Supply Demand Balance in an Integrated Energy System The role of Demand & Storage

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Singapore, Dec 5th 2016

erc electricity research centre

ENERGY INSTITUTE UCD

Some introductory remarks

- A complex issue
- Many different
  - Technologies
  - Applications
  - Energy vectors

- Energy system is more than just electricity
- Renewables are tied to storage and demand management in the debate but not fundamentally
- Cost trends in batteries in particular are declining rapidly, but will they continue ?
- Regulatory and policy framework critical
- Very
  - system specific
  - emotive topic
  - difficult to give make definitive statements

KEEP
CALM
AND
LET'S TRY IT
TOGETHER

My research involvement

- Ma, O., Cheung, K., Alkadi, N., Bhatnagar, D., Cappers, P., Currier, A.B., Denholm, P., Dudley, J., Goli, S., Hummon, M., Jorgenson, J., Kiliccote, S., MacDonald, J., Matson, N., Olsen, D., Palchak, D., Rose, C., Sohn, M.D., Starke, M., Kirby, B. and O'Malley, M. "Demand Response and Energy Storage Integration Study," DOE EE-1282, 2016.
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European Academies
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Science Advisory Council

EASAC Electricity Storage Study

'Valuing Dedicated Storage in Electricity Grids'

Confidential draft working document

Version of 20 September 2016

(for Peer Review)

1

draft 20/09/2016

U.S. DEPARTMENT OF ENERGY

Demand Response and Energy Storage Integration Study

March 2016

Chair: Mark O'Malley, to be published early 2017

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Electricity storage technologies

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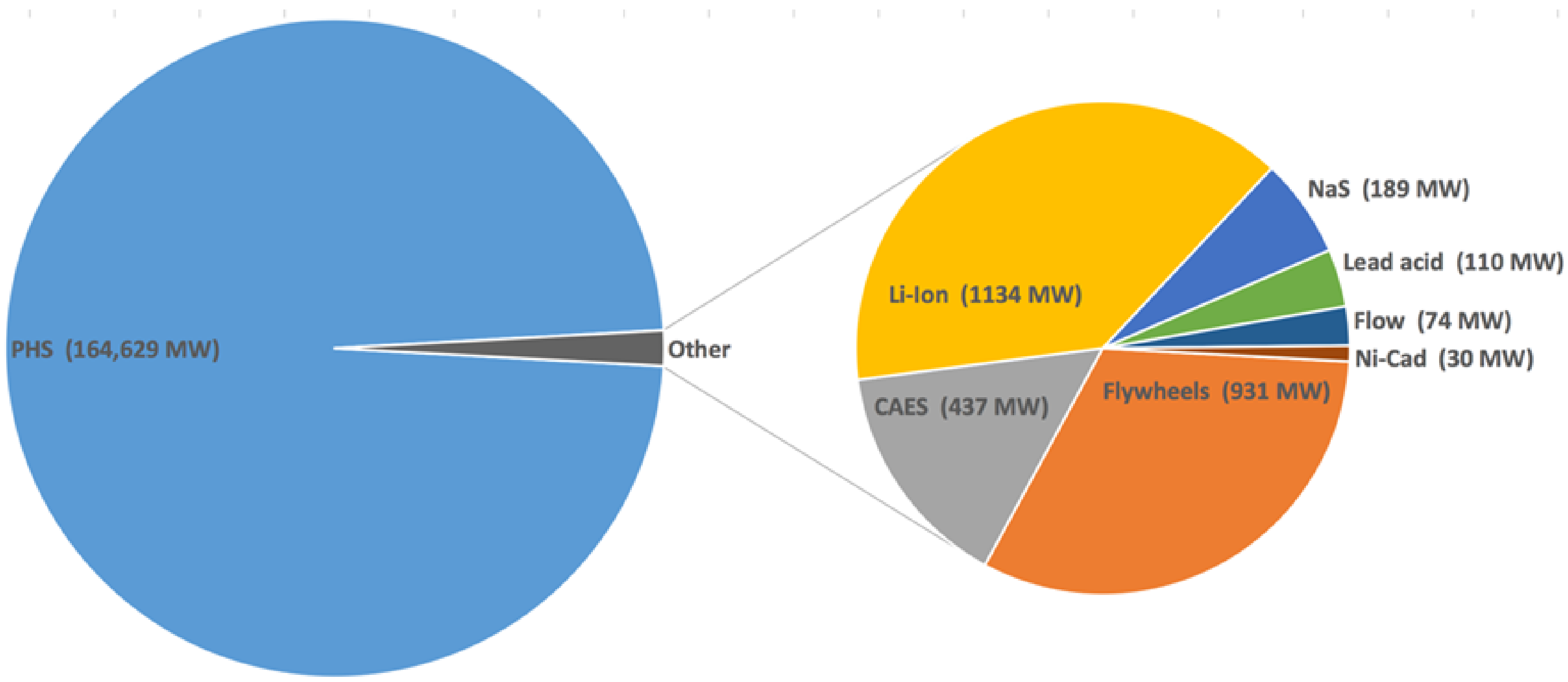
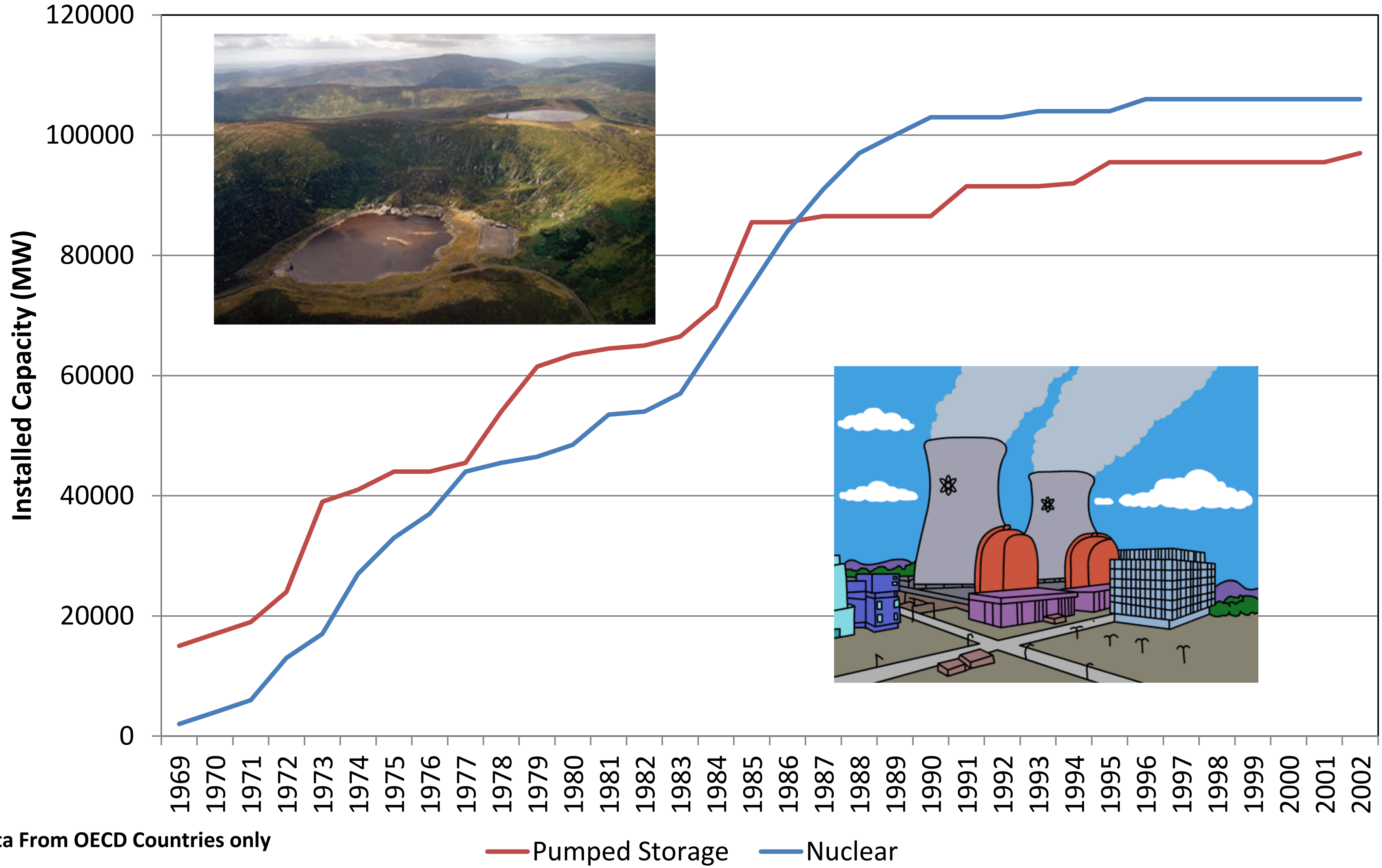


FIGURE 1 CURRENT GLOBAL GRID CONNECTED ELECTRICITY STORAGE CAPACITY (OPERATIONAL) (MW)

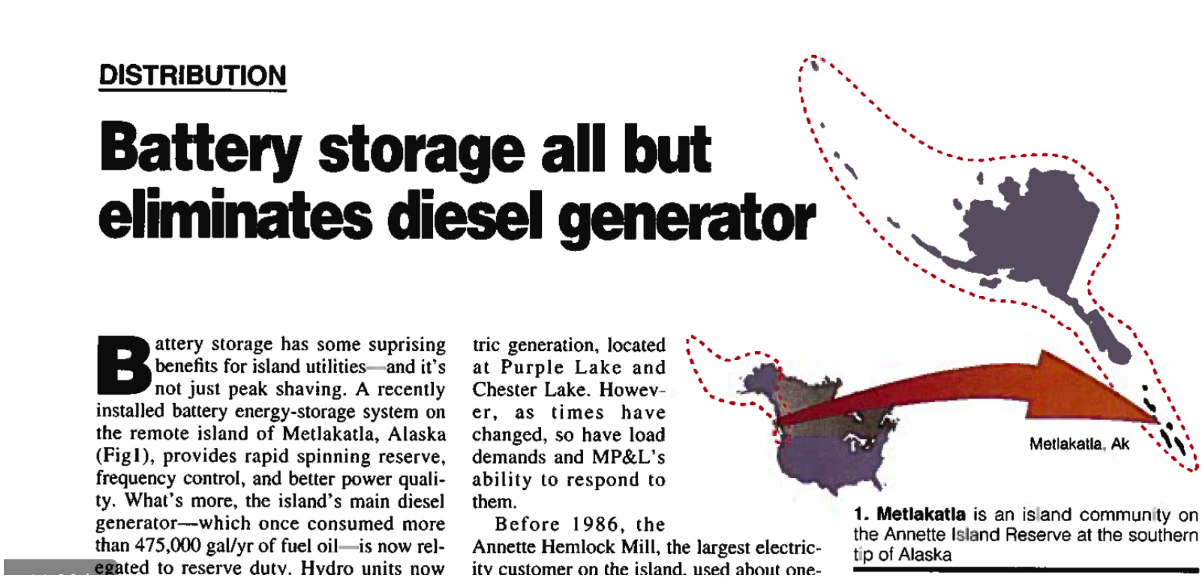
Historical Pumped Storage Driver



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

Island Applications


DISTRIBUTION

Battery storage all but eliminates diesel generator

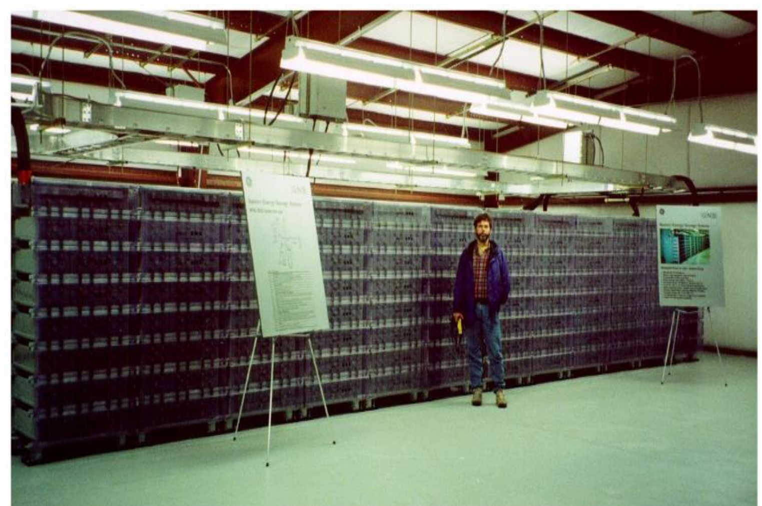
Battery storage has some suprising benefits for island utilities—and it's not just peak shaving. A recently installed battery energy-storage system on the remote island of Metlakatla, Alaska (Fig1), provides rapid spinning reserve, frequency control, and better power quality. What's more, the island's main diesel generator—which once consumed more than 475,000 gal/yr of fuel oil—is now relegated to reserve duty. Hydro units now tric generation, located at Purple Lake and Chester Lake. However, as times have changed, so have load demands and MP&L's ability to respond to them.

Before 1986, the Annette Hemlock Mill, the largest electricity customer on the island, used about one-

1. **Metlakatla** is an island community on the Annette Island Reserve at the southern tip of Alaska

DEMAREST, M., TAYLOR, P., ACHENBACH, H. and AKHIL, A., 1997. Battery storage all but eliminates diesel generator. *Electrical world*, *211*(6), pp.39-41.

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.



Does Wind Need Storage?

Wind Power Myths Debunked

Common Questions and Misconceptions

THE RAPID GROWTH OF WIND POWER IN THE UNITED STATES AND

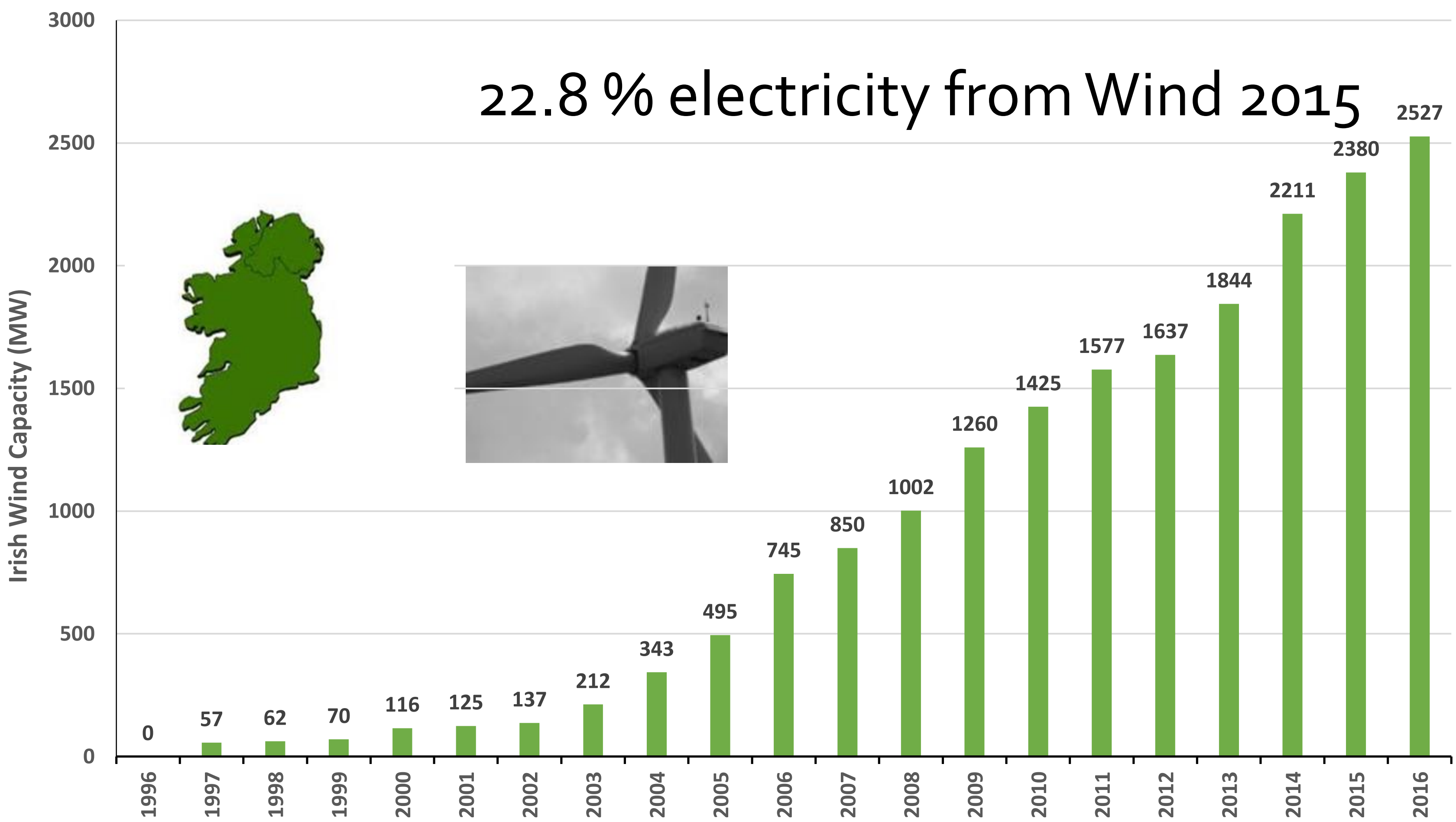
and delivers a variable level of power depending on the wind speed. Wind is primarily an energy resource and not a capacity resource. Its primary value is to offset fuel consumption and the resulting emissions, including carbon. Only a relatively small fraction of wind energy is typically delivered during peak and high-risk time periods; therefore, wind generators have limited capacity value. This leads to concerns about the impacts of wind power on maintaining reliability and the balance between load and generation.

This article presents answers to commonly asked questions concerning wind power. It begins by addressing the variability of wind and then discusses whether wind has capacity credit. The article addresses whether wind can stop blowing everywhere at once, the uncertainty of predicting wind generation, whether it is expensive to integrate wind

By Michael Milligan, Kevin Porter, Edgar DeMeo, Paul Denholm, Hannele Holttinen, Brendan Kirby, Nicholas Miller, Andrew Mills, Mark O'Malley, Matthew Schuerger, and Lennart Soder

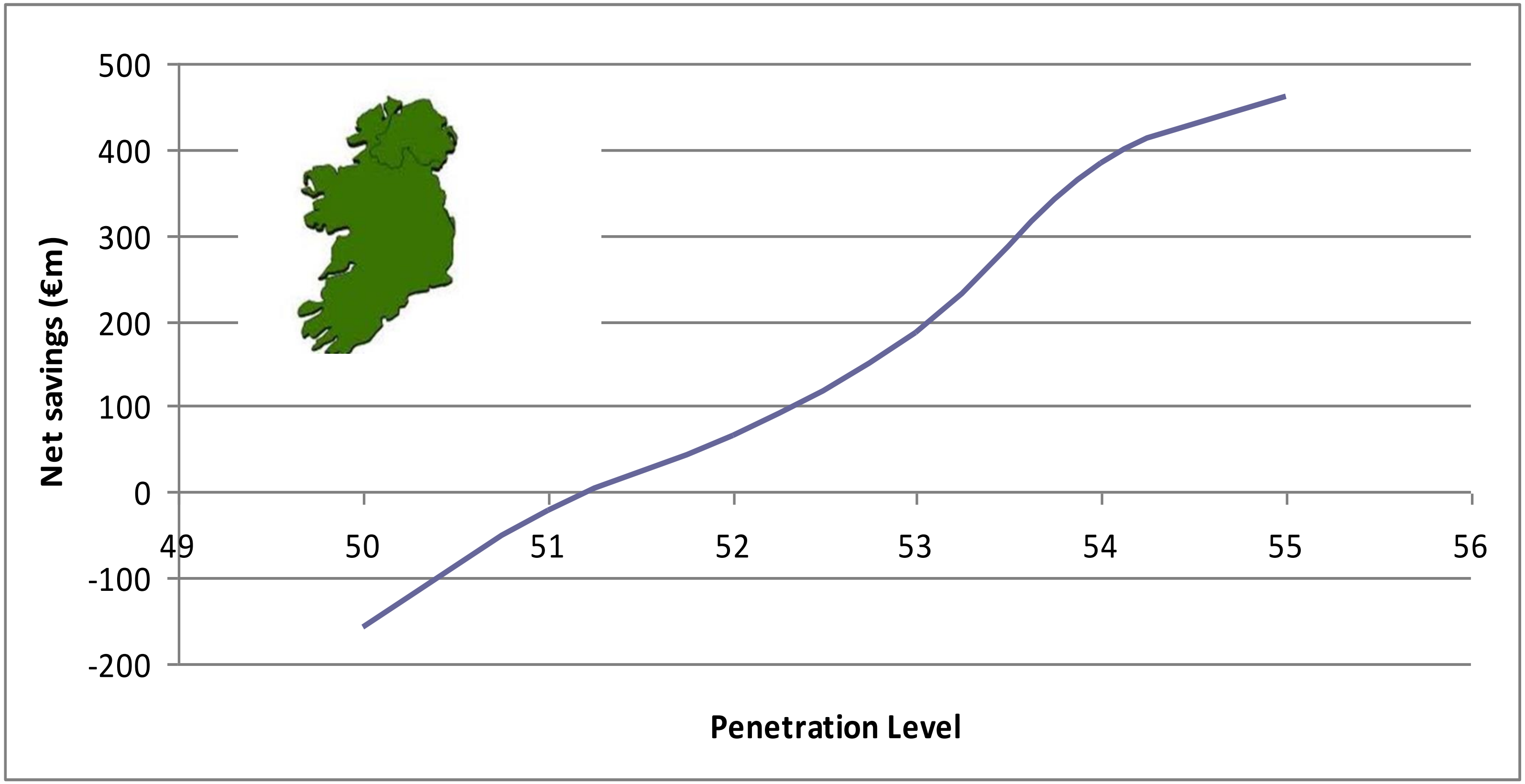
1540-7977/09/$26.00©2009 IEEE

Wind Installed in Ireland



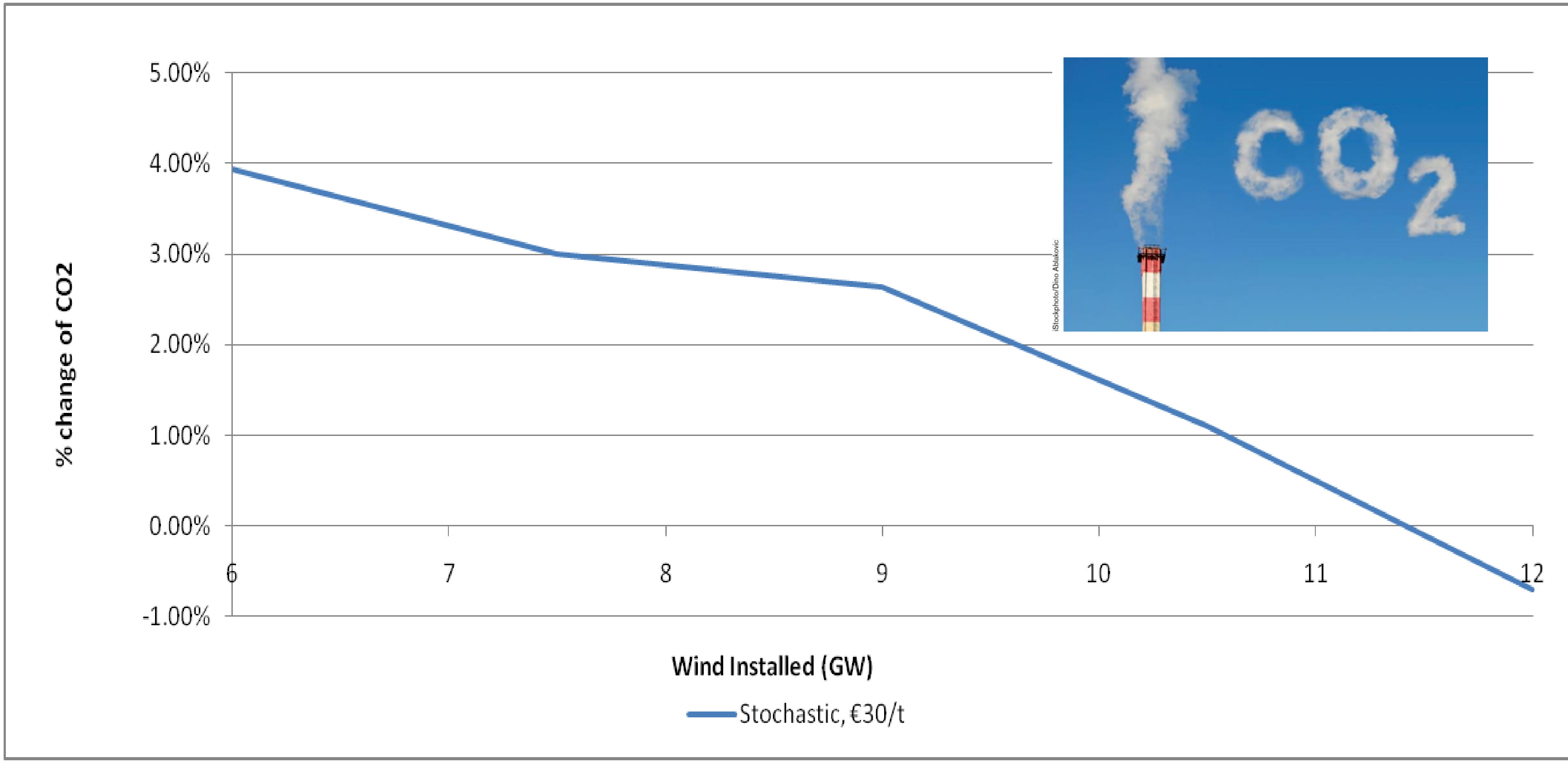
Sources: EirGrid http://www.eirgrid.com/operations/systemperformancedata/all-islandwindandfuelmixreport/ ,IWEA and Eirgrid Generation Capacity Statement 2016-2025 and Irish Wind Energy Association

Net Savings with storage



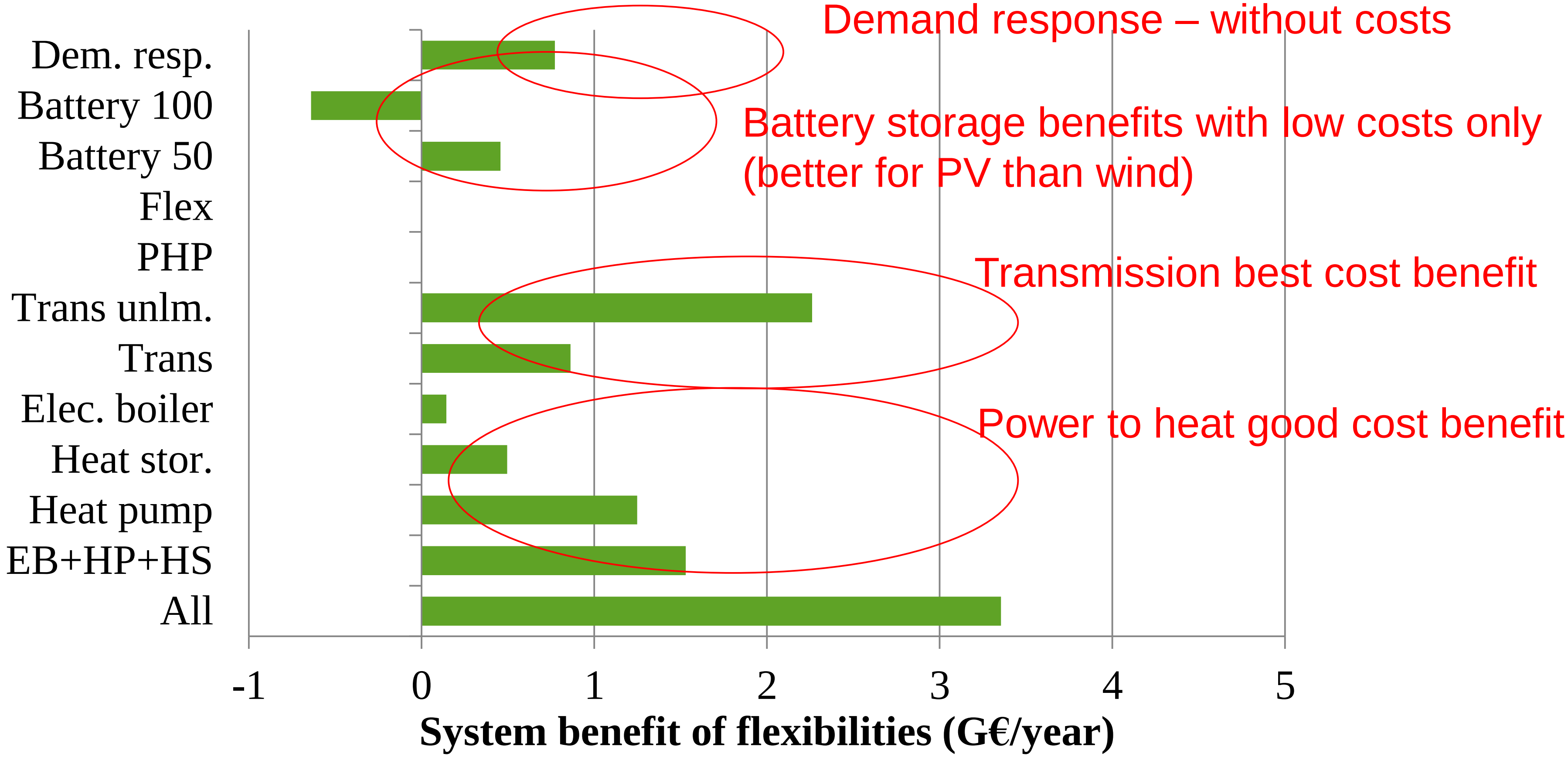
Tuohy, A. and O'Malley, M.J., "Pumped Storage in Systems with Very High Wind Penetration", E*nergy Policy*, Vol. 39, pp. 1965-1974, 2011.

Emissions with storage



Tuohy, A. and O'Malley, M.J., "Pumped Storage in Systems with Very High Wind Penetration", E*nergy Policy*, Vol. 39, pp. 1965-1974, 2011.

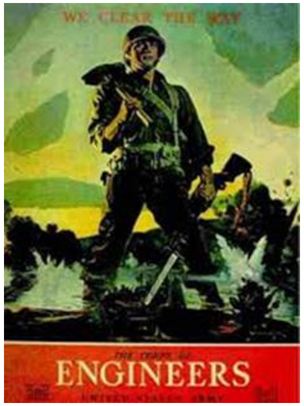
Comparing the flexibility options



- 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)

Boys and toys pumped storage in Ireland



Storage Low value and declines rapidly

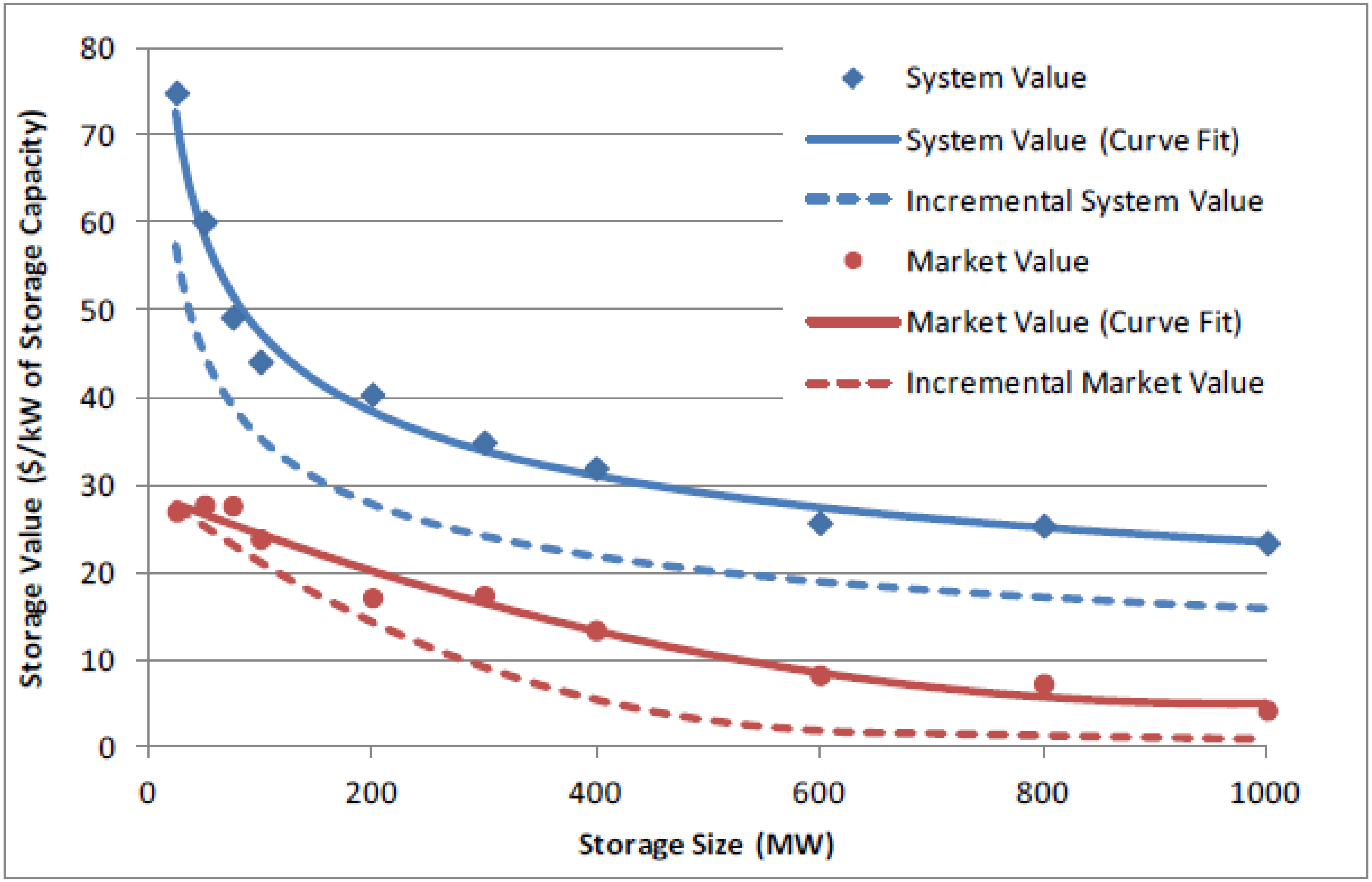


Figure 4-7. Storage operational value as a function of size for an energy-only device

Denholm, P., Jorgenson, J., Hummon, M., Jenkin, T., Palchak, D., Kirby, B., Ma, O. and O'Malley, M.J., "The Value of Energy Storage for Grid Applications", National Renewable Energy Laboratory, Technical Paper NREL/TP -6A20-58465, May 2013.
http://www.nrel.gov/docs/fy13osti/58465.pdf

Storage play that went wrong

Mark O'Malley, Chet Lyons, Brendan McGrath, Keith McGrane, NY, July 2011

Flywheel Energy Storage Lives On at Beacon Power

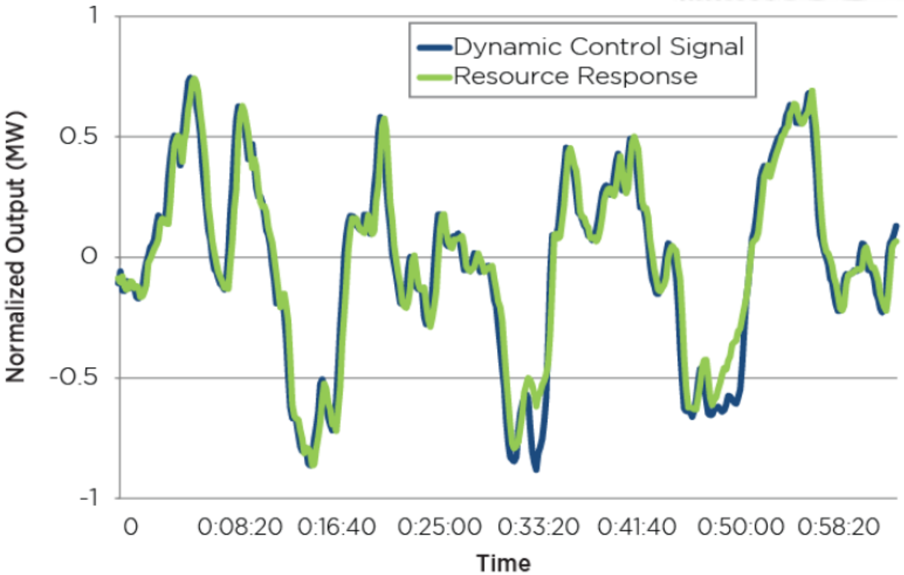
An update on Beacon, emerging from bankruptcy to work the frequency regulation markets

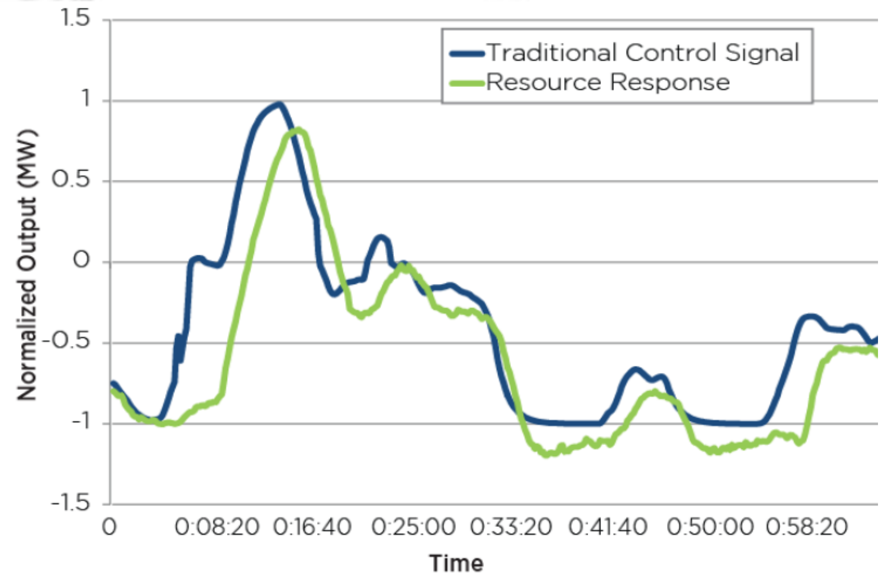
Eric Wesoff
May 31, 2013

The DOE loan program had its obvious big losers (Solyndra), its seemingly big winners (Tesla), and firms like Beacon Power, which are still works in

http://www.greentechmedia.com/articles/read/Flywheel-Energy-Storage-Lives-On-at-Beacon-Power

Not All Megawatts are Created Equal

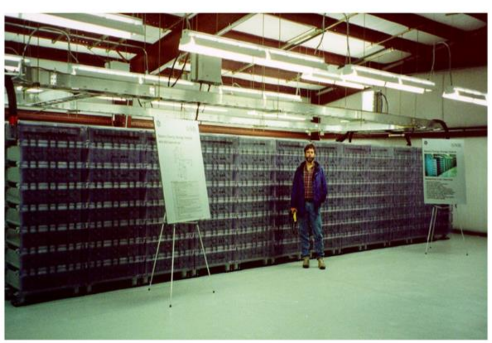


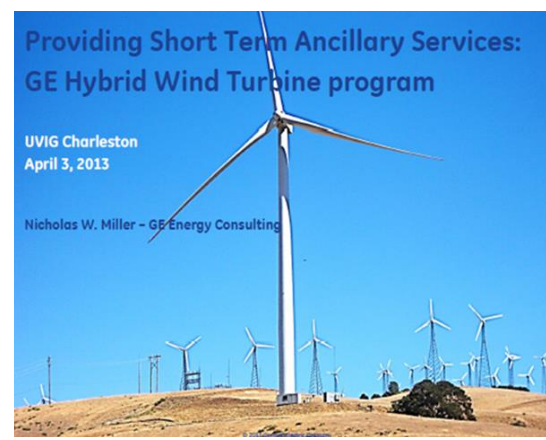


Energy Storage

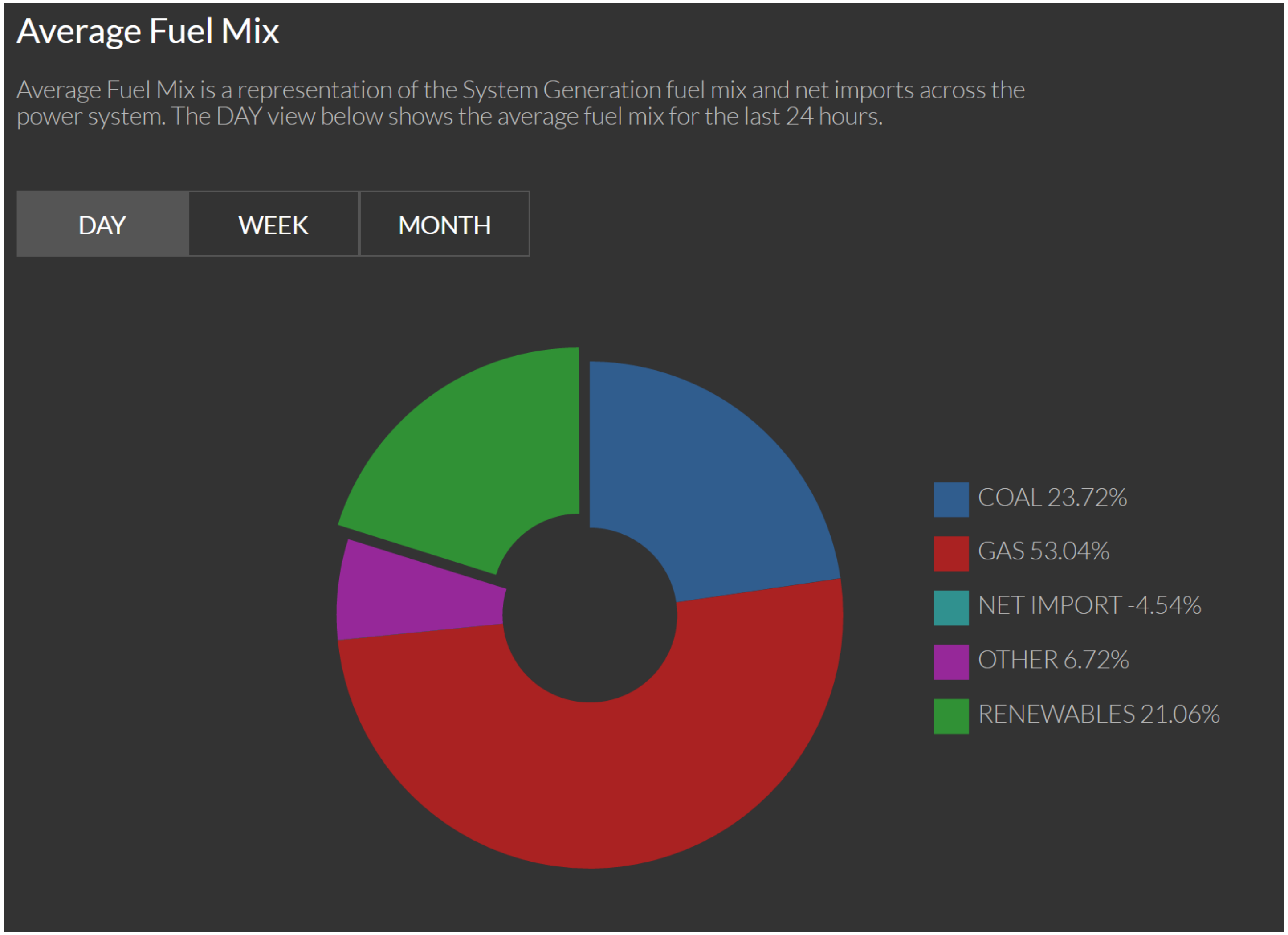
Steam Unit

Scott Baker, Energy Storage: Balancing the 21st Century Grid, UVIG, Oct 2015.

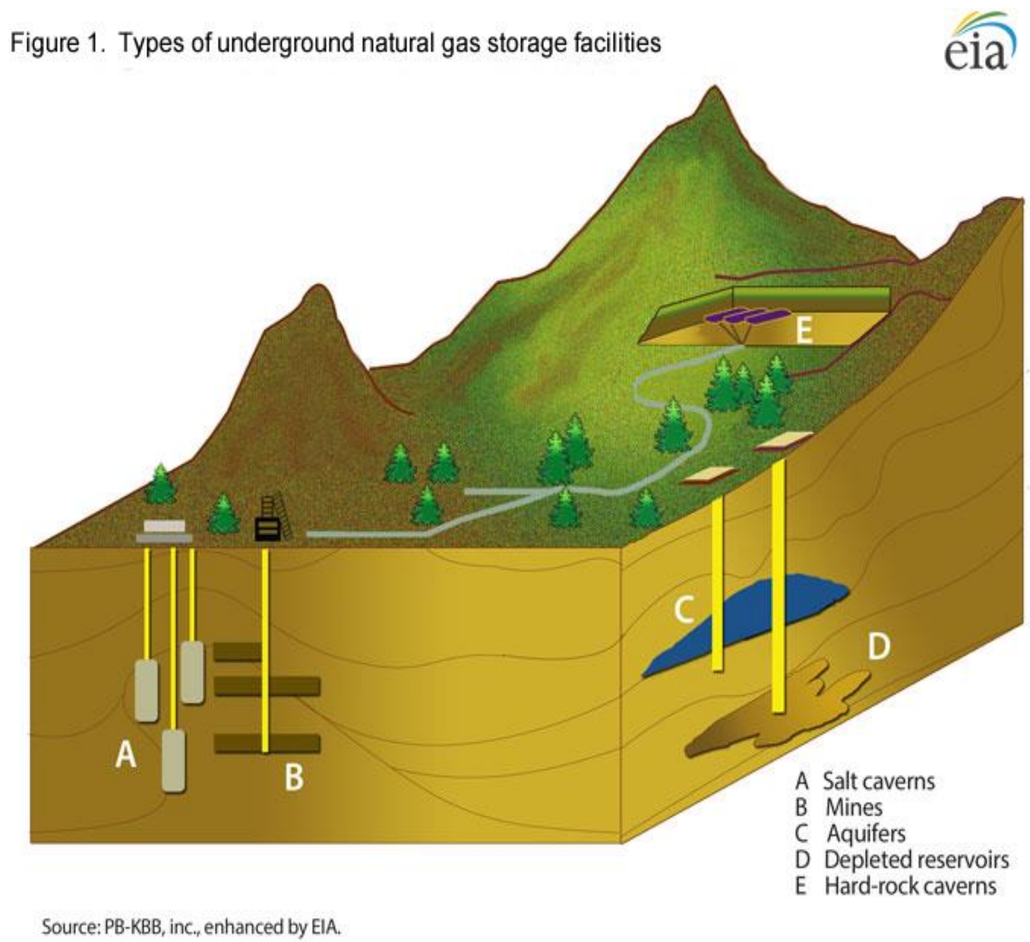




Fuel Mix Ireland Dec 4th 2016

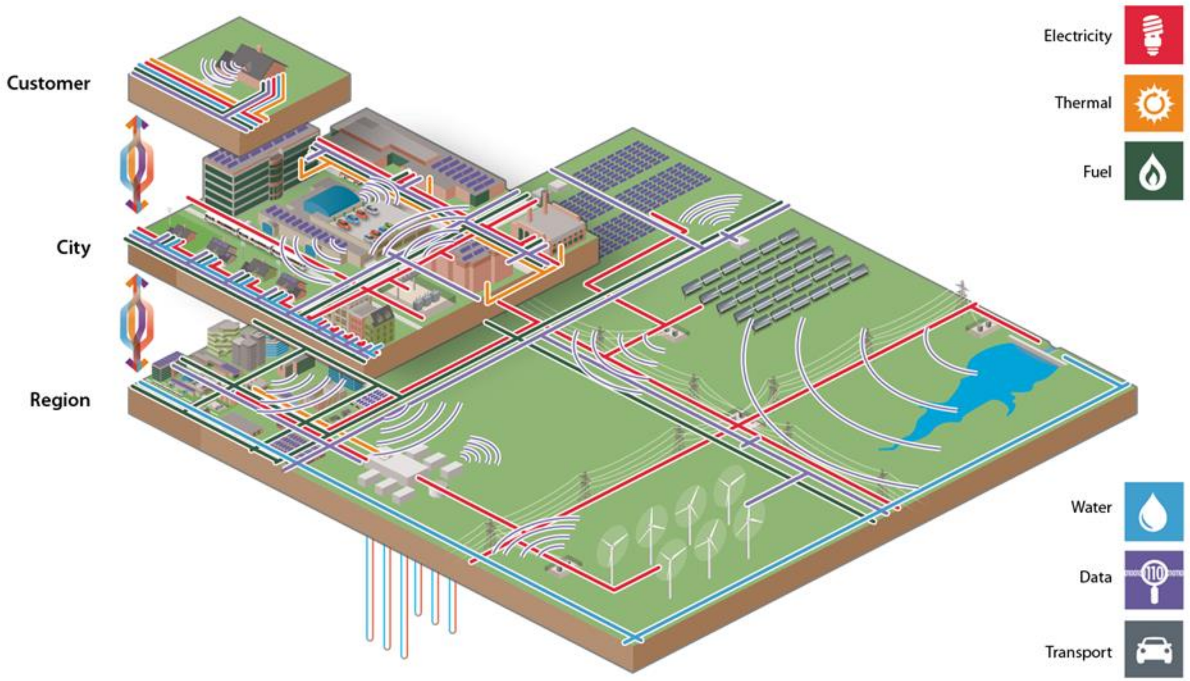


Gas grids have storage



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

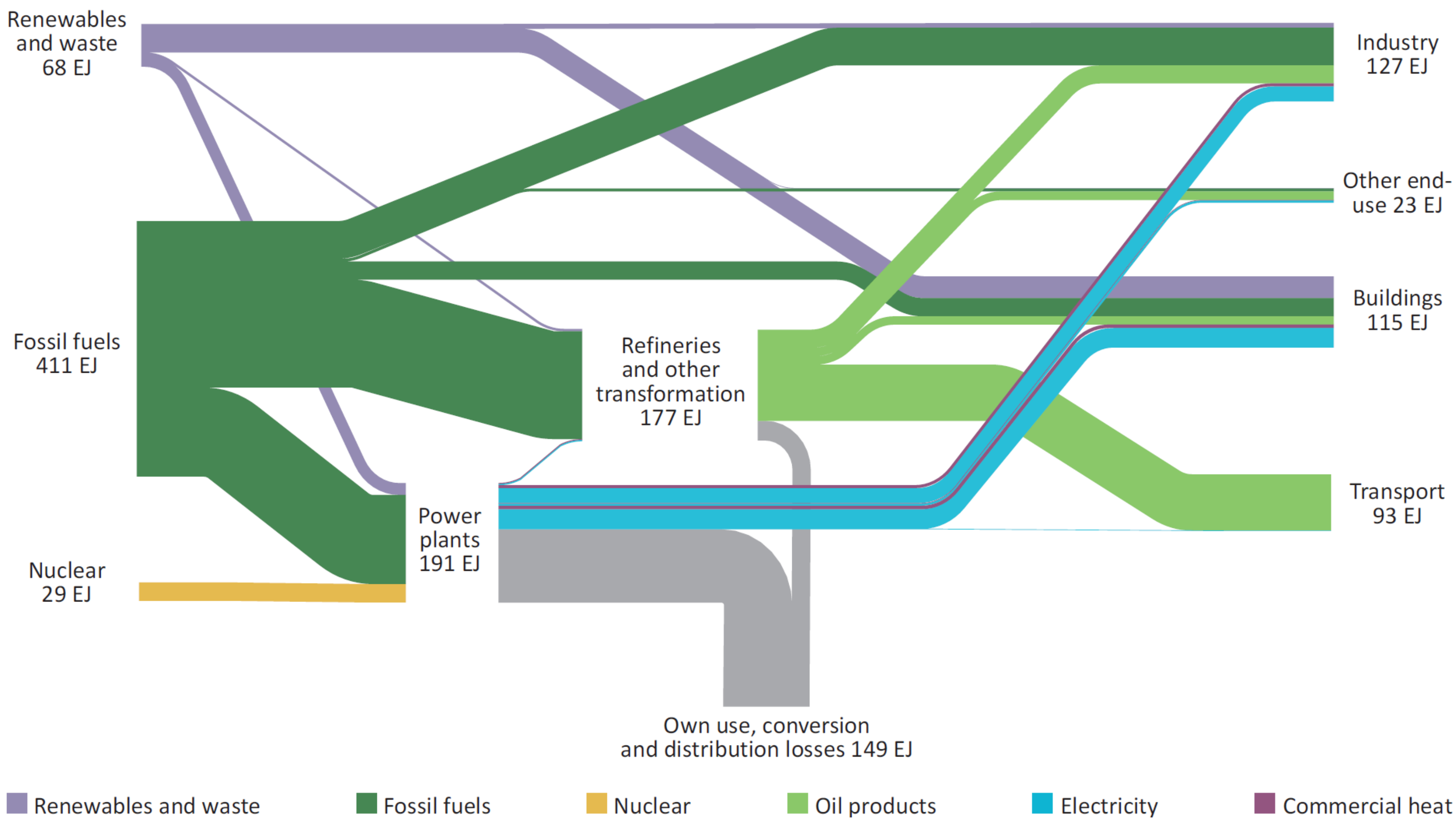
Energy Systems Integration



- **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**

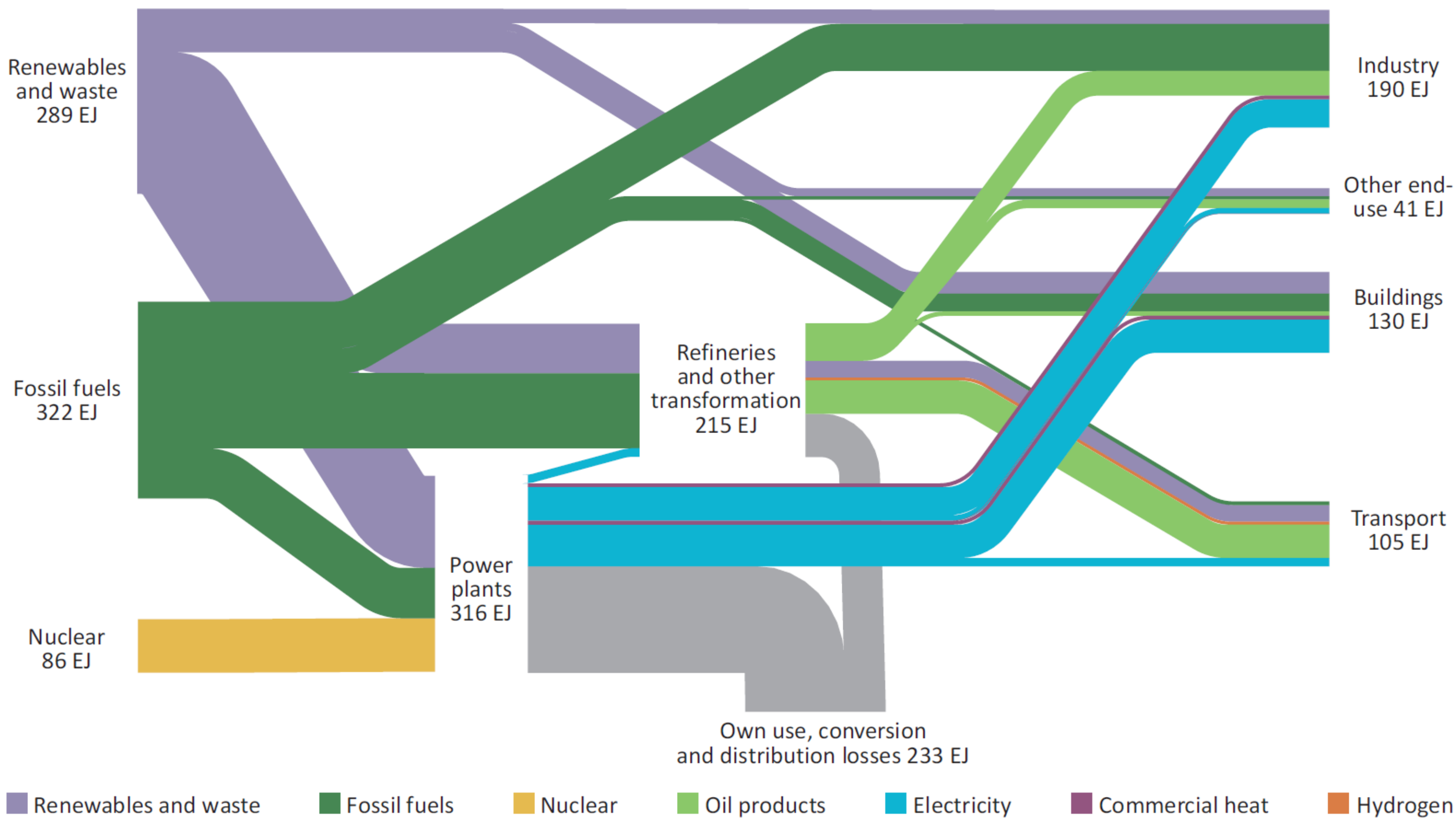
iiESI International Institute™ for Energy Systems Integration

The global energy system today



Dominated by fossil fuels in all sectors: (Source IEA)

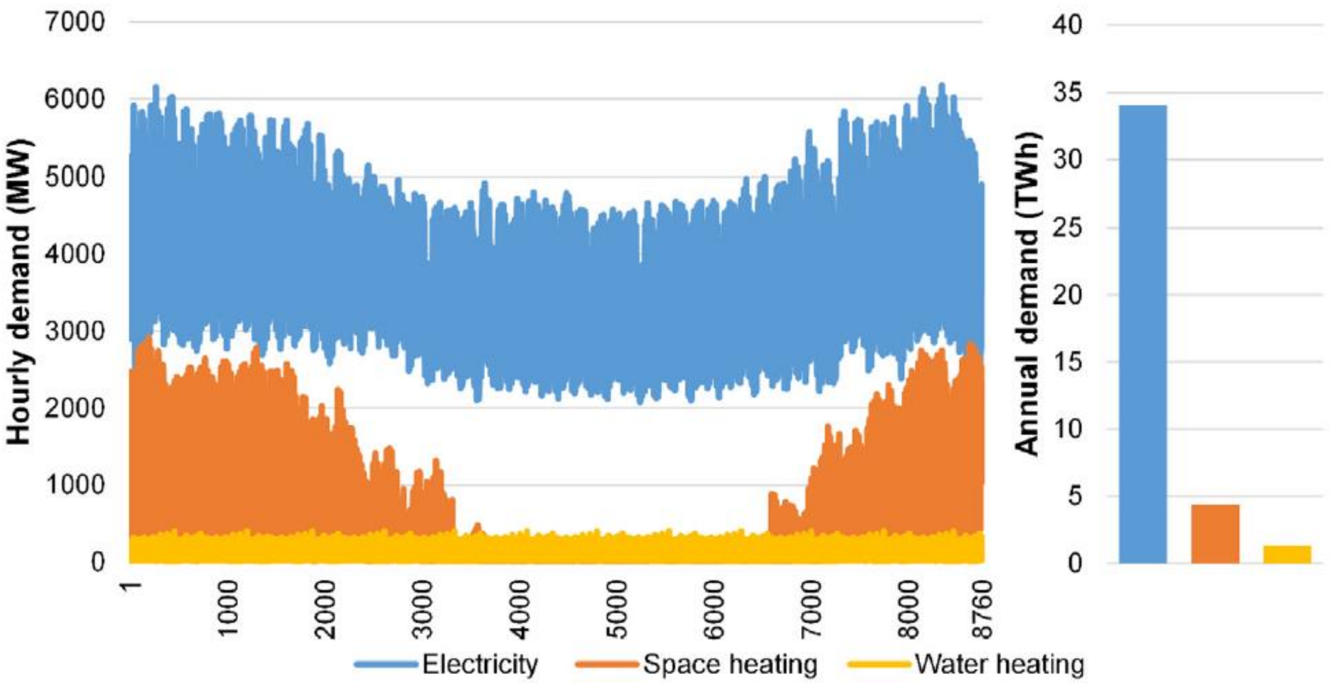
The future low-carbon energy system



The 2DS in 2050 shows a dramatic shift in energy sources and demands: (Source IEA)

Look at heat and demand management

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



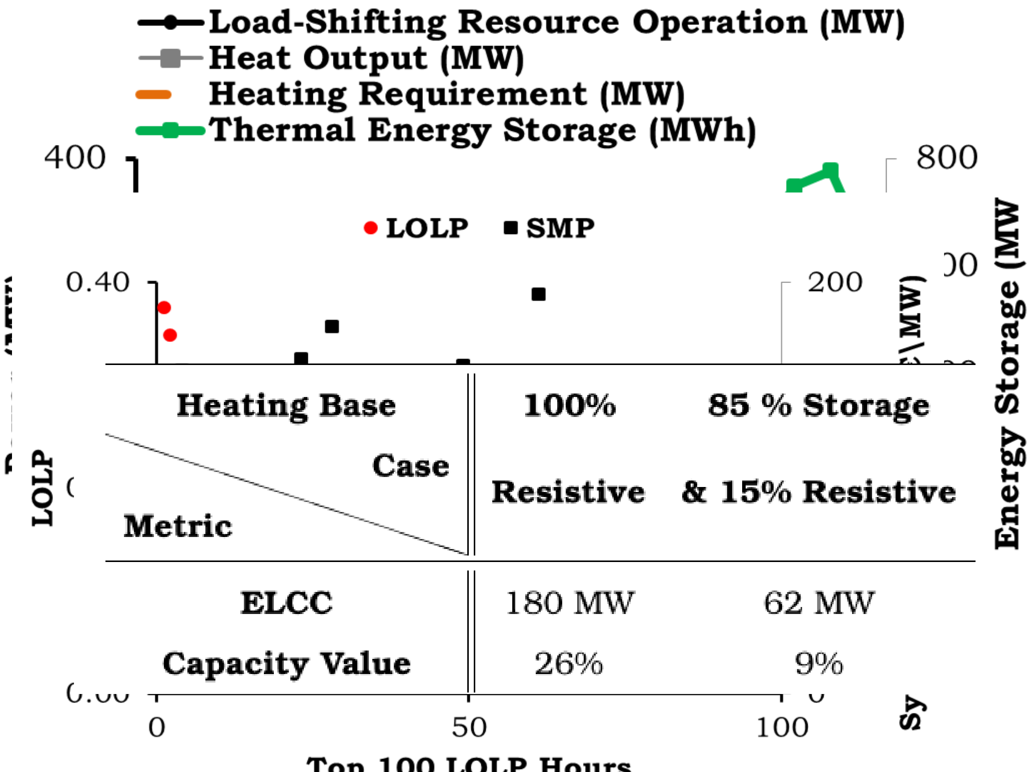
Note: The space heating demand shown is for well-insulated buildings (<75 kWh/m^2/year)

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.

Load shifting (thermal electric storage) in Ireland

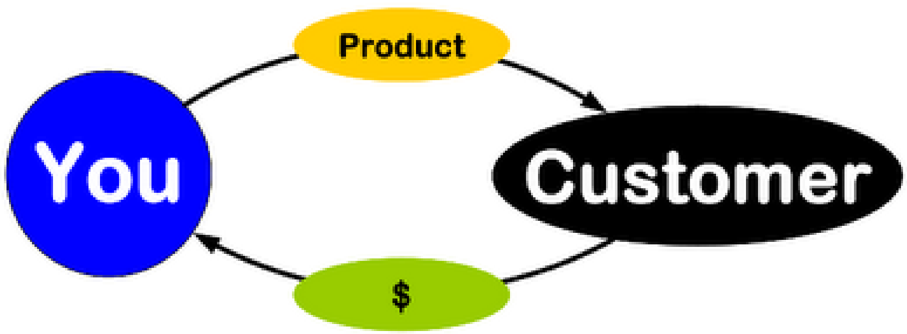
- Capacity value of resource is limited because:
- Consumer requirements



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, In Review

Demand response - the “consumer” and the “business model”



- Nolan, S and O’Malley, M.J., “Challenges and barriers to demand response deployment and evaluation”, Applied Energy, Vol. 152, pp.1-10, 2015.
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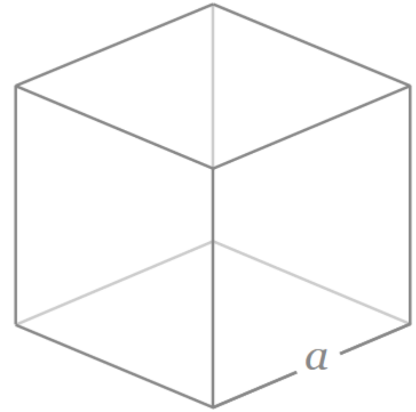
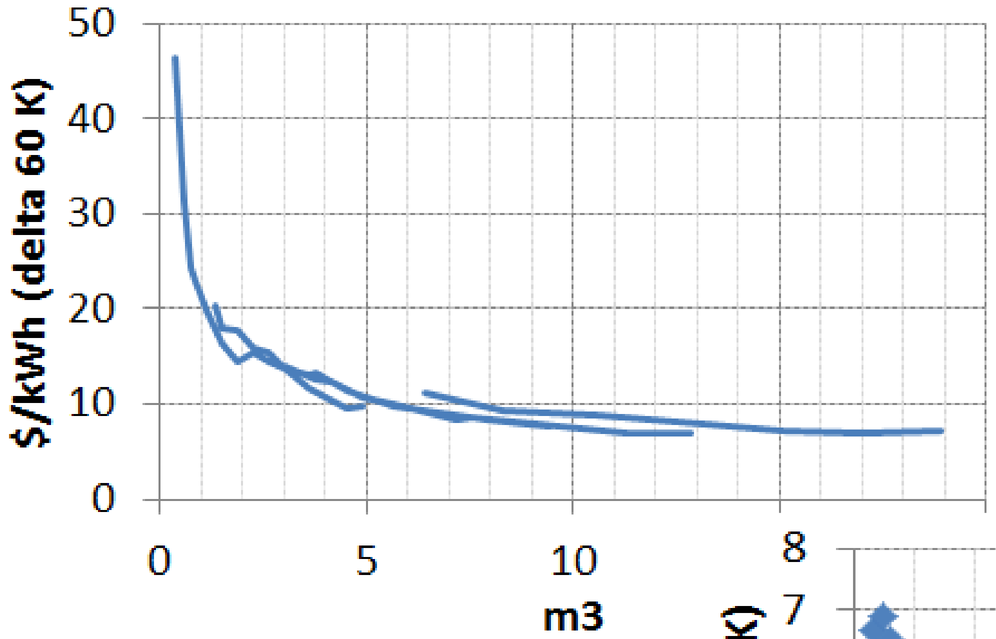
Heat storage is all about scale



$$V = a^3$$

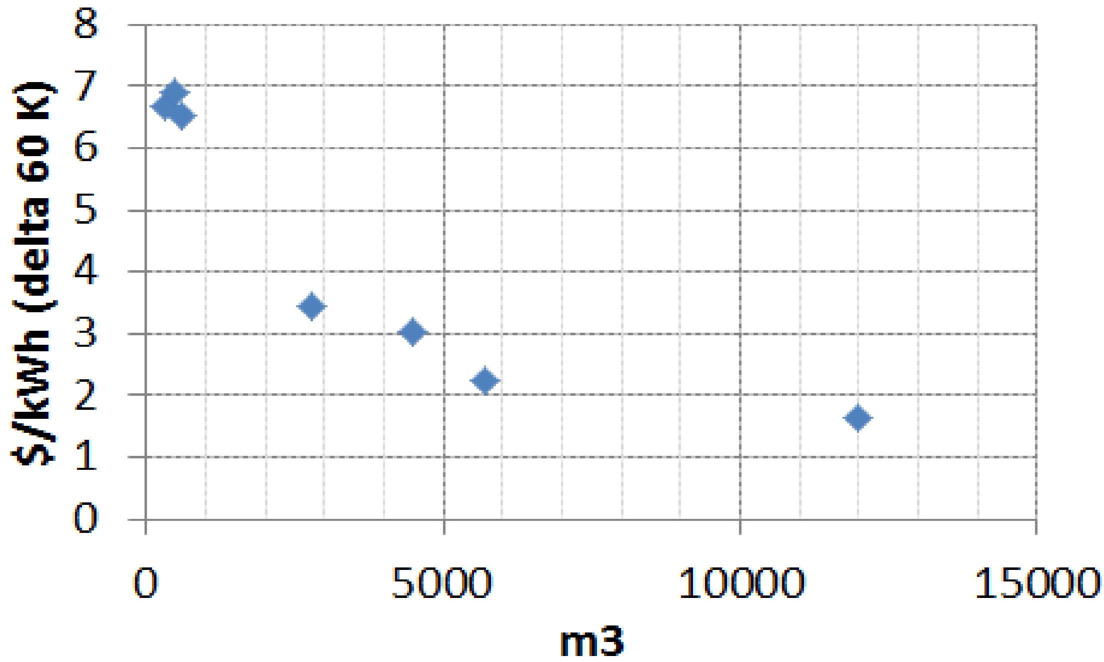
$$A = 6a^2$$

Cost of heat storage



Source: JRC 2012

Source: Market data



Source: Juha Kiviluoma

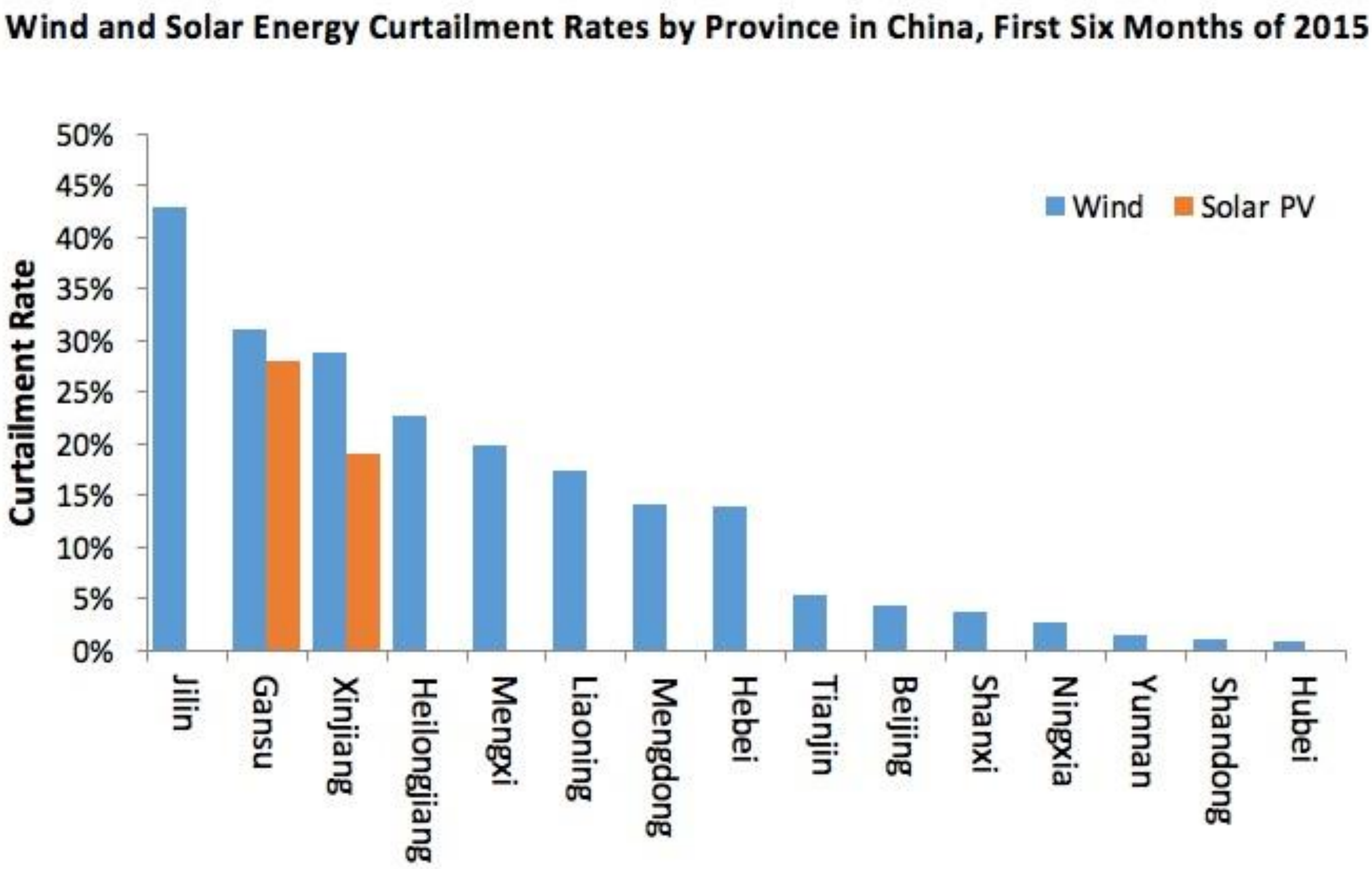
How they do it in China

- 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

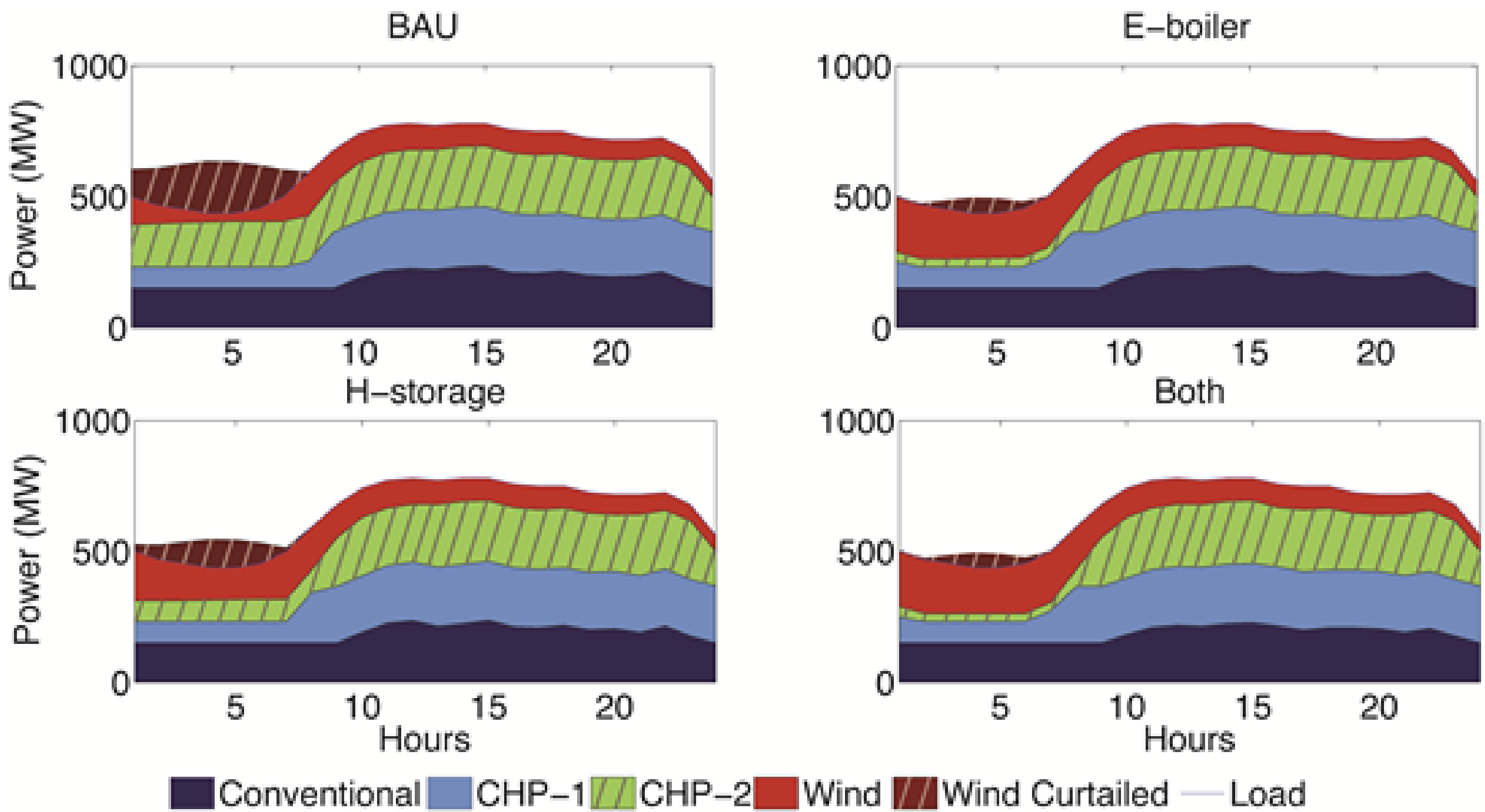
Chen, X., Kang, C., O'Malley, M.J., Xia, Q., Bai, J., Liu, C., Sun, R., Wang, W. and Hui, L., "Increasing the Flexibility of Combined Heat and Power for Wind Power Integration in China: Modeling and Implications", IEEE Transactions on Power Systems, Vol. 30, pp.1848-1857, 2015.

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.

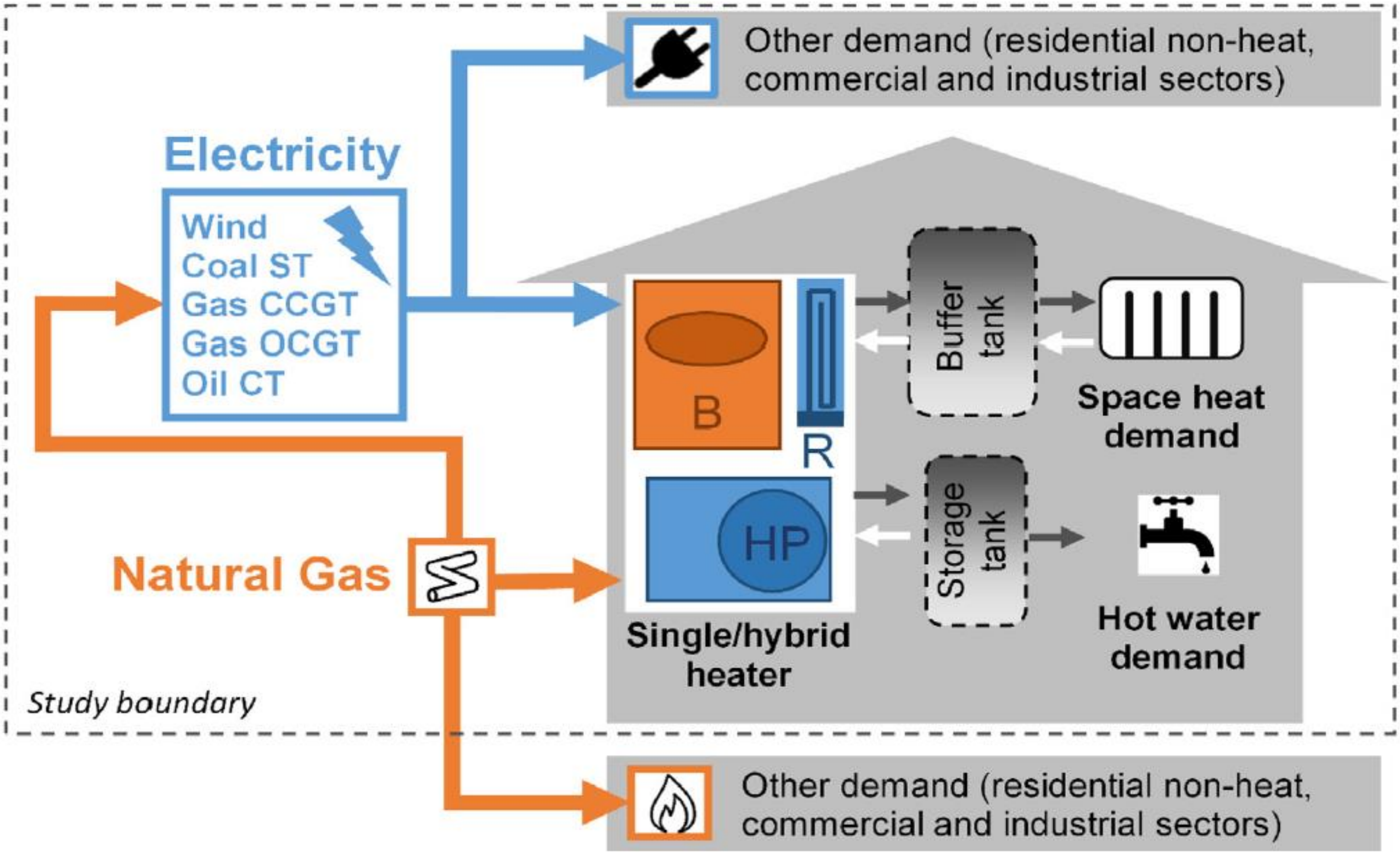


Fig. 1. Schematic of the integrated power-residential heat system studied.

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.

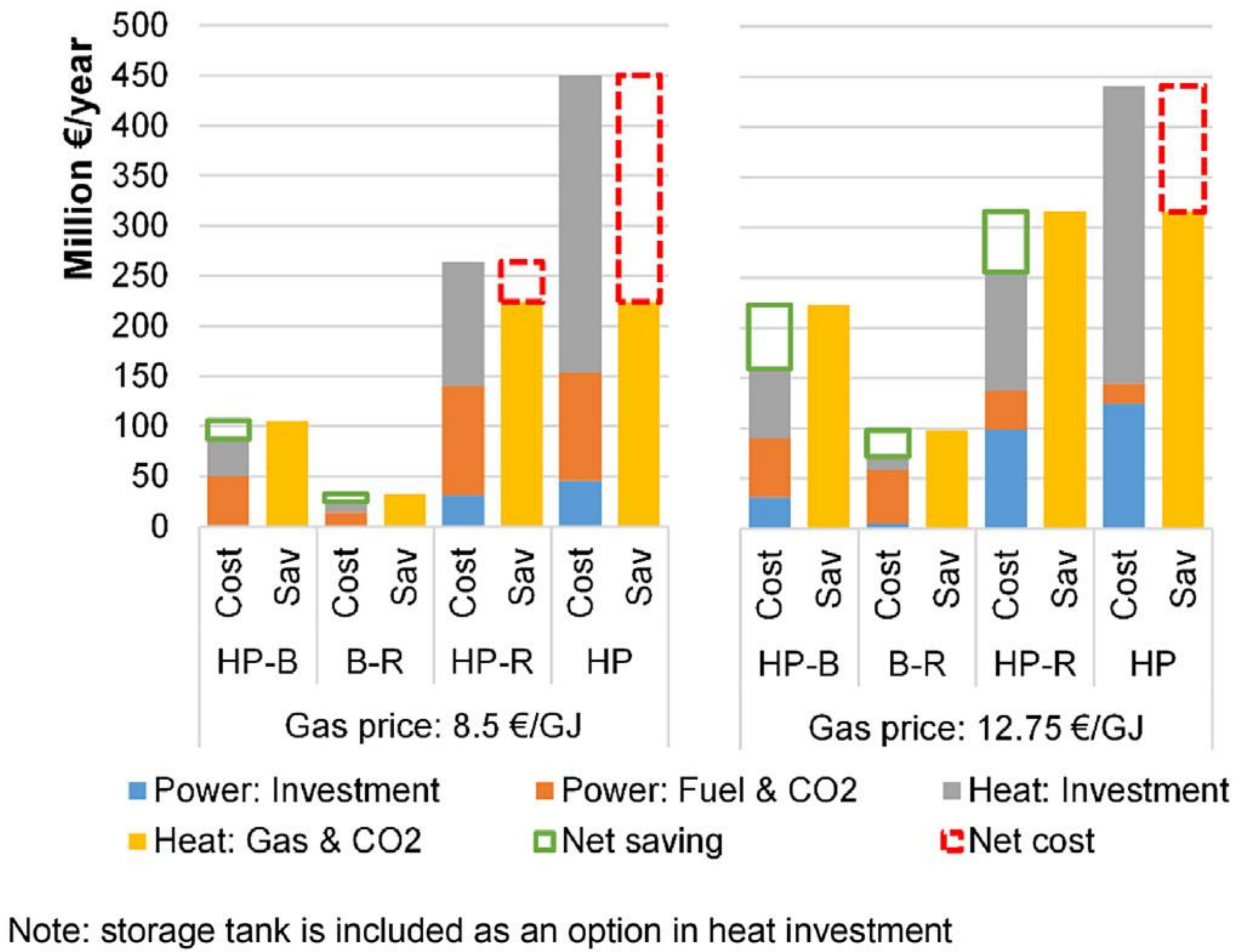
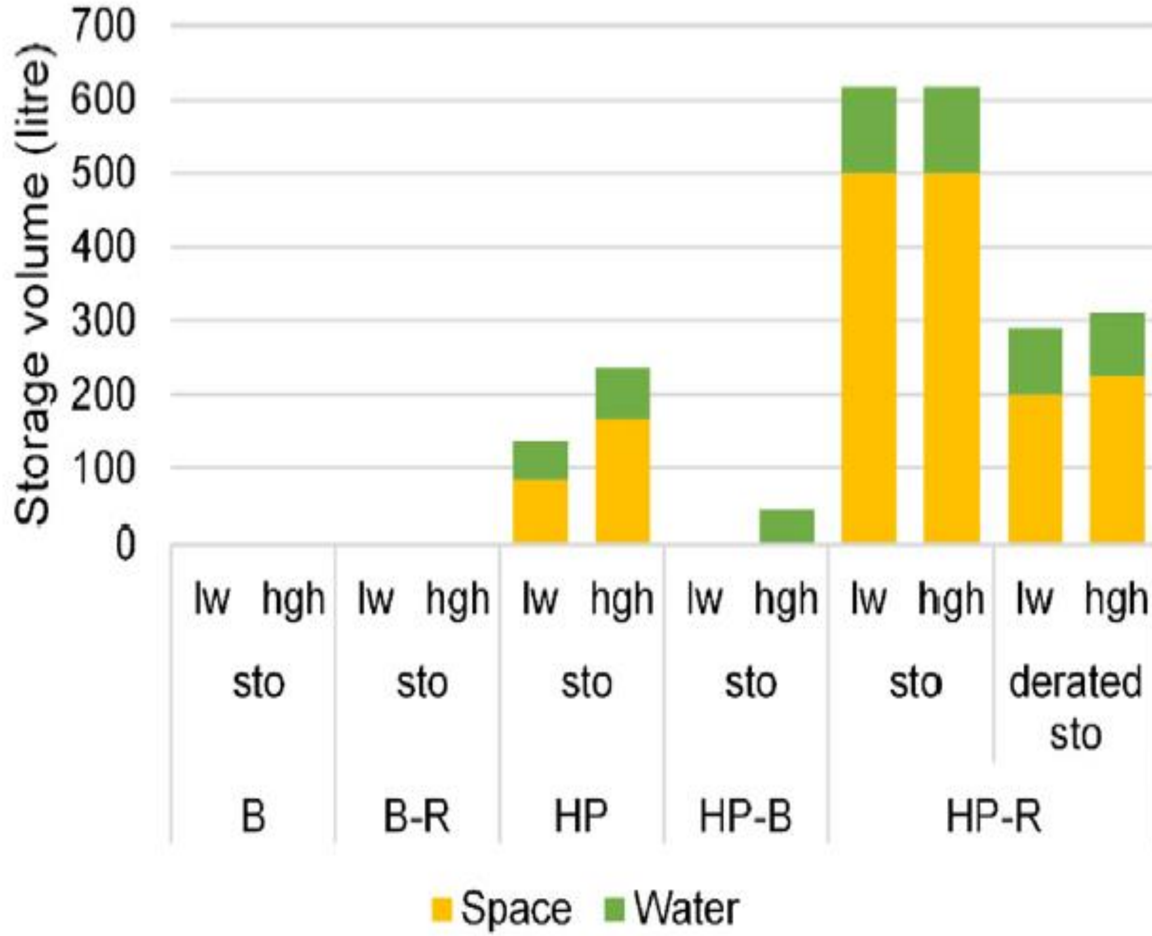


Fig. 5. Cost breakdown for deployment of different heating technologies (B-R, HP, HP-B, HP-R) relative to gas boiler (B).

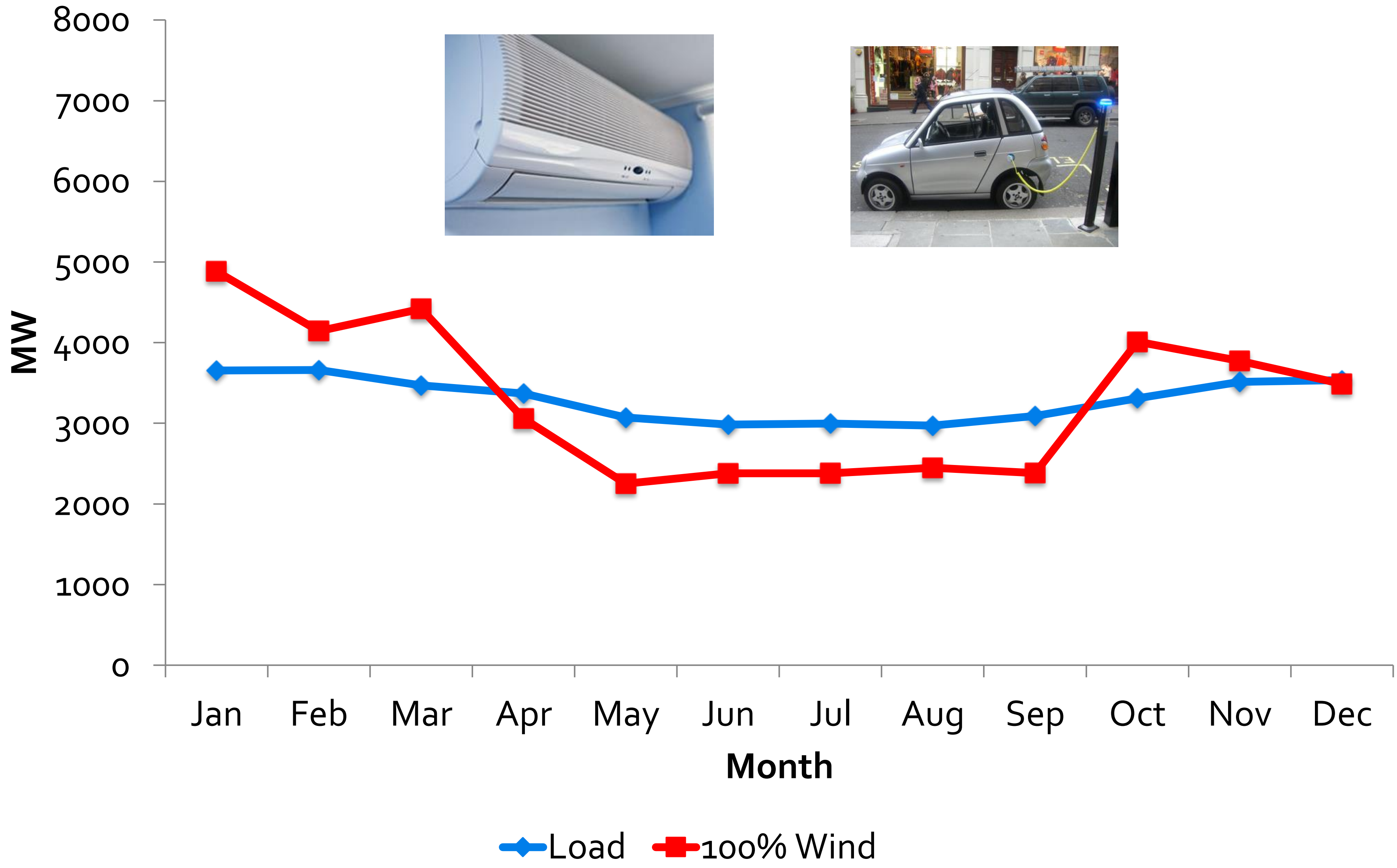


Note: lw: low gas price; hgh: high gas price; de-rated sto: storage enabled but with 10% stationary losses

Fig. 9. Storage capacities build for different technologies (for well-insulated buildings and carbon price 30 €/ton).

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.

Design the demand side to be flexible



What about solar

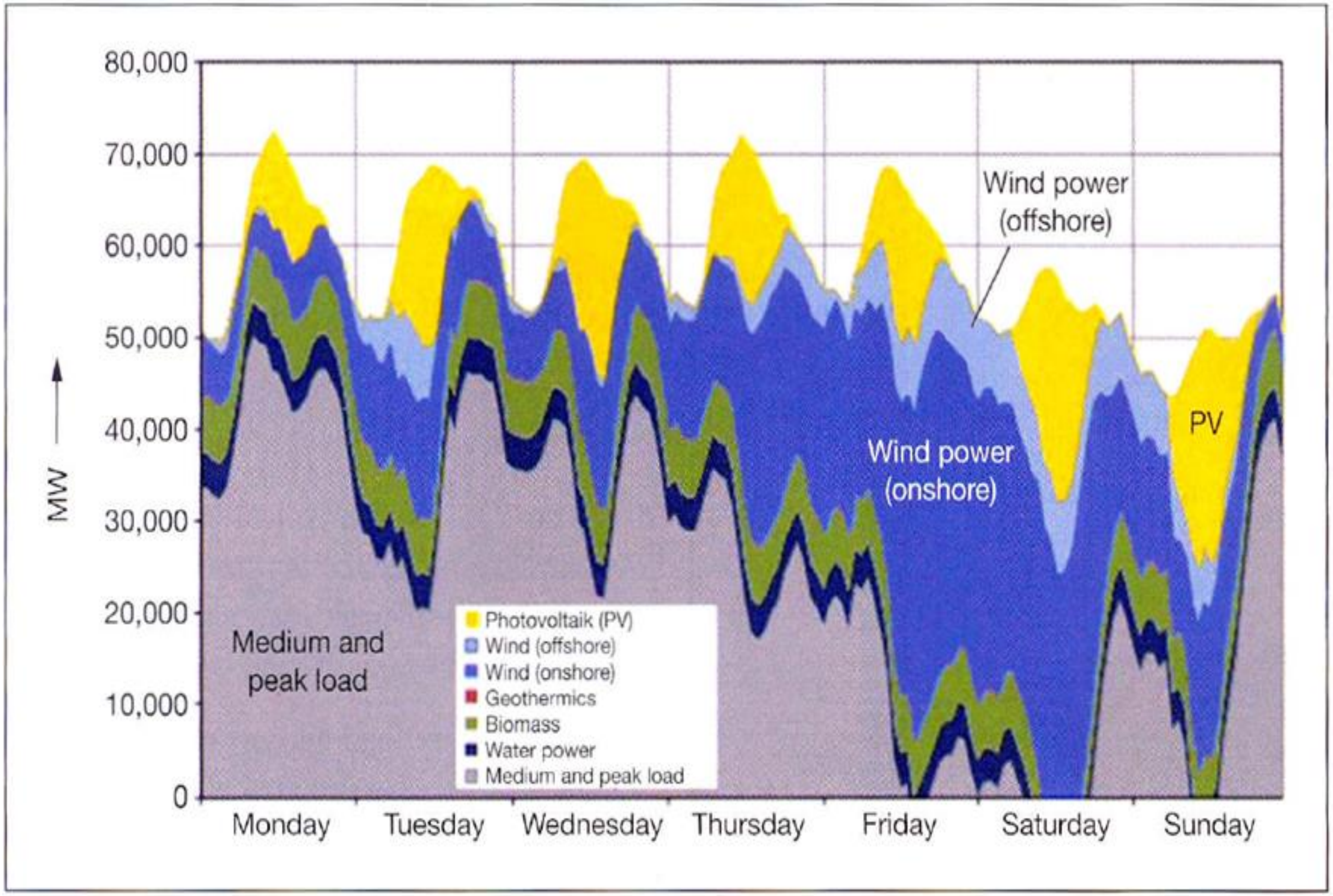


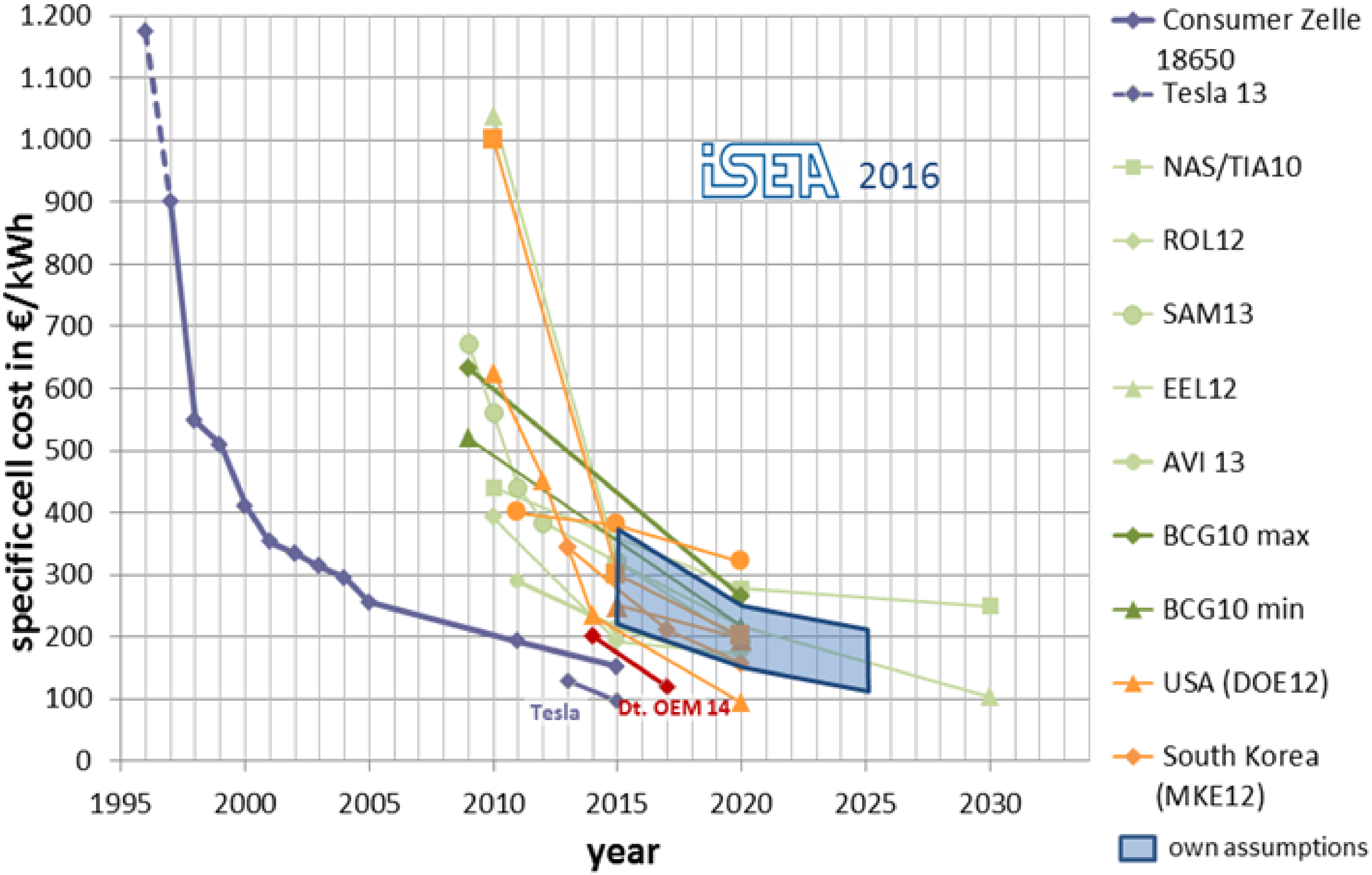
Figure 1. Power generation across one week in July 2020, BEE scenario [6].

Source: **William D'haeseleer**

Storage technology costs

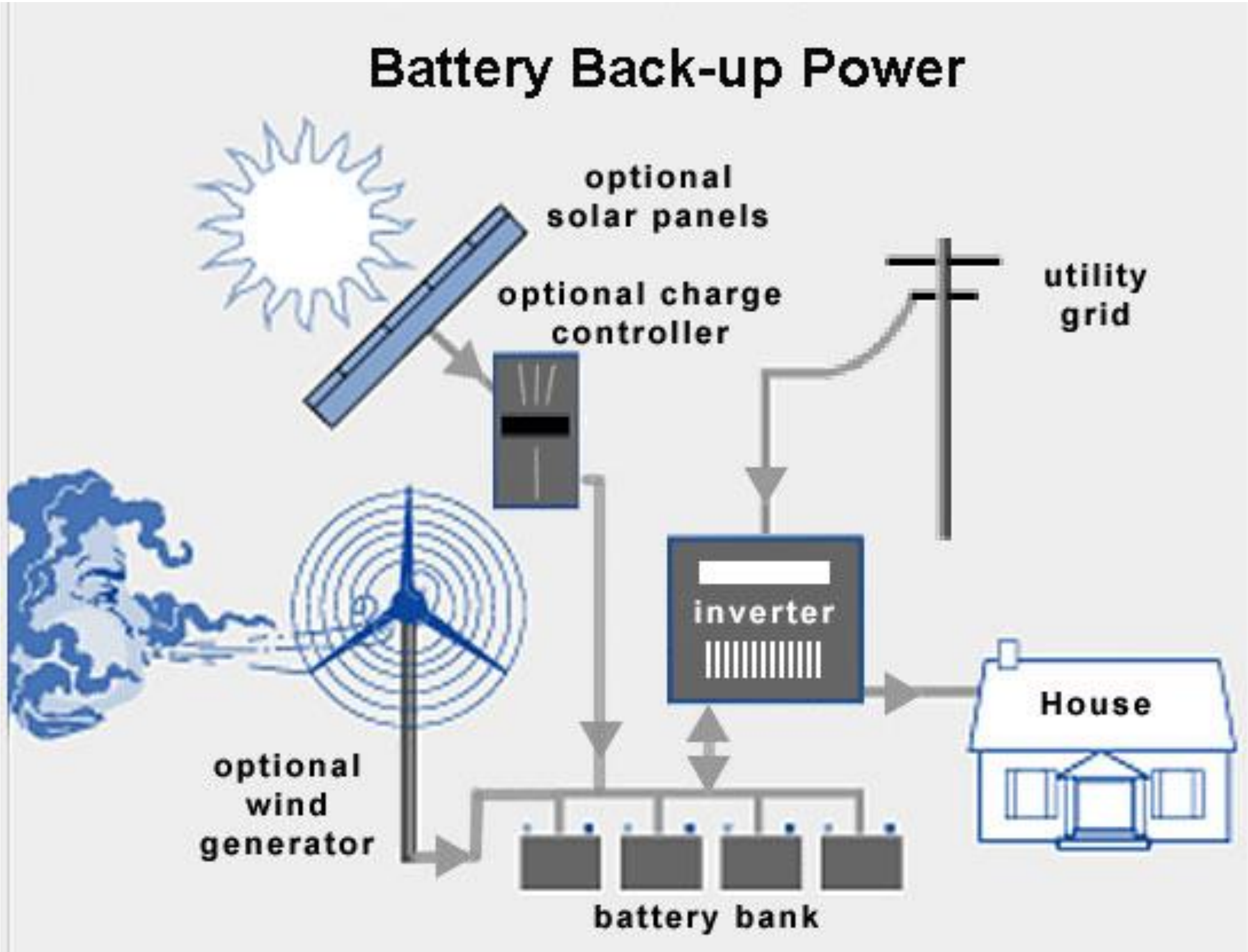
European Academies easac Science Advisory Council

Technology	Potential for future cost reductions
PHS	Low
Compressed air energy storage	Medium
Flywheels	Medium
Lead acid batteries	Low
Li-ion batteries	High
Sodium ion batteries	High
Redox flow batteries	Medium / High
Sodium sulphur batteries	Medium
Super capacitors	Medium
Power to gas to power	Medium

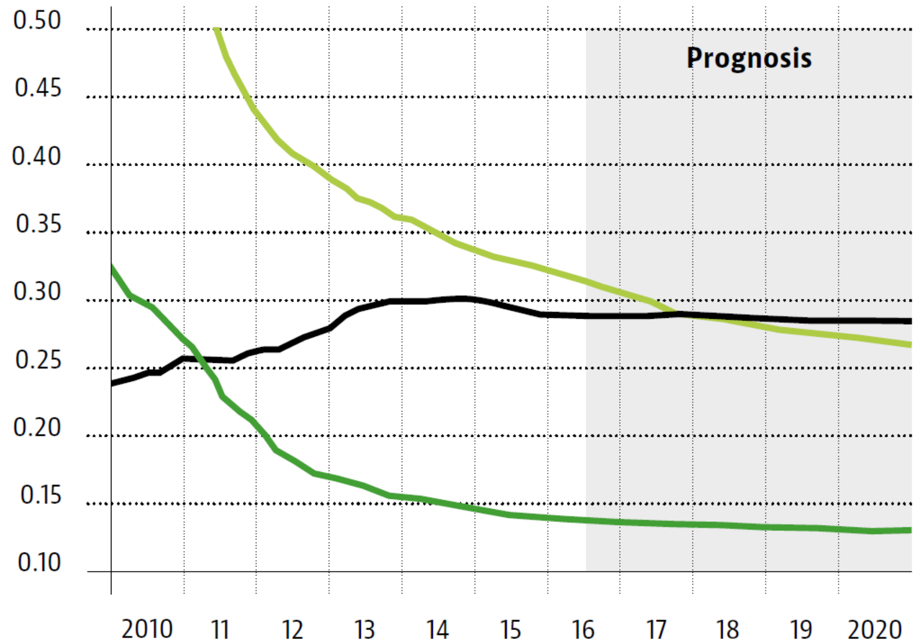


Institute for Power Electronics and Electrical Drives (ISEA)

Going off grid



From Grid Parity to Battery Parity
(in EUR/kWh)

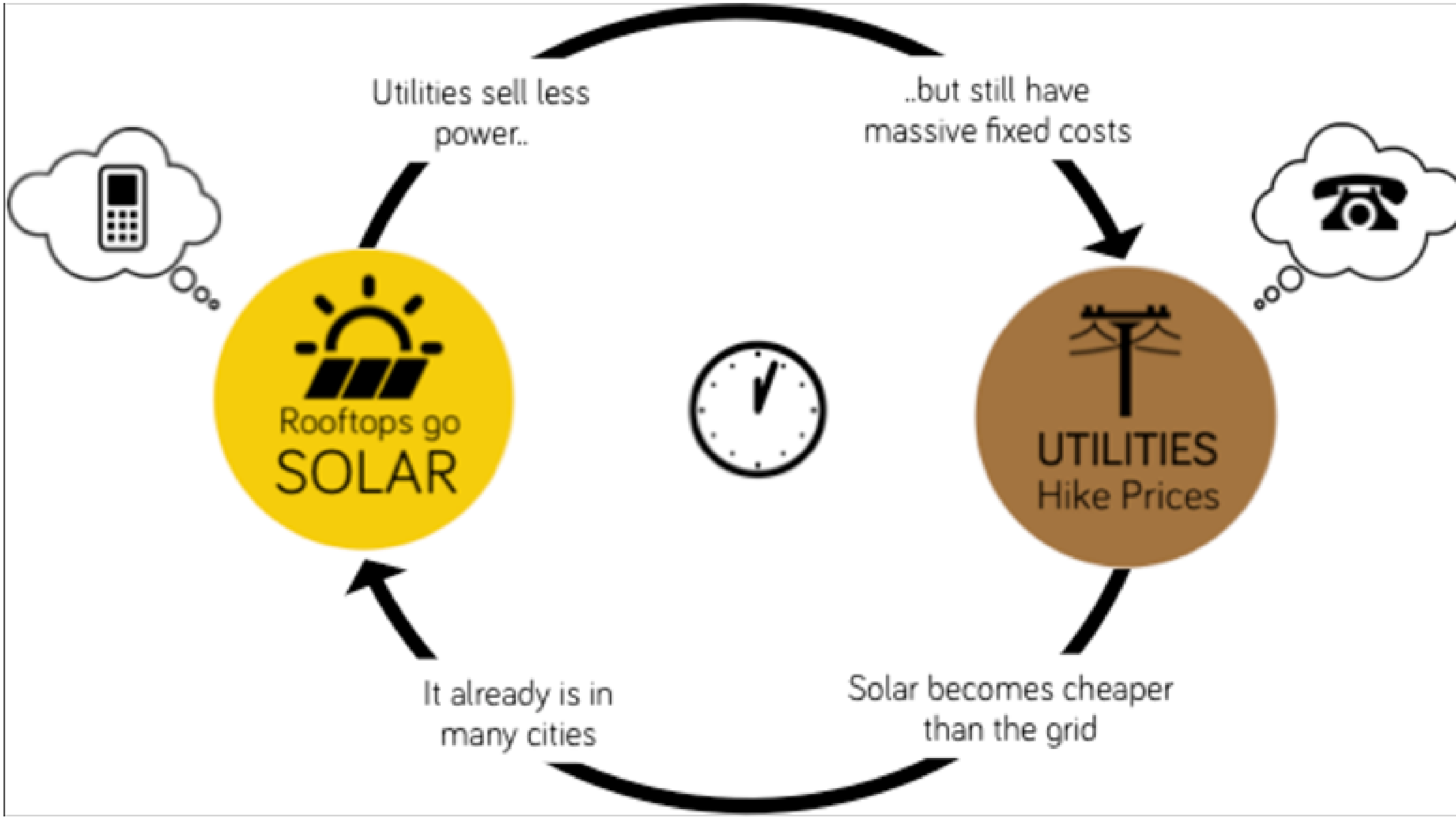


- Electricity price for households (2.5-5 MWh/a)
- Electricity costs for PV*
- Electricity costs for PV + Battery**

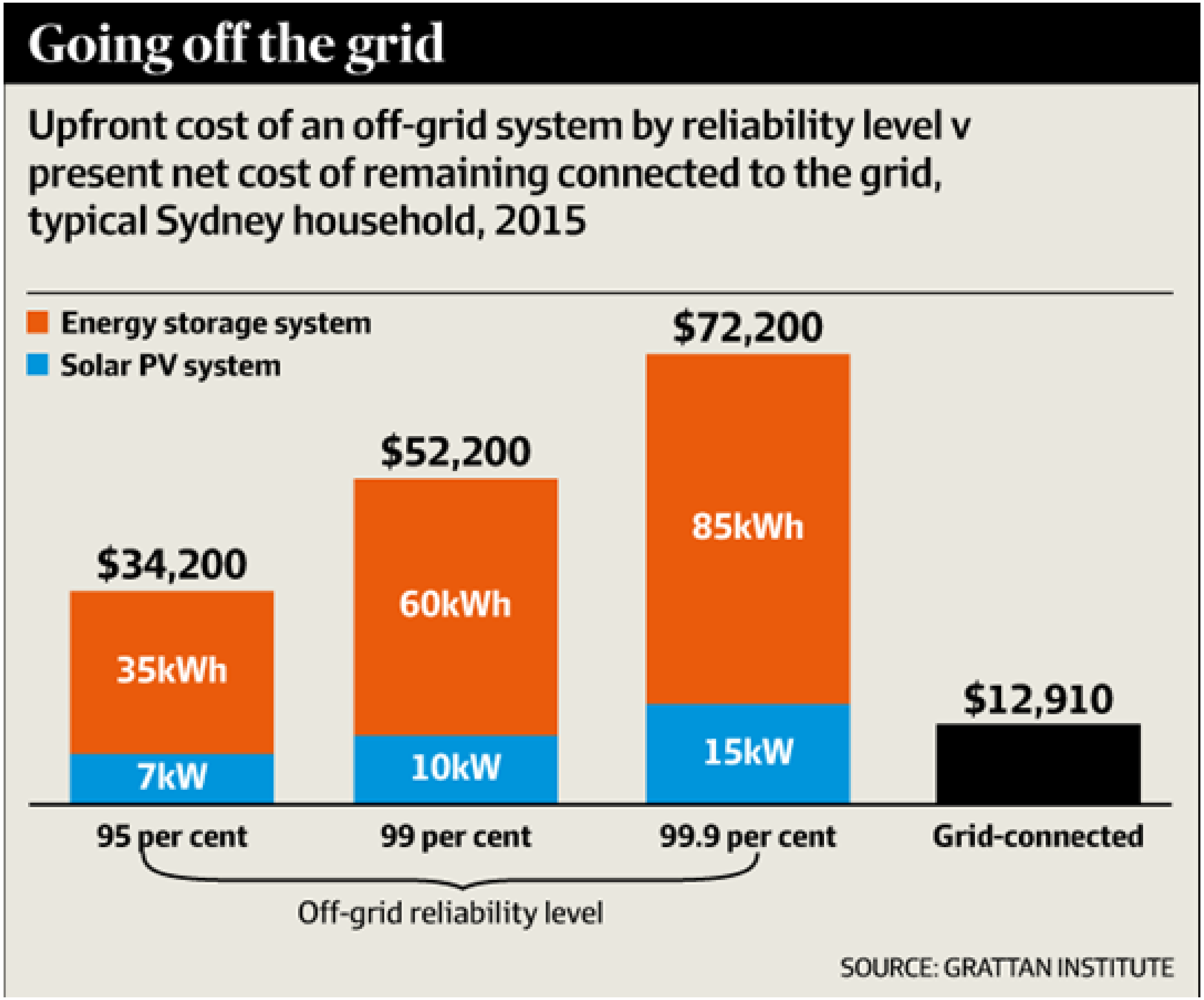
*Model calculation for rooftop systems, based on 802 kWh/kWp (Frankfurt/Main), 100% financing, 6% interest rate, 20 year term, 2% p.a. O&M costs
** Based on 5,000 cycles , 87% efficiency
Sources: Own calculation; System Prices: BSW 2015; Model Calculation: Deutsche Bank 2010; Electricity Prices 2007-2015: Eurostat 2015; Electricity Prices 2016-2020: own estimate at 0.29ct/kWh

Source: German Trade and Investment

The spiral of death



Going off grid is very expensive



Conclusions

- Storage and demand management have many potential roles in future energy systems
- In electricity, dedicated storage is very expensive (capital & operations) and has many competitors – only applied in niche applications
- Battery technology is declining in cost (and/or improving efficiency) but has a long way to go before it becomes ubiquitous
- Demand management is more competitive than storage in many applications BUT it is constrained by the user
- Price distortions can cause perverse incentives and improper deployment of storage technology
- Great research topic - interdisciplinary is important
- Sound scientific advice to policy makers is important

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