# The Economics of Integrating Renewables

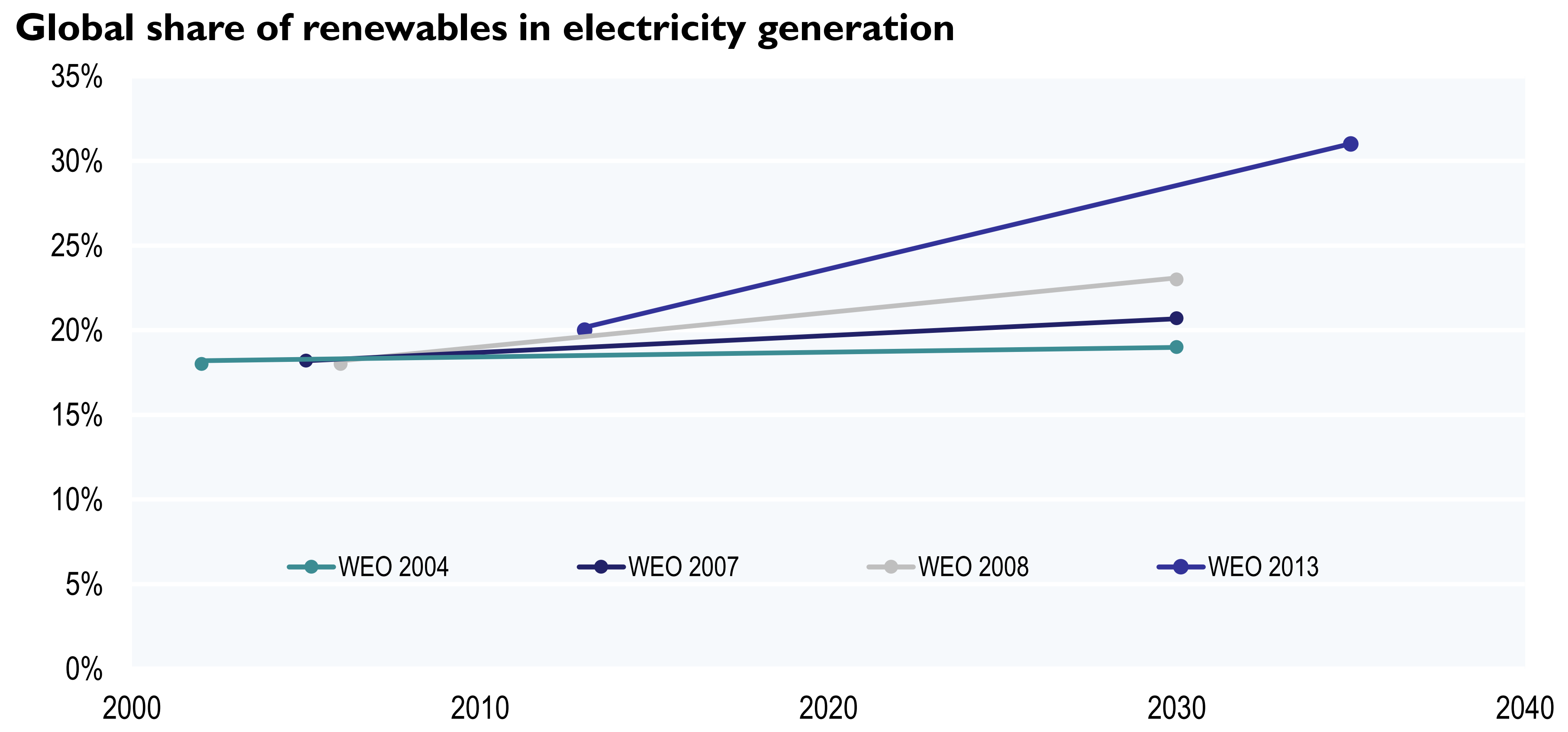
**Cameron Hepburn**
Professor of Environmental Economics
Smith School and INET at Oxford Martin School
University of Oxford and New College
Professorial Research Fellow, LSE

Oxford, 5 October, 2015

# Agenda

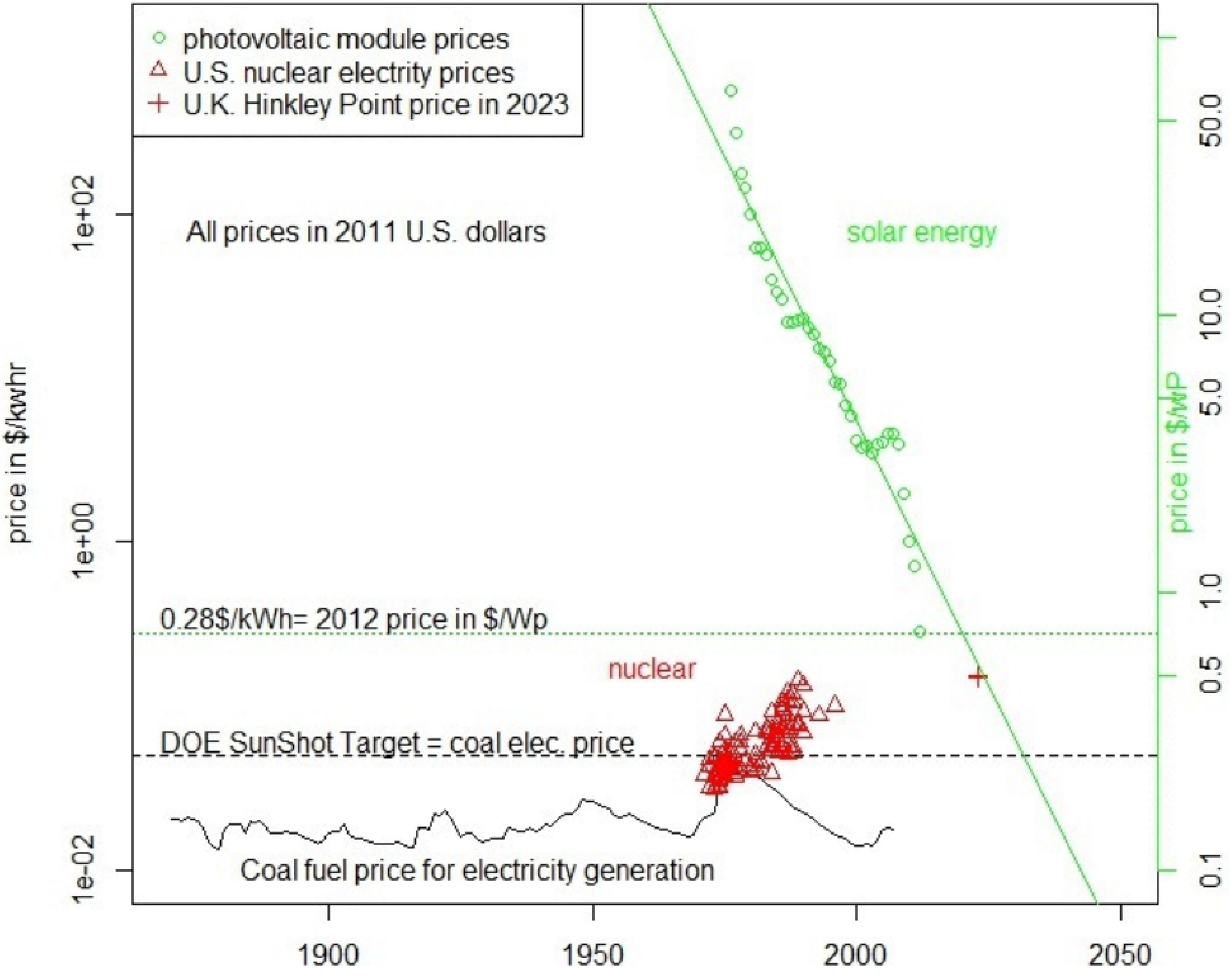
1. Economics of renewables without integration
2. Integration strategies and choices
3. Economic costs of integration
4. Conclusion

# Be warned: increases in renewables have surprised forecasters, such as the IEA, in the past



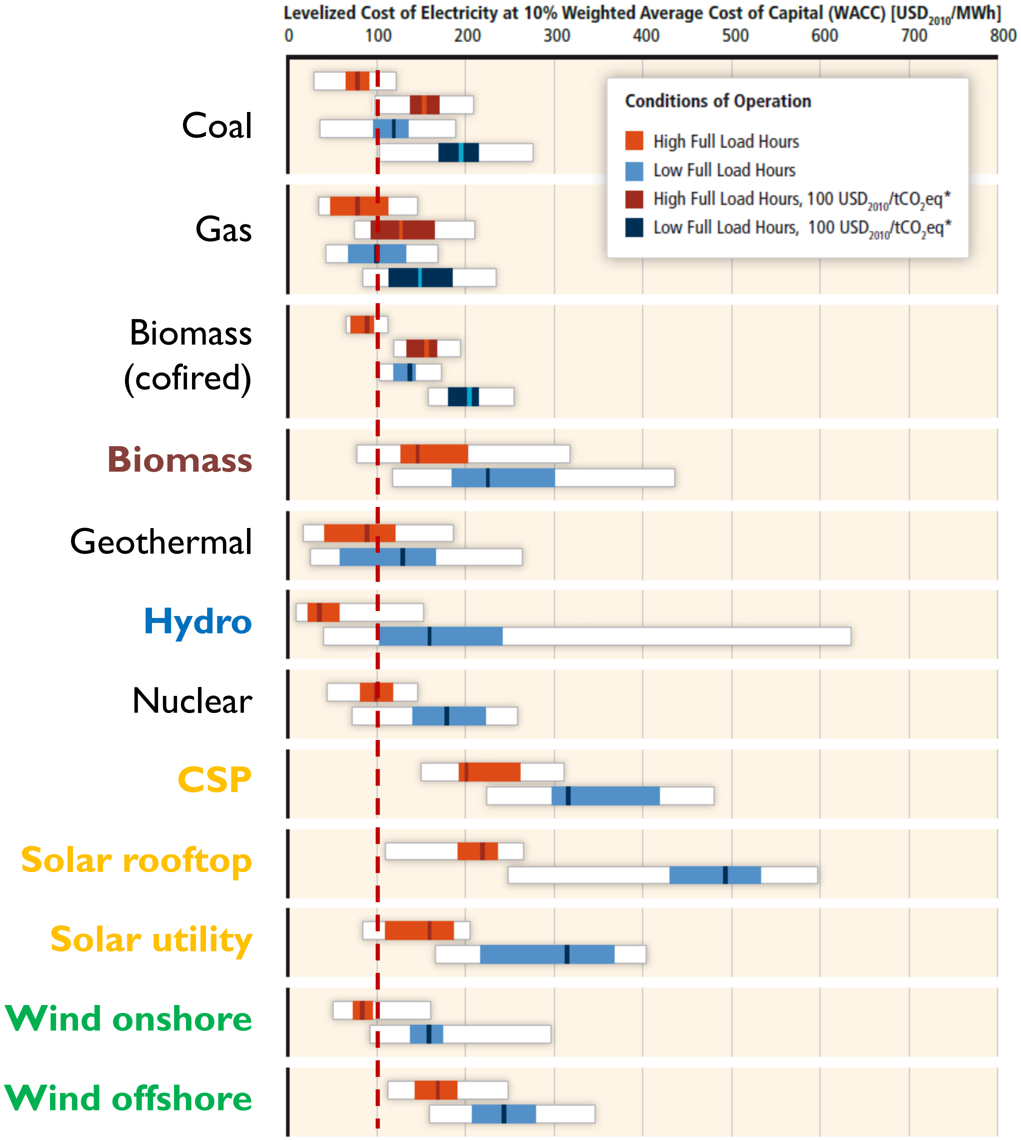
Source: IEA reference scenarios of WEO 2004, 2007, and 2008, and New Policies Scenarios in WEO 2013

# Cost of renewables (especially solar) have been falling faster than fossil fuels



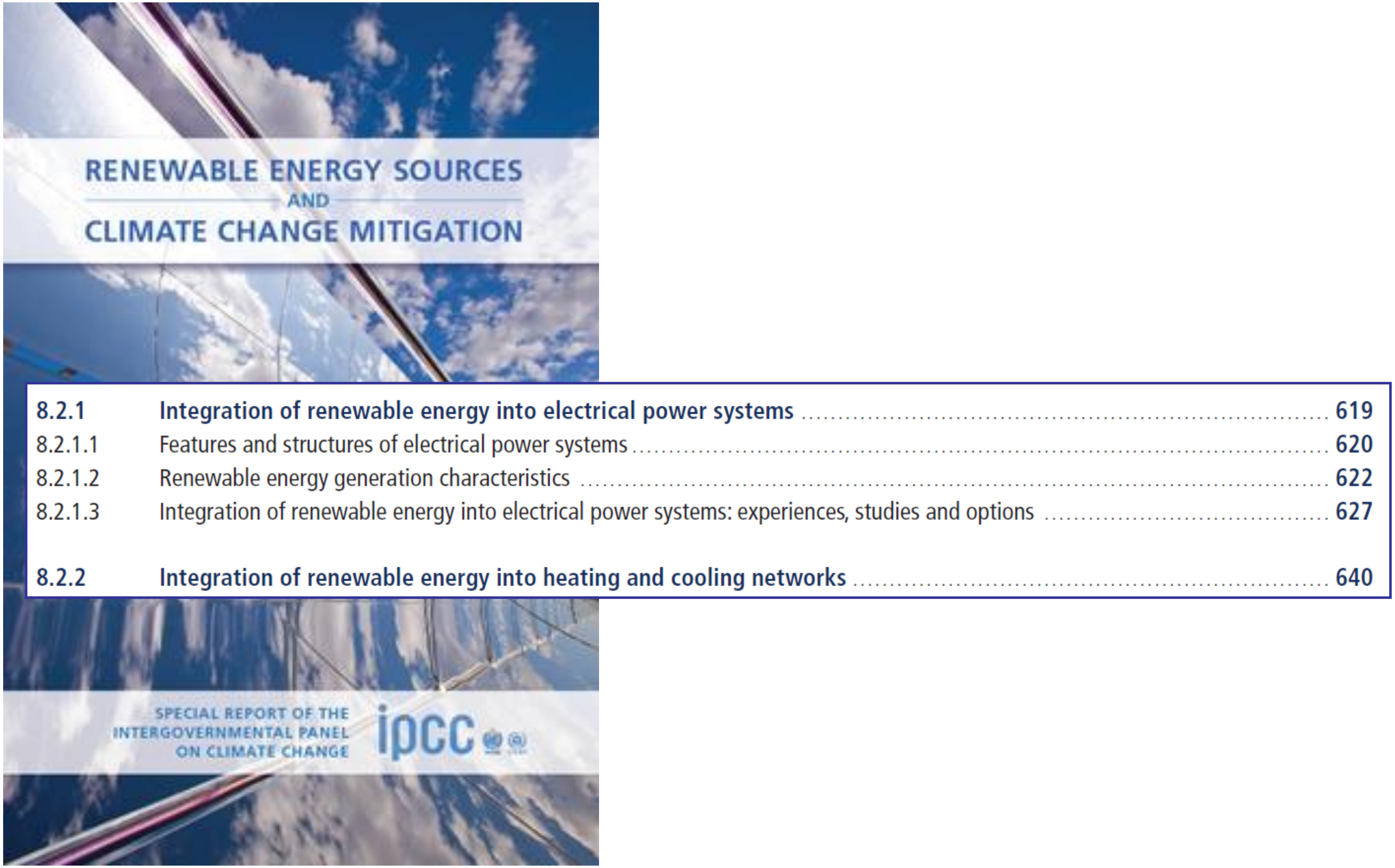
Source: Farmer and Lafond (2015)

# Now LCOE for renewables is getting close to fossil in some cases, *ignoring integration costs*



Source: IPCC (2014), Fifth Assessment Report

# In the enormous IPCC (2011) report on renewable energy, integration took only 21 of over 1000 pages



RENEWABLE ENERGY SOURCES
AND
CLIMATE CHANGE MITIGATION

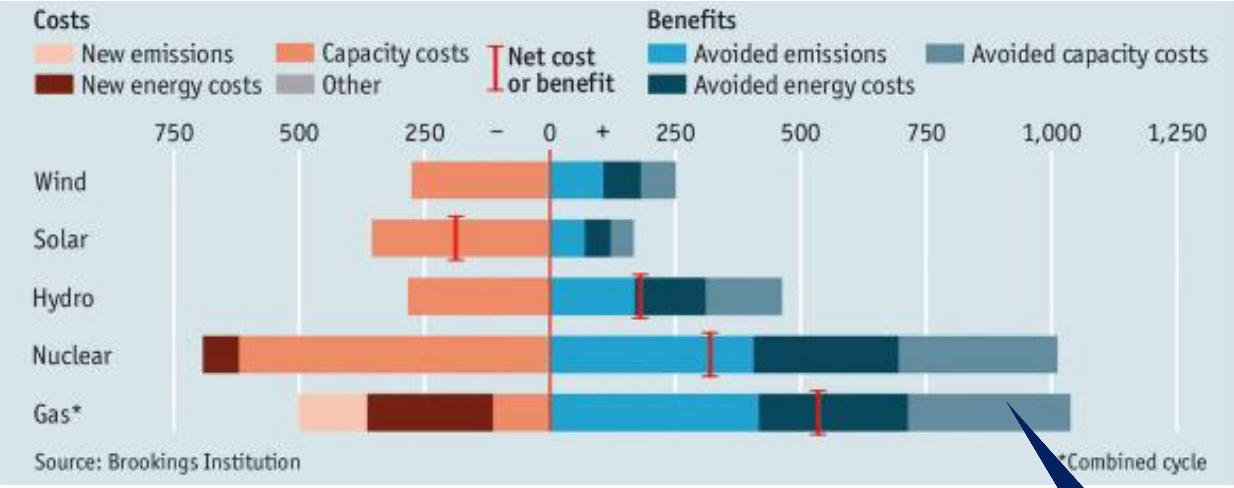
SPECIAL REPORT OF THE
INTERGOVERNMENTAL PANEL
ON CLIMATE CHANGE

ipcc

Source: IPCC (2011) Special Report on Renewable Energy Sources

# And now renewables are being written off because of integration issues, e.g. Brookings and The Economist 2014

**Net cost and benefits per MW and year compared to coal baseload generation,** United States
$ ‘000



- **Conclusion: coal to gas switching is the *only* answer…?**
- **Well, it is if you ignore all key integration possibilities, such as storage, interconnection, DSR and cheap peakers**

Significant “avoided capex” on **new** coal from gas and nuclear

- The paper calculated that solar and wind deliver very little reduction in the need to build new coal capacity
- But a search for the phrases “interconnection” and “DSR” and “response” yield nothing
- The paper does briefly consider storage, merely noting that: “In theory… Practically, however, the technology for electricity storage is not yet developed enough to make it economical without government subsidies.”

Source: The Economist; Frank (2014, Brookings) “The net benefits of low and no-carbon electricity technologies”

# Agenda

1. Economics of renewables without integration
2. Integration strategies and choices
3. Economic costs of integration
4. Conclusion

# There are four major categories for managing the integration of renewables at scale

1

### Energy storage

- ***Temporal*** supply smoothing
  - Pumped hydro
  - Battery storage
  - Compressed air (CAES)

2

### Interconnection

- ***Spatial*** supply smoothing
  - Norwegian hydro
  - Continental hydro
  - Icelandic geothermal…?

3

### DSR

- Demand Side Response including
  - Time of use pricing
  - Smart meters
  - Industrial consumers

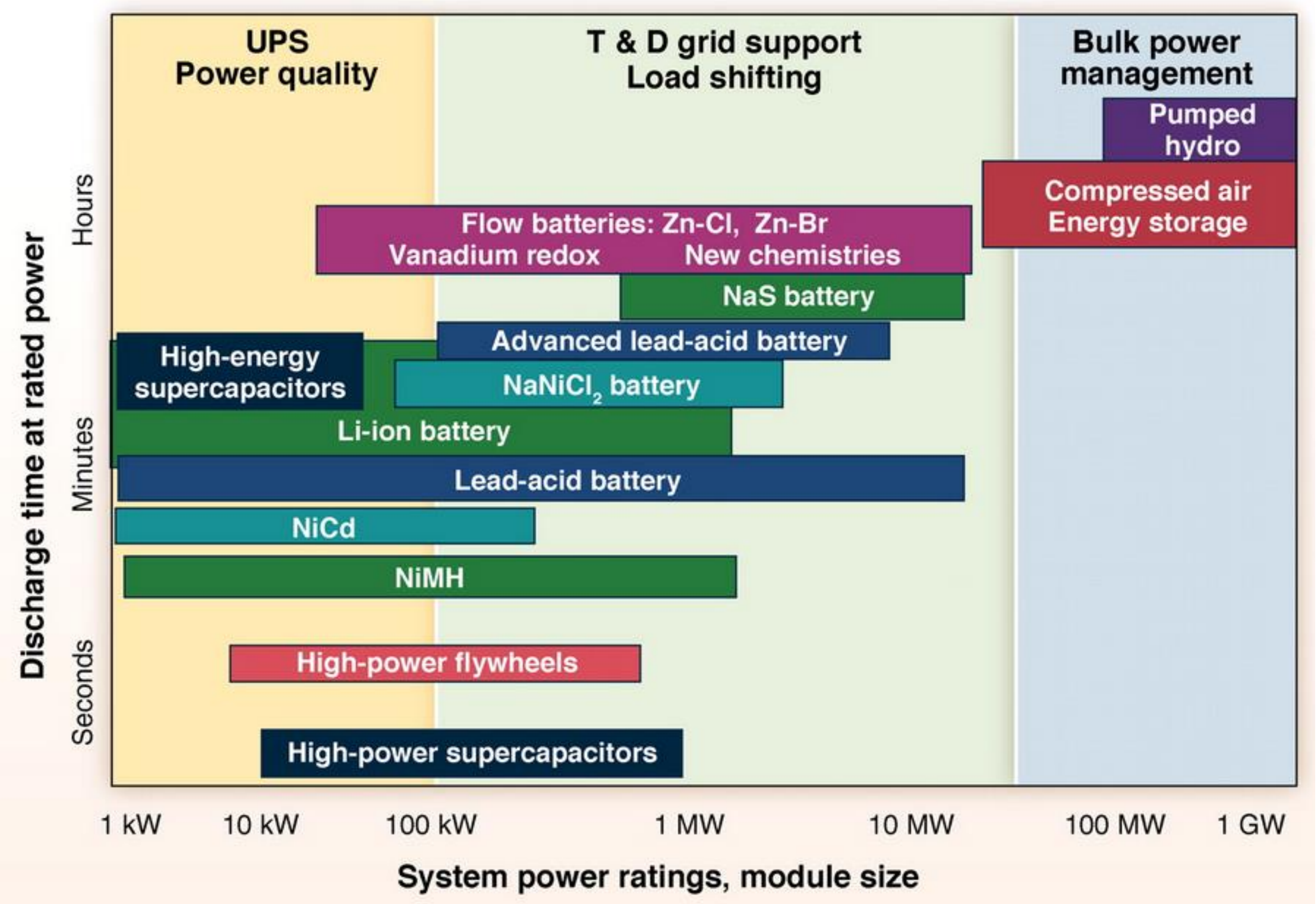
4

### Peakers / Flex Generation

- Largely thermal
  - Reciprocating engines
  - OCGT

1

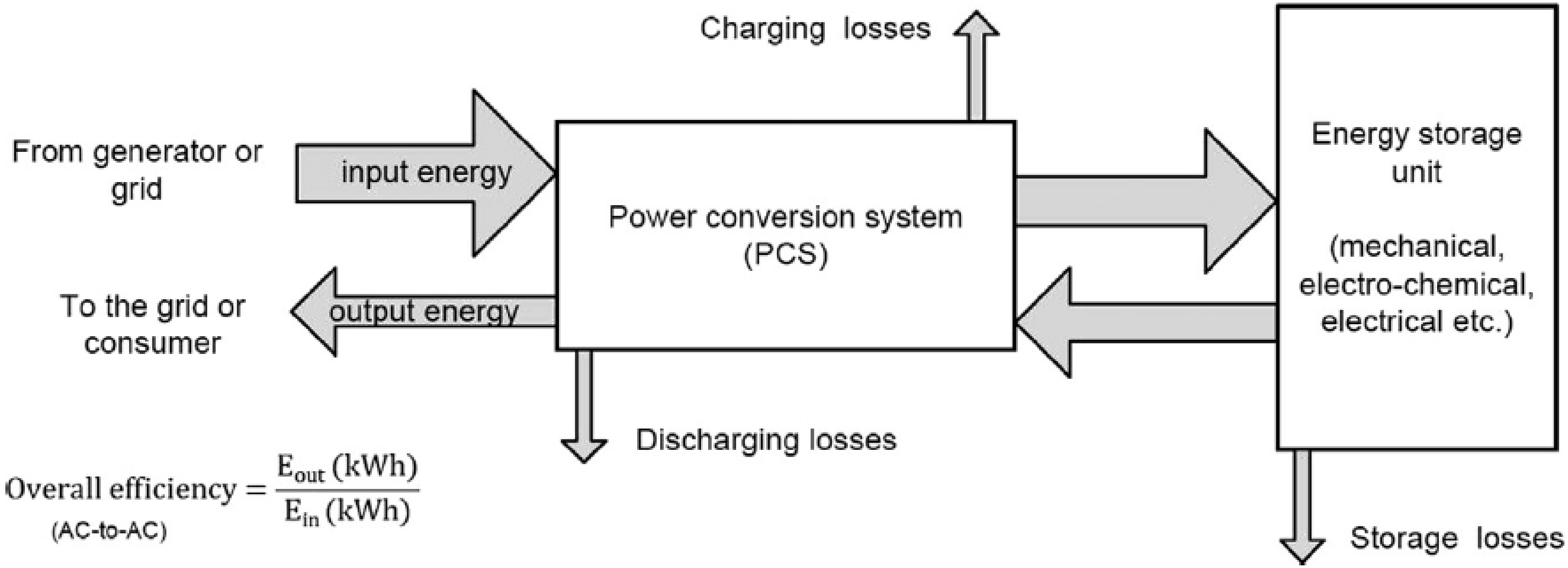
# There are different energy storage options for different purposes, as we have already seen



Source: Dunn et al (2011. Science)

1

# Energy storage: capex = PCS and storage unit; opex = input energy and losses

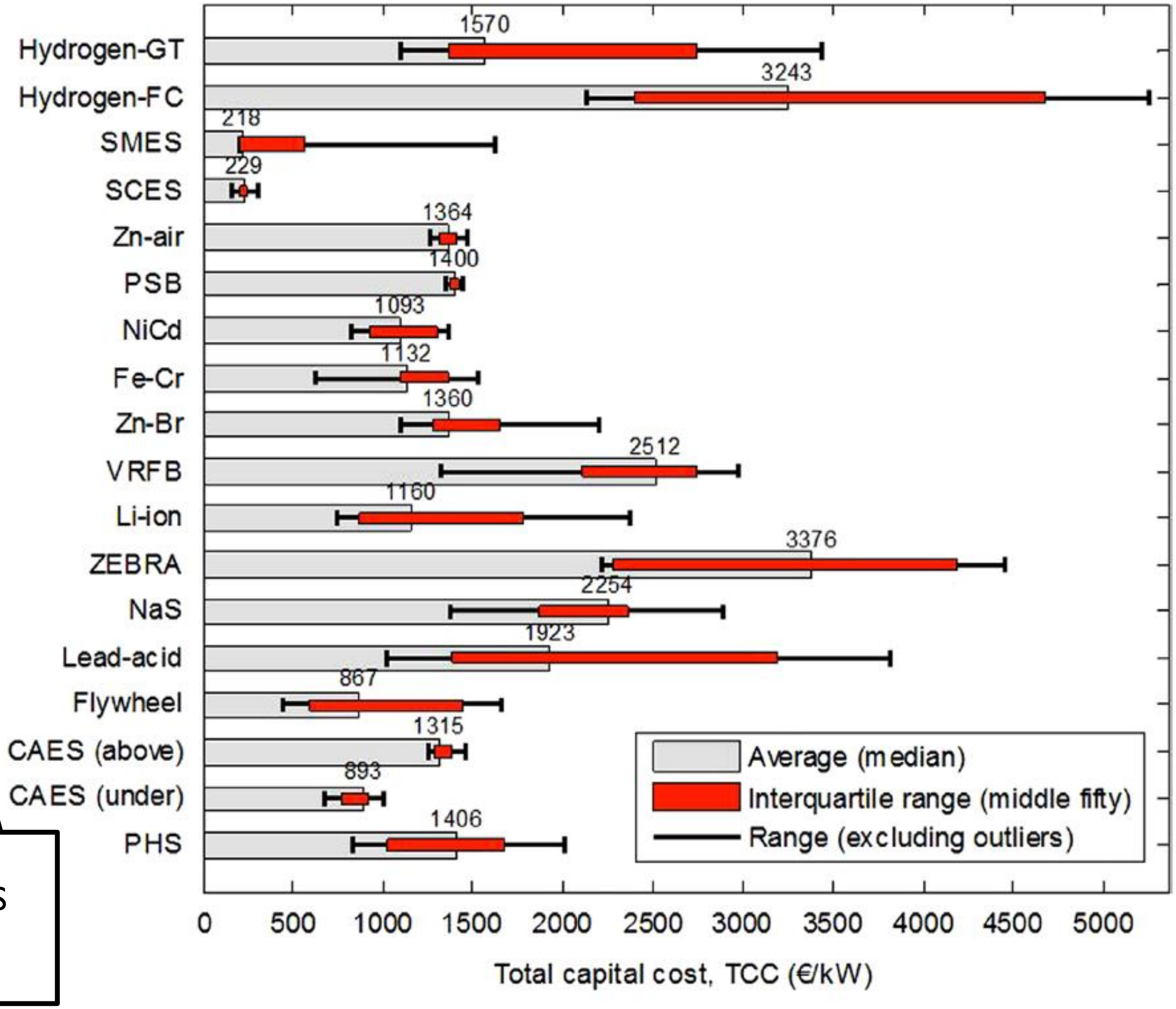


$$\text{Overall efficiency} = \frac{E_{out}\,(\text{kWh})}{E_{in}\,(\text{kWh})}$$

**Fig. 1.** Main sections of EES systems and energy losses.

Source: Zakeri and Syri (2015, Renewable and Sustainable Energy Reviews)

# 1 Total capex ranges from €200-4,000/kW once storage unit costs are converted

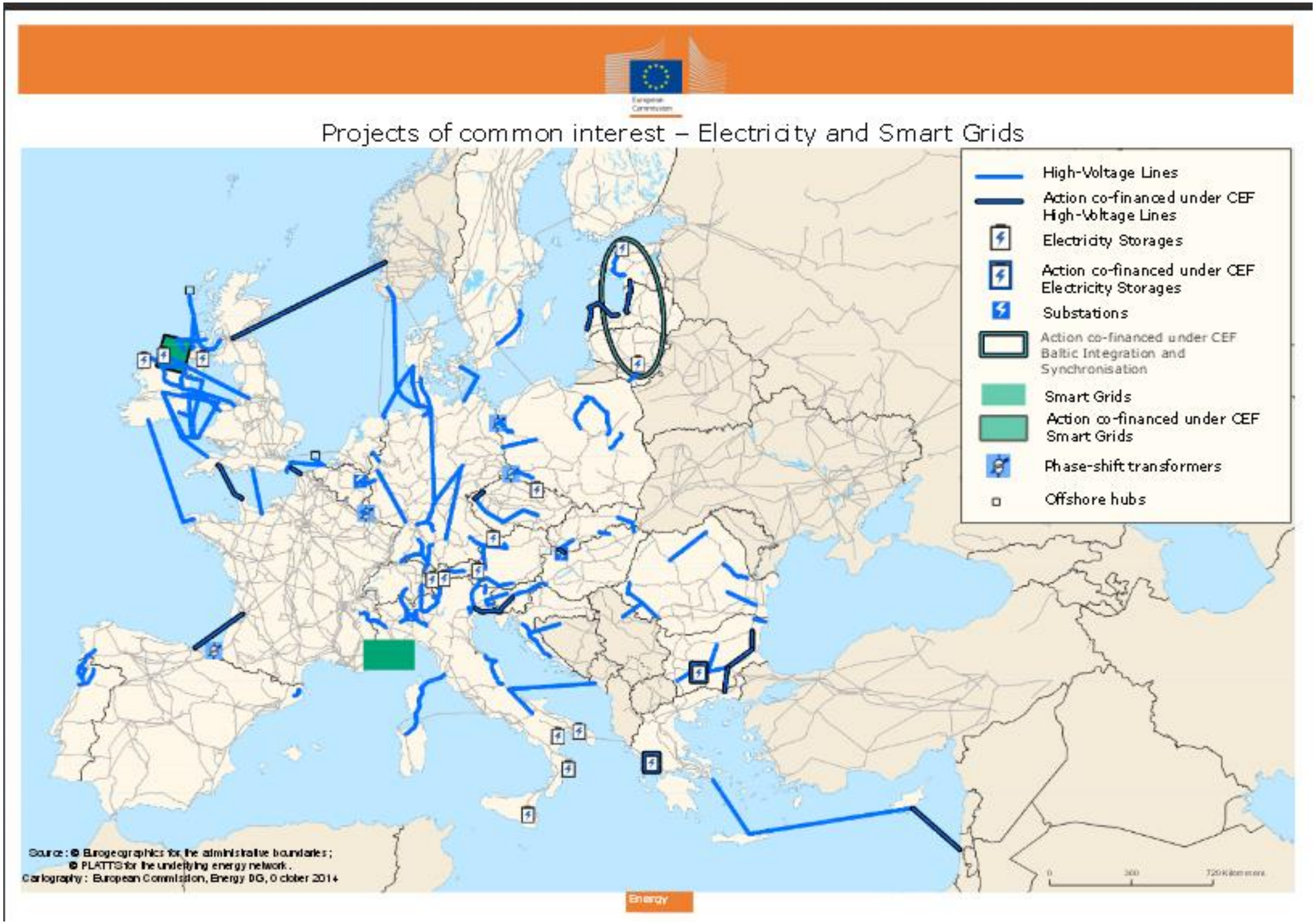


Pumped hydro and Underground CAES appears the lowest capex bulk storage

Source: Zakeri and Syri (2015, Renewable and Sustainable Energy Reviews)

2

# Interconnection with the EU's "projects of common interest" would help renewables



Projects of common interest – Electricity and Smart Grids

Source: © Eurogeographics for the administrative boundaries;
© PLATTS for the underlying energy network.
Cartography: European Commission, Energy DG, October 2014

Source: http://ec.europa.eu/energy/en/topics/infrastructure/projects-common-interest

2

# Interconnectors have low start up and variable costs, but not insubstantial fixed costs

- The value of an interconnector rests on two key elements:
  - Average price differential between the two markets being
  - Size of (negative) correlation in prices across the two markets (Chinese – EU sunshine!)
- Capital costs depend upon capacity and distance; roughly £1m / MW of capacity
- Losses can be 1.5% for conversion and 0.75% per 100km for transmission
- Interconnection between a high-price market and a low-price market almost always causes the following political economic structure:

| | Higher-price market | Lower-price market |
|---|---|---|
| Producer | Blocks | Supports |
| Consumer | Supports | Blocks |

- If the producer in the higher-price market is powerful enough to be able to block the interconnection, then it will not occur
- Note that regulated TSOs are often in favour if this increases the pool of regulated assets

3

# ‘Demand-side response’ at the industrial level is already working in the UK

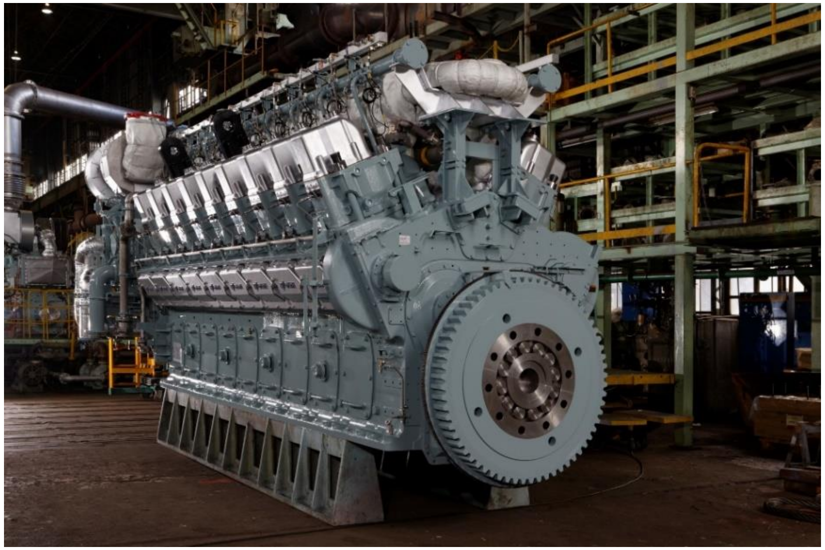
| Generation-led | Demand-led |
|---|---|
| - Use of back-up or embedded generators in response to an incentive payments or price changes<br>• Majority of current DSR contracted<br>• PJM: majority from back-up generation which are 81% powered by diesel | - Changes in electricity usage by end-use customers in response to incentive payments<br>- Normally adopted by domestic users |
| - Slower response: ramping time up to 30mins | - Fast response; no ramping<br>- Limited quantities of DSR delivered: 20-800kW |
| - More reliable than demand-led DSR<br>• Deliver an average 95kW of generation for each 100kw in service level agreement | - Less reliable as difficult to reduce demand without disrupting daily operations<br>• Only deliver an average 68kW for each 100kW of the service level agreement |

4

# Other than interconnectors, flexible generation is likely to offer lowest variable costs of integration

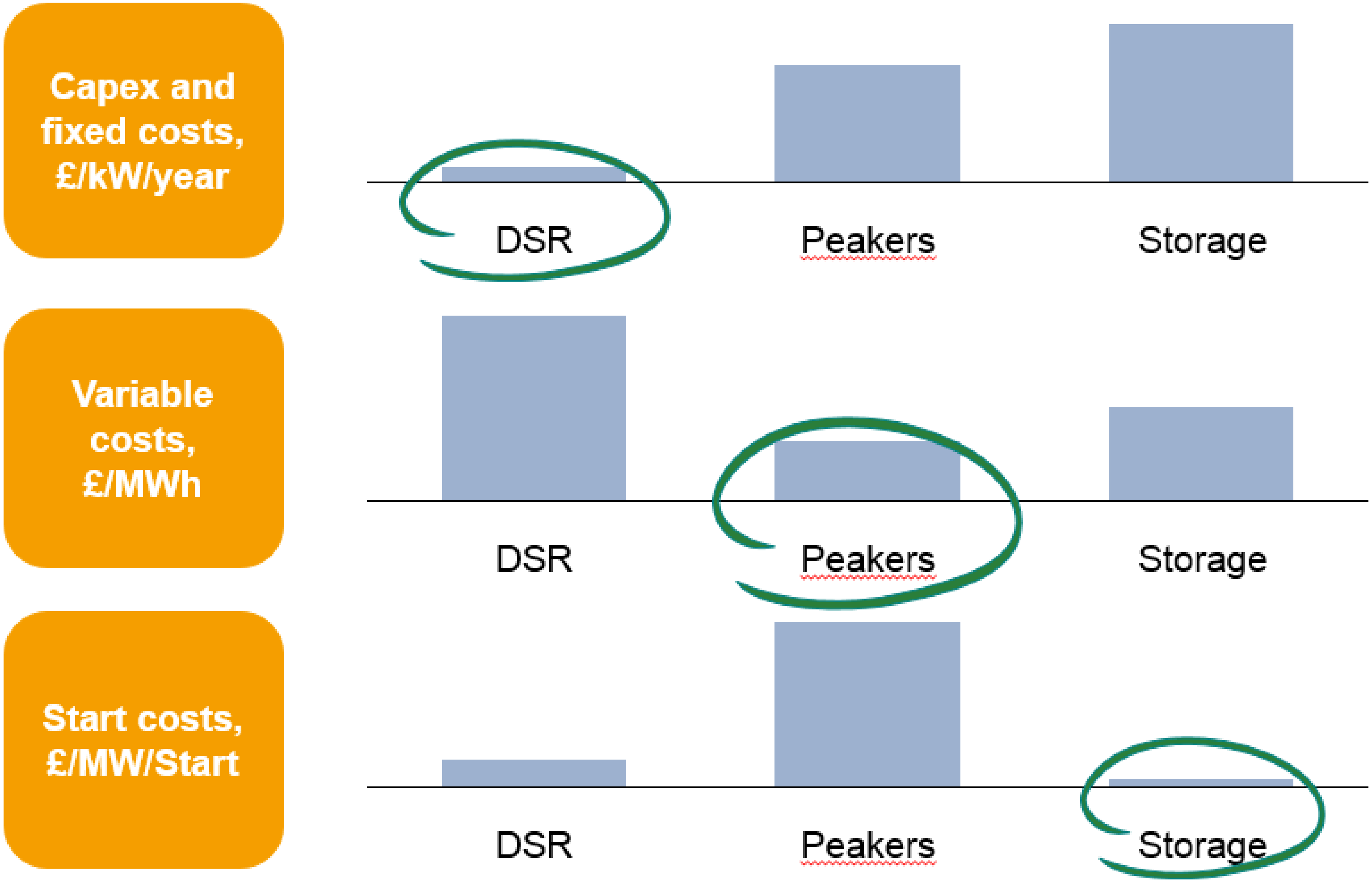
- OCGTs have moderate capex but low variable costs
- Response times up to 30 mins
  - Average price differential between the two markets being
  - Size of (negative) correlation in prices across the two markets (Chinese – EU sunshine!)

- Diesel or gas reciprocating engines have very rapid response, can ramp up and down economically in an hour
- Also have moderate capex, but moderate variable costs
- Hence more short duration peaking



# Putting it together does not yet reveal an obvious winner on every dimension

ILLUSTRATIVE



Source: Aurora Energy Research

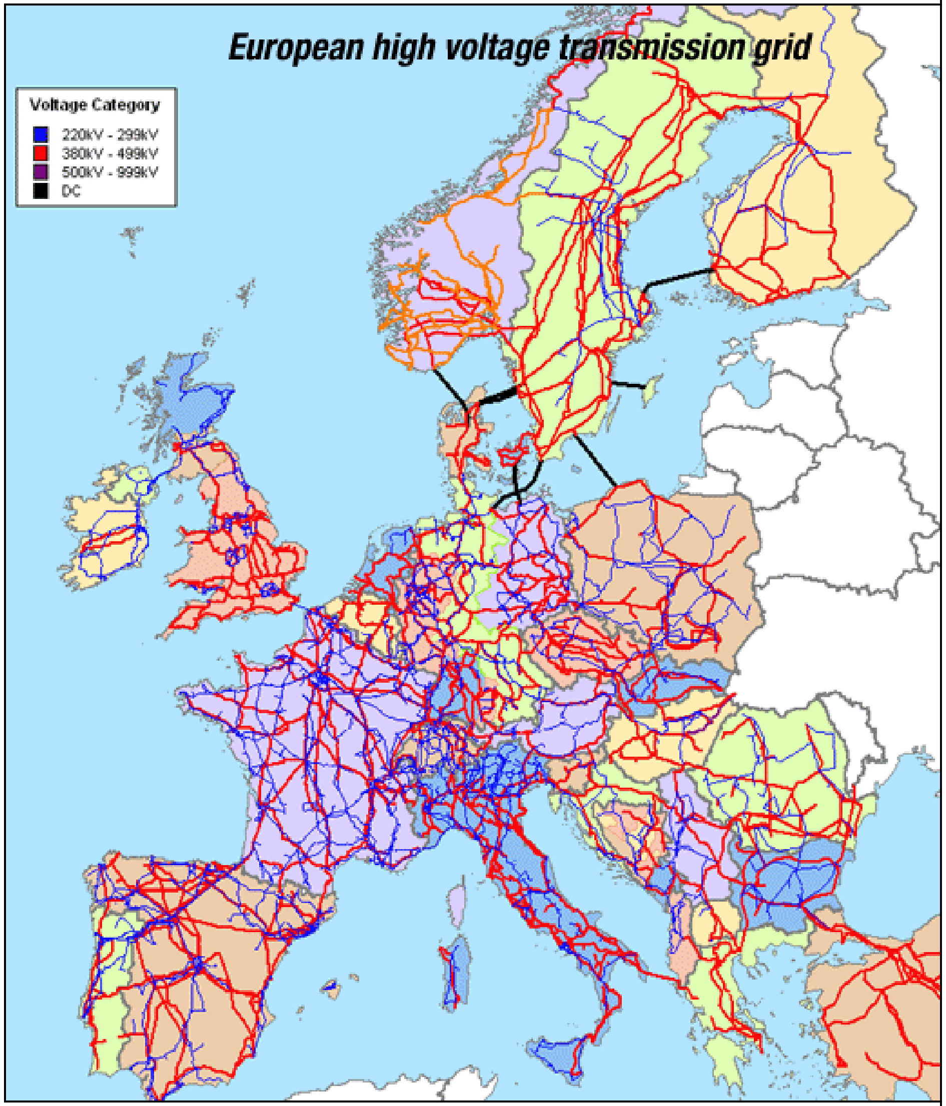
# Agenda

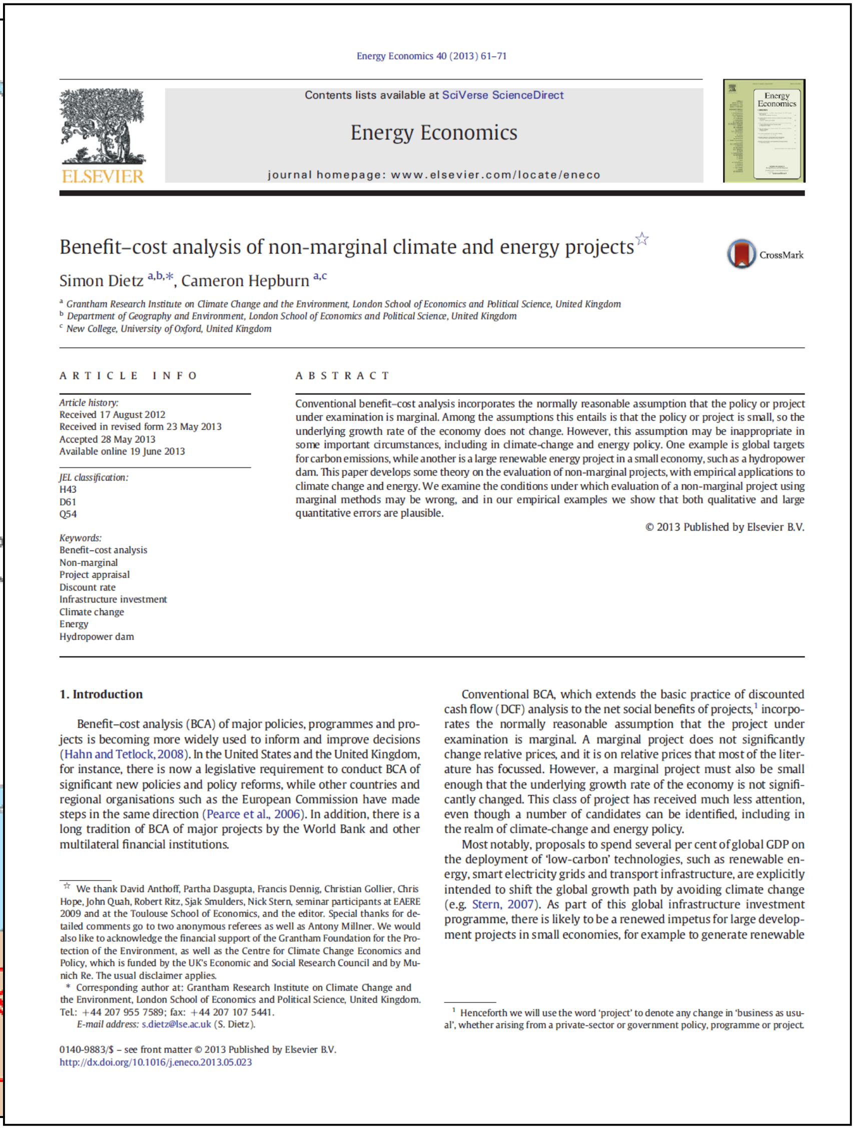
1. Economics of renewables without integration
2. Integration strategies and choices
3. Economic costs of integration
4. Conclusion

# What evidence do we have so far on costs of integrating large-scale renewables?

- Some countries have long had very high renewable penetration rates, mainly because of dispatchability (2008 figures on an energy basis, from IEA, 2010):
    - Iceland **100%** (hydro and geothermal)
    - Norway **99%** (hydro)
    - Austria **69%**
    - New Zealand **64%**
    - Canada **60%**
- But ultimately not abundant evidence on costs of integrating intermittent renewables
- Balancing costs (differences between bid wind generation and actual production) have been **US $1.4 – 3.0 / MWh** for Danish wind in Nordic market (IPCC, 2011)
- Costs of **US $9.2 / MWh** ($5.6 for network upgrades, $3.6 for additional reserves) to integrate 185GW of wind in Europe by 2015 (EWIS, 2010)
- Various studies have concluded in various places that even at penetration levels above 50%, the market incentive to add storage capacity is low at current costs

# The economics of integration are 'pleasingly non-trivial' – systems economics is required




Energy Economics 40 (2013) 61–71

Contents lists available at SciVerse ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

## Benefit–cost analysis of non-marginal climate and energy projects[☆]

Simon Dietz [a,b,*], Cameron Hepburn [a,c]

[a] Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science, United Kingdom
[b] Department of Geography and Environment, London School of Economics and Political Science, United Kingdom
[c] New College, University of Oxford, United Kingdom

ARTICLE INFO

*Article history:*
Received 17 August 2012
Received in revised form 23 May 2013
Accepted 28 May 2013
Available online 19 June 2013

*JEL classification:*
H43
D61
Q54

*Keywords:*
Benefit–cost analysis
Non-marginal
Project appraisal
Discount rate
Infrastructure investment
Climate change
Energy
Hydropower dam

ABSTRACT

Conventional benefit–cost analysis incorporates the normally reasonable assumption that the policy or project under examination is marginal. Among the assumptions this entails is that the policy or project is small, so the underlying growth rate of the economy does not change. However, this assumption may be inappropriate in some important circumstances, including in climate-change and energy policy. One example is global targets for carbon emissions, while another is a large renewable energy project in a small economy, such as a hydropower dam. This paper develops some theory on the evaluation of non-marginal projects, with empirical applications to climate change and energy. We examine the conditions under which evaluation of a non-marginal project using marginal methods may be wrong, and in our empirical examples we show that both qualitative and large quantitative errors are plausible.

### 1. Introduction

Benefit–cost analysis (BCA) of major policies, programmes and projects is becoming more widely used to inform and improve decisions (Hahn and Tetlock, 2008). In the United States and the United Kingdom, for instance, there is now a legislative requirement to conduct BCA of significant new policies and policy reforms, while other countries and regional organisations such as the European Commission have made steps in the same direction (Pearce et al., 2006). In addition, there is a long tradition of BCA of major projects by the World Bank and other multilateral financial institutions.

Conventional BCA, which extends the basic practice of discounted cash flow (DCF) analysis to the net social benefits of projects,[1] incorporates the normally reasonable assumption that the project under examination is marginal. A marginal project does not significantly change relative prices, and it is on relative prices that most of the literature has focussed. However, a marginal project must also be small enough that the underlying growth rate of the economy is not significantly changed. This class of project has received much less attention, even though a number of candidates can be identified, including in the realm of climate-change and energy policy.

Most notably, proposals to spend several per cent of global GDP on the deployment of 'low-carbon' technologies, such as renewable energy, smart electricity grids and transport infrastructure, are explicitly intended to shift the global growth path by avoiding climate change (e.g. Stern, 2007). As part of this global infrastructure investment programme, there is likely to be a renewed impetus for large development projects in small economies, for example to generate renewable

---

[☆] We thank David Anthoff, Partha Dasgupta, Francis Dennig, Christian Gollier, Chris Hope, John Quah, Robert Ritz, Sjak Smulders, Nick Stern, seminar participants at EAERE 2009 and at the Toulouse School of Economics, and the editor. Special thanks for detailed comments go to two anonymous referees as well as Antony Millner. We would also like to acknowledge the financial support of the Grantham Foundation for the Protection of the Environment, as well as the Centre for Climate Change Economics and Policy, which is funded by the UK's Economic and Social Research Council and by Munich Re. The usual disclaimer applies.

[*] Corresponding author at: Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science, United Kingdom. Tel.: +44 207 955 7589; fax: +44 207 107 5441.
*E-mail address:* s.dietz@lse.ac.uk (S. Dietz).

[1] Henceforth we will use the word 'project' to denote any change in 'business as usual', whether arising from a private-sector or government policy, programme or project.

0140-9883/$ – see front matter © 2013 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.eneco.2013.05.023

Source: Dietz and Hepburn (2013); http://www.geni.org/globalenergy/library/national_energy_grid/europe/europeannationalelectricitygrid.shtml

# The economic costs of integration depends upon how much of each type of renewable is already present

**Different types of renewables differ in relation to their:**

1. Dispatchability
2. Predictability
3. Geographical diversity
4. Capacity factor (average hours / total possible hours)
5. Capacity credit (reduction in residual peak demand / capacity)
6. Active power frequency control
7. Voltage and reactive power control

# Scale integration of renewables (SIR) will have major implications for the structure of power markets

**Consider a world with close to 100% renewables…**

1. The system marginal cost could be zero not infrequently, notwithstanding storage technologies soaking up low cost supply
2. Real-time power pricing would assist in DSR, matching supply and demand and providing security of supply, but would not be enough
3. Underlying price variability increases, the missing money problem gets worse, and energy-only markets may not deliver
4. Mechanisms (of one kind or another) will be required to cover fixed costs of all generation, including storage and interconnection

# Agenda

1. Economics of renewables without integration
2. Integration strategies and choices
3. Economic costs of integration
4. Conclusion

# Part of the INTEGRATE programme will plug gaps in our economic and market knowledge

- IPCC (2011) noted several “gaps in our knowledge relating to integration options” that “may become important in the future”, which are still open including…
  - Changes in the non-renewable generating portfolio (e.g. impact on retirements (“stranded assets”), flexibility characteristics and the value of possible fleet additions)
  - Quantification of the potential for load participation or demand response to provide grid services needed to integrate RE
  - Impacts of the integration of the electricity sector with other energy sectors
  - Benefits and costs of combining multiple RE resources in a complementary fashion
  - Better market arrangements for variable renewable and flexible sources”
- INET and SSEE research capability on specific economic questions – complementarities, network and spatial structures, market design

# Concluding remarks

1. Optimal integration strategy will be specific to the geography and system at hand, and will show strong path dependence
2. The economics of large-scale renewable integration are extremely interesting
3. The new INTEGRATE research programme will attempt to answer the key questions
4. Any comments, thoughts, corrections, please get in touch

# Thank you