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Energy Systems Integration

and its role in integrating variable renewable energy

Mark O'Malley

Wellington, New Zealand, March 15th 2017

iiESI International Institute™ for Energy Systems Integration

EERA
European Energy Research Alliance

Outline

- What is Energy System Integration (ESI) ?
- ESI and the low carbon agenda, including renewable integration
- Ireland, China, Denmark – similarities & differences
- International activities
- Conclusion

Men Dressed As Leprechauns Attempt To Rob All Blacks

Posted on November 18, 2016 by thaicastle1 in Sports // 0 Comments

Startling news out of Dublin this evening as four men dressed as leprechauns attempted a robbery on the All Blacks team bus.

Ireland 9 New Zealand 21: All Blacks exact immediate revenge in Dublin thriller

share

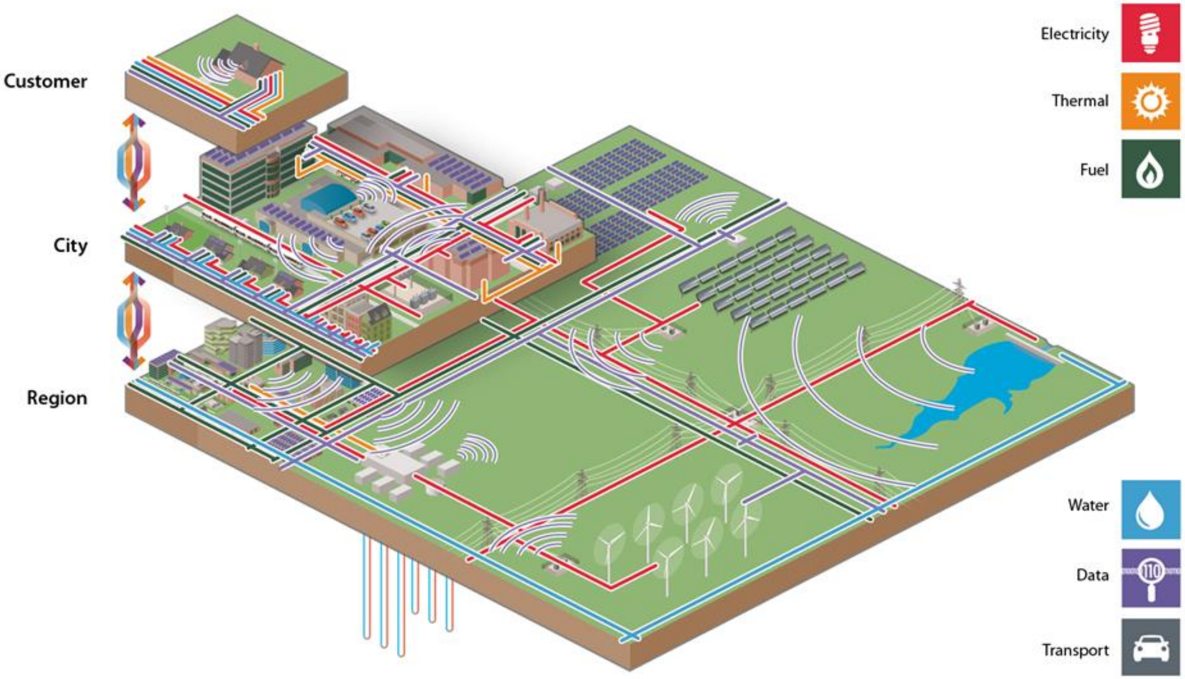
3 Comments

Ireland 40-29 New Zealand – as it happened

Ireland scored five tries to stun New Zealand, claim a first win against the All Blacks in 111 years of trying and end the world champions' record run of 18 straight victories

Ireland full of respect for the All Blacks after historic win, says Rory Best

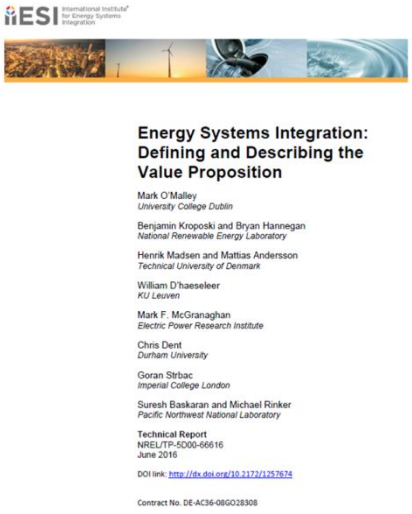
Energy Systems Integration



- **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**

What is Energy System 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.



iiESI International Institute for Energy Systems Integration

Energy Systems Integration: Defining and Describing the Value Proposition

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Technical Report
NREL/TP-5D00-66616
June 2016

DOI link: http://dx.doi.org/10.2172/1257674

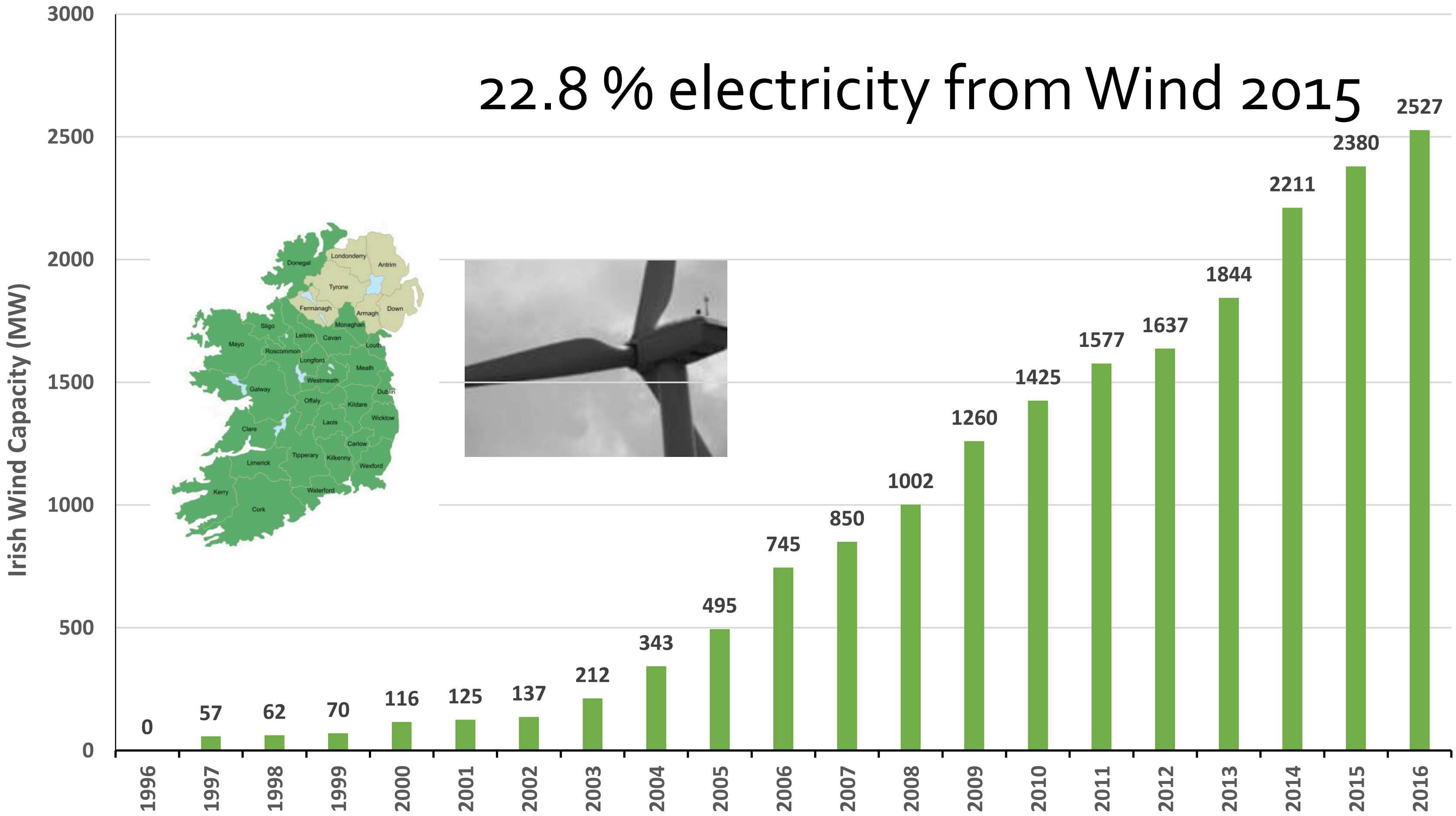
Contract No. DE-AC36-08GO28308

O'Malley, M.J., Kroposki, B., Hannegan, B., Madsen, H., Andersson, M., D'haeseleer, W., McGranaghan, M., Dent, C., Strbac, G., Baskaran, S. and Rinker, M., "Energy System Integration Defining and Describing the Value Proposition", NREL Technical Report NREL/TP-5D00-66616, June 2016. [10.2172/1257674]

“Whenever I run into a problem I can’t solve, I always make it bigger. I can never solve it by trying to make it smaller, but if I make it big enough I can begin to see the outline of a solution.” 34th President of US

Ireland

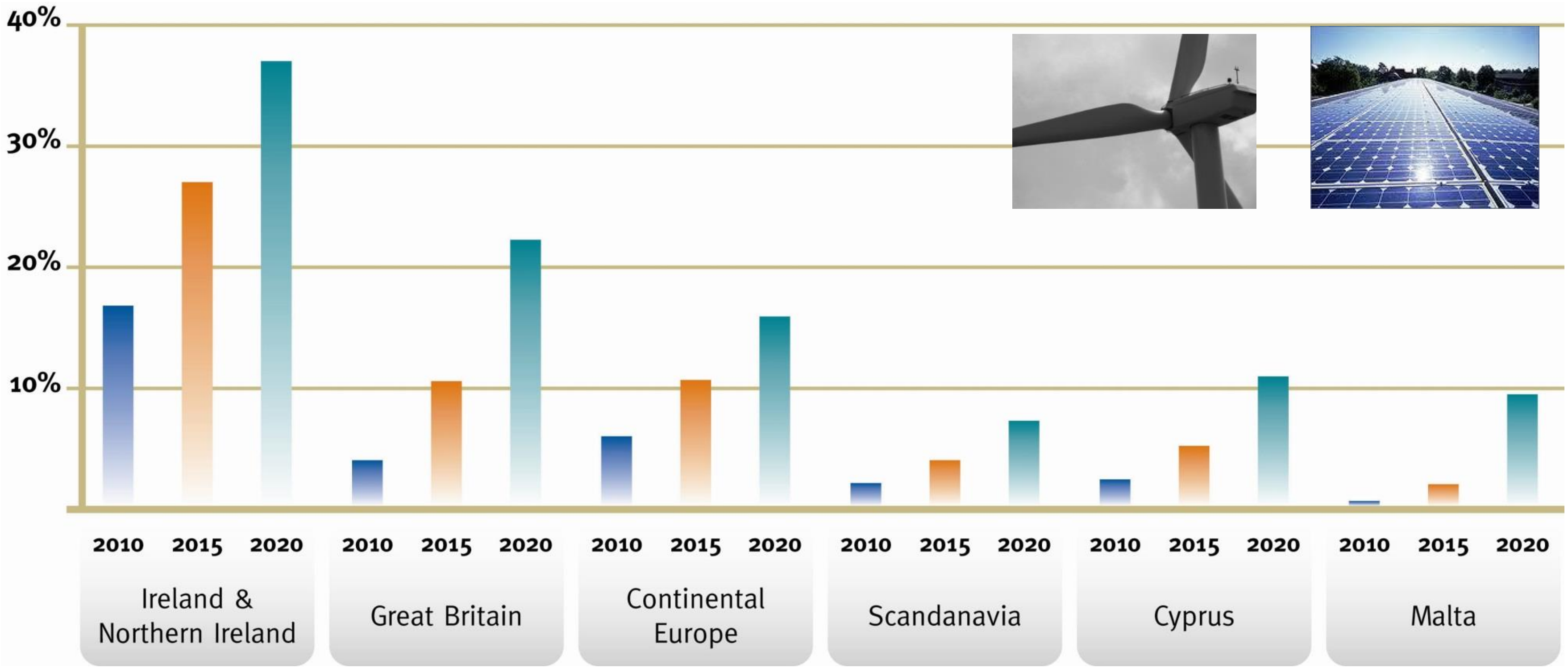
Wind Installed in Ireland



22.8 % electricity from Wind 2015

Sources: EirGrid http://www.eirgrid.com/operations/systemperformancedata/all-islandwindandfuelmixreport/ ,IWEA and Eirgrid Generation Capacity Statement 2016-2025 and Irish Wind Energy Association

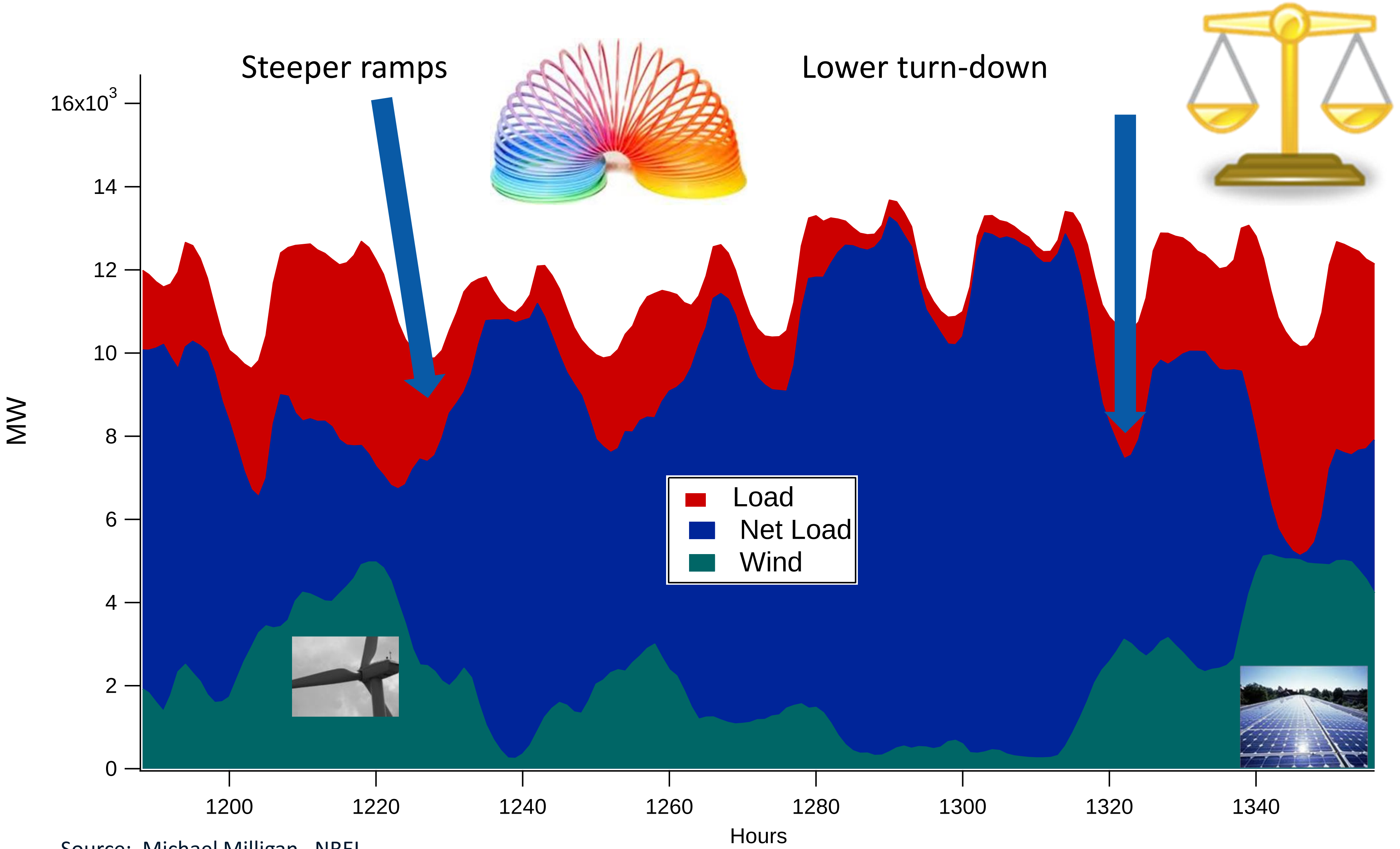
Targets for non-synchronous sources in European Systems



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

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

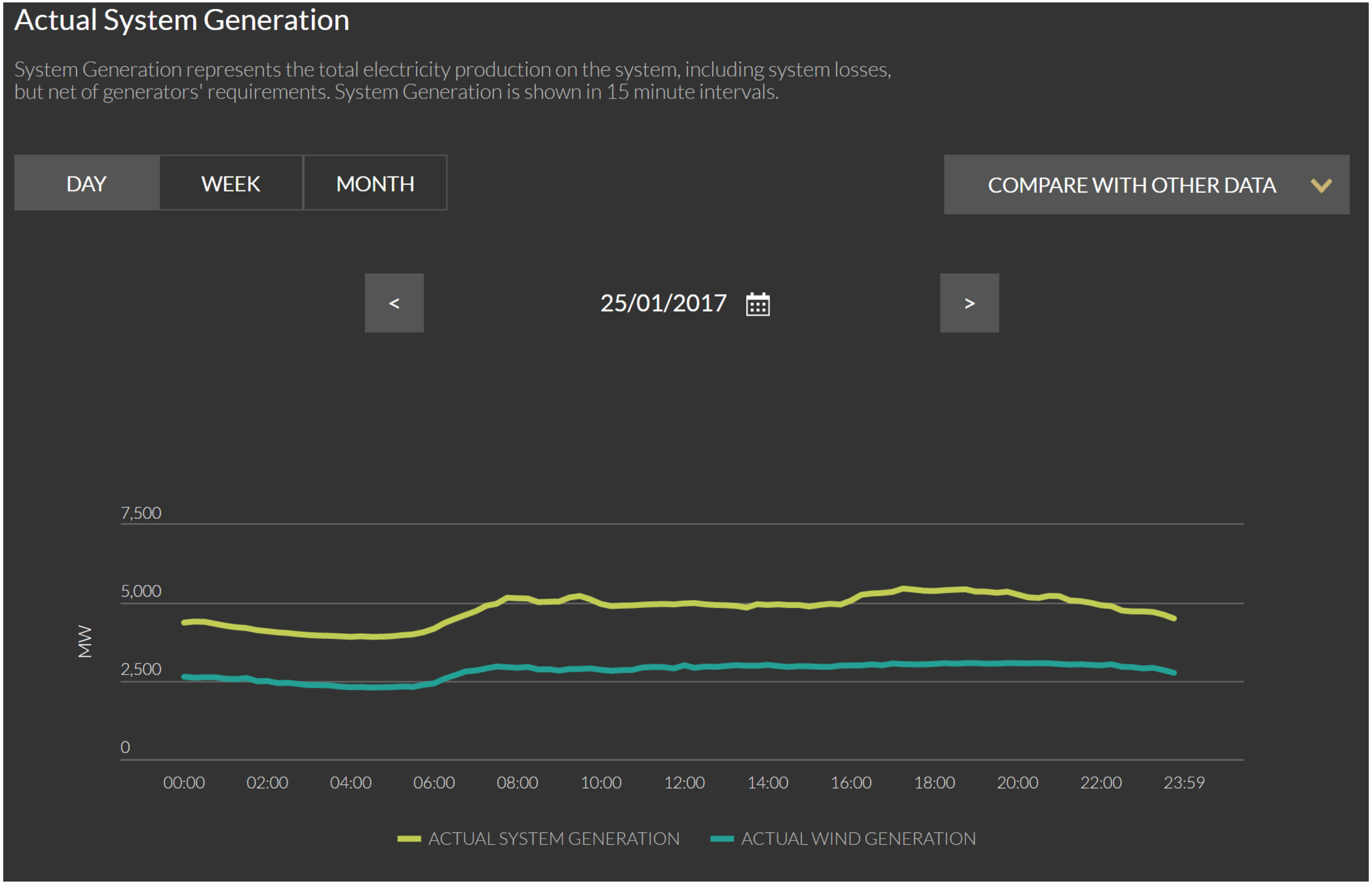
With Variable Renewables More Flexibility is Needed


Steeper ramps

Lower turn-down

Source: Michael Milligan , NREL

Variable renewable energy penetration increasing

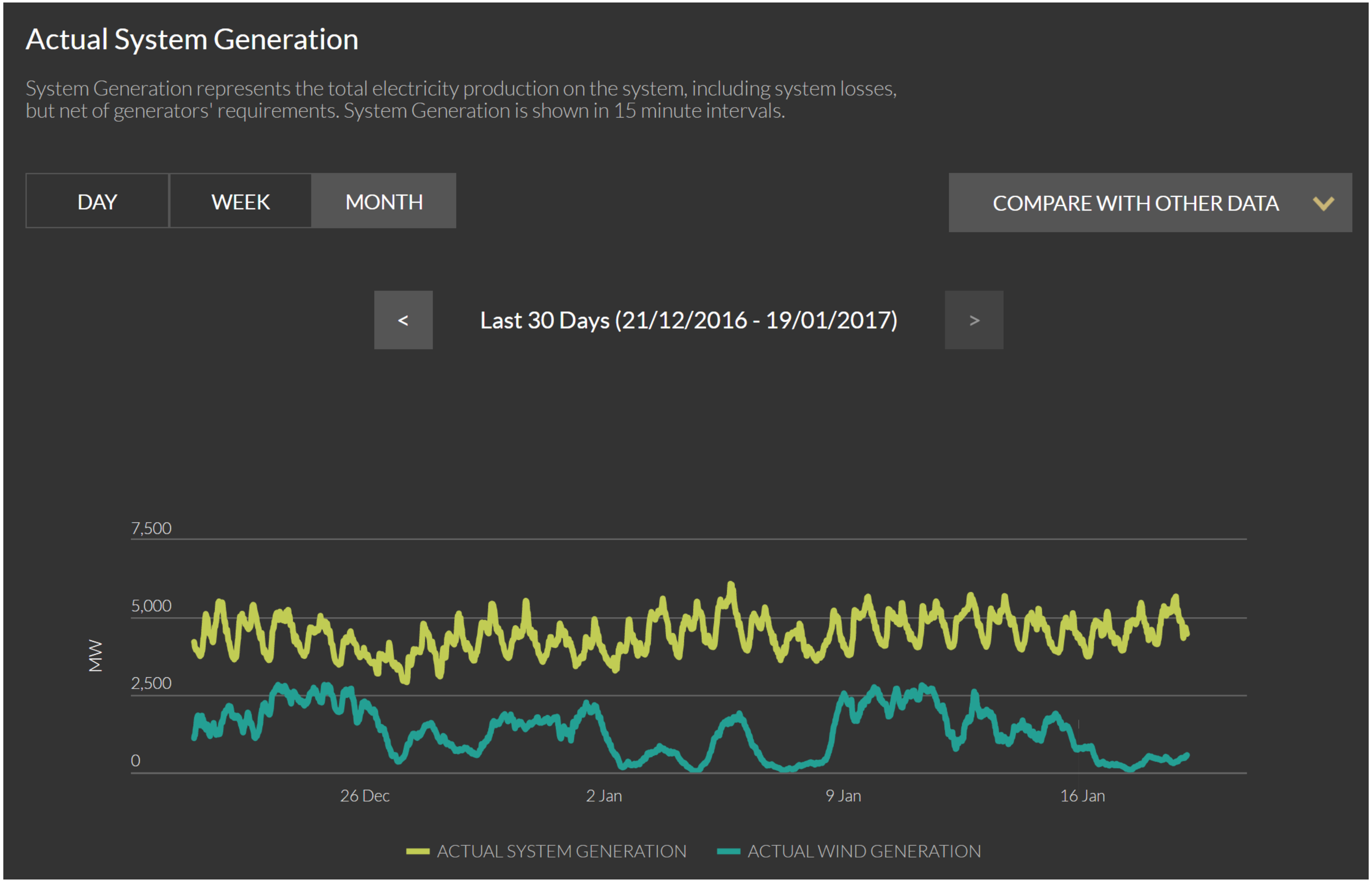


Actual System Generation

System Generation represents the total electricity production on the system, including system losses, but net of generators' requirements. System Generation is shown in 15 minute intervals.

http://smartgriddashboard.eirgrid.com

Monthly Wind and Generation Ireland Jan 18th 2017

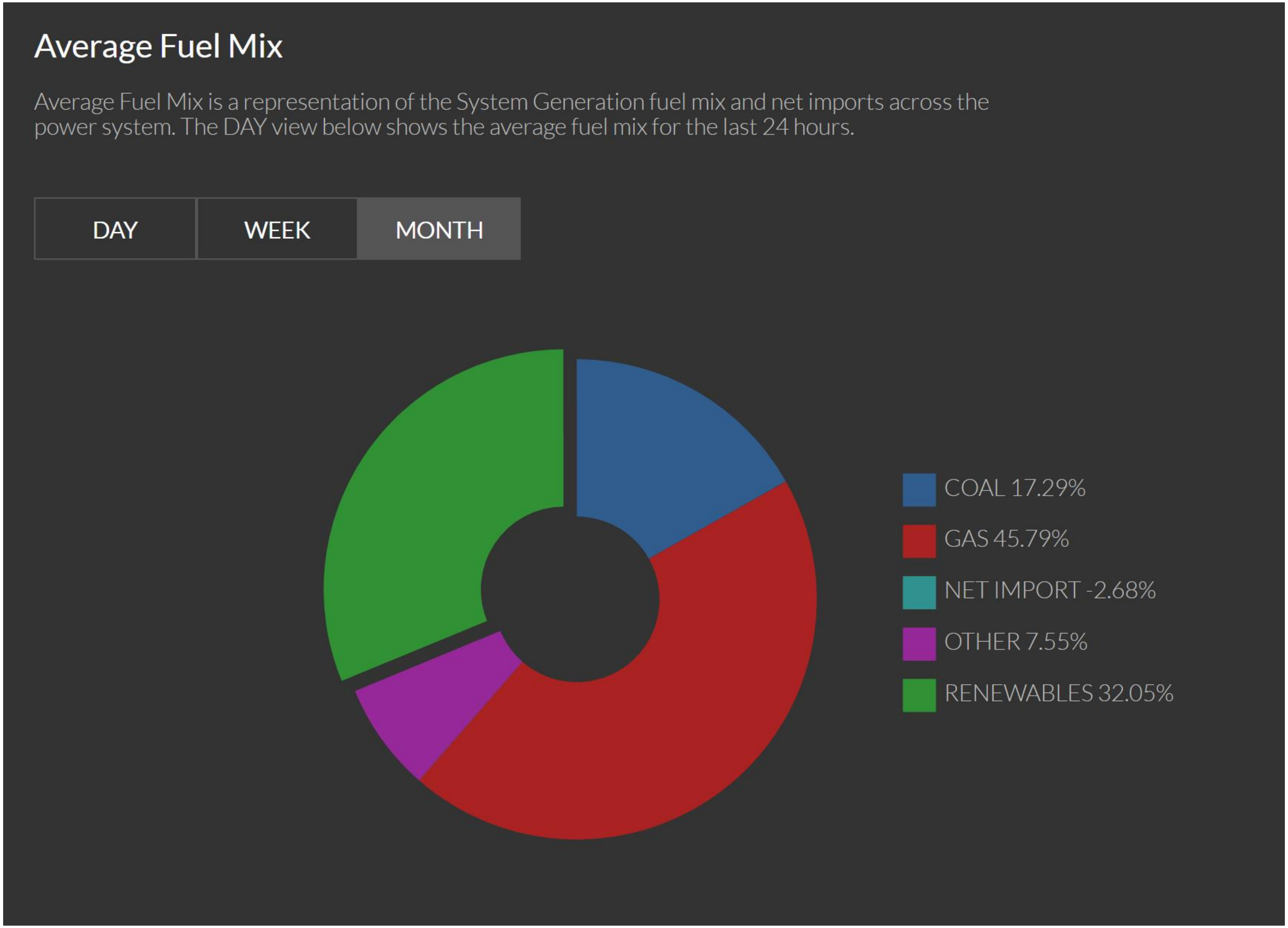


Actual System Generation

System Generation represents the total electricity production on the system, including system losses, but net of generators' requirements. System Generation is shown in 15 minute intervals.

http://smartgriddashboard.eirgrid.com

Monthly Fuel Mix Ireland Jan 18th 2017



Average Fuel Mix

Average Fuel Mix is a representation of the System Generation fuel mix and net imports across the power system. The DAY view below shows the average fuel mix for the last 24 hours.

http://smartgriddashboard.eirgrid.com

Gas grids have storage and gas generators are flexible

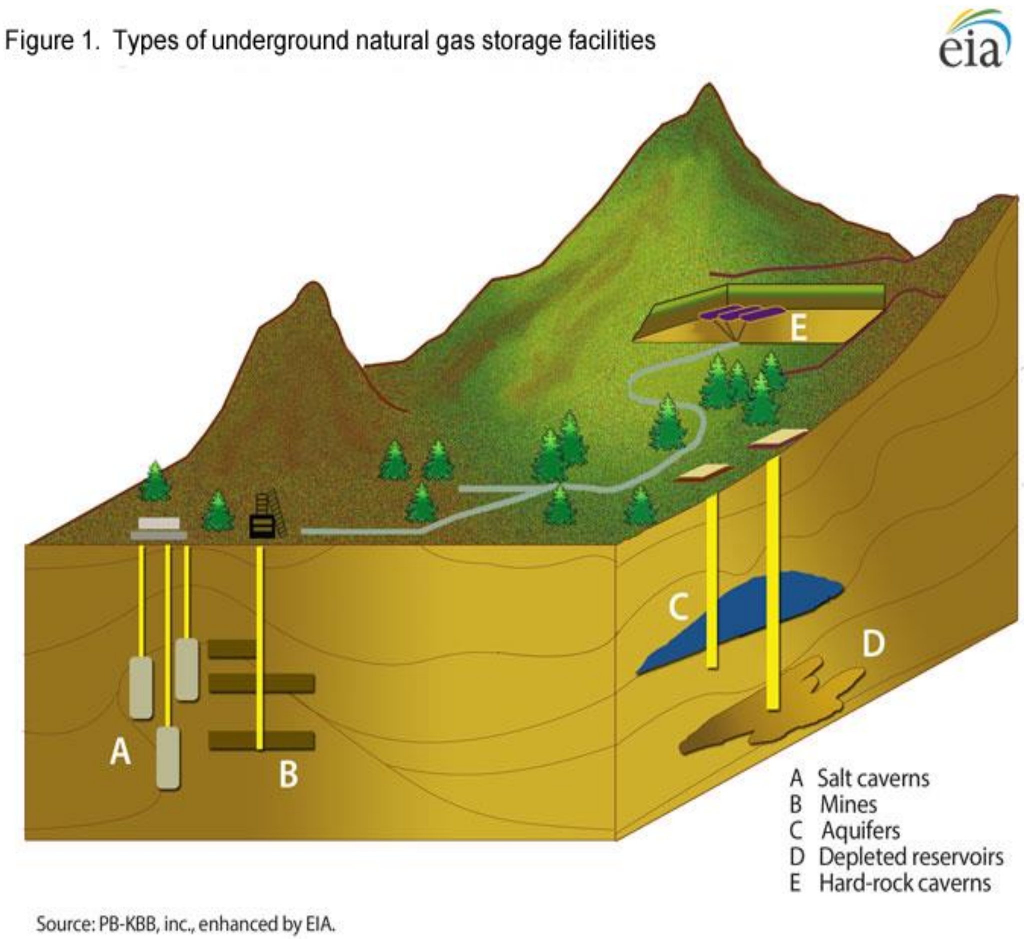


Figure 1. Types of underground natural gas storage facilities

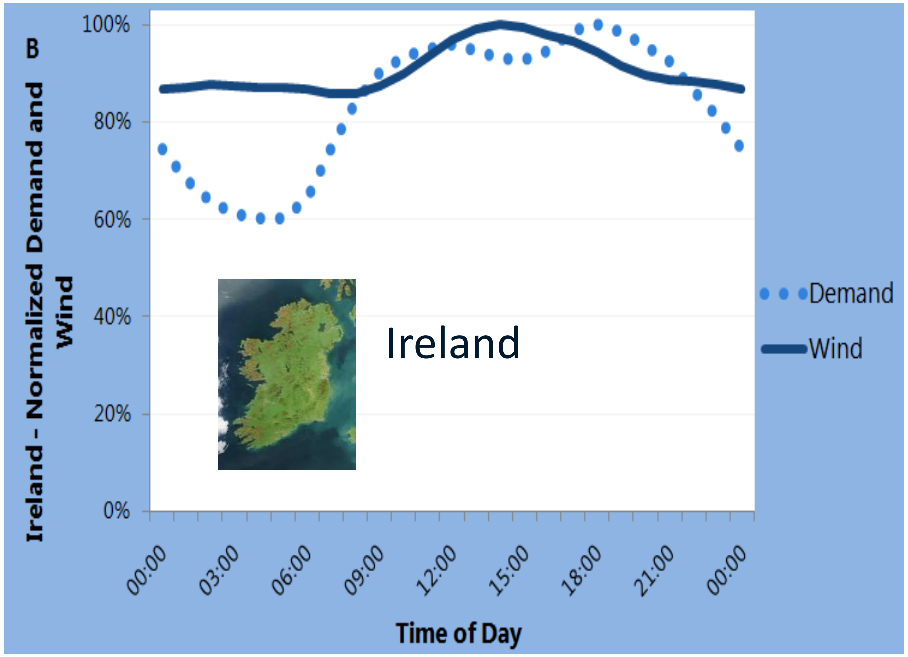
Source: PB-KBB, inc., enhanced by EIA.

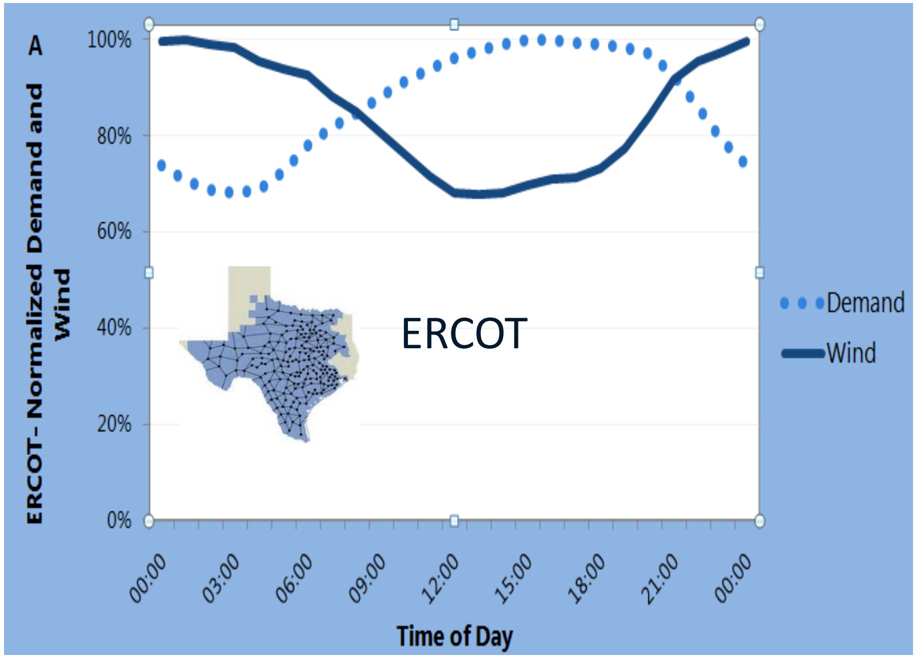
Importance of dynamic modeling of gas networks for energy system reliability

http://www.solarstorms.org/Pictures/AlaskanPipeline.jpg

Renewable energy and load characteristics

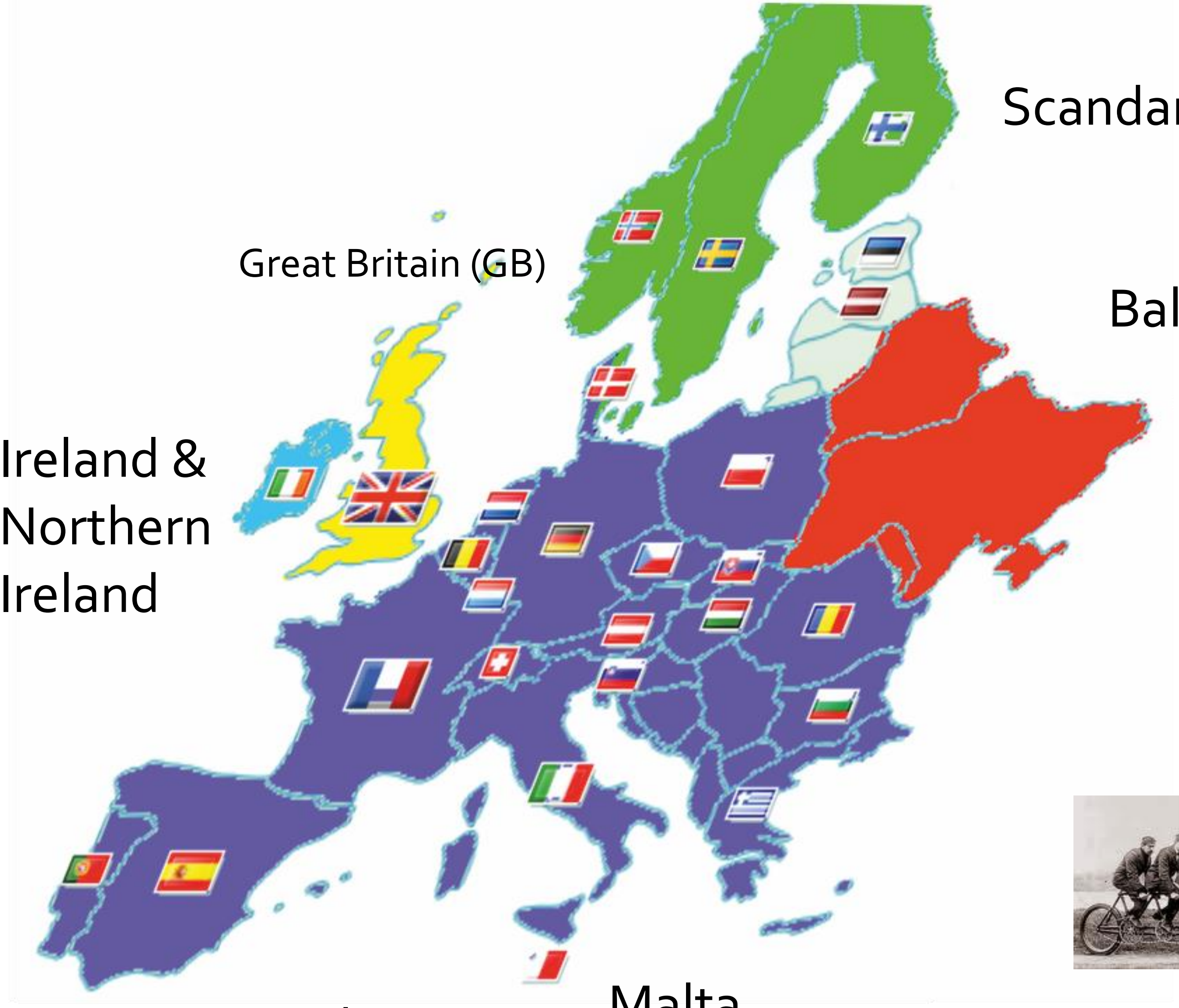
Dance partners



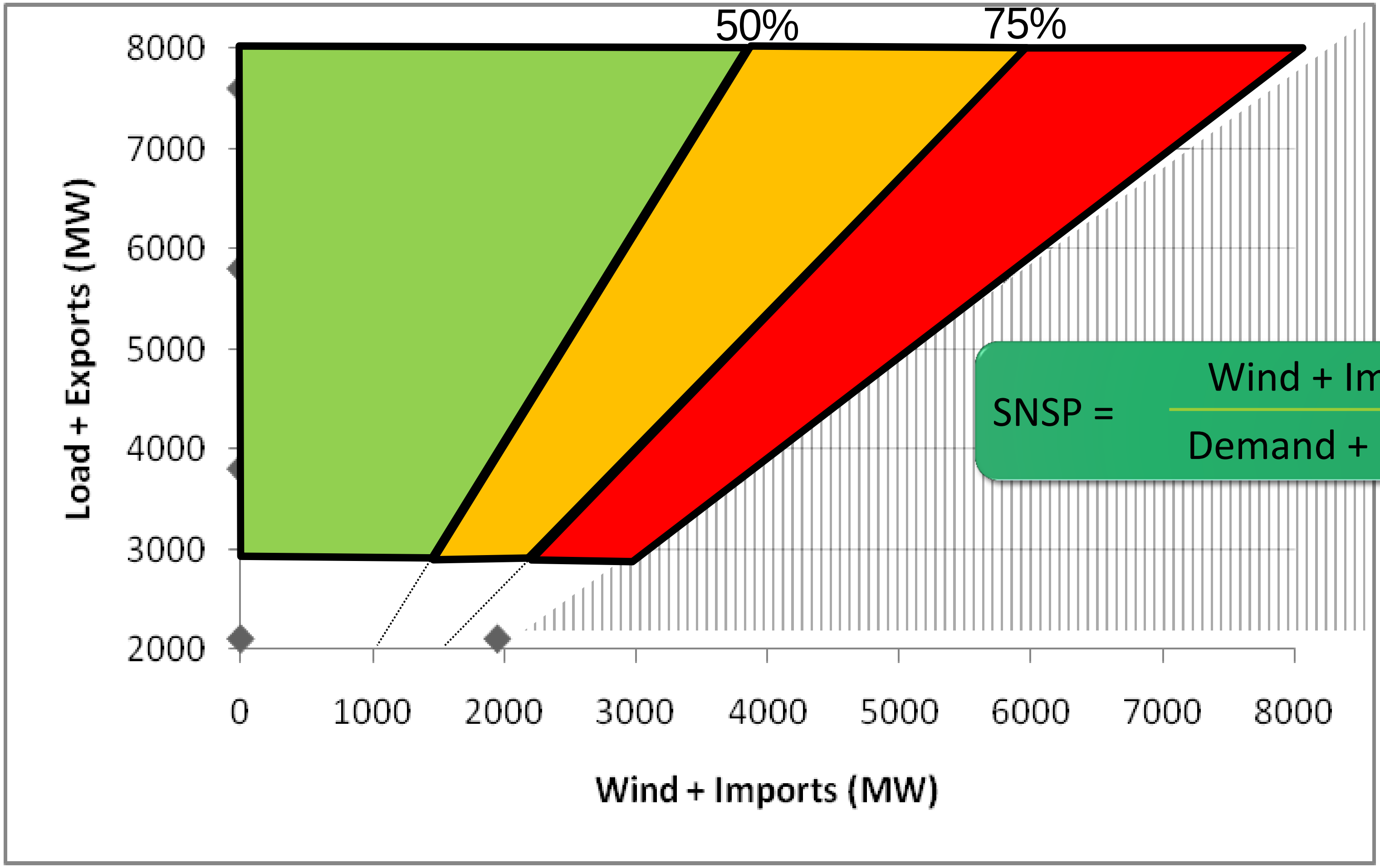


AEMO, Australian Energy Market Operator, "Wind Integration In Electricity Grids: International Practice And Experience" Work Package 1, 2011.
http://www.aemo.com.au/~/media/Files/Other/planning/0400-0049%20pdf.pdf

Synchronous systems in Europe



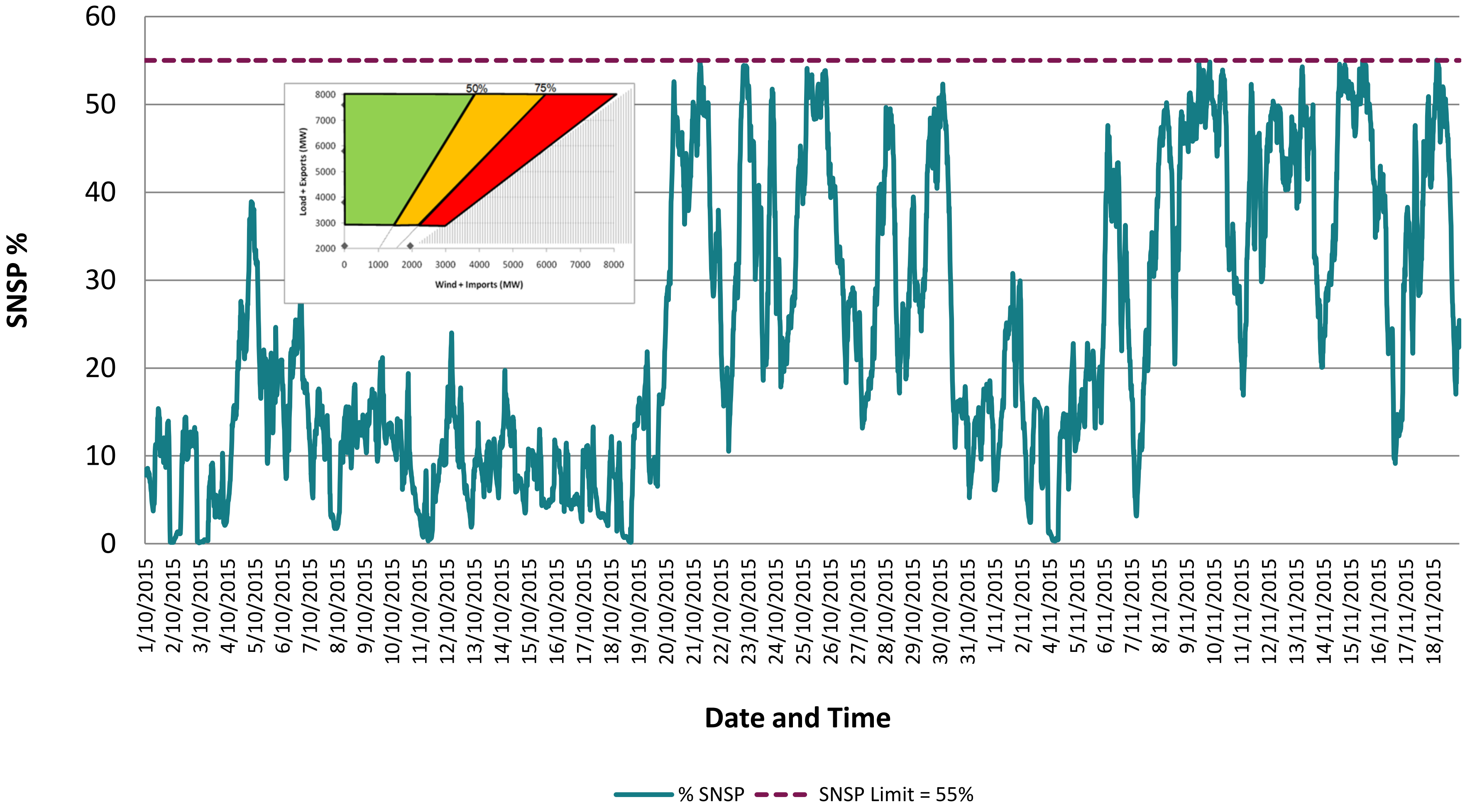
System Non-Synchronous Penetration (SNSP)



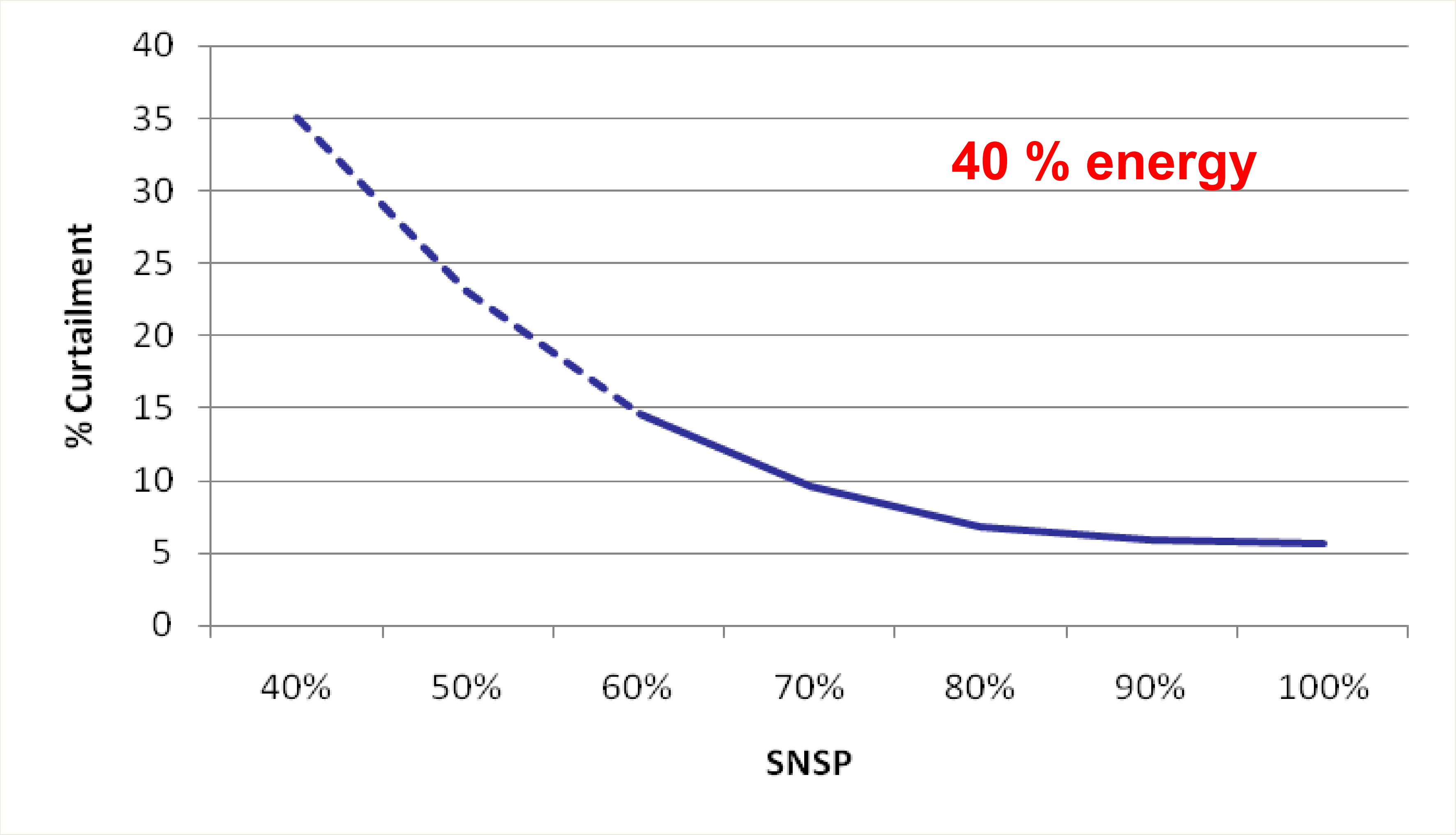
$$\text{SNSP} = \frac{\text{Wind + Imports}}{\text{Demand + Exports}}$$

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 – Ireland – October 2015

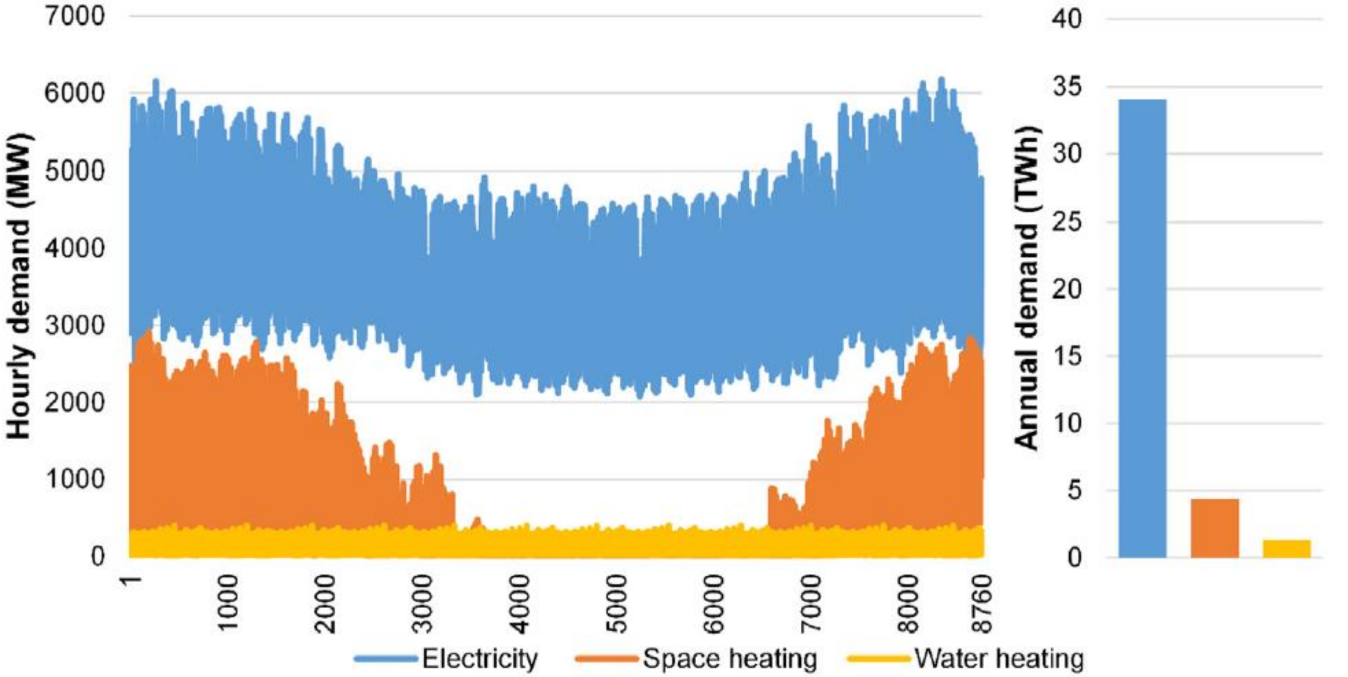


Impact of SNSP on Wind Curtailment



Look at heat and electricity

S. Heinen et al. / Energy 109 (2016) 906–919



Note: The space heating demand shown is for well-insulated buildings (<75 kWh/m^2/year)

Fig. 3. 2030 hourly demand profile and annual demand for electricity in Ireland and residential heat for 400 000 well-insulated Irish households [35,46].

Heinen, S., Burke, D. and O'Malley M.J. "Electricity, gas, heat integration via residential hybrid heating technologies - An investment model assessment", Energy, Vol 109, pp. 906-919, 2016.

RealValue Consortium


RealValue

Environmental *Change* Institute
eci
UNIVERSITY OF OXFORD

sse Airtricity

ESB NETWORKS

DIW BERLIN

Glen Dimplex

Glen Dimplex DEUTSCHLAND

VTT

RIGA TECHNICAL UNIVERSITY

EIRGRID

MVV Energie

BEEGY Better Energy.

intel

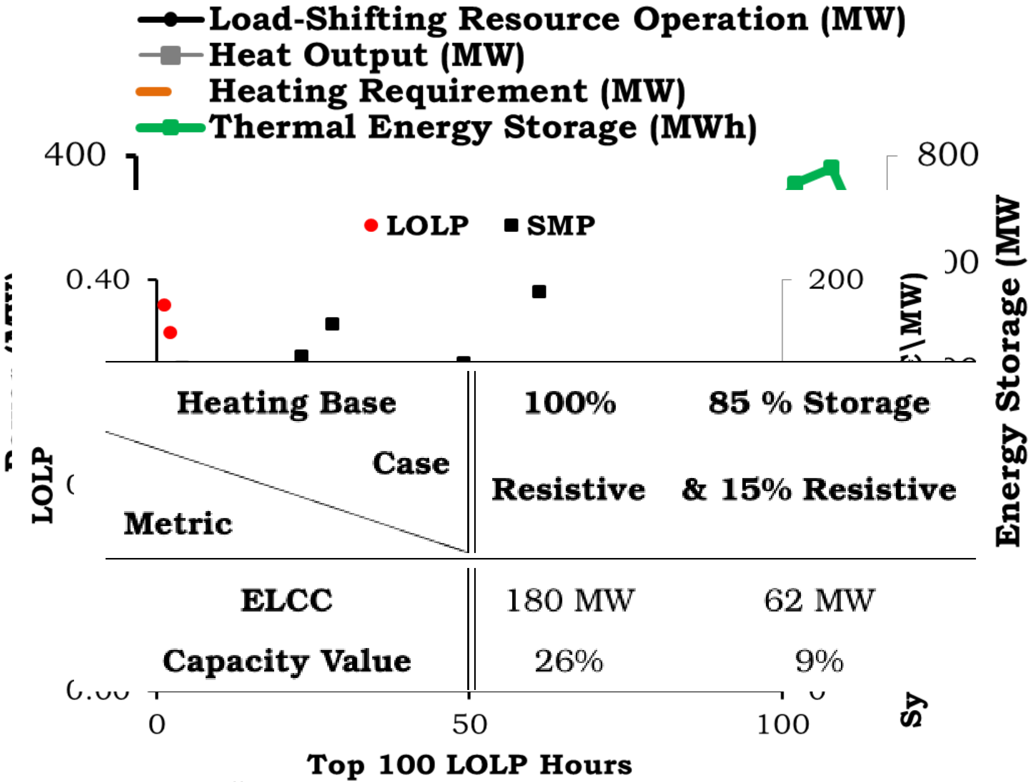
erc electricity research centre

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646116

Load shifting (thermal electric storage) in Ireland

- Capacity value of resource is limited because:

- Consumer requirements

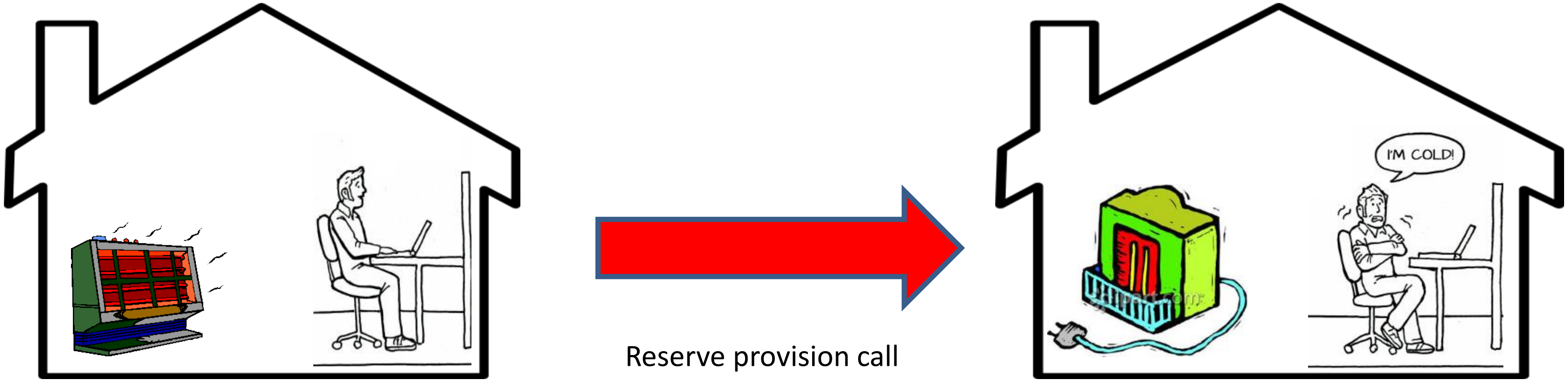


Heating Base Case / Metric	100% Resistive	85 % Storage & 15% Resistive
ELCC	180 MW	62 MW
Capacity Value	26%	9%

S Nolan, O Neu, M O'Malley. ``Capacity Value Estimation of a Load-Shifting Resource using a Coupled Building and Power System Model", Applied Energy, Vol. 192, pp. 71 – 82, 2017.

Consumer satisfaction at the heart of unlocking demand side flexibility

- Implementation of DR should not cause discomfort to end users
- Energy/**Reserve** scheduling models would overestimate DR potential if consumer comfort is not considered
- Need integration of building dynamics and consumer preferences in power systems models



Reserve provision call

Heater ON – thermal comfort

Heater OFF to provide reserve – might cause thermal discomfort

Trilemma plus the “consumer” a Quadrilemma


Russia
Kazakhstan
Mongolia
Kyr.
Taj.
China
Beijing
N. Korea
Pakistan
Shanghai
Nepal
Bhutan
Chongqing
Taiwan
India
Guangzhou
Myan.
Viet.
Laos
Hong Kong
Macau

China

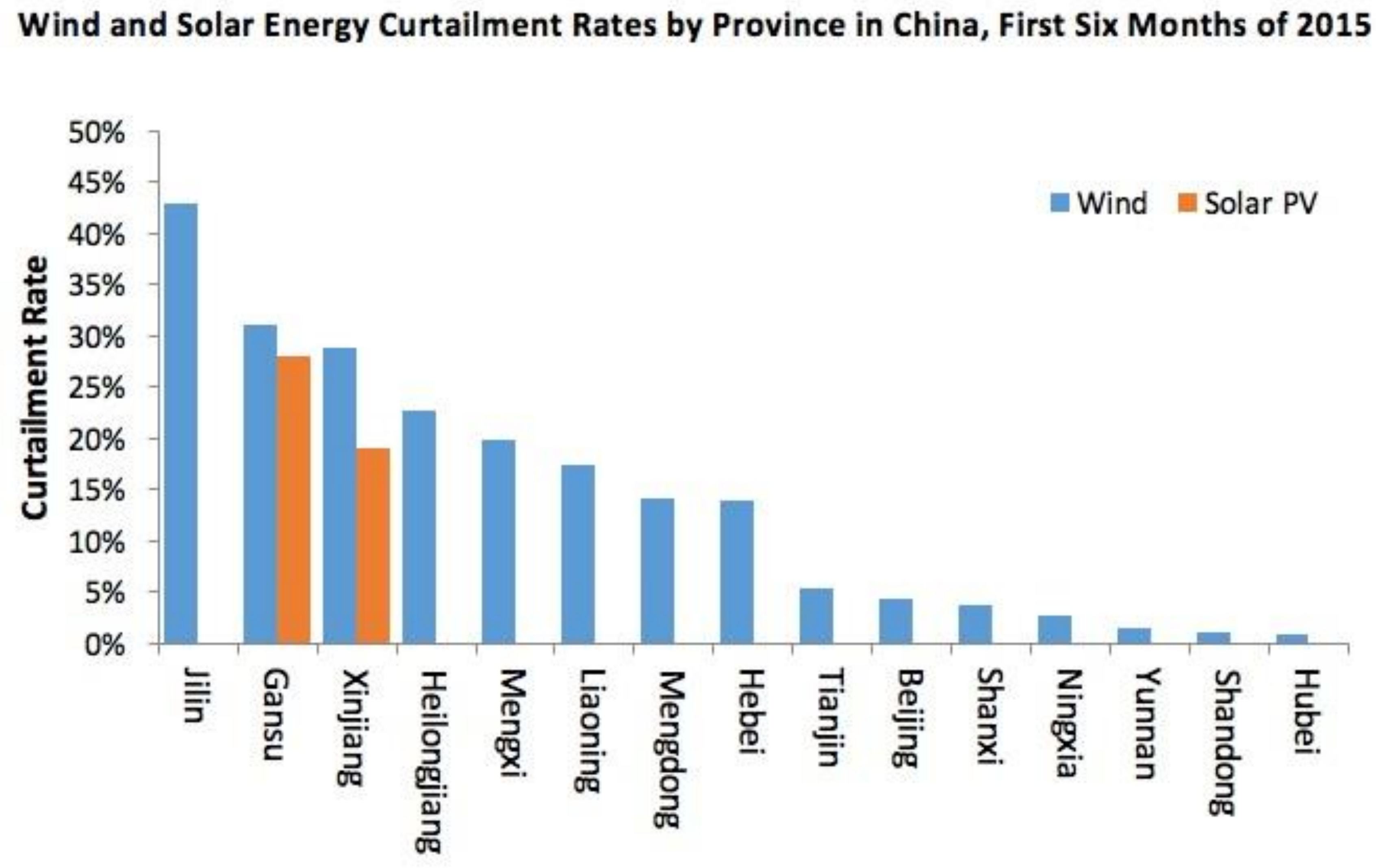
How they do it in China

- Established in Inner Mongolia, 2014, with 20 electric boilers
- 500,000 m^3 heat supply
- 75 GWh wind power annually, equivalent to 19,000t coal
- Decrease CO_2 emission by 68,000t

Source: Chongqing Kang, Tsinghua University

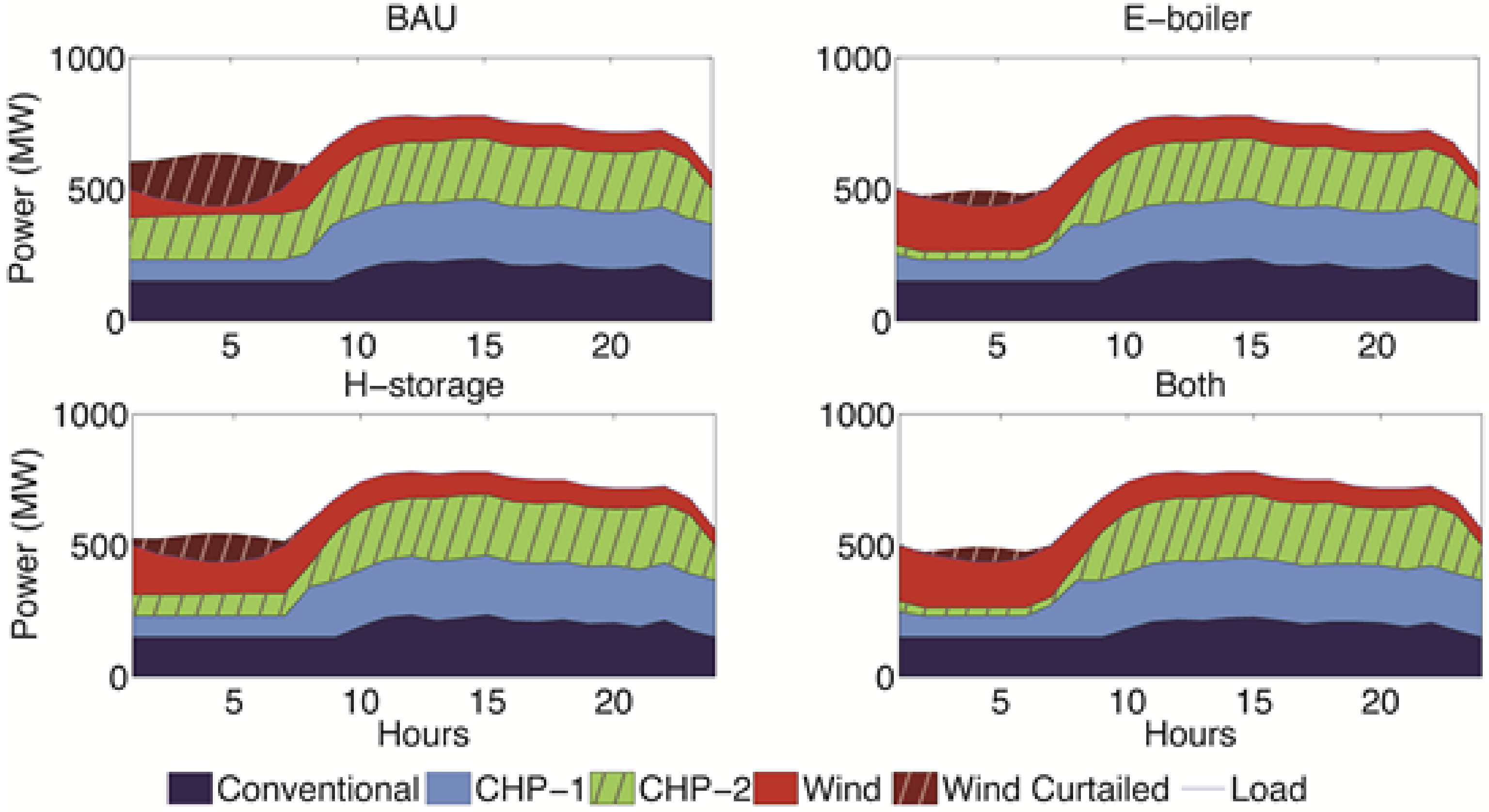
Chen, X., Kang, C., O'Malley, M.J., Xia, Q., Bai, J., Liu, C., Sun, R., Wang, W. and Hui, L., "Increasing the Flexibility of Combined Heat and Power for Wind Power Integration in China: Modeling and Implications", IEEE Transactions on Power Systems, Vol. 30, pp.1848-1857, 2015.

Wind & solar PV curtailment in China



Source: raponline.org

Flexible CHP can reduce wind curtailment

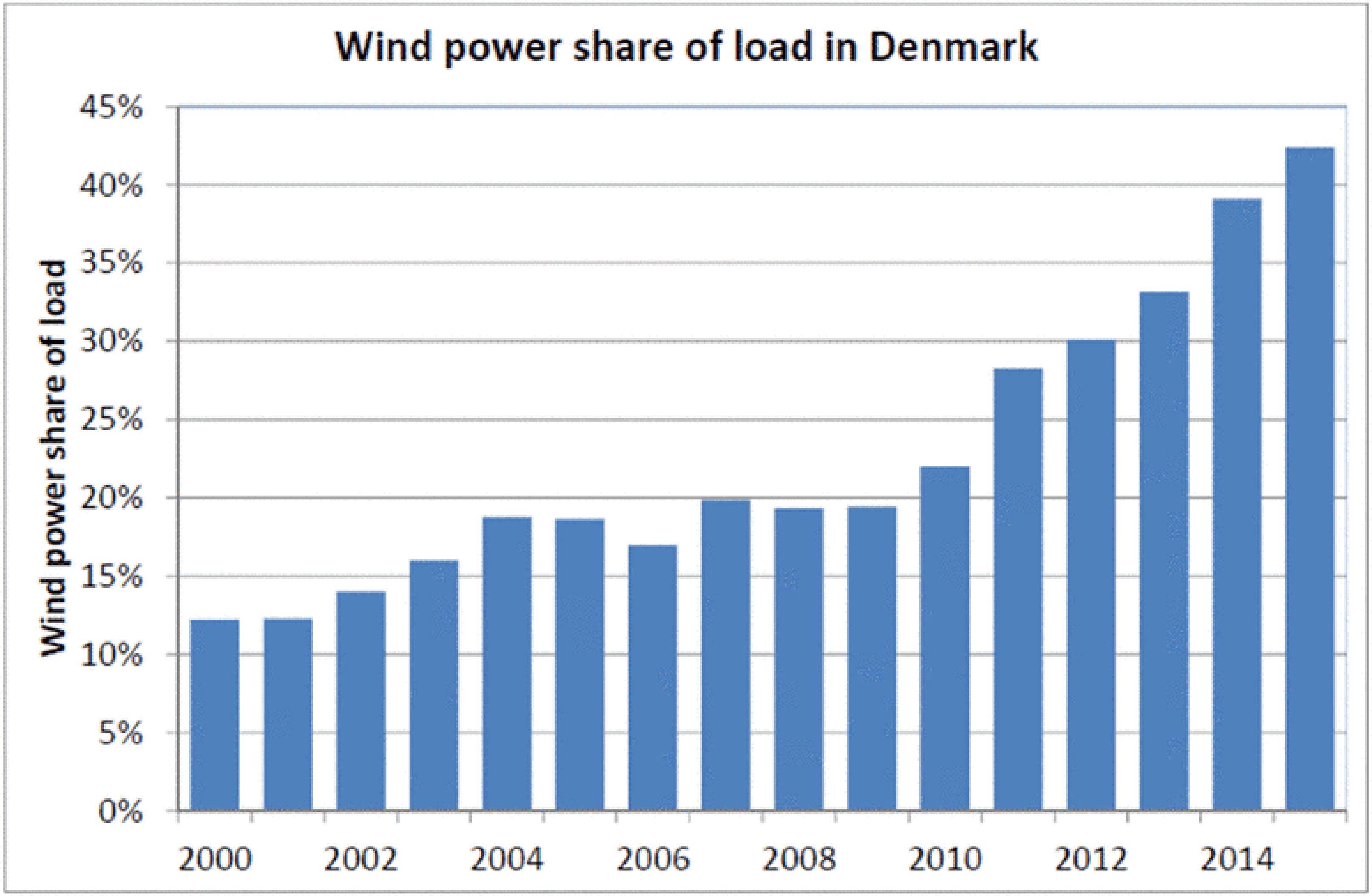


Chen, X., Kang, C., O'Malley, M.J., Xia, Q., Bai, J., Liu, C., Sun, R., Wang, W. and Hui, L., "Increasing the Flexibility of Combined Heat and Power for Wind Power Integration in China: Modeling and Implications", IEEE Transactions on Power Systems, Vol. 30, pp.1848-1857, 2015.

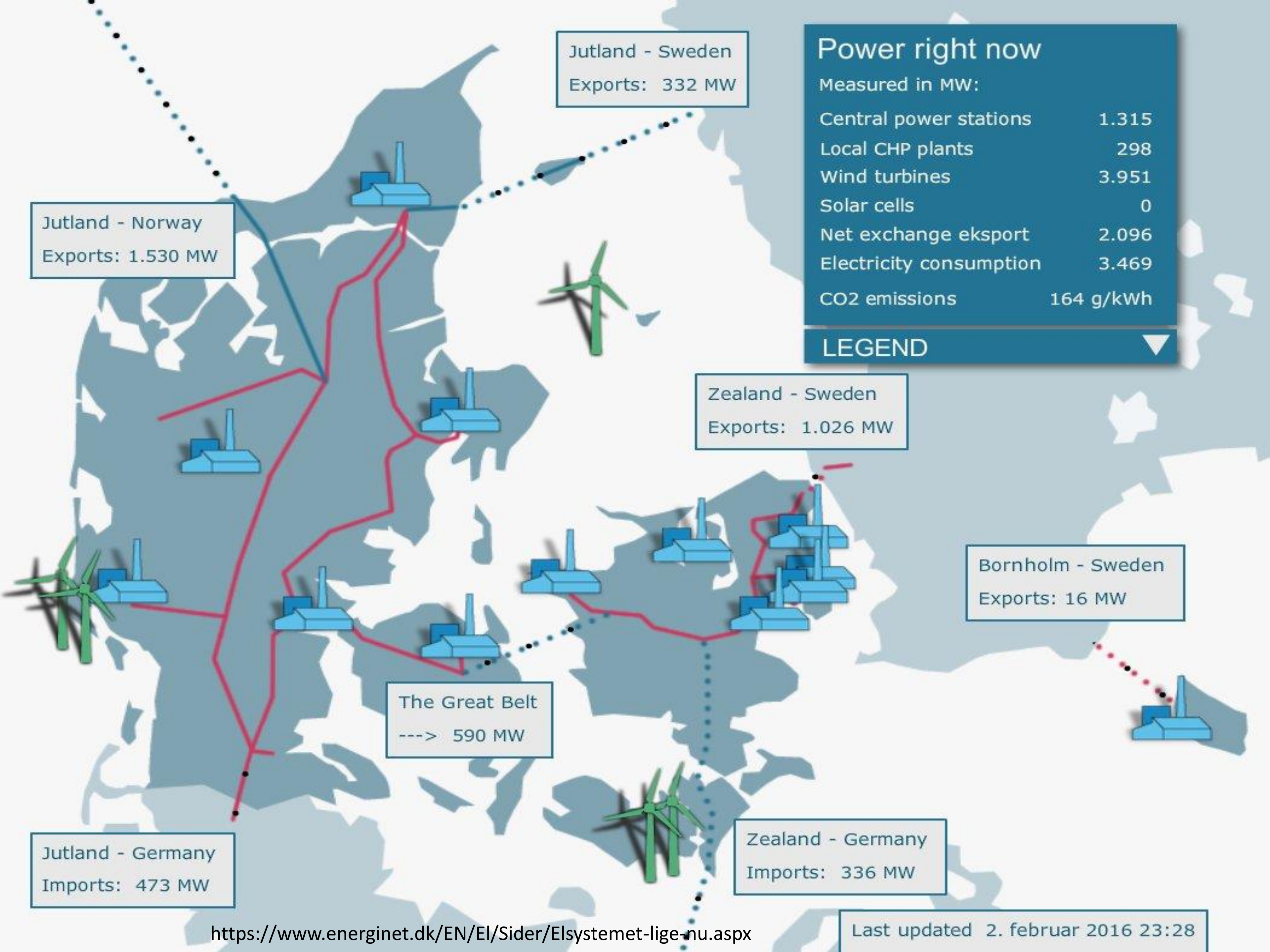

NORWAY
North Sea
SWEDEN
Alborg
DENMARK
Arhus
Copenhagen
Odense
Baltic Sea
GERMANY

Denmark

Wind energy %, electricity, Denmark



Source: Energinet.dk



Power right now

Measured in MW:

Central power stations	1.315
Local CHP plants	298
Wind turbines	3.951
Solar cells	0
Net exchange eksport	2.096
Electricity consumption	3.469
CO2 emissions	164 g/kWh

LEGEND ▼

Jutland - Sweden
Exports: 332 MW

Jutland - Norway
Exports: 1.530 MW

Zealand - Sweden
Exports: 1.026 MW

Bornholm - Sweden
Exports: 16 MW

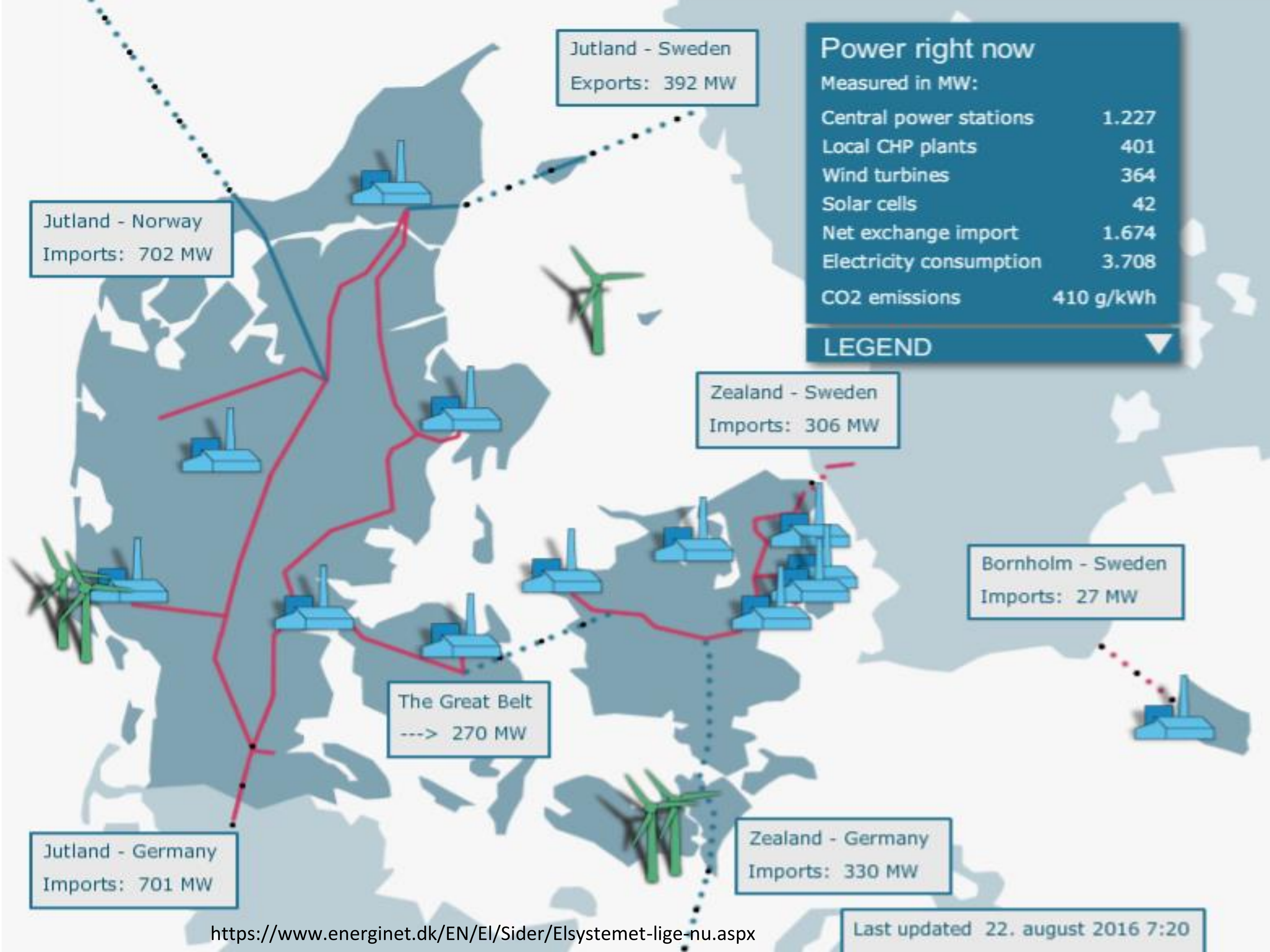
The Great Belt
---> 590 MW

Jutland - Germany
Imports: 473 MW

Zealand - Germany
Imports: 336 MW

Last updated 2. februar 2016 23:28

https://www.energinet.dk/EN/El/Sider/Elsystemet-lige-nu.aspx



Power right now

Measured in MW:

Central power stations	1.227
Local CHP plants	401
Wind turbines	364
Solar cells	42
Net exchange import	1.674
Electricity consumption	3.708
CO2 emissions	410 g/kWh

Jutland - Sweden
Exports: 392 MW

Jutland - Norway
Imports: 702 MW

Zealand - Sweden
Imports: 306 MW

Bornholm - Sweden
Imports: 27 MW

The Great Belt
---> 270 MW

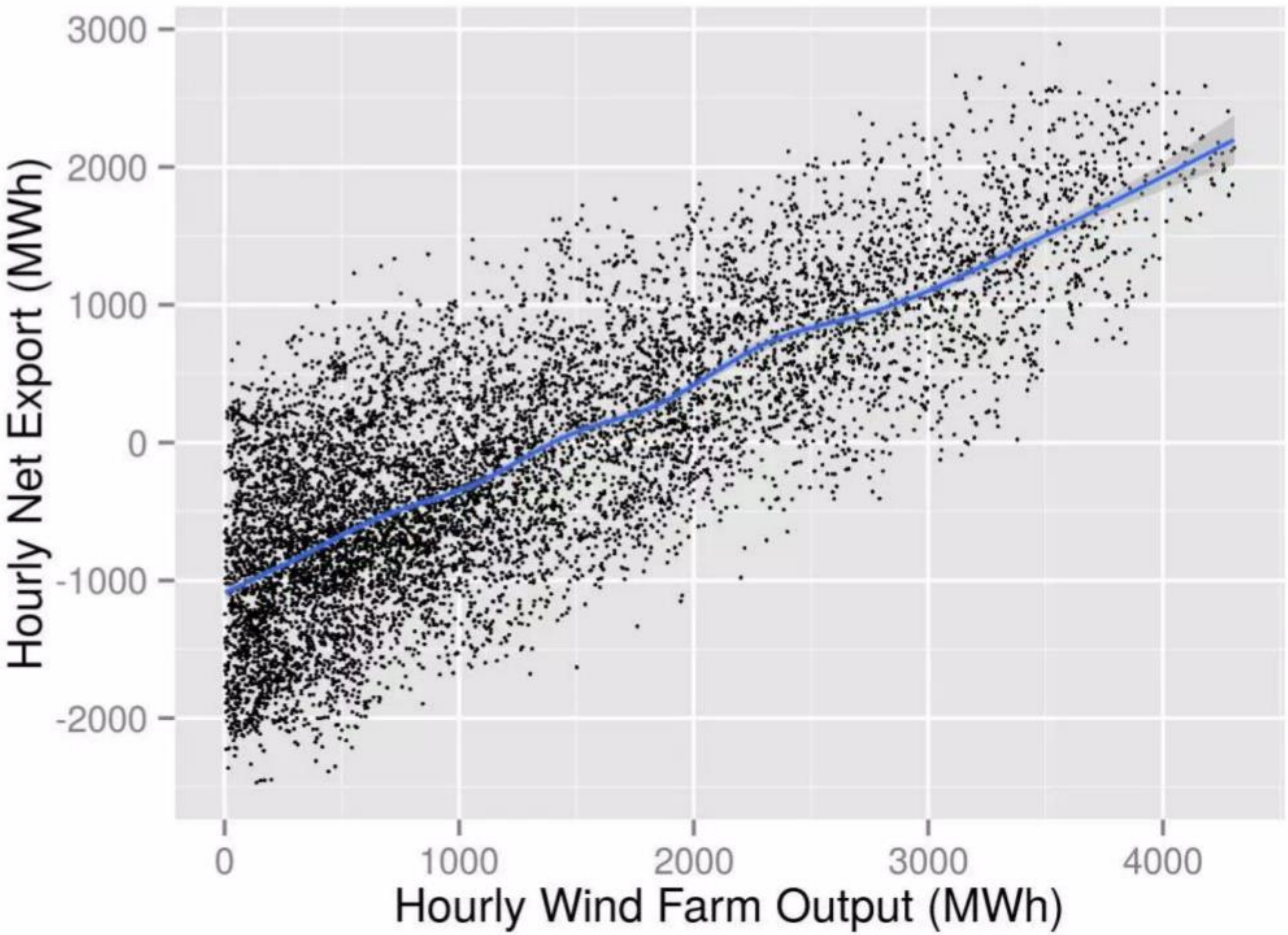
Jutland - Germany
Imports: 701 MW

Zealand - Germany
Imports: 330 MW

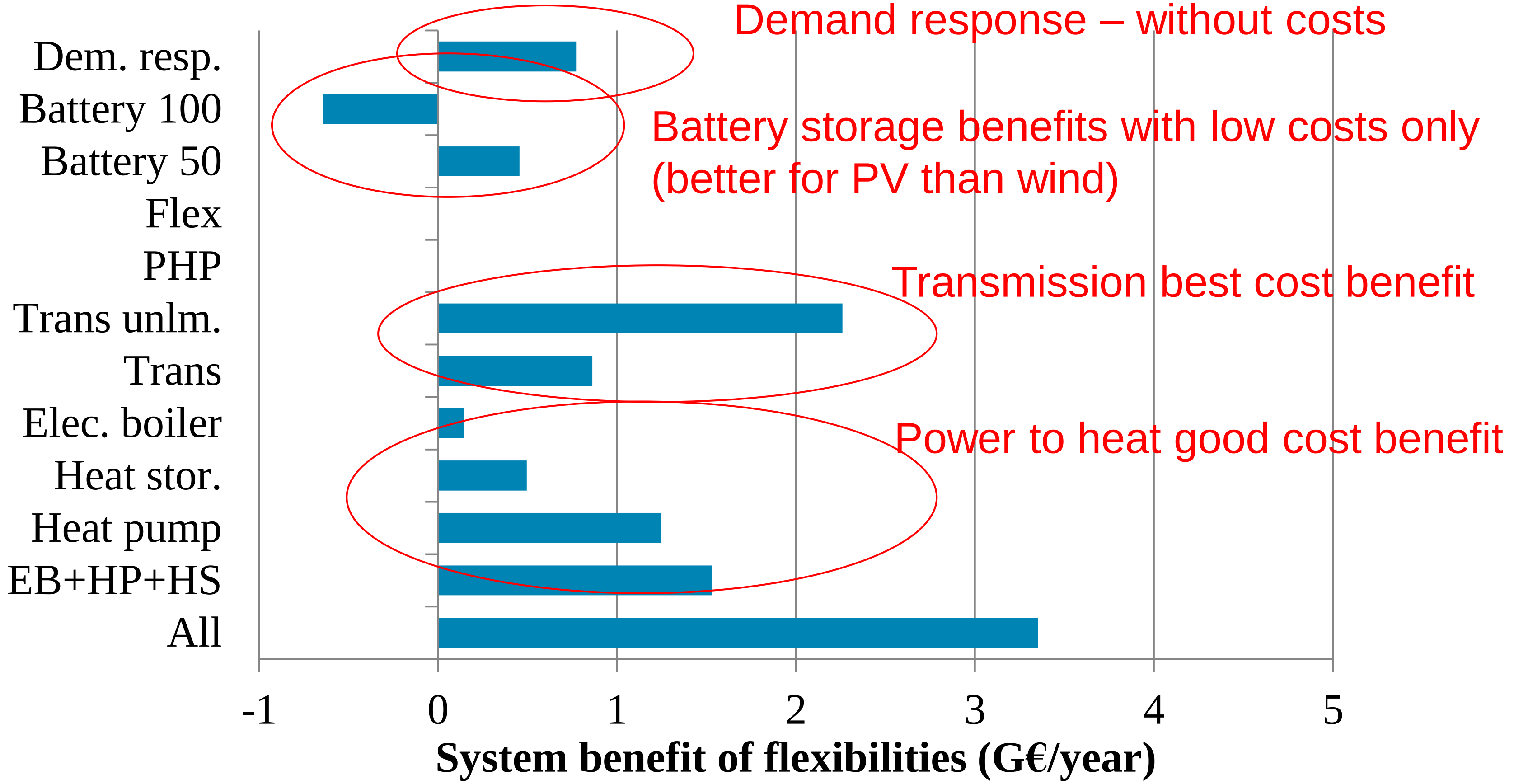
Last updated 22. august 2016 7:20

https://www.energinet.dk/EN/El/Sider/Elsystemet-lige-nu.aspx

Denmark integration of wind: The role of interconnection



Comparing the flexibility options



Demand response – without costs

Battery storage benefits with low costs only (better for PV than wind)

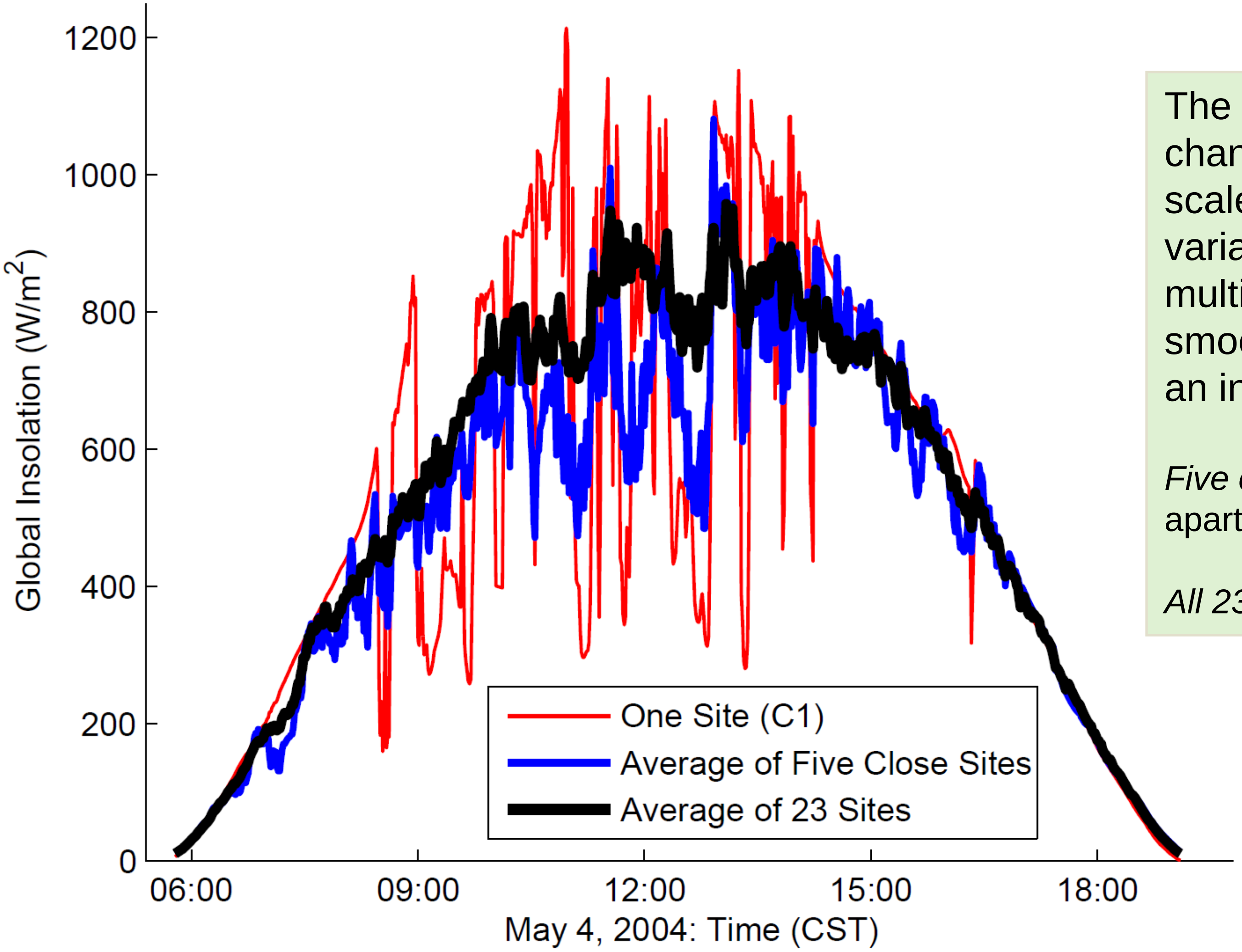
Transmission best cost benefit

Power to heat good cost benefit

- Relative value of new flexibility options for Northern Europe, scenarios with lot of wind power: 42-55% of energy
- For wind, transmission, heat sector flexibility and demand response most important

(Source: Kiviluoma et al, VTT)

Aggregation of solar



The lack of correlation in changes solar over short time scales means that the variability of the aggregated multiple sites is significantly smoother than the variability of an individual site.

Five closest sites: 50 – 170 km apart

All 23 sites: 20 – 440 km apart

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

Storage

Courtesy of Julia Badeda, ISEA-RWTH Aachen, Germany, and data from refs: Deutsche Bank (2009), BCG [Din10] (2010), Roland Berger (2010), TIAX 18650 (2010), CE Delft (2011), AT Kearney (2012), Roland Berger Automotive [Ber12a] (2012), Roland Berger Lithium [Ber12] (2012), Element Energy [Clu12] (2012), Avicenne (2013), Roland Berger (2013), ISI (2013), MW Group (2013), Navigant (2014), ISI (2015), UBS (2014), UBS-A (2014)..

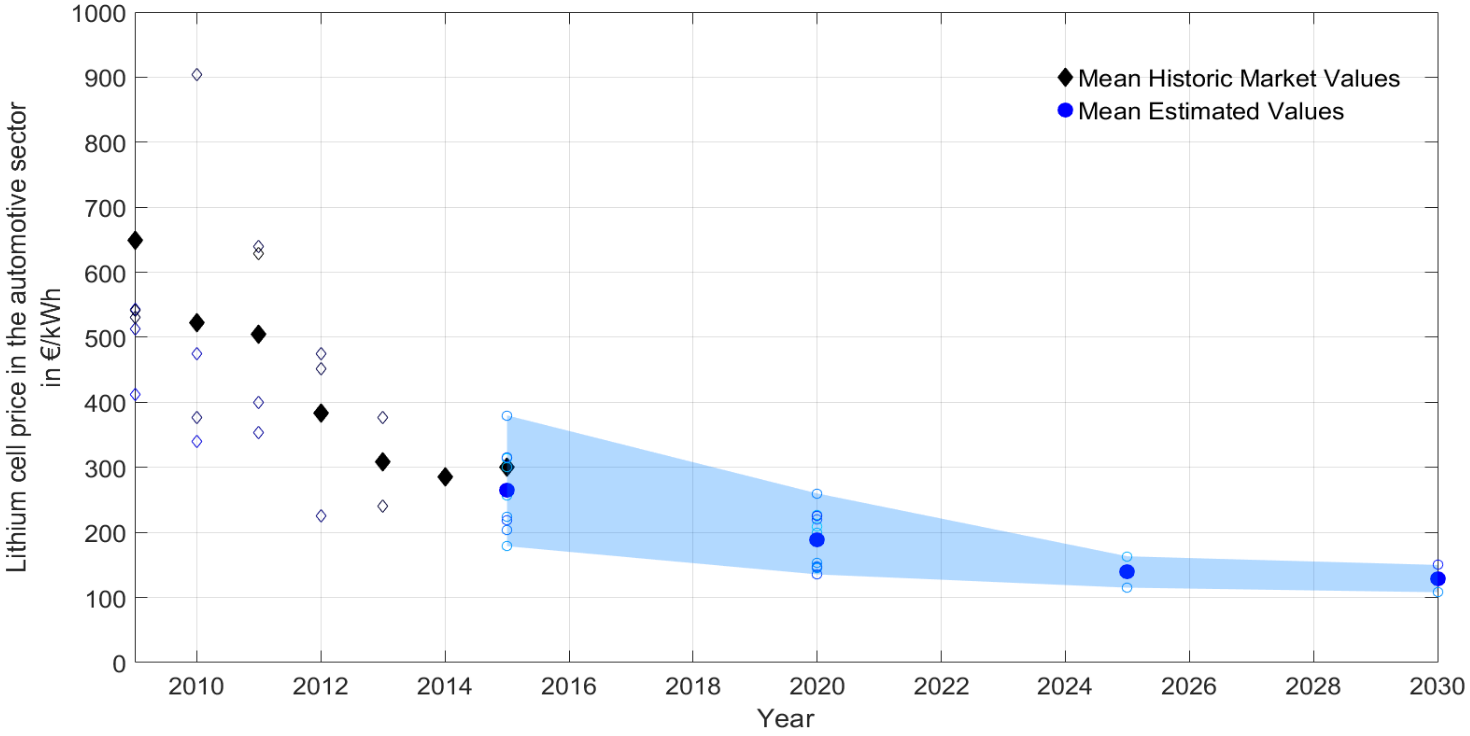
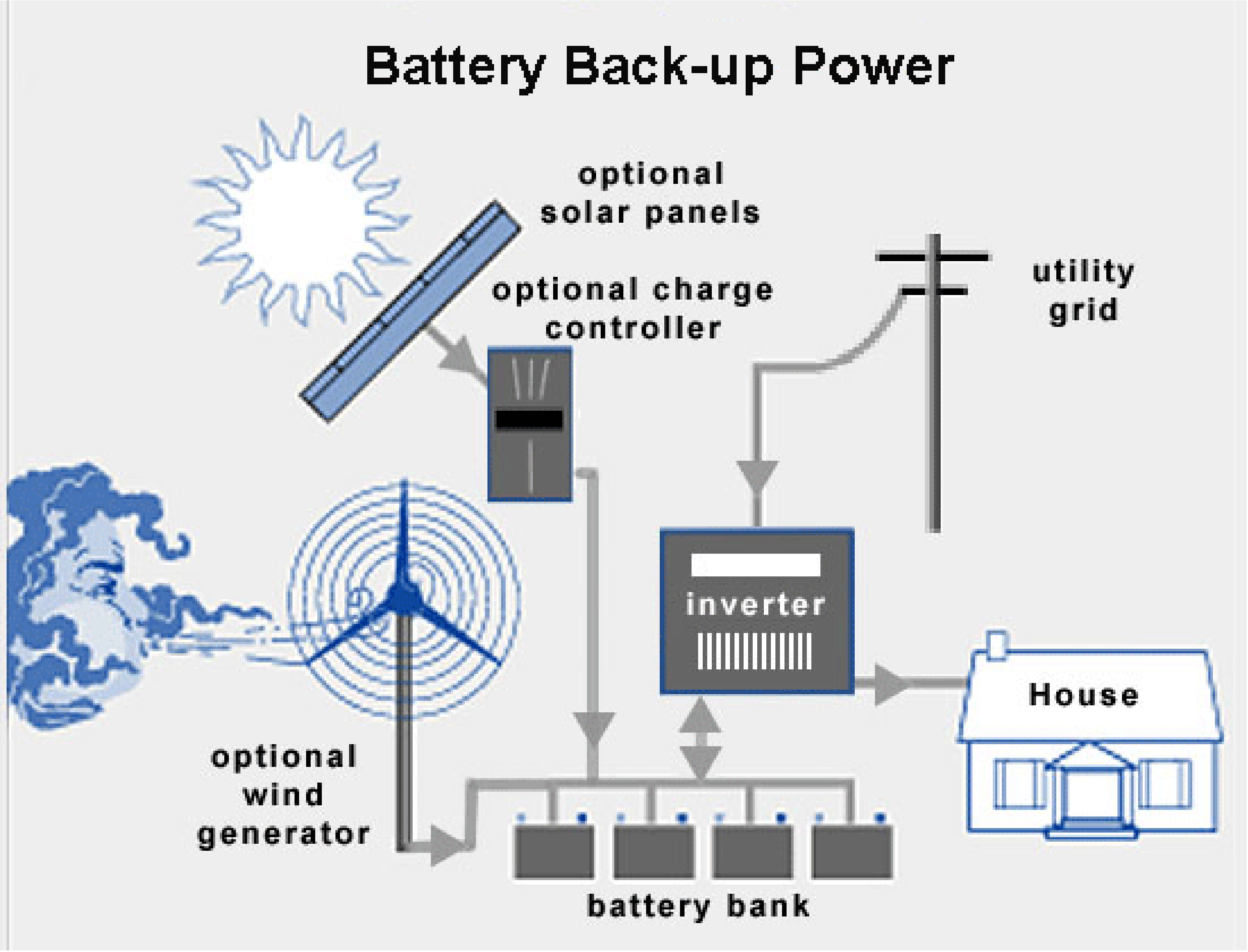


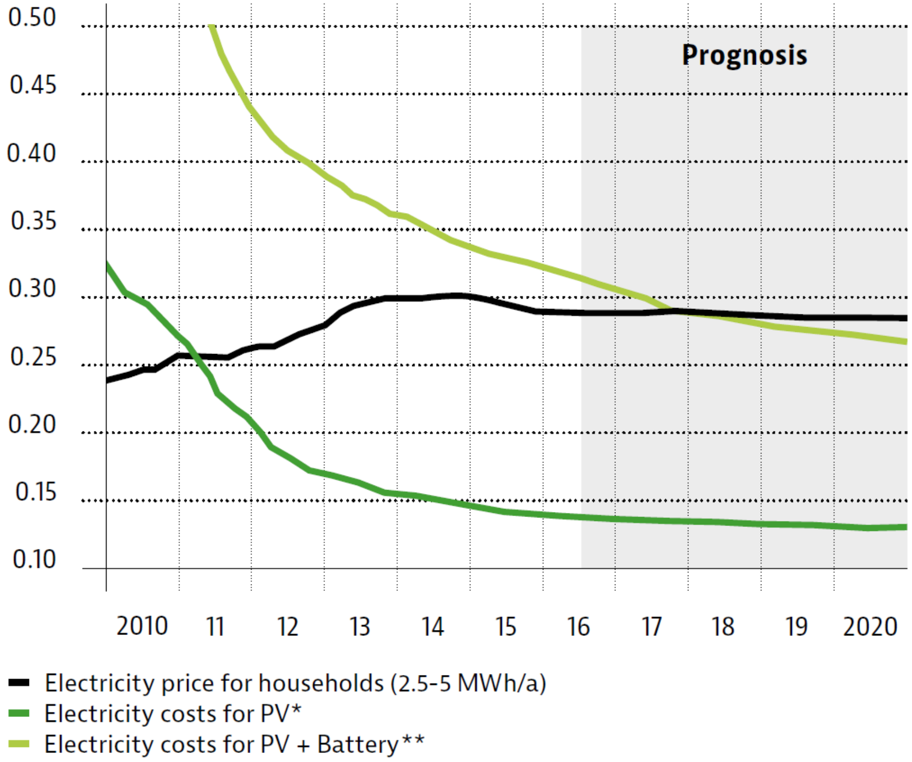
Figure 2 History and future projections of prices for Li-ion batteries.

Going off grid



From Grid Parity to Battery Parity

(in EUR/kWh)



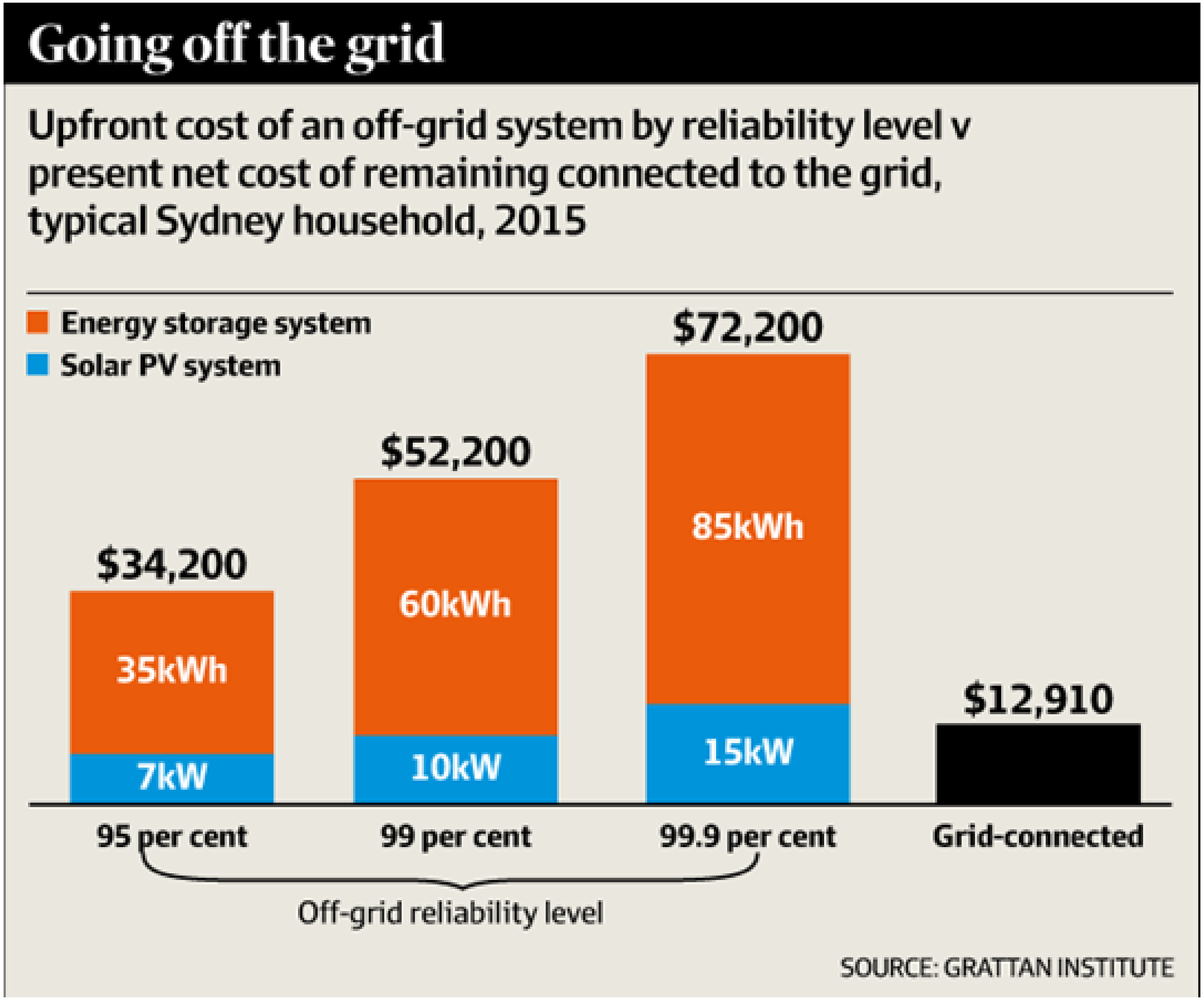
*Model calculation for rooftop systems, based on 802 kWh/kWp (Frankfurt/Main), 100% financing, 6% interest rate, 20 year term, 2% p.a. O&M costs

** Based on 5,000 cycles , 87% efficiency

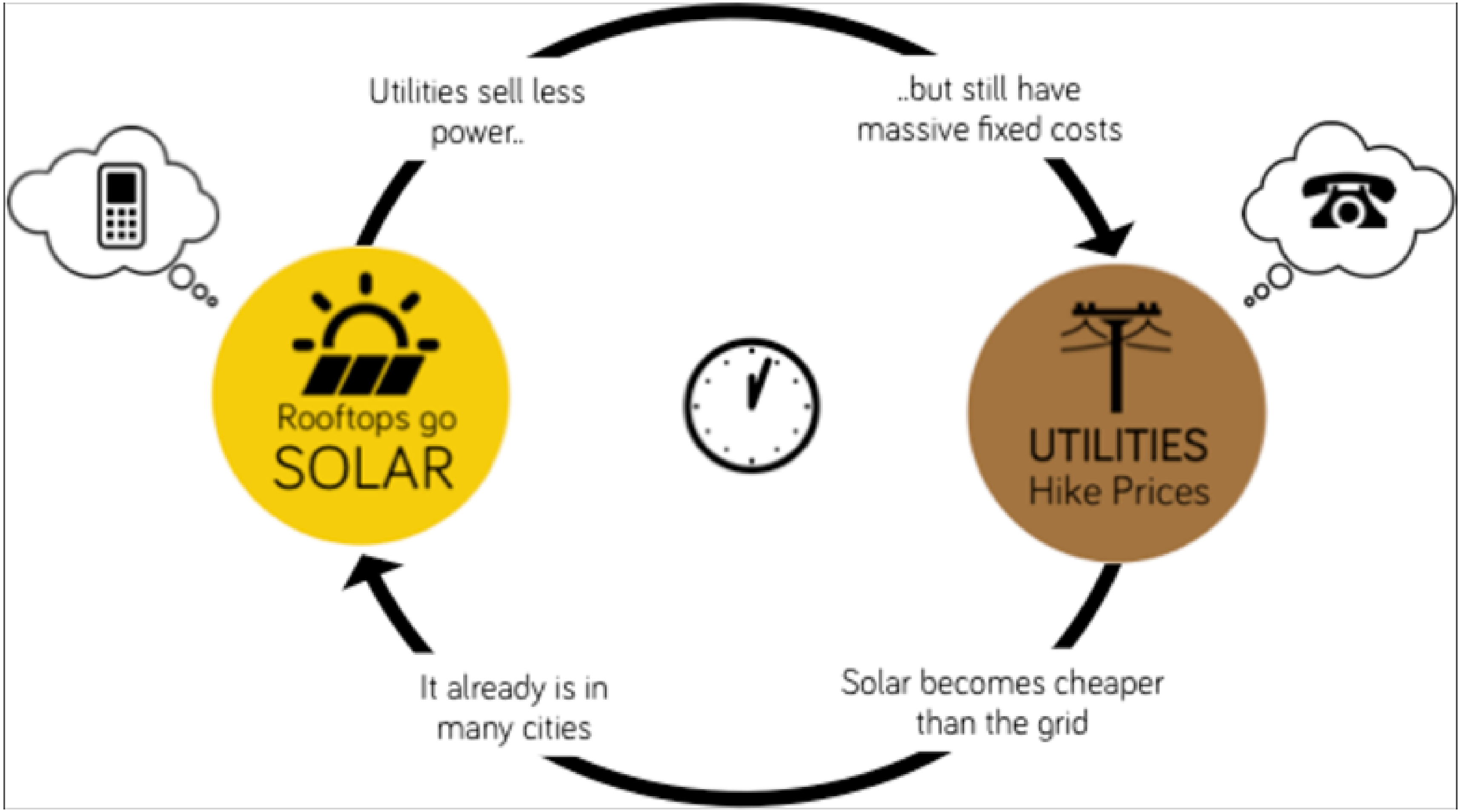
Sources: Own calculation; System Prices: BSW 2015; Model Calculation: Deutsche Bank 2010; Electricity Prices 2007-2015: Eurostat 2015; Electricity Prices 2016-2020: own estimate at 0.29ct/kWh

Source: German Trade and Investment

Going off grid is very expensive



The spiral of death



Policy failure

Distribution network capacity is constrained

1640 IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 20, NO. 3, AUGUST 2005

Optimal Allocation of Embedded Generation on Distribution Networks

Andrew Keane, *Student Member, IEEE,* and Mark O'Malley, *Senior Member, IEEE*

***Abstract*—As a result of the restructuring of electricity markets and the targets laid down for renewable energy, increasing amounts of embedded generation (EG) are being connected to distribution networks. To accommodate this new type of generation, the existing distribution network should be utilized and developed in an optimal manner. This paper explains the background to the technical constraints faced by EG projects, and a new methodology is developed using linear programming to determine the optimal allocation of EG with respect to these constraints. The methodology is implemented and tested on a section of the Irish distribution network. Results are presented, demonstrating that the proper placement and sizing of EG is crucial to the accommodation of increasing levels of EG on distribution networks.**

***Index Terms*—Dispersed storage and generation, linear programming, power distribution planning.**

I. INTRODUCTION

EMBEDDED generation (EG) can be defined as small-scale generation, which is not directly connected to the transmission system and is not centrally dispatched. Generation is now being connected at distribution level, which has led to the characteristics of the network being changed. If increasing levels of generation are to be accommodated, then there must be a change of thinking regarding the planning and design of the distribution network.

There is increasing demand for the development of the distribution network from a passive network to an active one in order to facilitate increasing levels of embedded generation [1]. It is envisaged that there will be a large investment in the distribution network, transforming it from a passive to an active network. If this is to be the case, a number of steps should be followed. First, best use should be made of the existing distribution network by optimal allocation of EG. Second, the development from passive to active should be planned optimally with all relevant considerations taken account of. The placement of generation on a first-come first-serve basis invariably limits the overall capacity of EG [2]. Here, a new methodology is developed to determine the suitable locations and ratings for EG on distribution networks with respect to the technical constraints, which will enable a high penetration of generation on the network and avoid network sterilization. Network sterilization results when capacity is allocated to the bus/buses whose voltage and/or short-circuit levels (SCLs) are most sensitive to power injections. Thus, no more generation can be connected as the buses are constrained.

In [2], the authors employ an optimal power flow technique to maximize EG capacity with respect to voltage and thermal constraints. SCLs, SCRs, equipment ratings, and losses are not considered. The effect of network sterilization is clearly demonstrated by comparison between allocating generation to buses individually rather than as a group. In [3], genetic algorithms were used to place generation such that losses, costs, and network disruption were minimized and the rating of the generator maximized. The constraints considered were voltage, thermal, short circuit, and generator active and reactive power capabilities. Generation is placed in single units at individual buses, while ignoring the interdependence of the buses and the network sterilization that can result from improper EG placement. In [4], the authors use a heuristic approach to determine the optimal EG size and site from an investment point of view. Once again, short circuit constraints are not considered, and the focus of the objective function is on optimal investment rather than maximizing renewable energy. It uses a cost benefit analysis to evaluate various placements of EG.

The basis for the new methodology is in exploiting the interdependence, if any, of the buses with regard to the constraints. The constraints all have either linear or approximately linear characteristics with respect to increasing power injections, or they place a fixed and independent limit on the power injection. The new methodology described here determines the optimal allocation with respect to all of the relevant technical constraints. Optimal allocation ensures best use of the existing assets and achieves a higher penetration of EG in a cost-effective manner. In Section II, the technical constraints on EG are outlined, and the implementation of the methodology is explained. A section of the Irish distribution network is modeled in DIgSILENT Powerfactory using network data obtained from the distribution network operator (DNO) and is described in Section III. The methodology is tested on this section, and results and discussion are shown in Section IV, which illustrate how network sterilization is avoided if EG is optimally allocated. Conclusions are given in Section V.

II. OPTIMAL ALLOCATION METHODOLOGY

The objective is to maximize generation subject to the constraints outlined. Under the European Union (EU) Directive 2001/77/EC, Ireland must provide 13.2% of its electricity generation from renewable sources [5]. The EU Directive for renewable energy penetration is part of a strategy to meet the Kyoto Protocol national targets for reducing greenhouse gas

Manuscript received September 30, 2004; revised January 28, 2005. This work was conducted in the Electricity Research Centre, University College Dublin, which is supported by ESB Networks, ESB Powergen, ESB National Grid, Cylon, the Commission for Energy Regulation, Sustainable Energy Ireland, and Enterprise Ireland. Paper no. TPWRS-00525-2004.

The authors are with the Department of Electronic and Electrical Engineering, University College Dublin, Dublin 4, Ireland (e-mail: andrew.keane@ee.ucd.ie; mark.omalley@ucd.ie).

Digital Object Identifier 10.1109/TPWRS.2005.852115

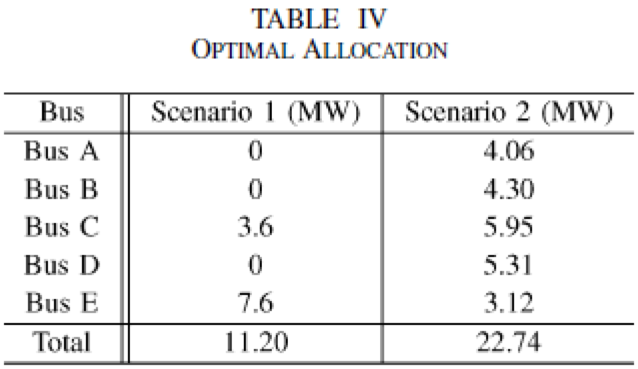


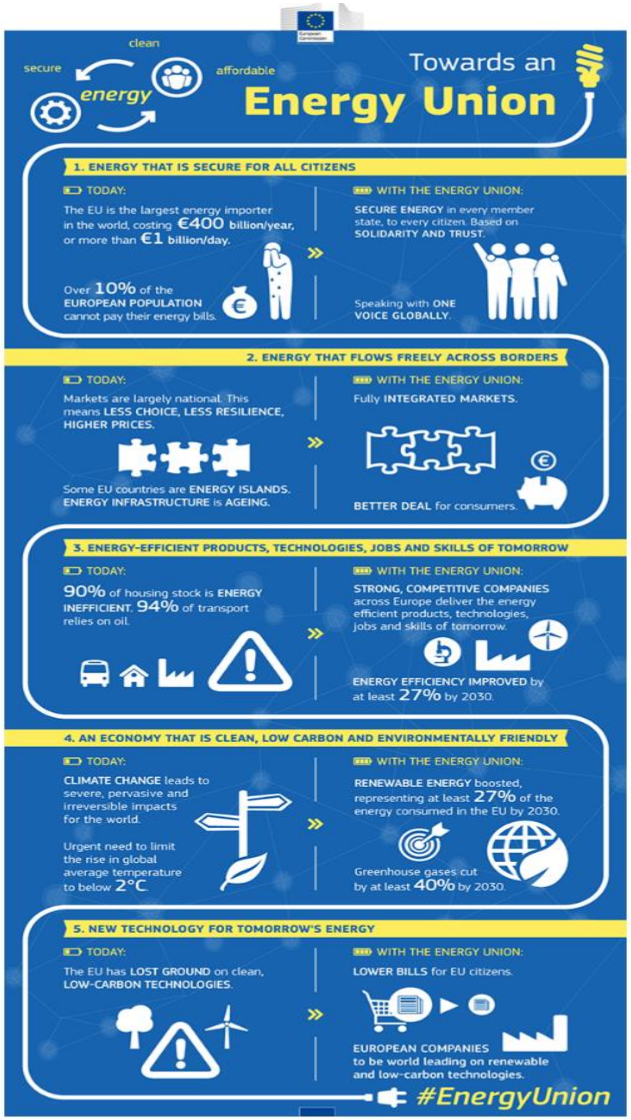
TABLE IV
OPTIMAL ALLOCATION

Bus	Scenario 1 (MW)	Scenario 2 (MW)
Bus A	0	4.06
Bus B	0	4.30
Bus C	3.6	5.95
Bus D	0	5.31
Bus E	7.6	3.12
Total	11.20	22.74

There are ways of maximising the hosting capacity of the distribution network

International activities in ESI

Energy Union and the SET PLAN



Towards an

Energy Union

1. ENERGY THAT IS SECURE FOR ALL CITIZENS

TODAY:

The EU is the largest energy importer in the world, costing €400 billion/year, or more than €1 billion/day.

Over 10% of the EUROPEAN POPULATION cannot pay their energy bills.

WITH THE ENERGY UNION:

SECURE ENERGY in every member state, to every citizen. Based on SOLIDARITY AND TRUST.

Speaking with ONE VOICE GLOBALLY.

2. ENERGY THAT FLOWS FREELY ACROSS BORDERS

TODAY:

Markets are largely national. This means LESS CHOICE, LESS RESILIENCE, HIGHER PRICES.

Some EU countries are ENERGY ISLANDS. ENERGY INFRASTRUCTURE is AGEING.

WITH THE ENERGY UNION:

Fully INTEGRATED MARKETS.

BETTER DEAL for consumers.

3. ENERGY-EFFICIENT PRODUCTS, TECHNOLOGIES, JOBS AND SKILLS OF TOMORROW

TODAY:

90% of housing stock is ENERGY INEFFICIENT. 94% of transport relies on oil.

WITH THE ENERGY UNION:

STRONG, COMPETITIVE COMPANIES across Europe deliver the energy efficient products, technologies, jobs and skills of tomorrow.

ENERGY EFFICIENCY IMPROVED by at least 27% by 2030.

4. AN ECONOMY THAT IS CLEAN, LOW CARBON AND ENVIRONMENTALLY FRIENDLY

TODAY:

CLIMATE CHANGE leads to severe, pervasive and irreversible impacts for the world.

Urgent need to limit the rise in global average temperature to below 2°C

WITH THE ENERGY UNION:

RENEWABLE ENERGY boosted, representing at least 27% of the energy consumed in the EU by 2030.

Greenhouse gases cut by at least 40% by 2030.

5. NEW TECHNOLOGY FOR TOMORROW'S ENERGY

TODAY:

The EU has LOST GROUND on clean, LOW-CARBON TECHNOLOGIES.

WITH THE ENERGY UNION:

LOWER BILLS for EU citizens.

EUROPEAN COMPANIES to be world leading on renewable and low-carbon technologies.

#EnergyUnion

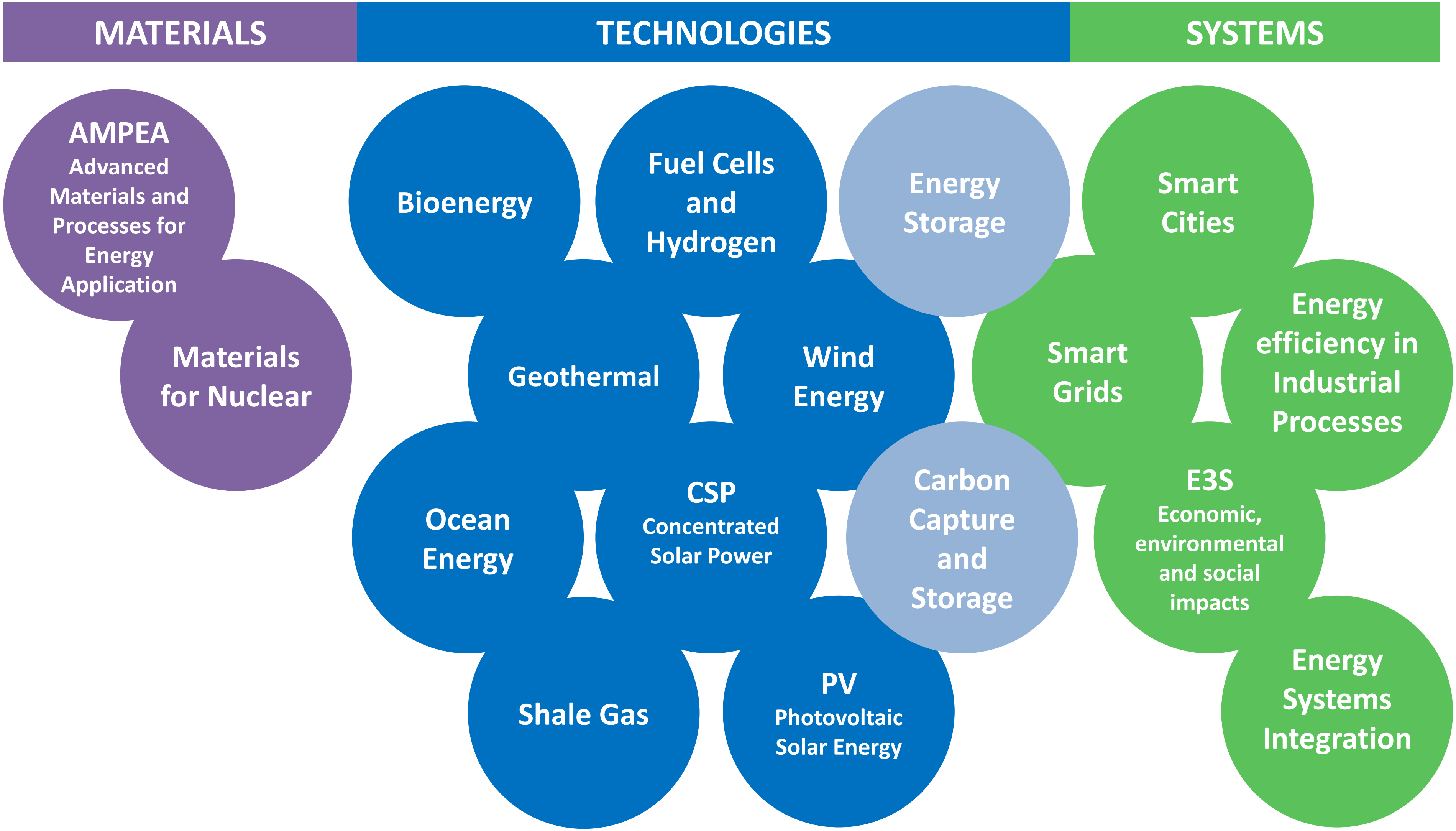
Info graphic provided by the European Commission

Strategic Energy Technology (SET) Plan

Towards an Integrated Roadmap:
Research & Innovation Challenges and Needs
of the EU Energy System

EERA
European Energy Research Alliance

Joint Programmes technology portfolio



MATERIALS

- **AMPEA** Advanced Materials and Processes for Energy Application
- Materials for Nuclear

TECHNOLOGIES

- Bioenergy
- Fuel Cells and Hydrogen
- Energy Storage
- Geothermal
- Wind Energy
- Ocean Energy
- **CSP** Concentrated Solar Power
- Carbon Capture and Storage
- Shale Gas
- **PV** Photovoltaic Solar Energy

SYSTEMS

- Smart Cities
- Smart Grids
- Energy efficiency in Industrial Processes
- **E3S** Economic, environmental and social impacts
- Energy Systems Integration

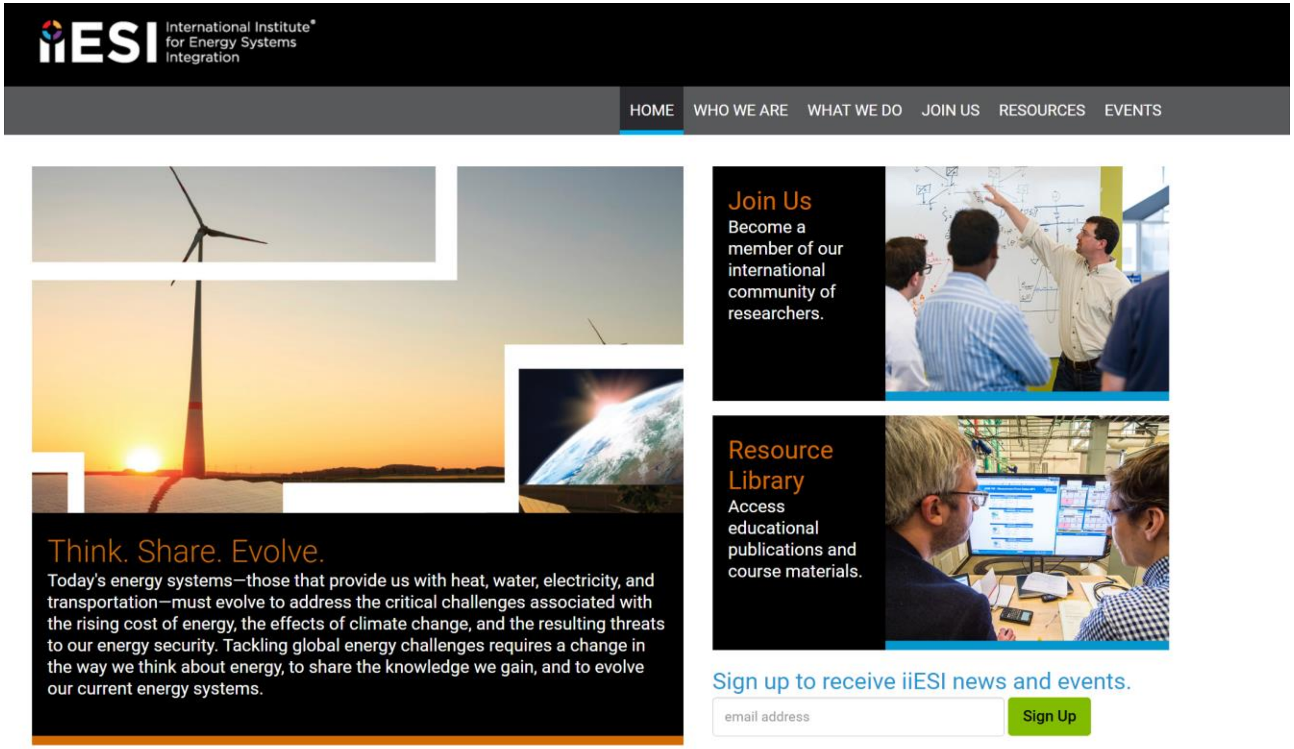
http://www.eera-set.eu/eera-joint-programmes-jps/list-of-jps/

iiESI.org

Imperial College London

NREL NATIONAL RENEWABLE ENERGY LABORATORY

EPRI ELECTRIC POWER RESEARCH INSTITUTE



Think. Share. Evolve.

Today's energy systems—those that provide us with heat, water, electricity, and transportation—must evolve to address the critical challenges associated with the rising cost of energy, the effects of climate change, and the resulting threats to our energy security. Tackling global energy challenges requires a change in the way we think about energy, to share the knowledge we gain, and to evolve our current energy systems.

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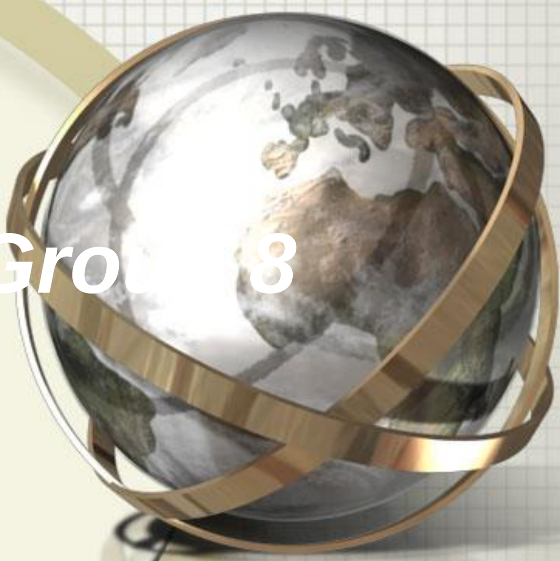
KIT Karlsruhe Institute of Technology

NANYANG TECHNOLOGICAL UNIVERSITY

iiESI Course 2014 Denver Colorado

Energy System Integration: *New Zealand Case Study, 2030 & 2050 Futures.*



Group 8

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(Group 8)

07.25.14

Background & Overview

- NZ has LOTS of domestic energy resources!
  - Natural gas
  - Coal
  - *Lots of renewables – hydro, geothermal, wind, solar*
- National energy risks
  - Islanded system → no benefits from "neighbors"
  - Reliance on hydro→ energy - limited → vulnerable systems during drought
  - Earthquakes are common
- Population & energy outlook
  - Population – 2013:~4.5M, 2030: ~5.5M; 2050: ~6.5M
  - Per capita energy use 2011
    - Electricity: 2011 - 9,300 kWh-capita/yr → will likely decrease due to increased EE measures
    - 42.245 GWh annual electric energy
- Strong renewable policies (90% electric sector by 2020)

Energy System Integration

Emphasize Fuel Diversity & Synergies

- Transportation electrification
  - EVs and CNG based commercial transport to be encouraged.
  - Research work to be done for development of bio-fuels.
  - Increased solar PV network may help in dealing with increasing EV load.
- District heating/energy implemented in urban areas
  - Inputs: CHP (gas/biomass), geothermal, “excess” wind, waste industrial heat.
  - All this coupled with intelligent control for maximum efficiency.
- Integration of wind/solar → increased fuel diversity
  - Times of drought = high solar resource
  - Pumped storage for maintaining spinning reserve.
- Gas system
  - Use of biogas, synthetic methane for storage in depleted gas/petroleum reservoirs.
  - These storage units will serve as a back-up for the system in times of seasonal emergencies (ex. Drought conditions restricting operation and output of hydro power plants)
- Efficient water usage
  - Water treatment plants to be linked with biogas facility as well as CHP plants for a highly efficient, symbiotic operation.
- Thus, the New Zealand energy system will be well integrated in the coming years, along with 100% contribution of renewable energy sources for electricity generation.

Conclusions

- Energy Systems Integration (ESI) is an increasingly important research area

- It is fundamental to successful decarbonisation and in particular integration of large volumes of variable renewable energy

- Planning, operating and POLICY making in integrated energy systems require whole system thinking

- Every system is different

- Social sciences research is fundamental to planning and operating an integrated energy system

- There are international initiatives that support energy systems integration

Acknowledgements

- Dinah Towle, Basil Sharp, Golbon Zakeri
- Tina Schirr, John Carnegie
- My colleagues for many of the slides

Go raibh maith agat