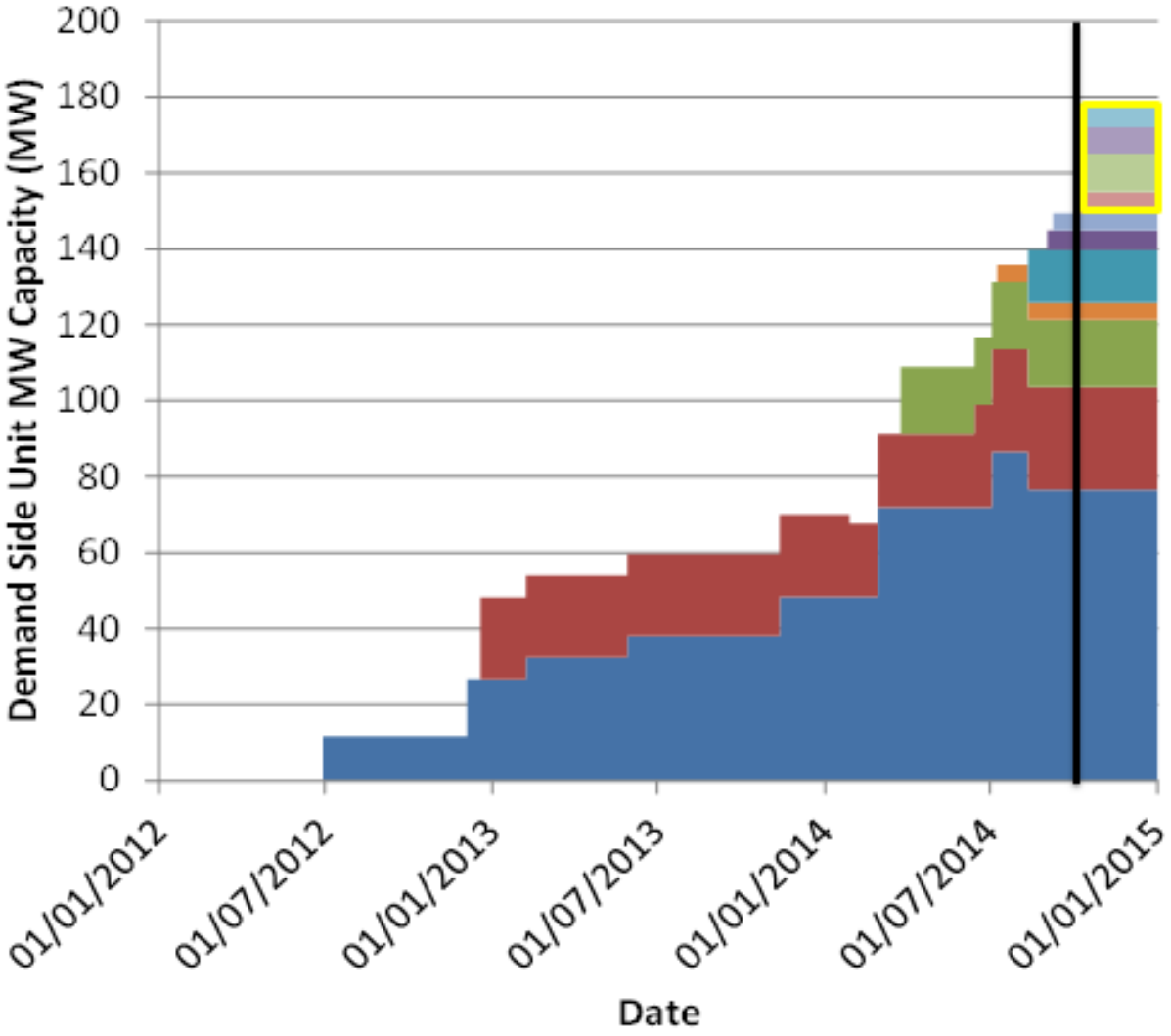
System services: Incentivising the Portfolio

- 60 €m
- 7 Services



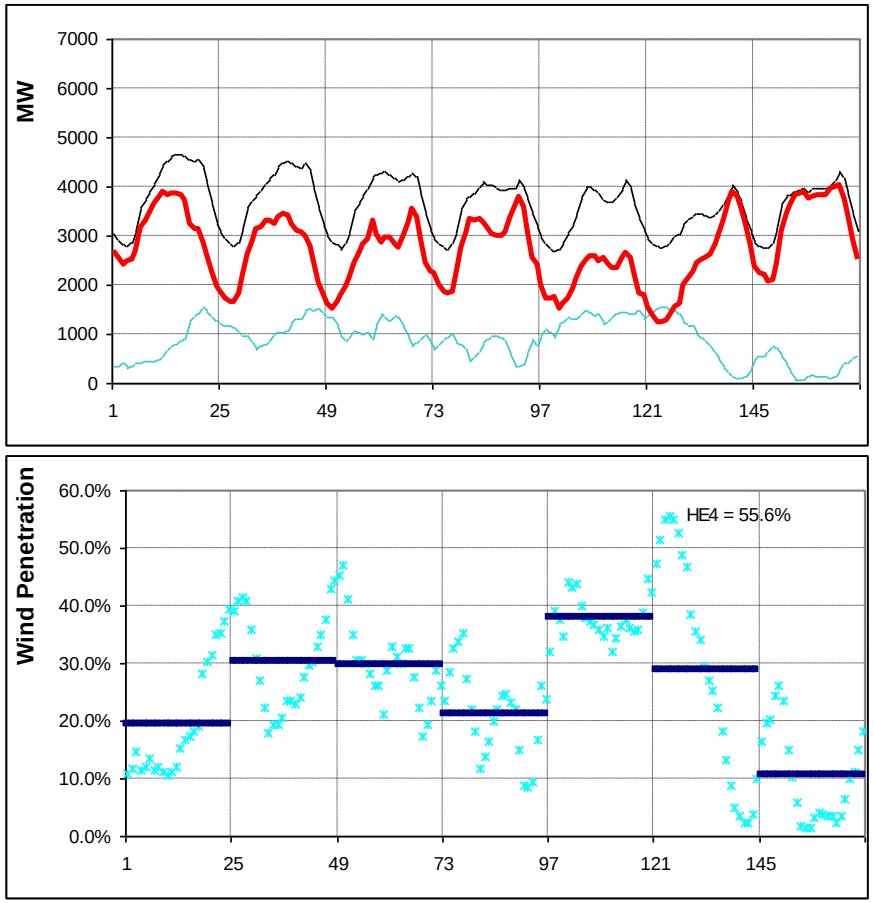
- 235 €m
- 14 Services

DSM – A New Service Provider…



…and the U.S. has similar experience

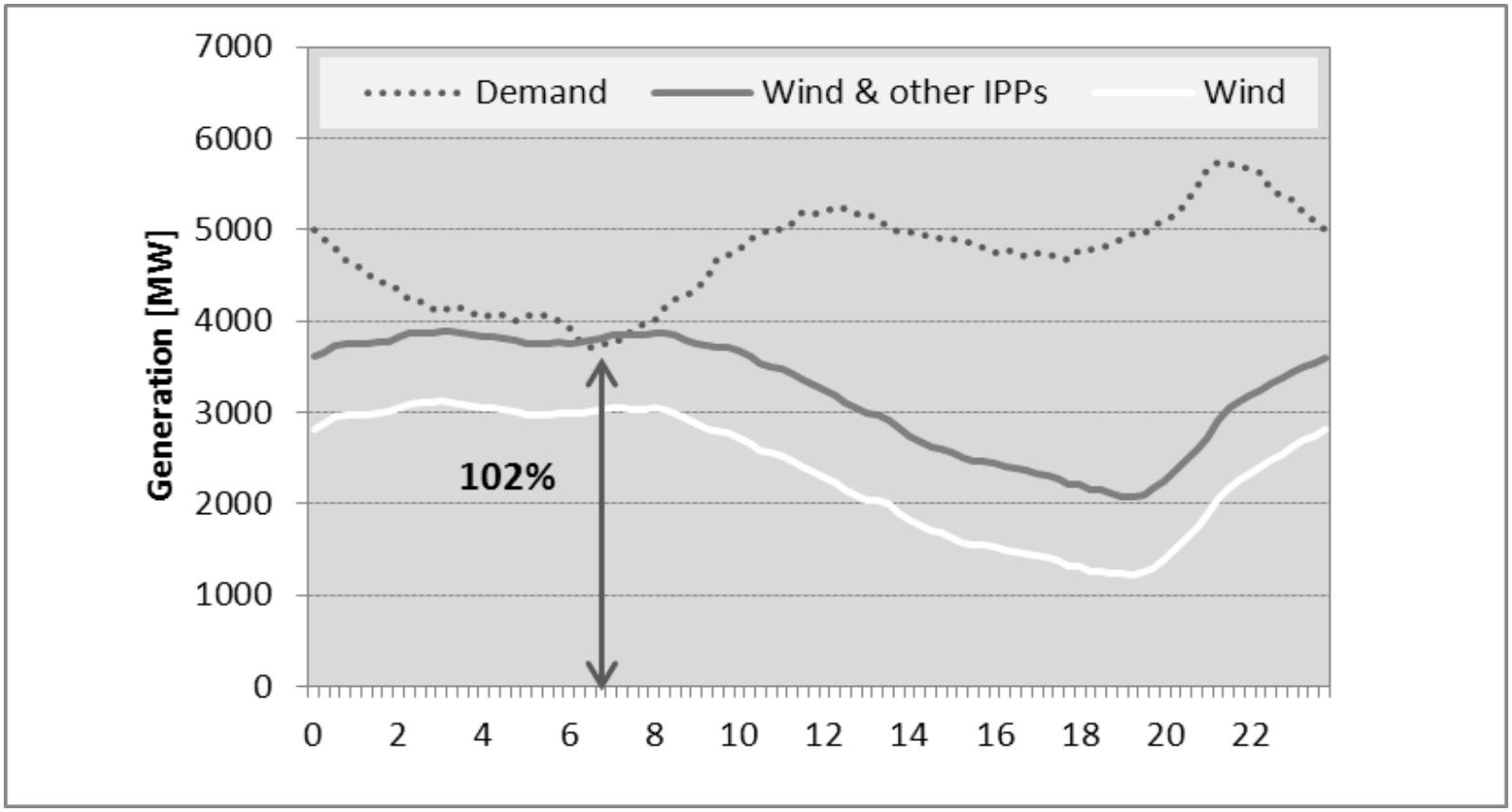
- Public Service of Colorado (PSCo) reached record levels of wind penetration in October 2011
  - Hourly Record: 55.6% October 9, 2011 HE4
  - Daily Record: 37.0% October 8, 2011



Public Service of Colorado - October 4-10, 2011

Source: Michael Milligan

…and Portugal



Portuguese load and generation profiles for May 15, 2011

Söder, L., Abildgaard, H., Estanqueiro, A., Hamon, C., Holttinen, H, Lannoye, E, Gómez Lázaro, E., O'Malley, M.J. and Zimmermann, U. "Experience and challenges with short-term balancing in European systems with large share of wind power", *IEEE Transactions on Sustainable Energy*, Vol. 3, pp. 853 – 861, 2012.

… and South Australia

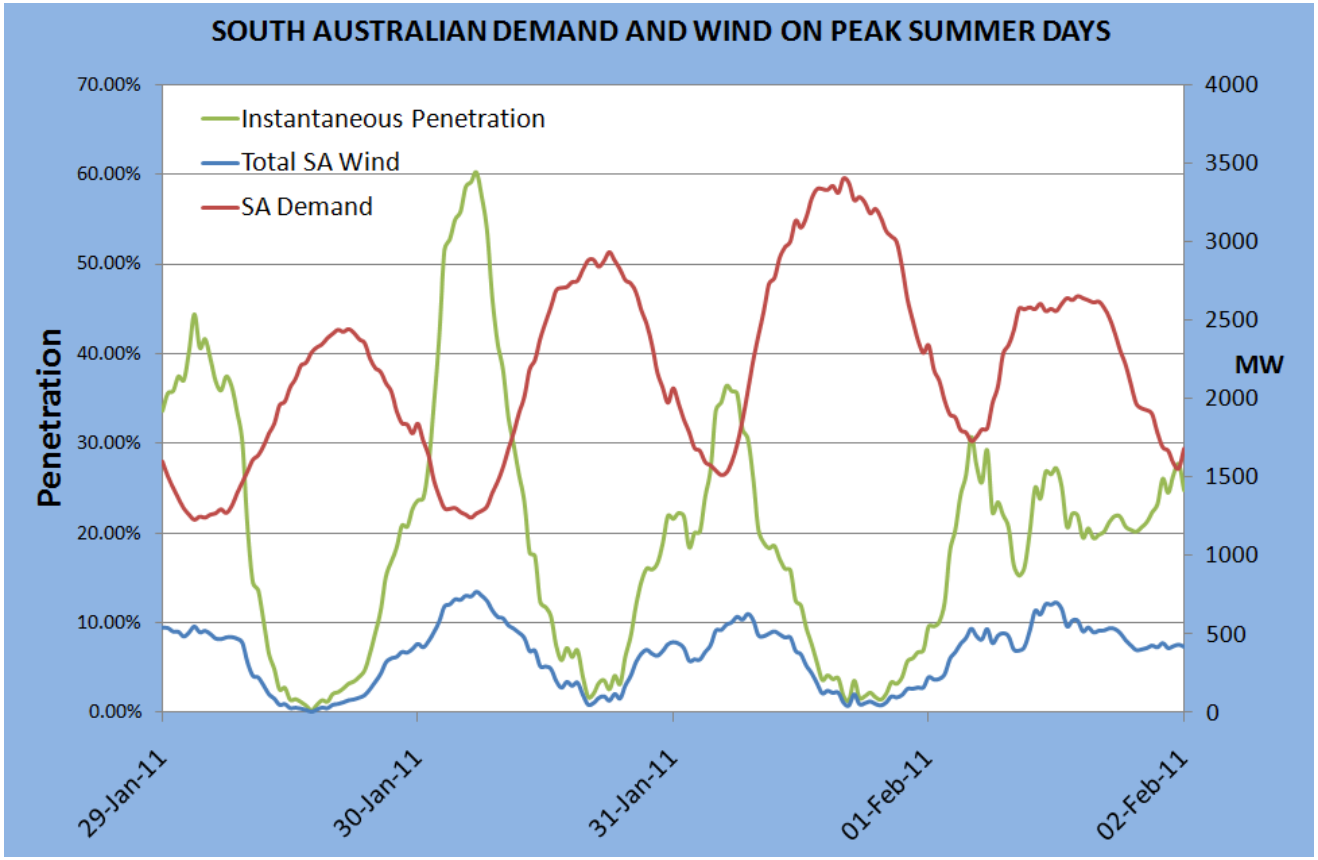
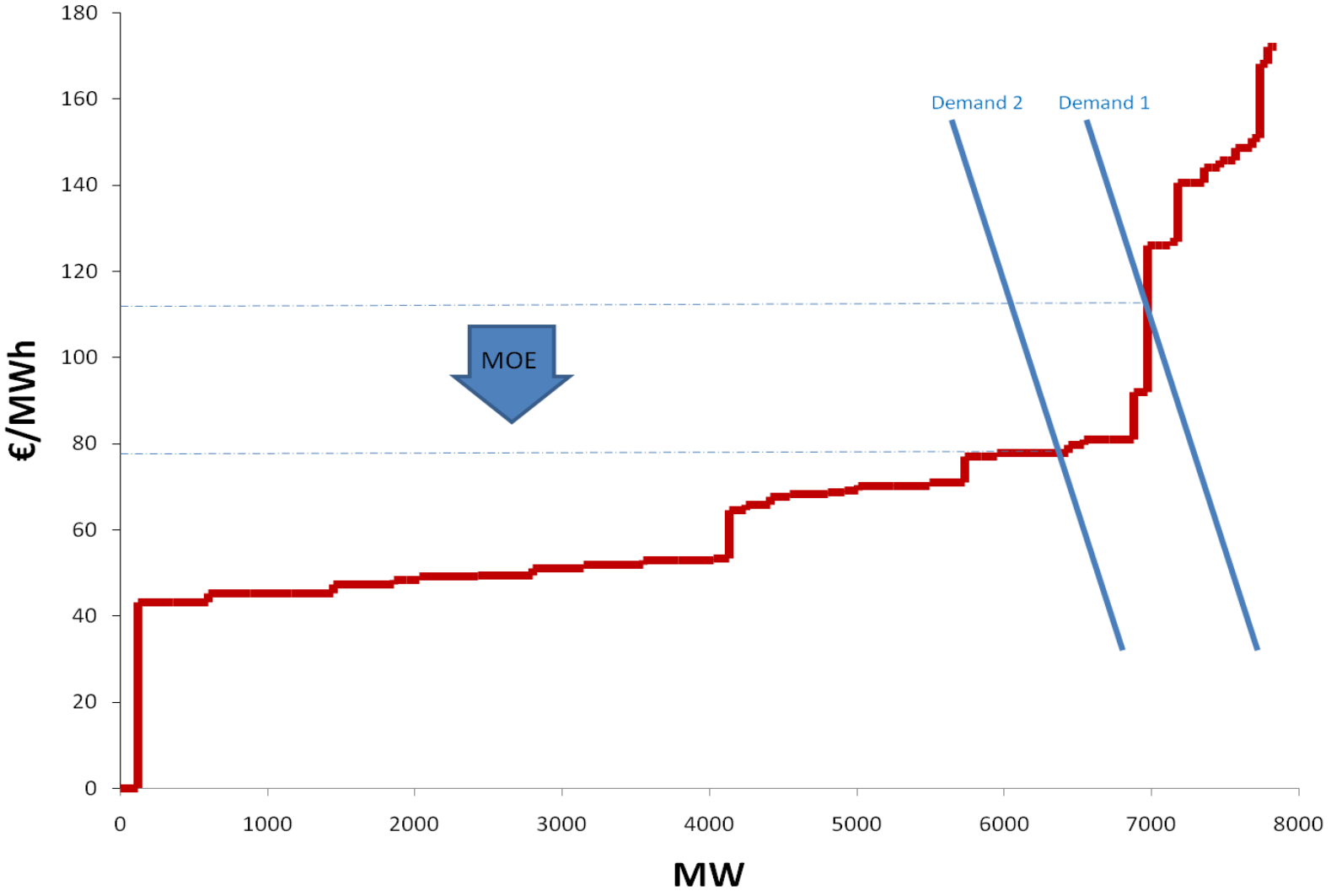


Figure 6: Four days of wind and demand South Australia. Instantaneous penetration (excluding exports) (%) also shown (http://aemo.com.au).

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

Merit Order Effect

Merit Order Effect



O'Mahoney, A., Denny, E. 30th IAEE/USAEE North American Conference, Washington DC, USA, October 2011.

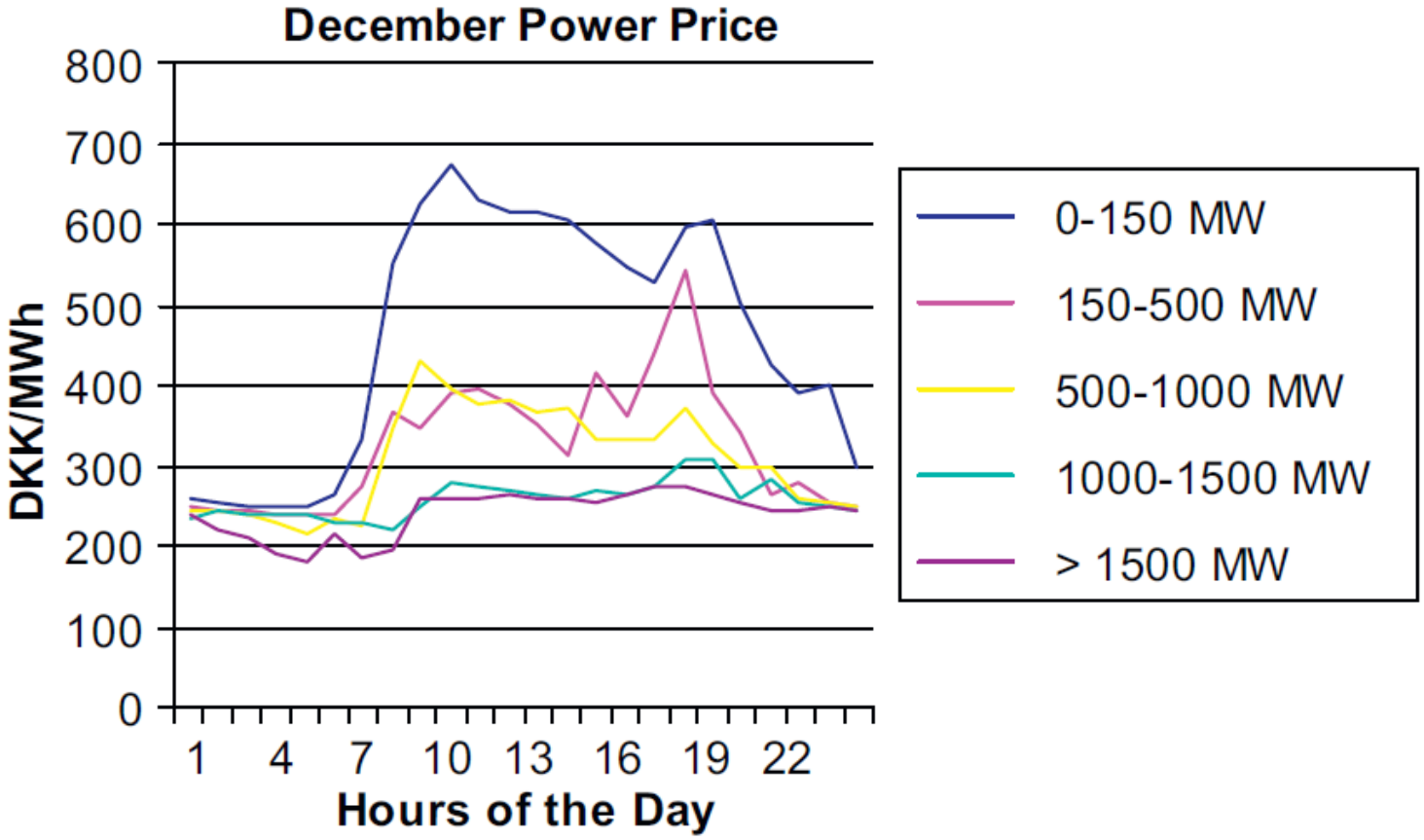
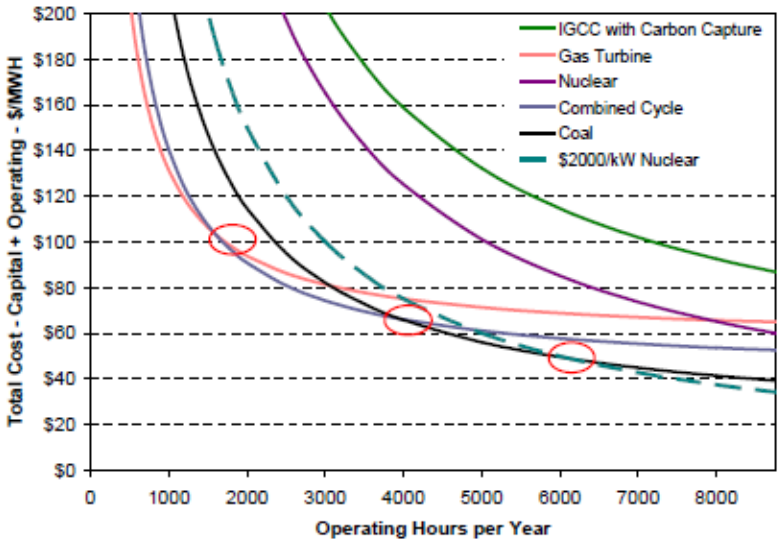
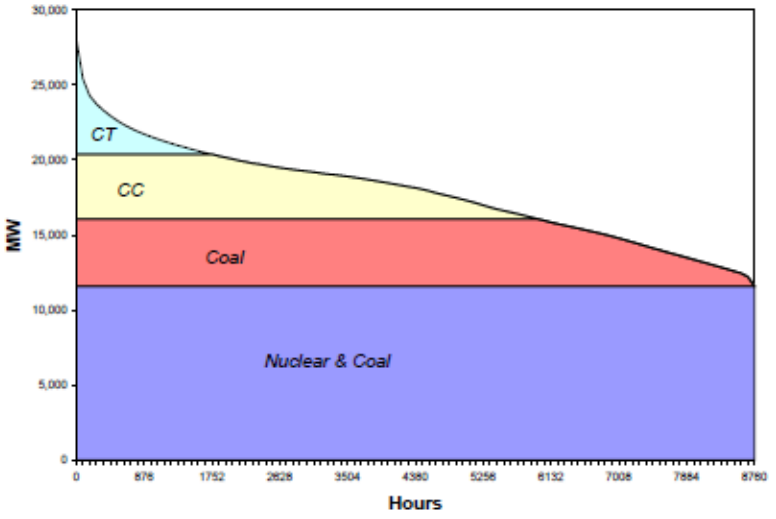


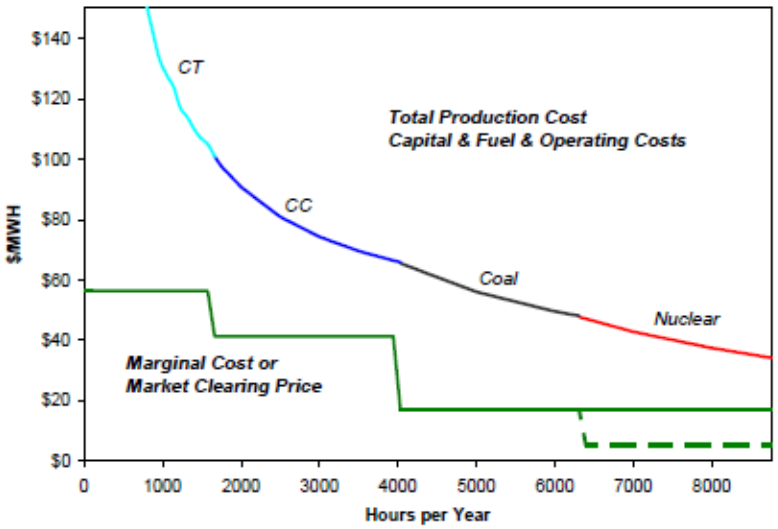
Fig. 3. The impact of wind power on the spot-market price of electricity in Western Denmark, December 2005.

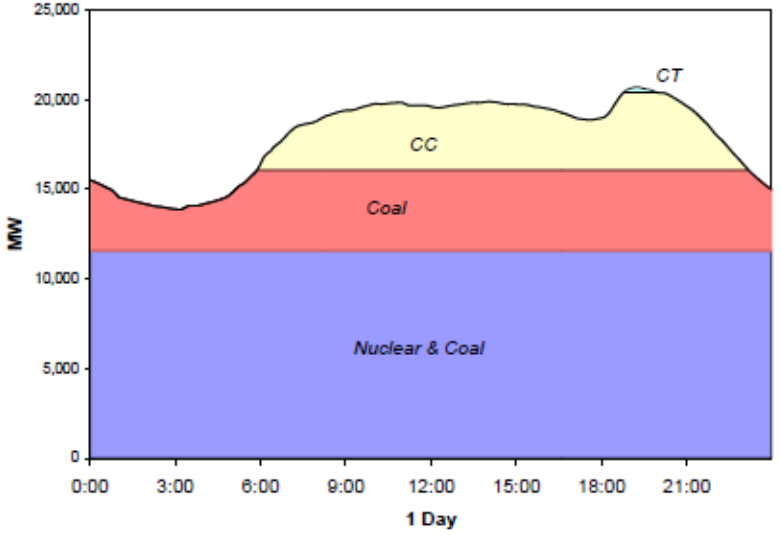
Munksgaard, J., and P. E. Morthorst, 2008: Wind power in the Danish liberalized power market - Policy measures, price impact and investor incentives, *Energy Policy*, 36:3940-3947.

Having the right generation set

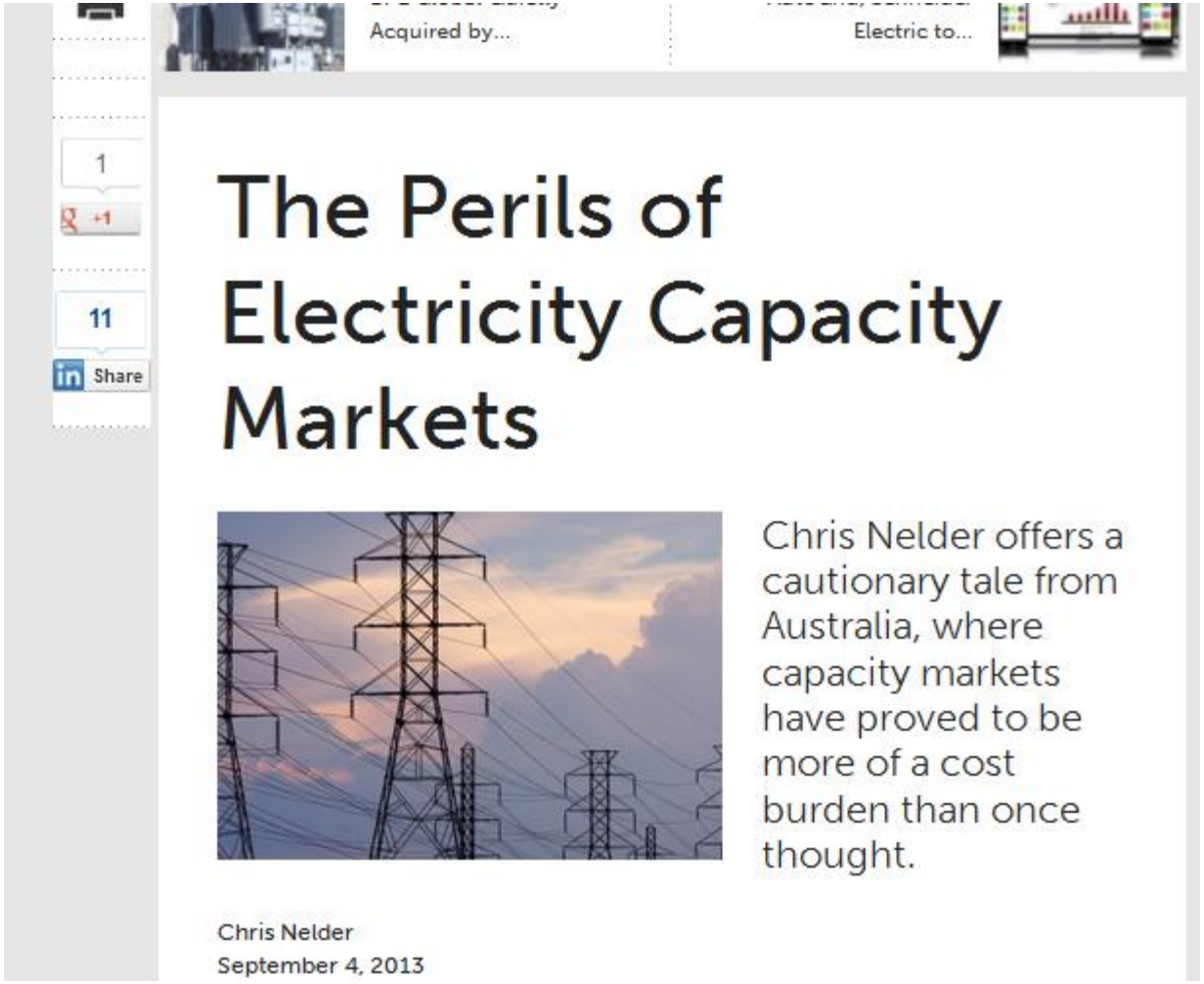








Having enough generation



Acquired by...

Electric to...

1

+1

11

Share

The Perils of Electricity Capacity Markets

Chris Nelder offers a cautionary tale from Australia, where capacity markets have proved to be more of a cost burden than once thought.

Chris Nelder
September 4, 2013

http://www.greentechmedia.com/articles/read/The-Perils-of-Electricity-Capacity-Markets

Reliability

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Windmills Overload East Europe's Grid Risking Blackout: Energy

By Ladka Bauerova and Tino Andresen - Oct 26, 2012 12:01 AM GMT

15 COMMENTS QUEUE

Sean Gallup/Getty Images

Germany is dumping electricity on its unwilling neighbors and by wintertime the feud should come to a head.

Germany is dumping electricity on its unwilling neighbors and by wintertime the feud should come to a head.

- http://ec.europa.eu/energy/gas_electricity/studies/doc/electricity/20131 0_loop-flows_study.pdf

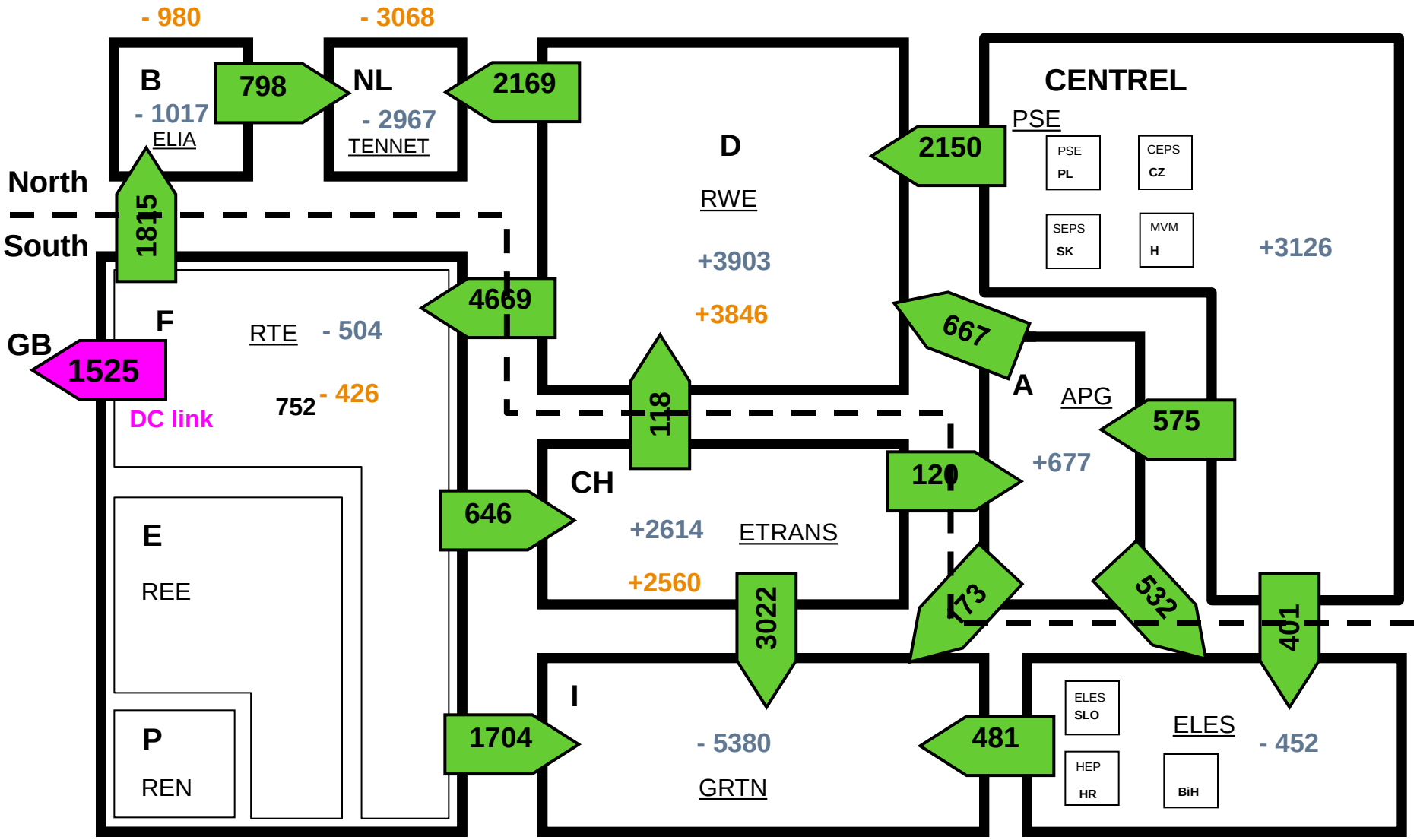
THEMA CONSULTING GROUP

Prepared for The European Commission
October 2013

THEMA Report 2013-36

Unannounced Wind Power in the Northern Germany

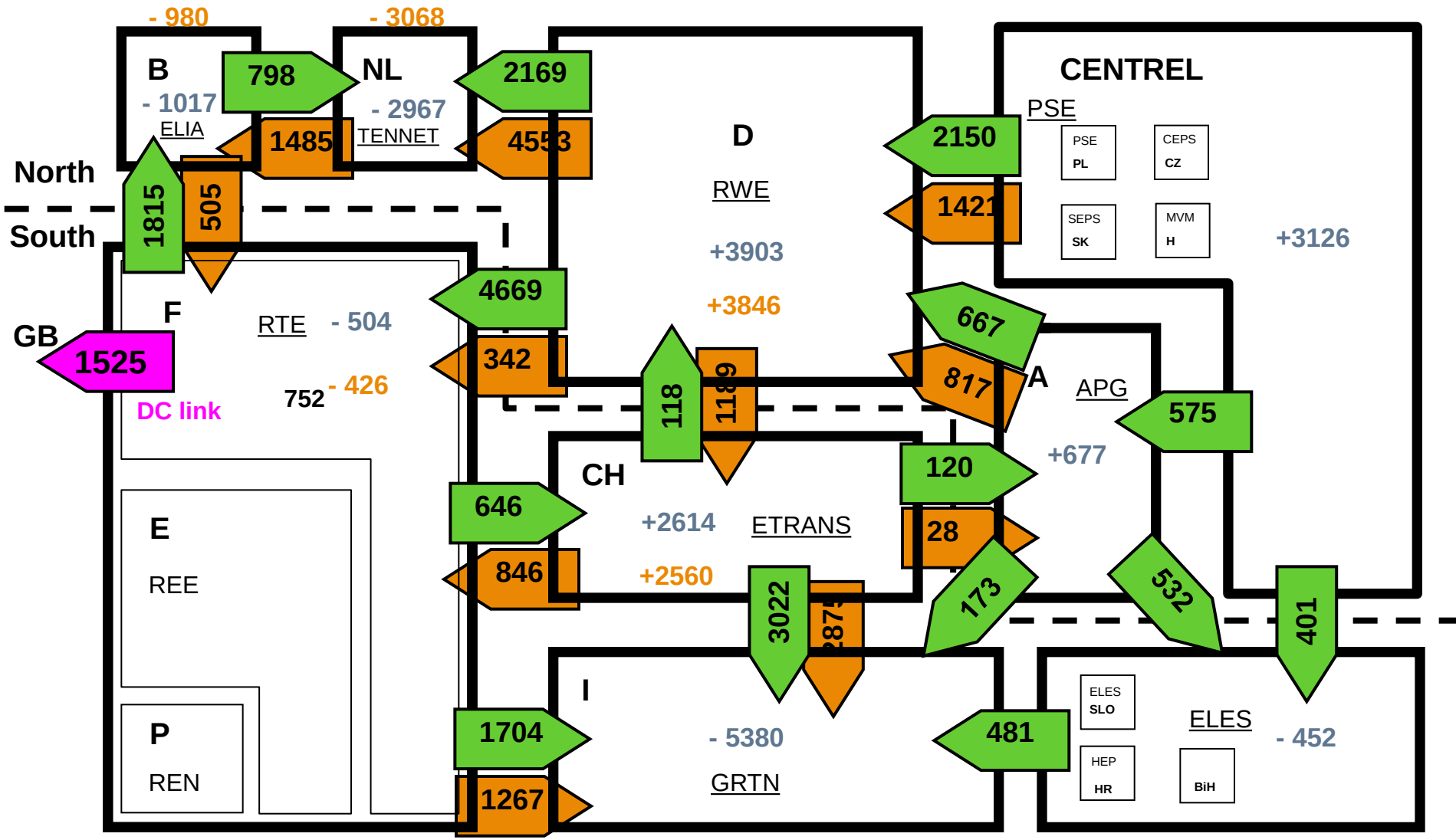
Scheduled Power Exchanges



Source: Ronnie Belmans, ELIA

Unannounced Wind Power in the Northern Germany

Scheduled Power Exchanges vs Physical Power Flows

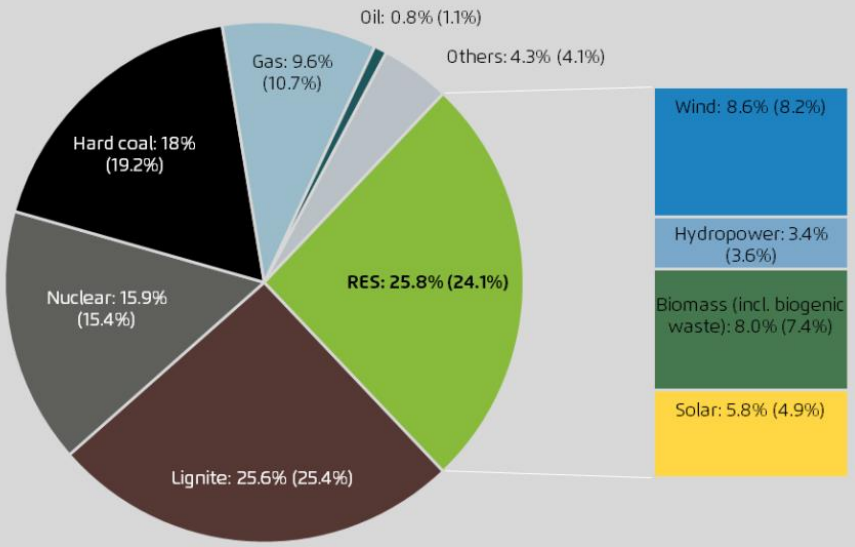


Source: Ronnie Belmans, ELIA

Emissions

Renewables 2014 win first place in German electricity generation – just bevor lignite. Hard coal and gas are losers in the electricity mix 2014.

Share of energy sources in gross power production in 2014 (2013 values in parentheses)



AG Energiebilanzen 2014

7

http://www.agora-energiewende.org/fileadmin/downloads/publikationen/Analysen/Jahresauswertung_2014/Agora_Energiewende_Review_2014_EN.pdf

ENVIRONMENT

German CO_2 emissions targets at risk

A new coal-fired power plant has opened in Germany a day after an expert commission told the energy minister the country must triple its annual rate of decarbonization to meet its ambitious 2020 climate policy goals.

On Thursday in the Hamburg suburb of Moorburg, Hamburg's mayor Olaf Scholz, a leading figure in Germany's Social Democratic Party (SPD), stood alongside Magnus Hall, president of Swedish energy utility Vattenfall, and pushed a big button.

Germany leads world in solar photovoltaic BUT

Germany now EU's worst polluter as CO2 emissions rise

May 07, 2014

Smoke rises from the chimney of a factory in Plattling, southern Germany, on October 9, 2012

The European Union's attempt to cap greenhouse-gas emissions over the next 16 years is threatened again as rising pollution from the bloc's biggest economies shows even developed nations want to burn cheap coal.

Photographer: Krisztian Bocsi/Bloomberg

Germany, Europe's largest economy, boosted consumption of coal by 13 percent in the past four years.

Germany, **Europe**'s largest economy, boosted **consumption of the fuel** by 13 percent in the past four years, while use in Britain, No. 3 in the region economically, rose **22 percent**, statistics from oil company BP Plc show. While Germany pledged to cut heat-trapping gases 55 percent by 2030 from 1990 levels, it's managed 25 percent so far and is moving in the wrong direction, according to the European Environment Agency.

The EU is seeking to craft a deal in October that would cut **greenhouse gases** 40 percent by 2030 in the world's biggest effort to combat global warming since the Kyoto climate treaty of 1997. Countries including **Poland**, which relies on coal to generate more than 80 percent of its power, want to guarantee their right to use the fuel before signing off on targets they say penalize lower-income nations.

http://phys.org/news/2014-05-germany-eu-worst-polluter-co2.html

http://www.bloomberg.com/news/2014-06-19/rising-german-coal-use-imperils-european-emissions-deal.html

The Global Crisis - various effects on the Power Sector

- Low interest rates - increased incentive for renewables investments
- Reduced power demand also in neighbouring countries
- Reduced CO_2 prices
- Reduced coal prices (also due to shale gas effect)
- Drastic effects on the Merit-Order curve

EU Emissions Trading Scheme (EU ETS)

- Goal: provide an incentive to reduce carbon emissions by creating a carbon market
- Cap and Trade scheme covering around 45% of the EU's greenhouse gas emissions since 2005
- Within the cap, companies receive or buy emission allowances which they can trade with one another as needed to cover their emissions, otherwise heavy fines are imposed
- Limits emissions from:
  - More than 11,000 heavy energy-using installations in power generation and manufacturing industry
  - Aircraft operators performing aviation activities in the EU and EFTA states
- Video on EU ETS: https://www.youtube.com/watch?feature=player_embedded&v=yfNgsKrPKsg

"***A sufficiently high carbon price also promotes investment in clean, low-carbon technologies***." European Commission. **Discuss!**

ETS Carbon price is too low

EU Market: Carbon dips to €5 to post another weekly loss

Published 18:49 on February 26, 2016 / Last updated at 18:56 on February 26, 2016 / EMEA, EU ETS / No Comments

EU carbon prices slipped to €5 on Friday to post their seventh weekly loss out of eight for the year, though traders grew more certain that a bottom has been reached.

The Dec-15 EUA contract settled down 8 cents at €5.00 on ICE, near the bottom of the day's €4.94-5.24 range on relatively thin volume of 13.6 million.

That put the benchmark carbon contract down 17 cents on the week, but well above its low point on Wednesday of €4.67, which was just five cents off the 22-month low hit earlier this month.

Traders said prices had climbed on Friday in anticipation that higher power prices would trigger an uptick in utility buying, but EUAs faded when that did not emerge.

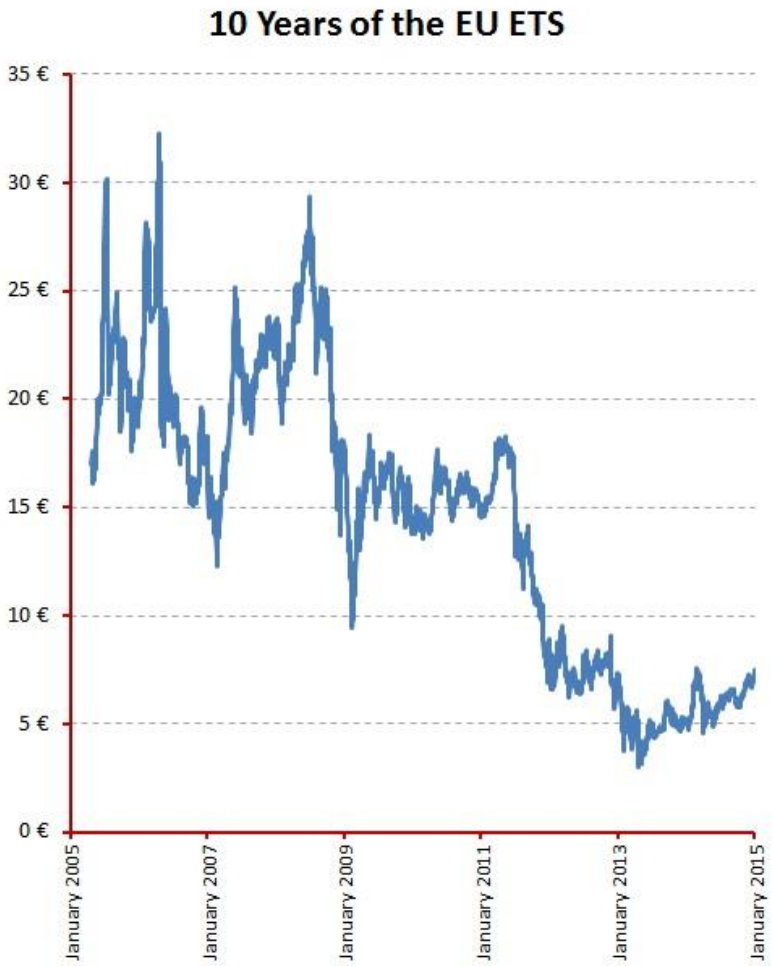
"We saw steady gains on the Cal-17 and I was expecting some utilities to step in, but there seems to be decent support to keep EUA prices near €5," one trader said.

Spurred by overnight gains in oil prices, Cal-17 baseload German power prices ended up 18 cents or 0.8% at €21.66/MWh on EEX, having hit as high as €21.75/MWh earlier.

This helped push clean dark spreads to their highest since Tuesday and up around 10% week-on-week, boosting the incentive for utilities to buy carbon.

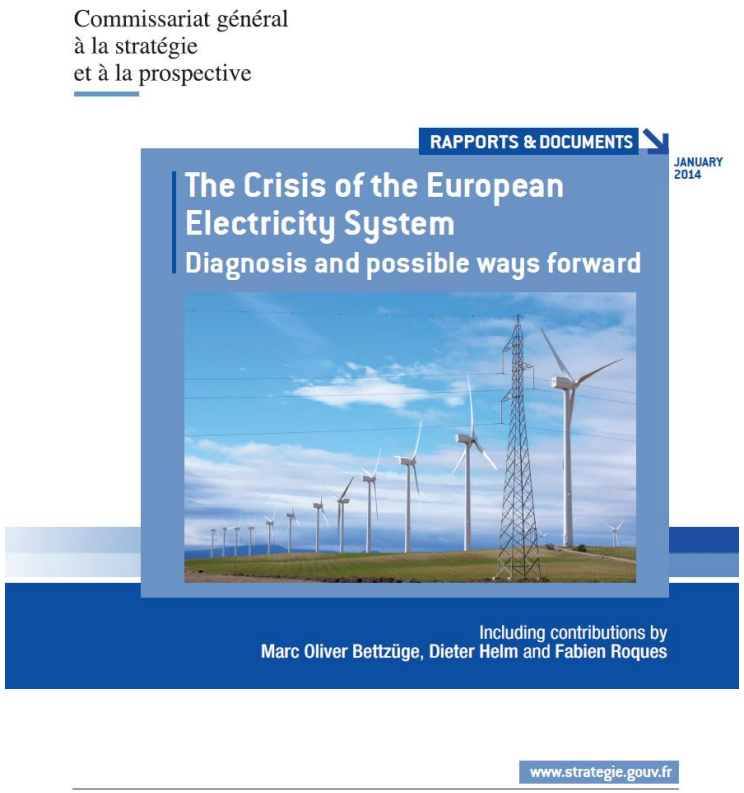
Carbon prices ticked up to the day's high after the Germany's auction, which cleared 3 cents below market at €5.08 with bid coverage of 1.76, well below the 2.37 average of other sales this week.

Next week's auction supply nudges slightly higher at 17.3 million, from 17.26 million this week, as Poland's sale replaces the fortnightly UK one on Wednesday.



How did they get it so wrong

- What are the drivers
- What went wrong
- What can be done about it



http://www.strategie.gouv.fr/sites/strategie.gouv.fr/files/archives/CGSP_Report_European_Electricity_System_030220141.pdf

Coordination is the key

RES-E-NEXT
Next Generation of RES-E Policy Instruments

RETD
IEA - RENEWABLE ENERGY TECHNOLOGY DEPLOYMENT

M. Miller, L. Bird, J. Cochran, M. Milligan, M. Bazilian
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Study commissioned by IEA-RETD
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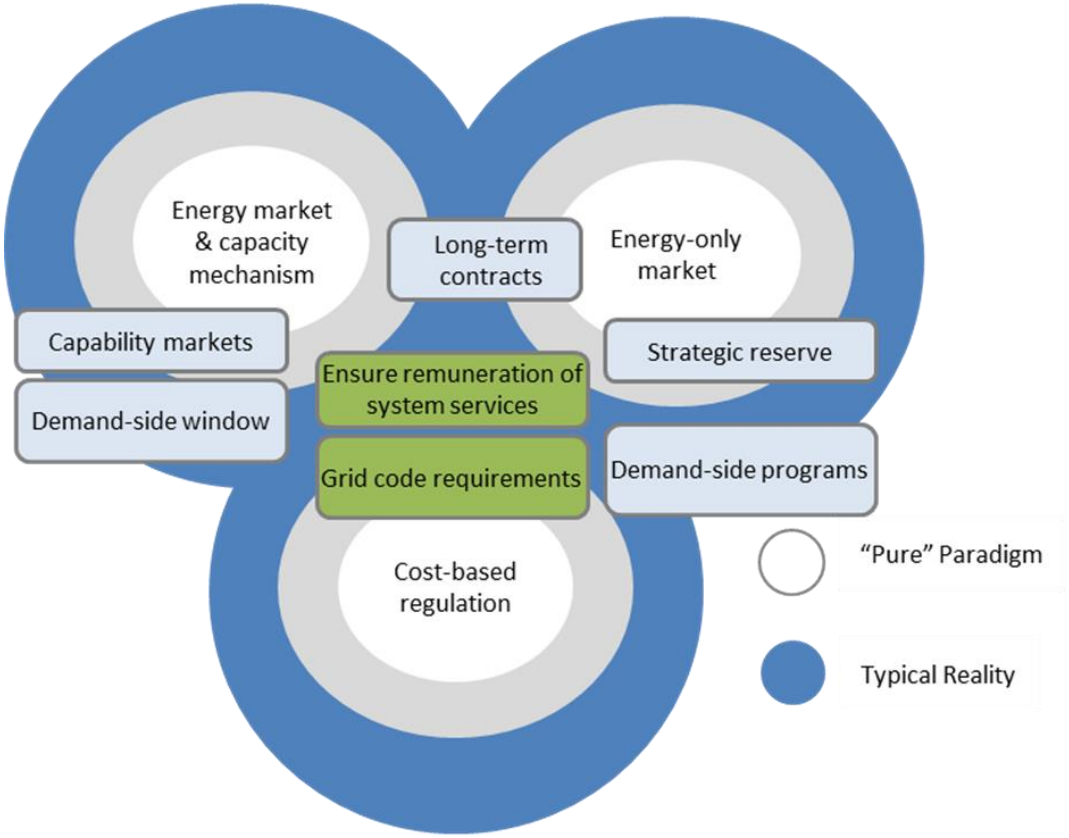
4 July 2013

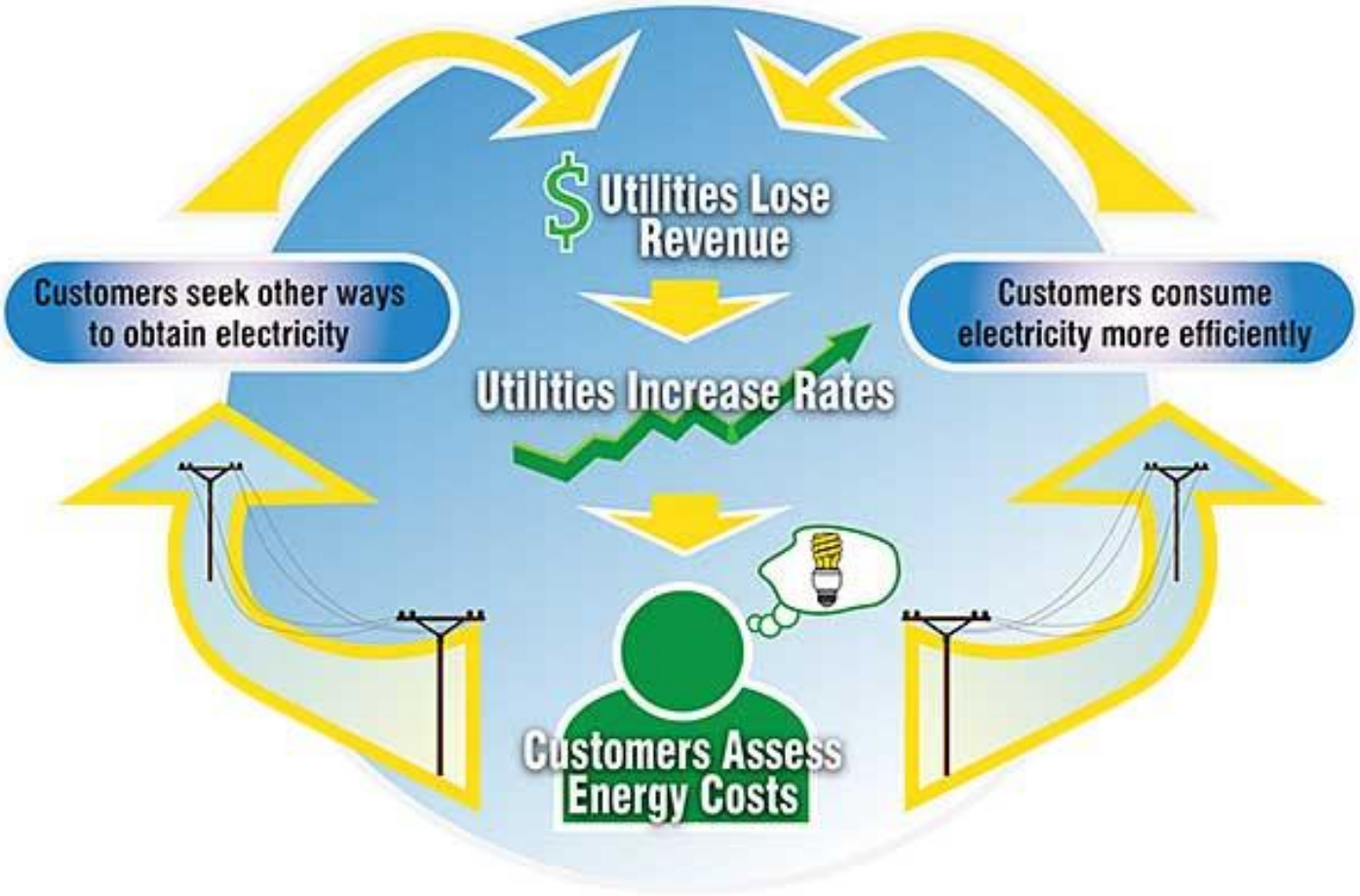
Mackay, M., Bird, L., Cochran, J., Milligan, M., Bazilian, M., Neuhoff, K., Denny, E., Dillon, J., Bialek, J. and O'Malley, M.J., "RES-E-NEXT, Next Generation of RES-E Policy Instruments", IEA RETD, July 2013.
http://iea-retd.org/wp-content/uploads/2013/07/RES-E-NEXT_IEA-RETD_2013.pdf

Different market designs should all work

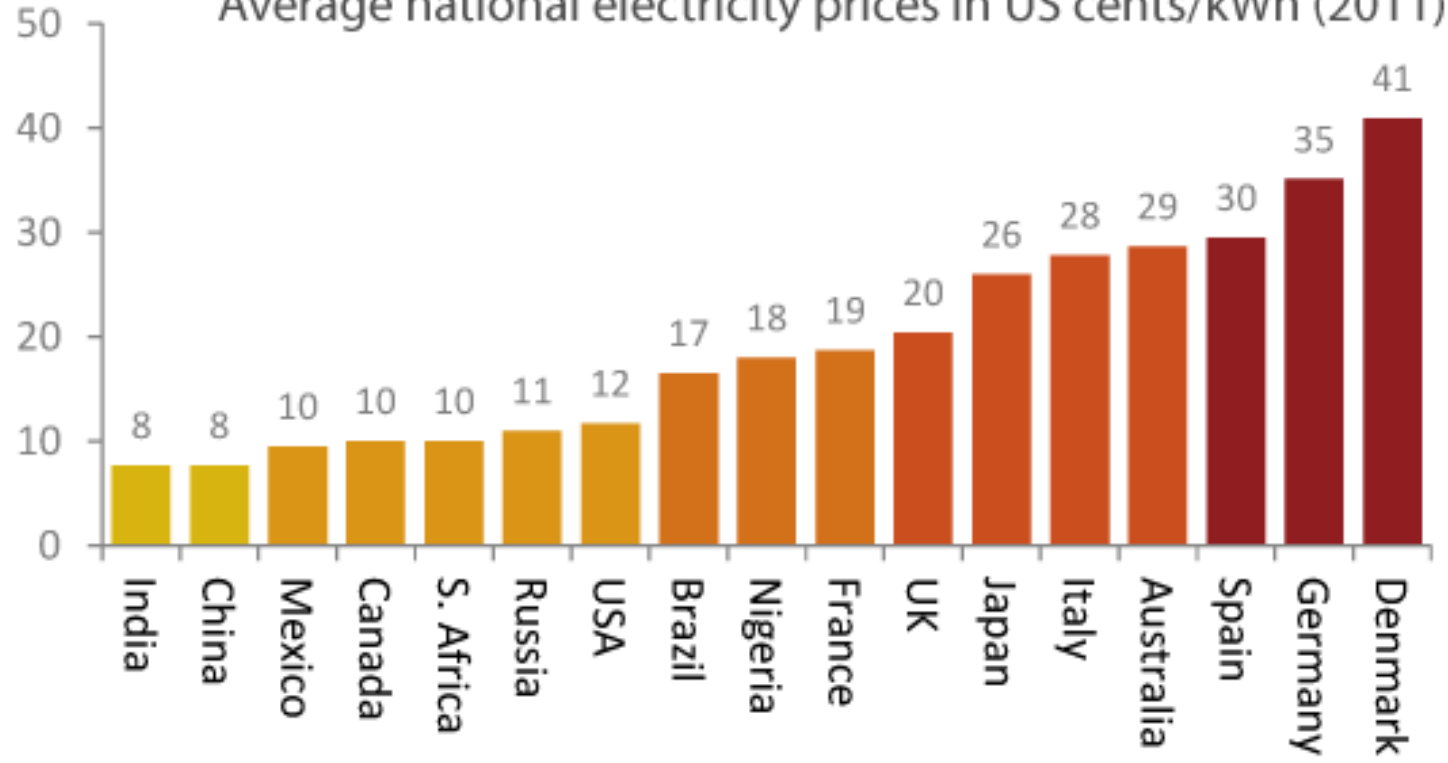


Mackay, M., Bird, L., Cochran, J., Milligan, M., Bazilian, M., Neuhoff, K., Denny, E., Dillon, J., Bialek, J. and O'Malley, M.J., "RES-E-NEXT, Next Generation of RES-E Policy Instruments", IEA RETD, July 2013. http://iea-retd.org/wp-content/uploads/2013/07/RES-E-NEXT_IEA-RETD_2013.pdf

Spiral of death



How much does electricity cost?



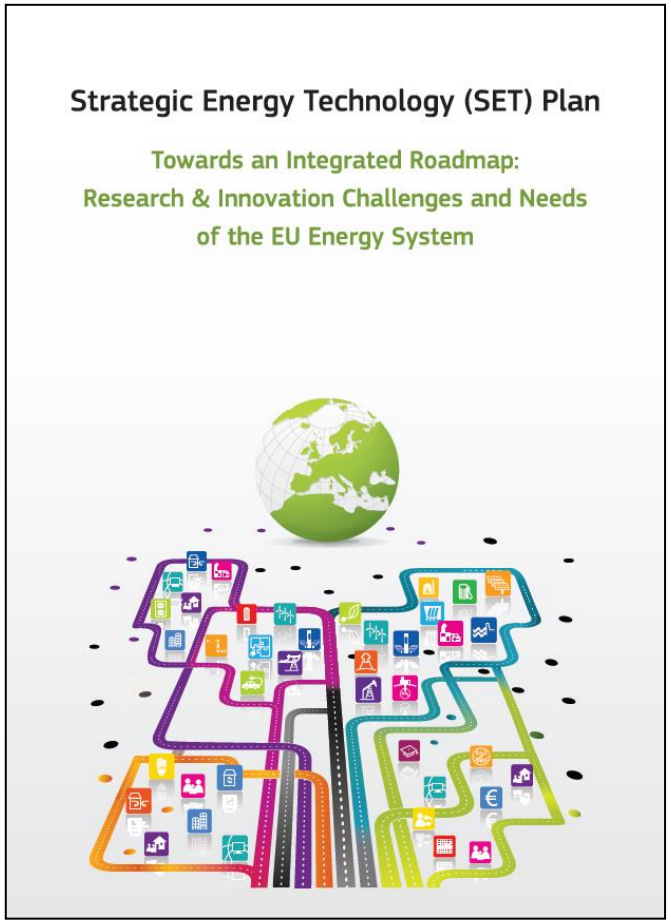
Data: average prices from 2011 converted at mean exchange rate for that year

Sources: IEA, EIA, national electricity boards, OANDA shrinkthatfootprint.com

Key Take Aways

- Falling marginal energy price is undermining long term investments
  - Capacity from thermal generation may need to be incentivised
- Whole system thinking and proper market signals required
- Coordination in policies and market design is necessary
- Remember it is an “integrated” energy system so everything impact son everything else !
- But do the policy makers understand ?

International Context



https://setis.ec.europa.eu/system/files/Towards%20an%20Integrated%20Roadmap_0.pdf

http://www.nrel.gov/esi/esif.html

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Energy Systems

https://es.catapult.org.uk/

iiESI.org

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DTU

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Solving complex global energy challenges requires changing the way we THINK about energy systems, providing opportunities to SHARE knowledge, and helping nations EVOLVE by informing the discussions that are guiding energy investments and policy decisions.

EERA
European Energy Research Alliance

Joint Programme on Energy System Integration (**ESI**)

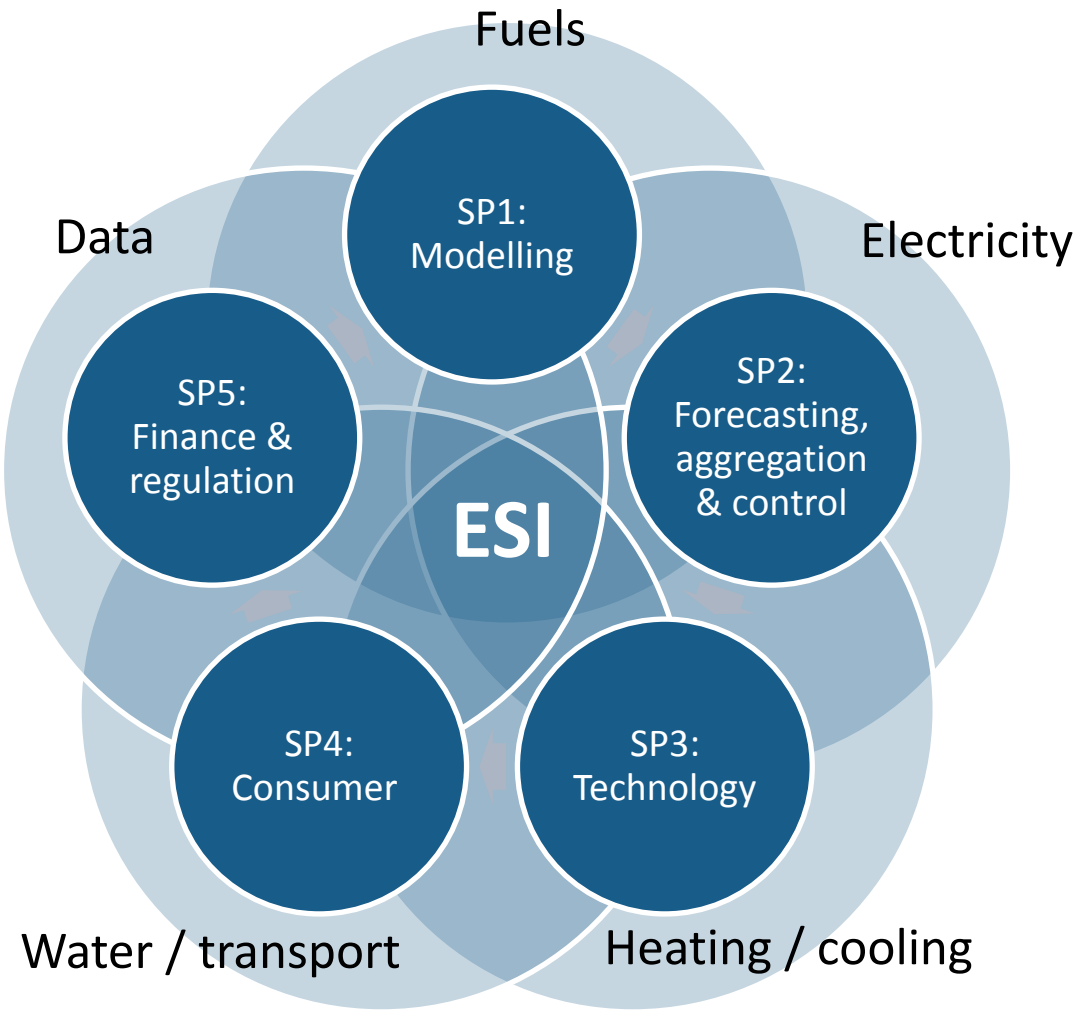
EERA Summer Strategy Meeting
Amsterdam
24th & 25th June, 2015

www.eera-set.eu

EERA is an official part of the EU SET-Plan.

http://setis.ec.europa.eu/

DESCRIPTION OF WORK



Conclusions

- Energy Systems Integration (ESI) is an increasingly important research area
- It is fundamental to successful integration of large volumes of variable renewable energy
- It has technological, societal, policy and market aspects that are all important
- ESI is well suited to international collaboration