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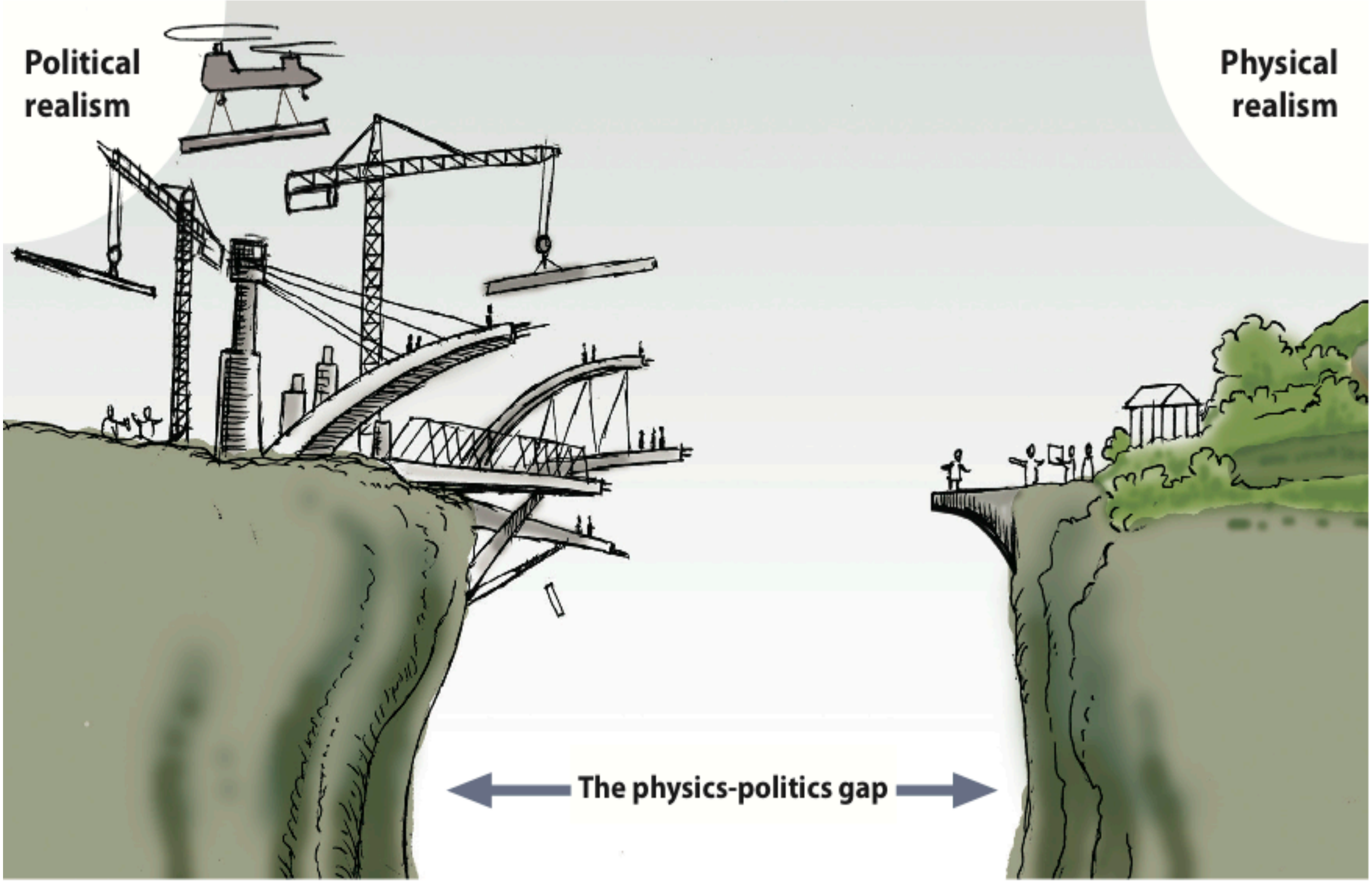
Canolfan y Dechnoleg Amgen

Modelling keeping the lights on with 100% renewables

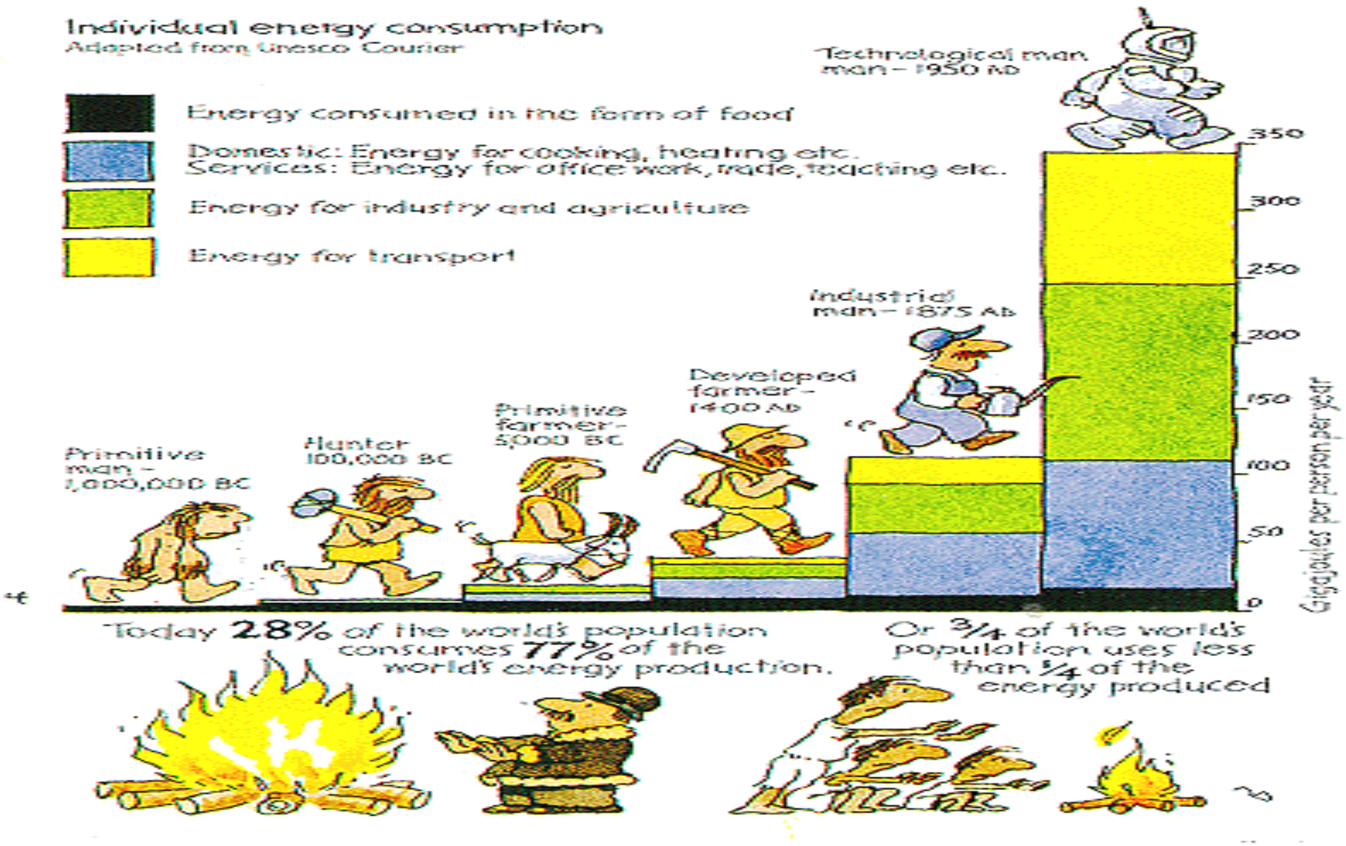


[Figure UK3]: An illustration of the physics-politics gap and efforts to try and bridge it from the politically realistic and physically realistic perspectives.

100% renewable scenario - our rules:

- Minimise lifestyle disruption
- 100% renewable energy
  - No new nuclear
  - No un-proven CCS
- UK resources only
- Use only existing technology
  - No relying on ‘magic bullets’

Recognising where we are today



Where we are today

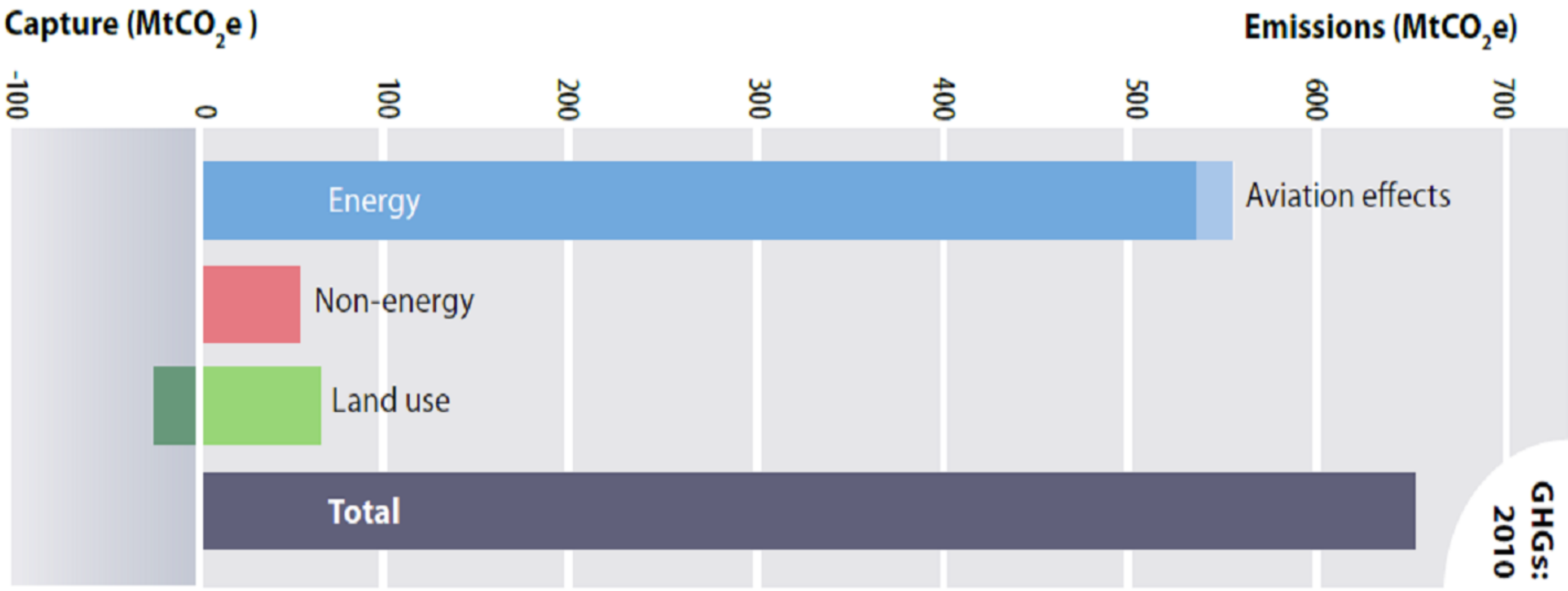


Figure 3.1: UK Greenhouse gas emissions in 2010, including international aviation and shipping, and the enhanced effect of emissions from aviation (DECC, 2013).

Power down

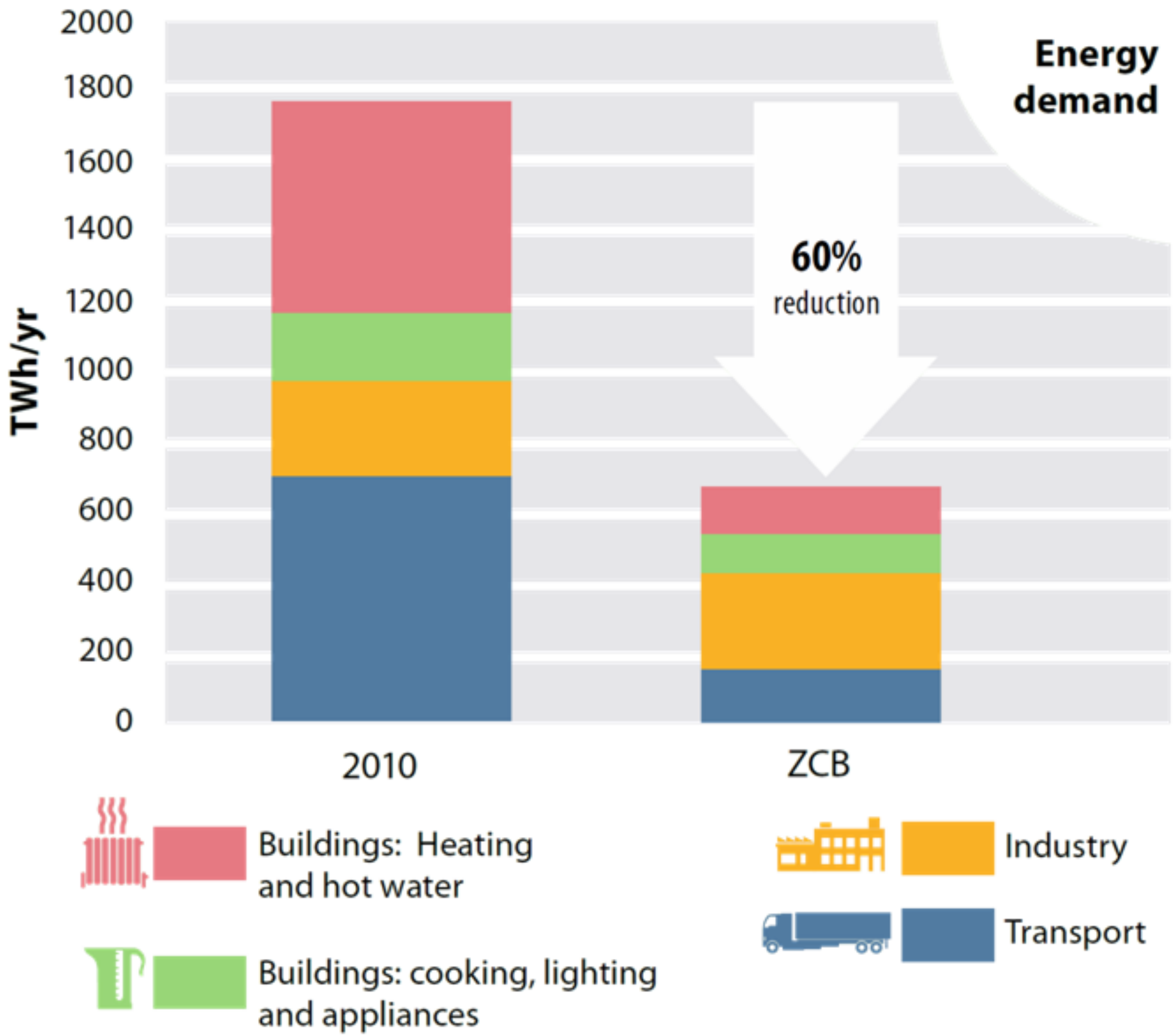


Figure 3.4: Total annual energy demand by sector in the UK in 2010 (DECC, 2012) and in our scenario.

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Power up

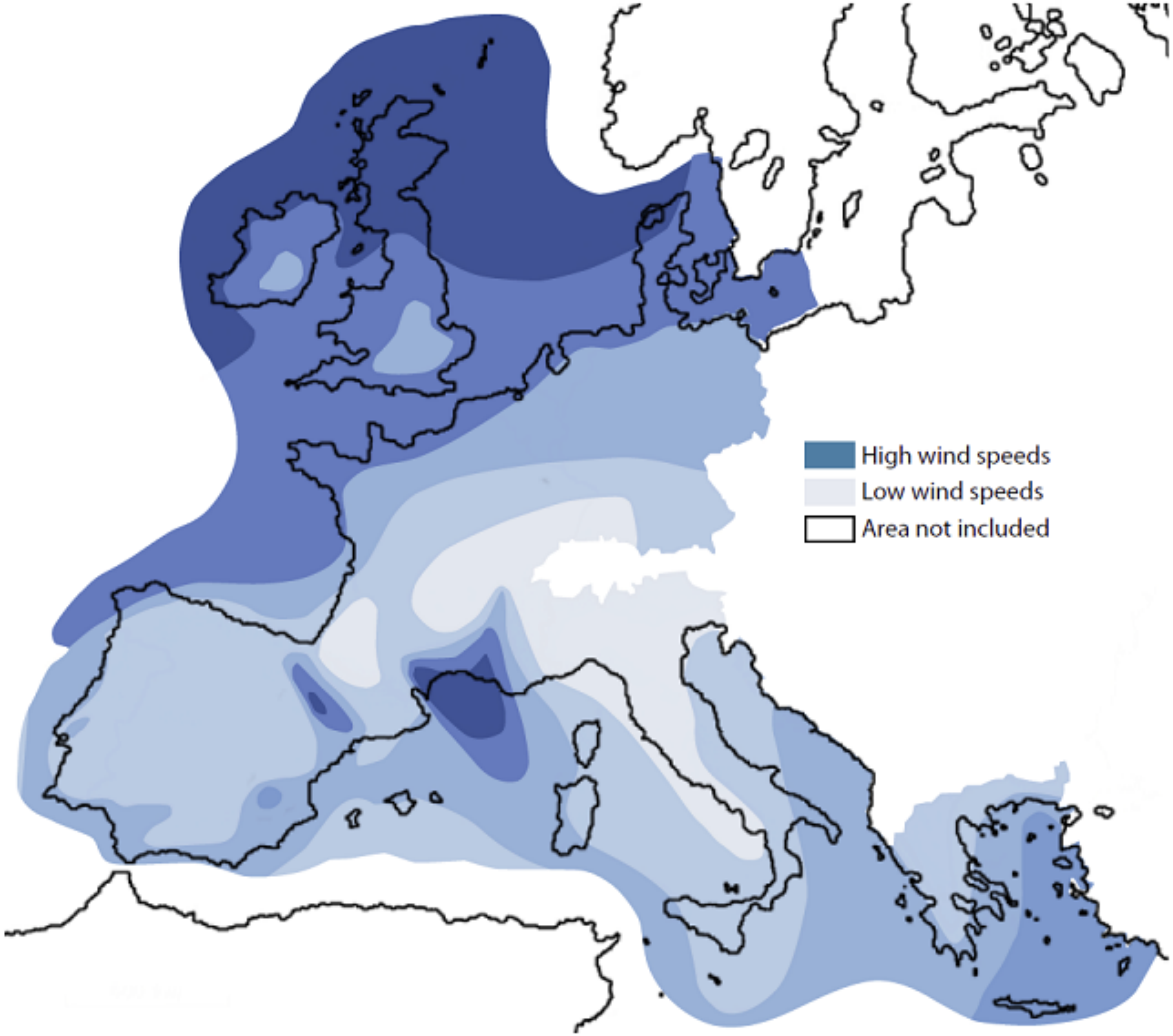


Figure 3.17: European wind speeds at 50 meters above ground level, ranging from the highest (dark blue), to the lowest (light blue). This represents sheltered and open areas, on hills and ridges, coastal areas, and in the open sea, though the highest wind speed and lowest wind speed will be different in each topographical area. Adapted from Troen and Petersen (1989).

Single 3.6 MW wind turbine

10,000 MWh/yr

10 MW PV farm
20 ha

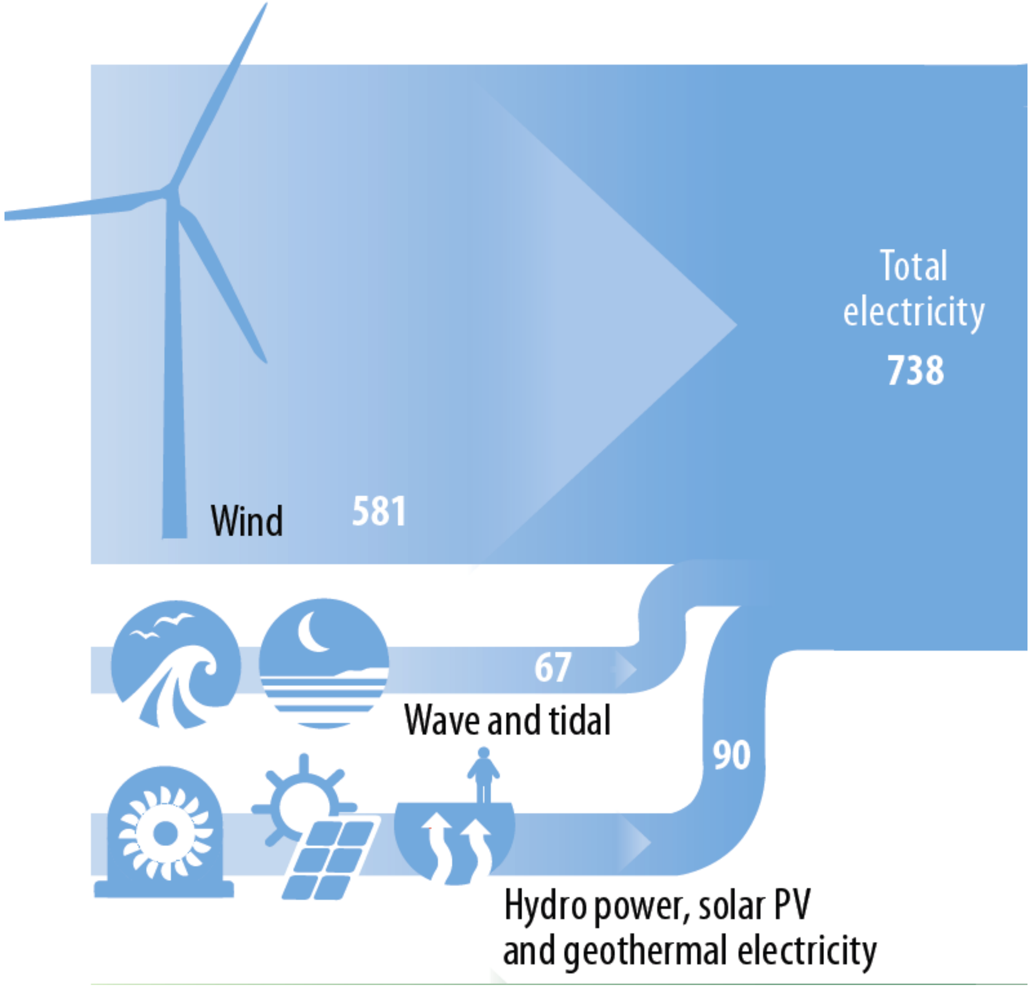
10,000 MWh/yr

Willow biomass
200 ha

10,000 MWh/yr

But…

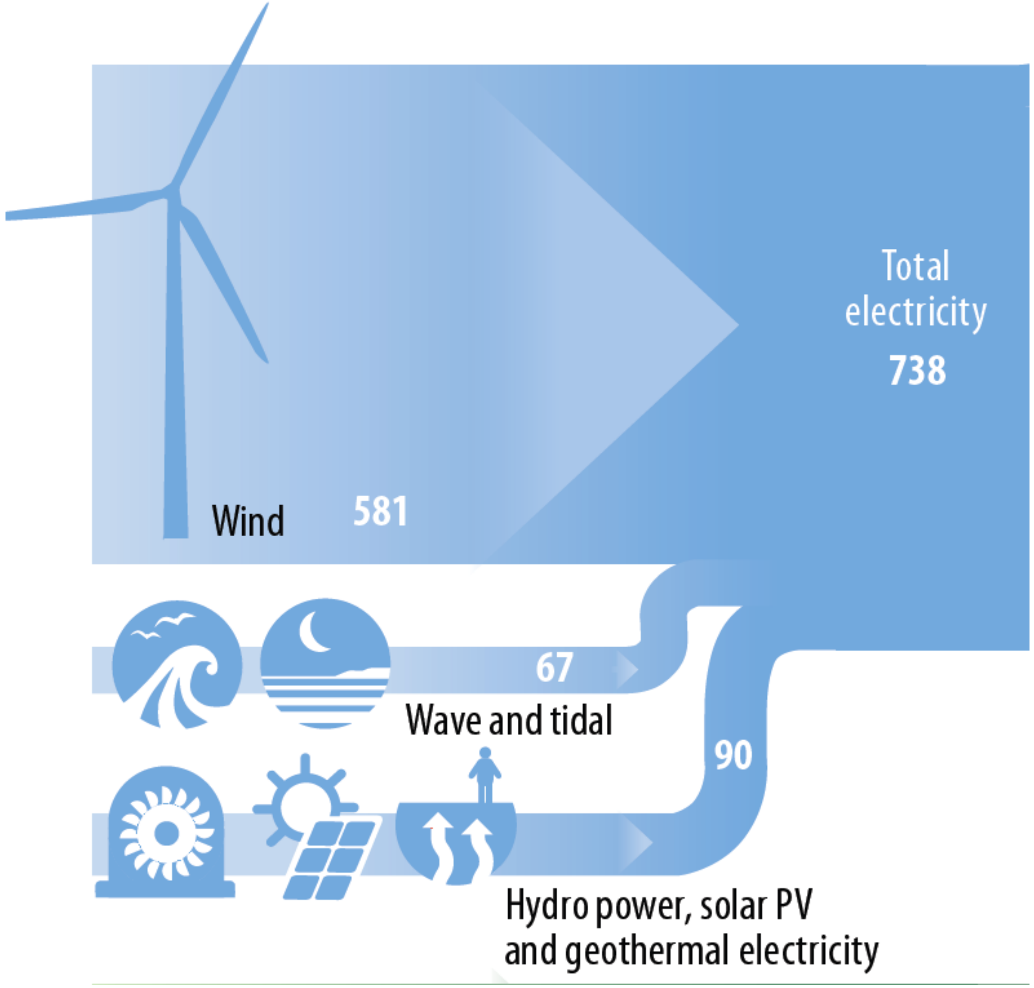
"Can we keep the lights on?"



Yes we can!

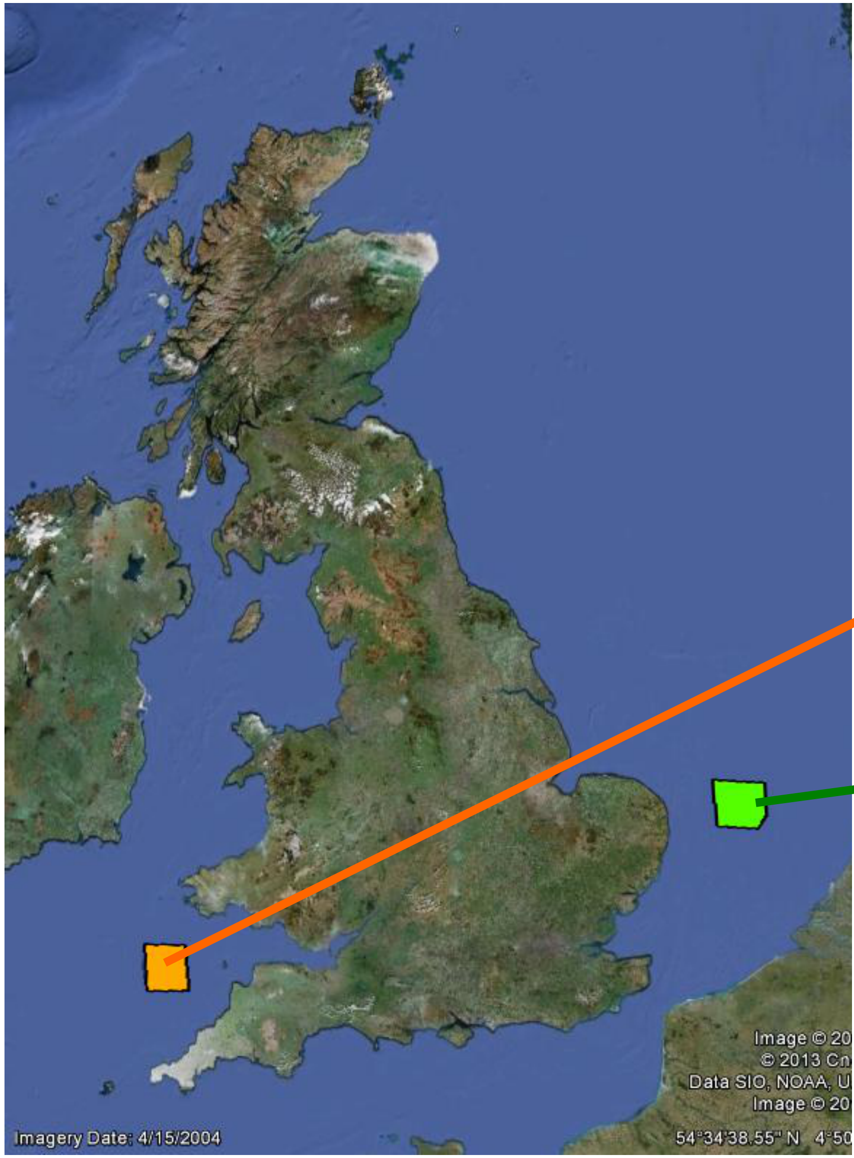
The ZCB Energy Model: Based on ten years of real-world hourly data

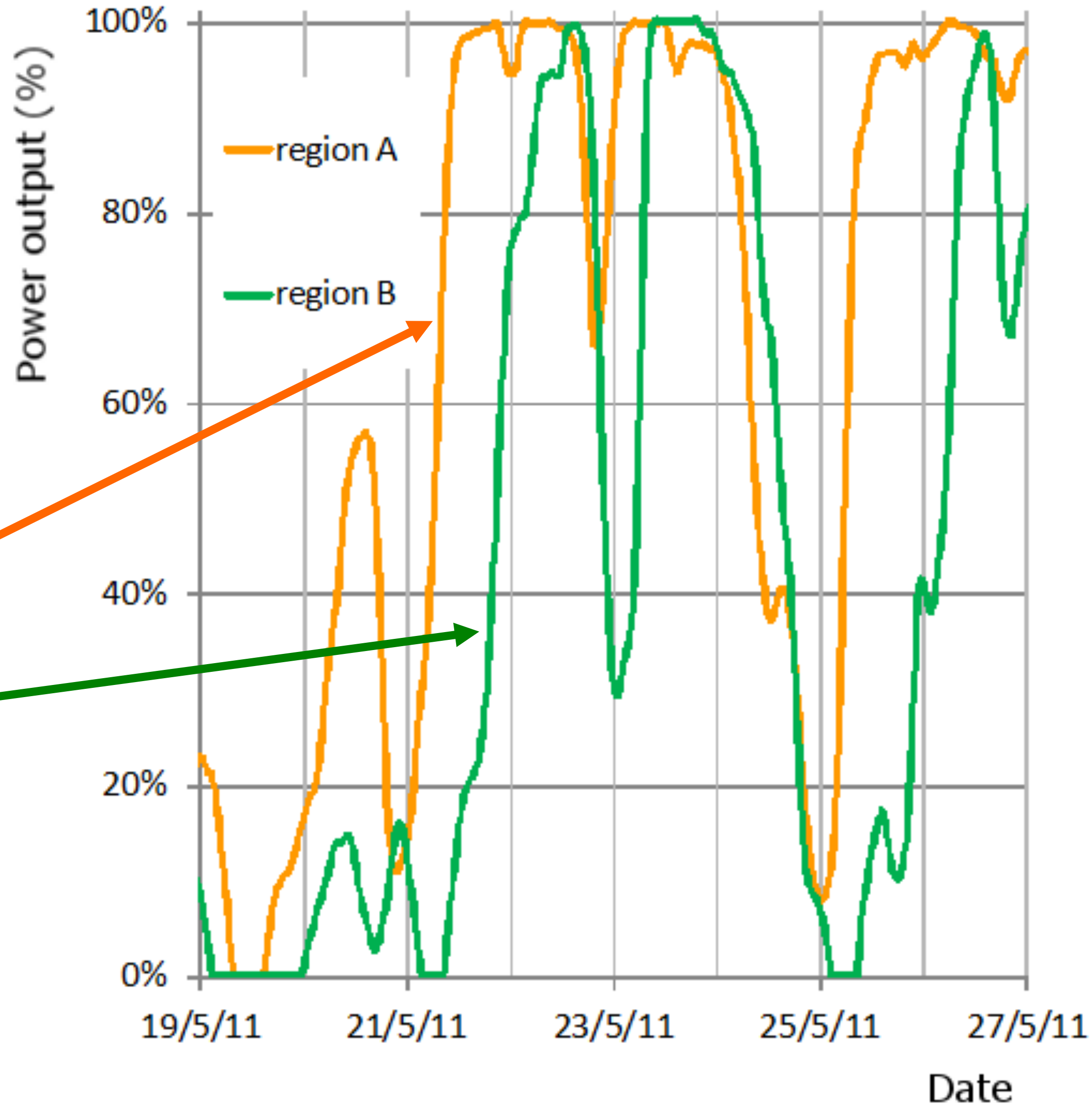
2002 - 2011
87,648 hours



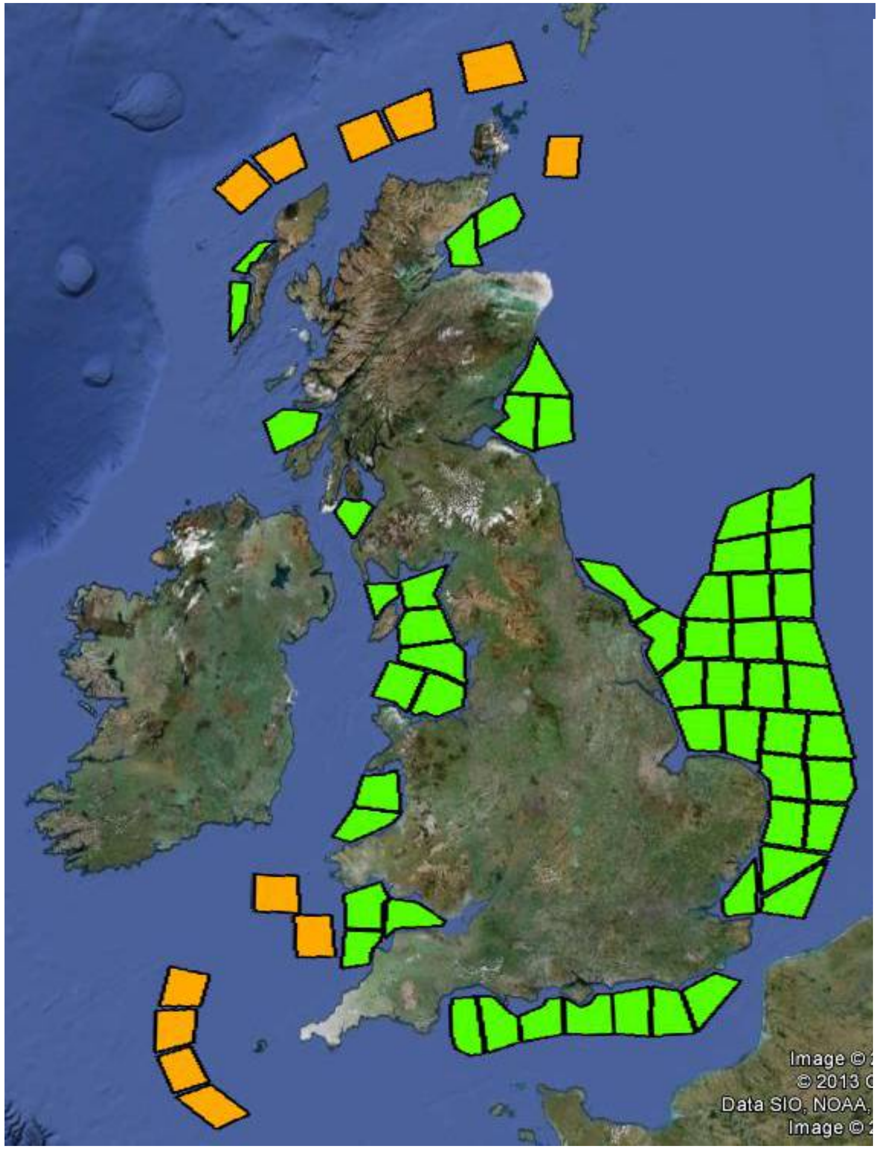
Example: Offshore wind

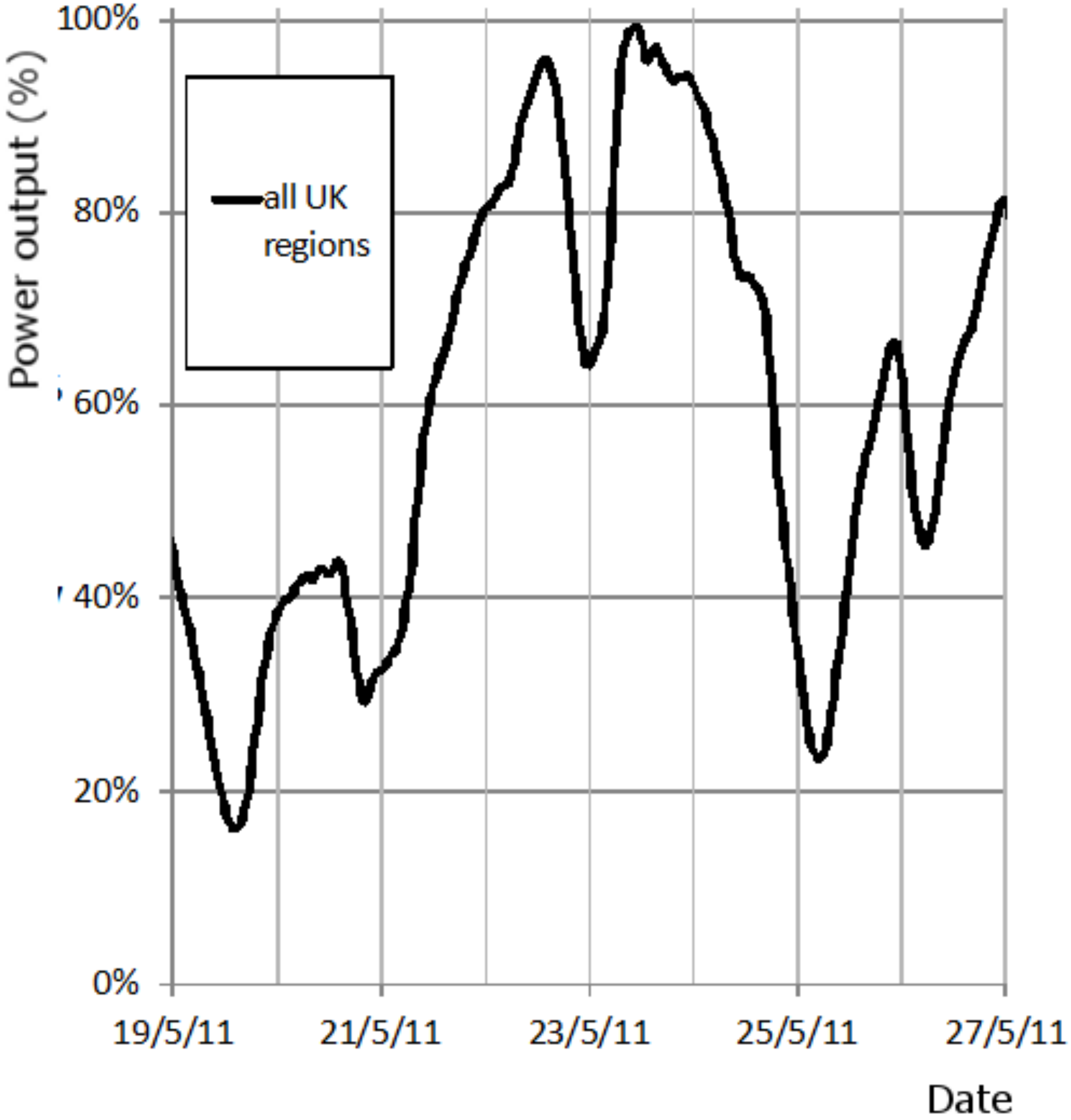
Example: Offshore wind

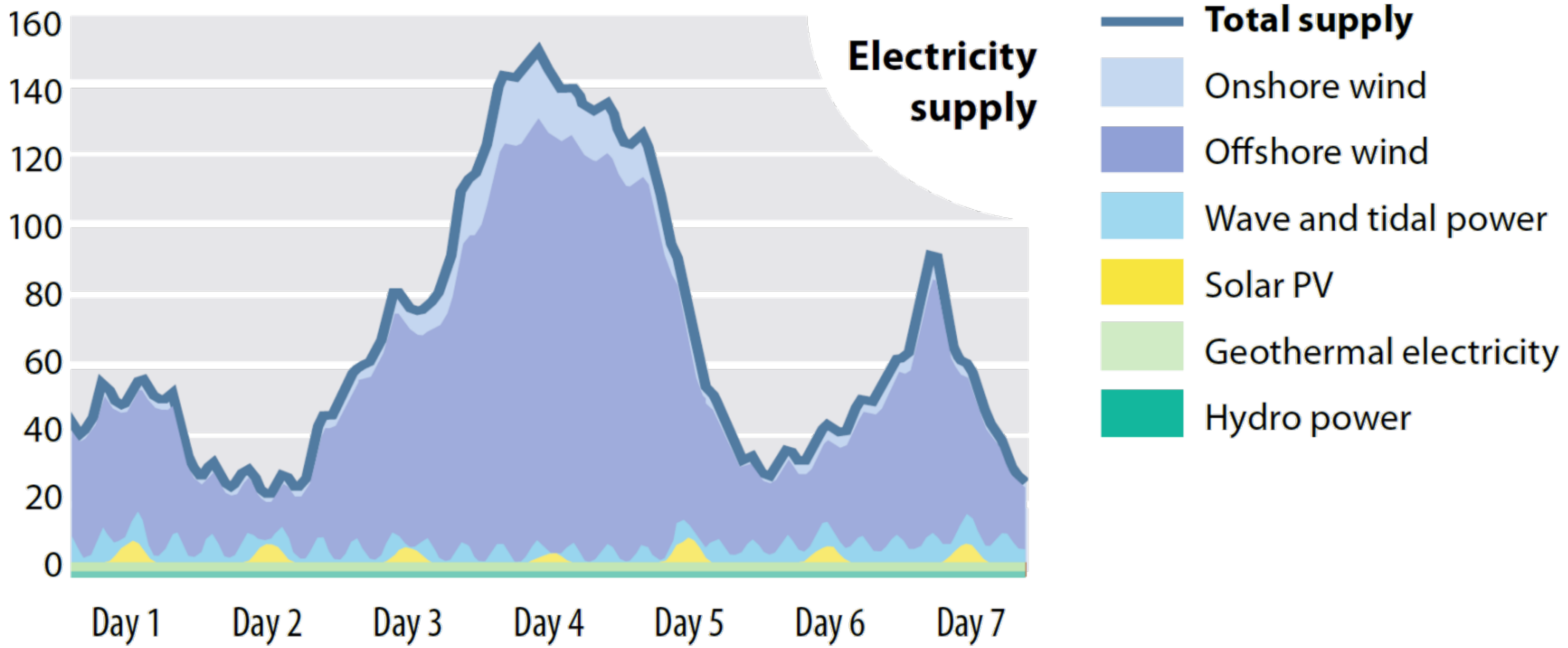


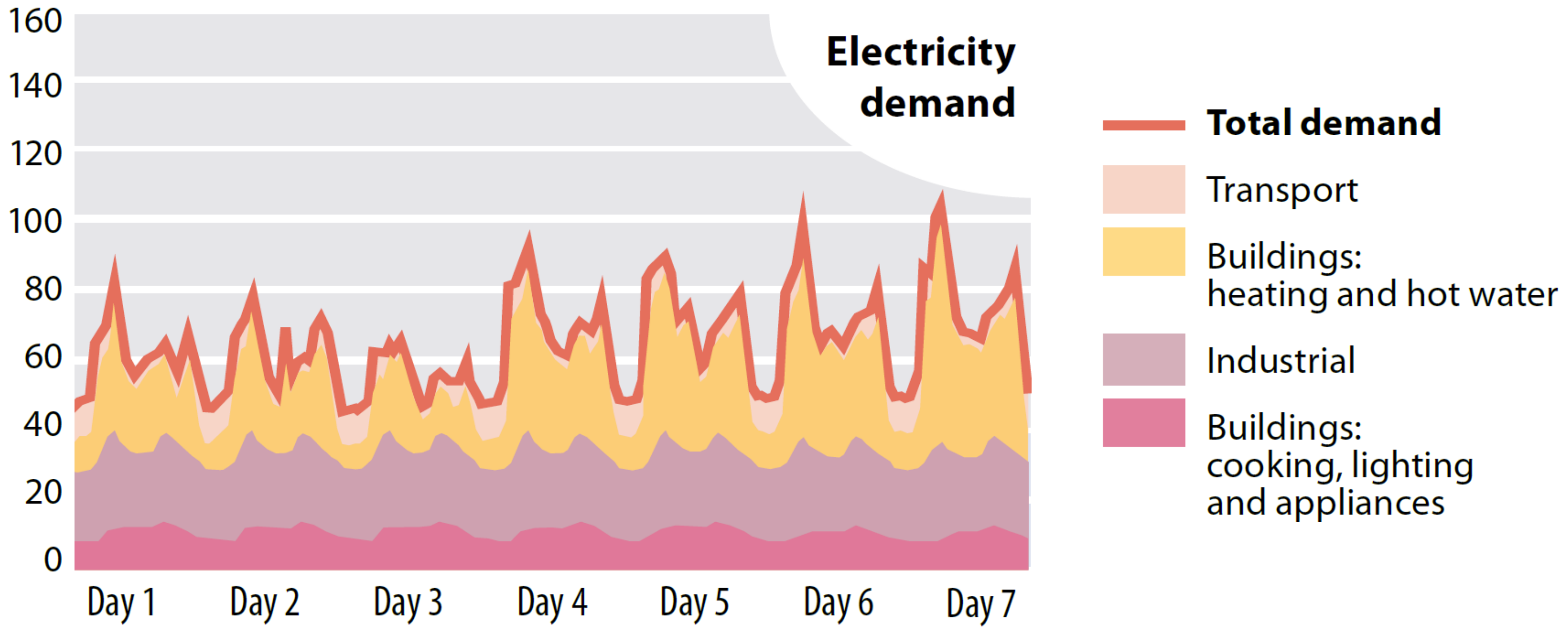


Example: Offshore wind






Electricity supply
160
140
120
100
80
60
40
20
0
Day 1
Day 2
Day 3
Day 4
Day 5
Day 6
Day 7
Total supply
Onshore wind
Offshore wind
Wave and tidal power
Solar PV
Geothermal electricity
Hydro power


Electricity demand
160
140
120
100
80
60
40
20
0
Day 1
Day 2
Day 3
Day 4
Day 5
Day 6
Day 7
Total demand
Transport
Buildings: heating and hot water
Industrial
Buildings: cooking, lighting and appliances

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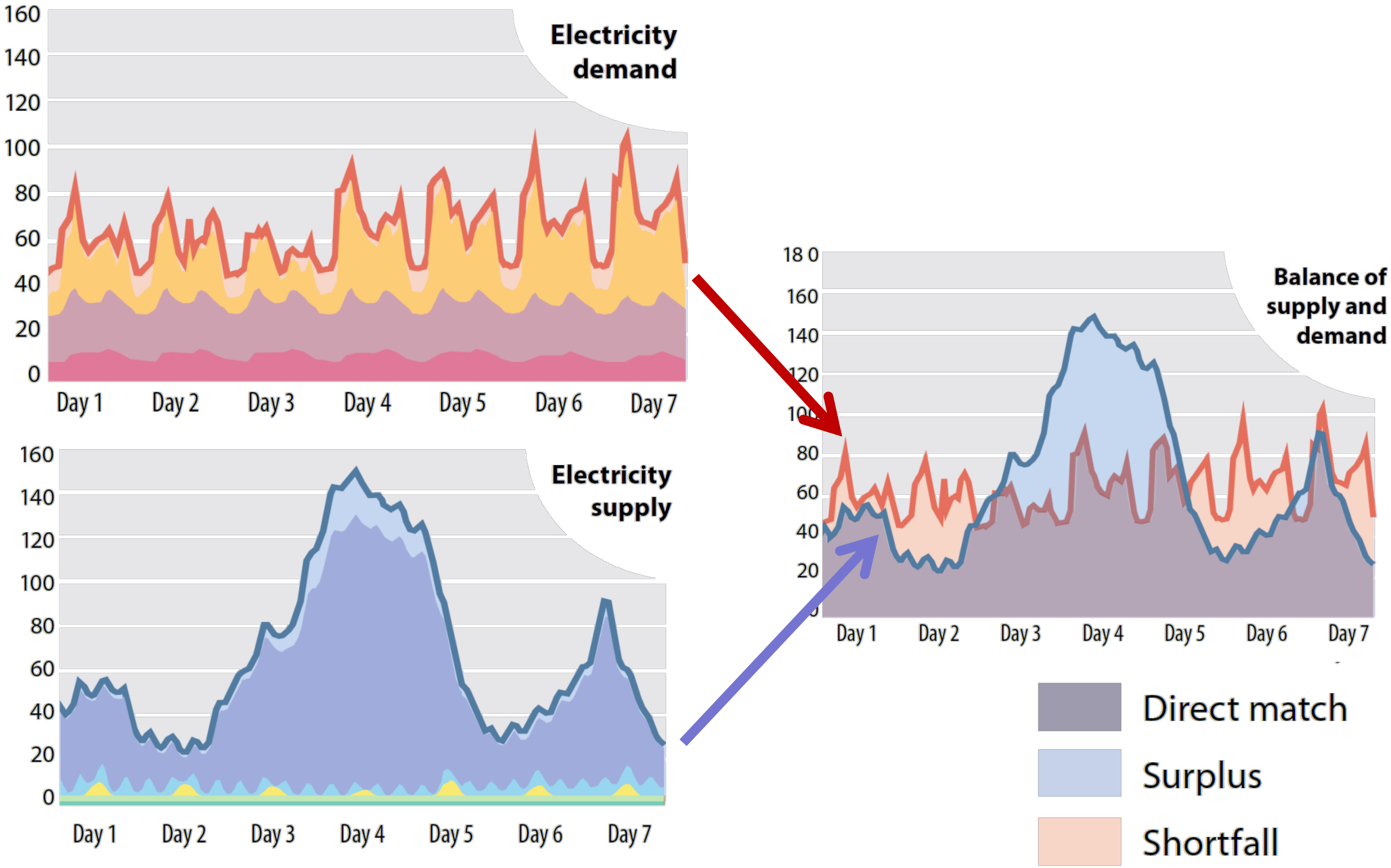
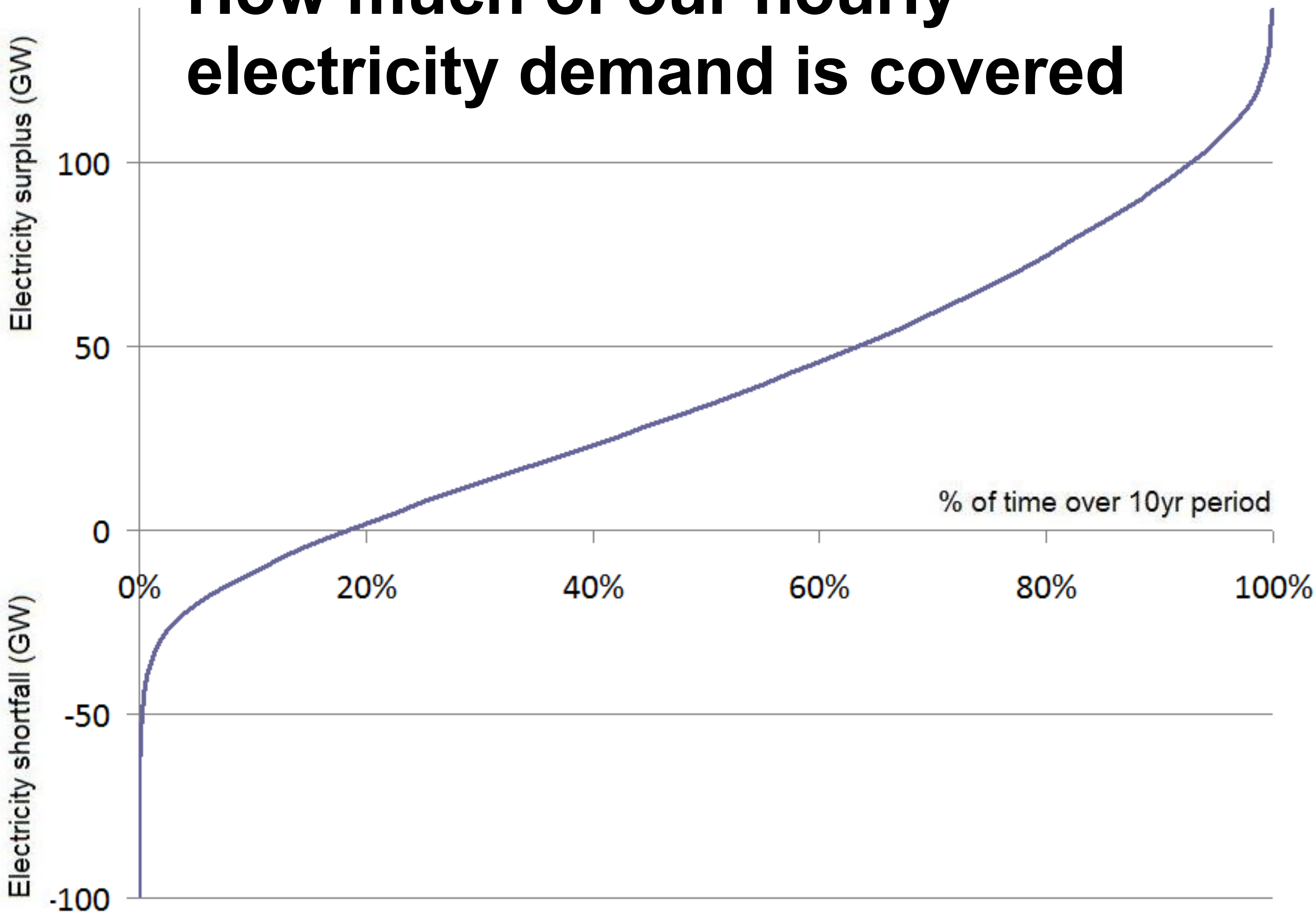


How much of our hourly electricity demand is covered



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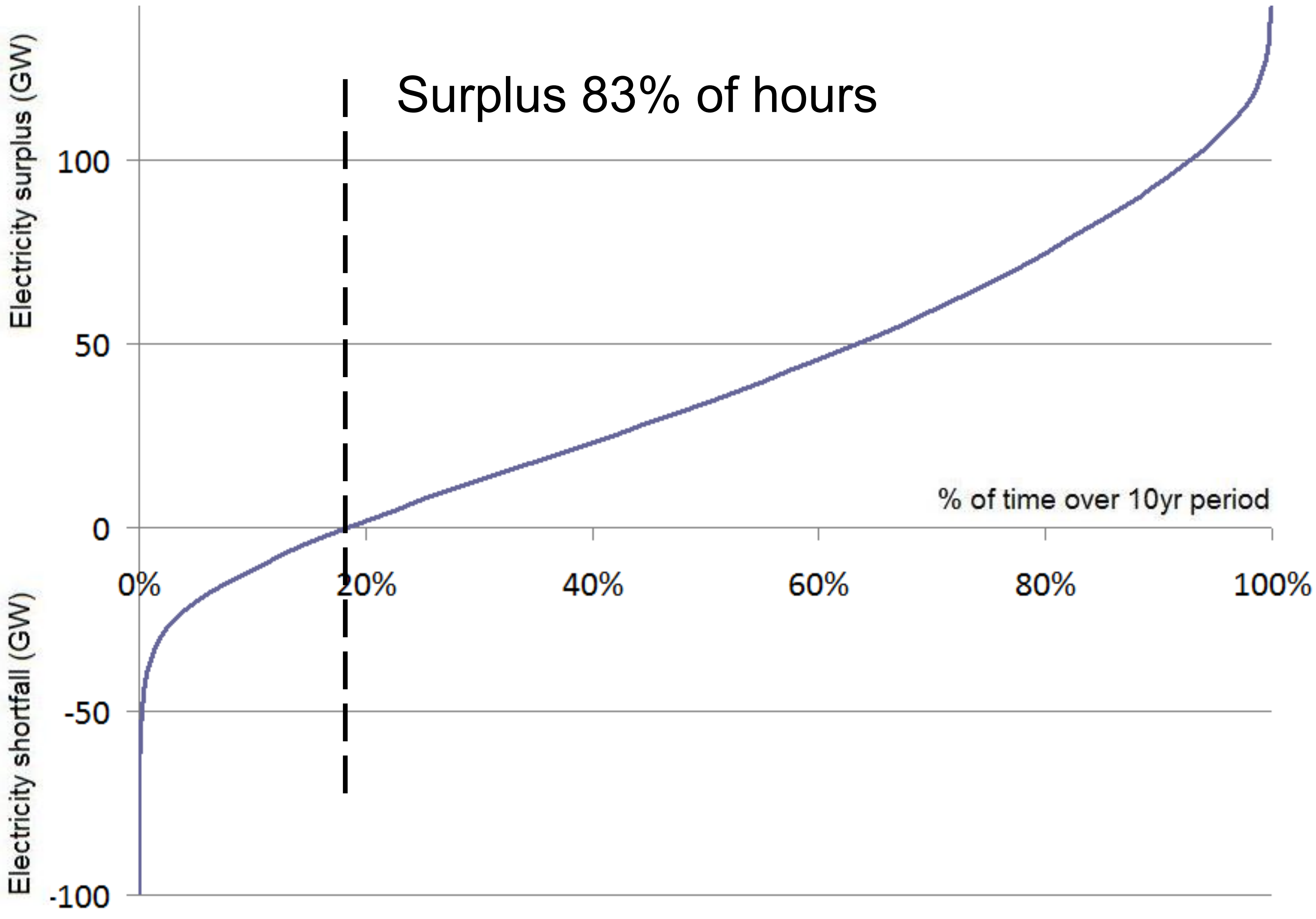

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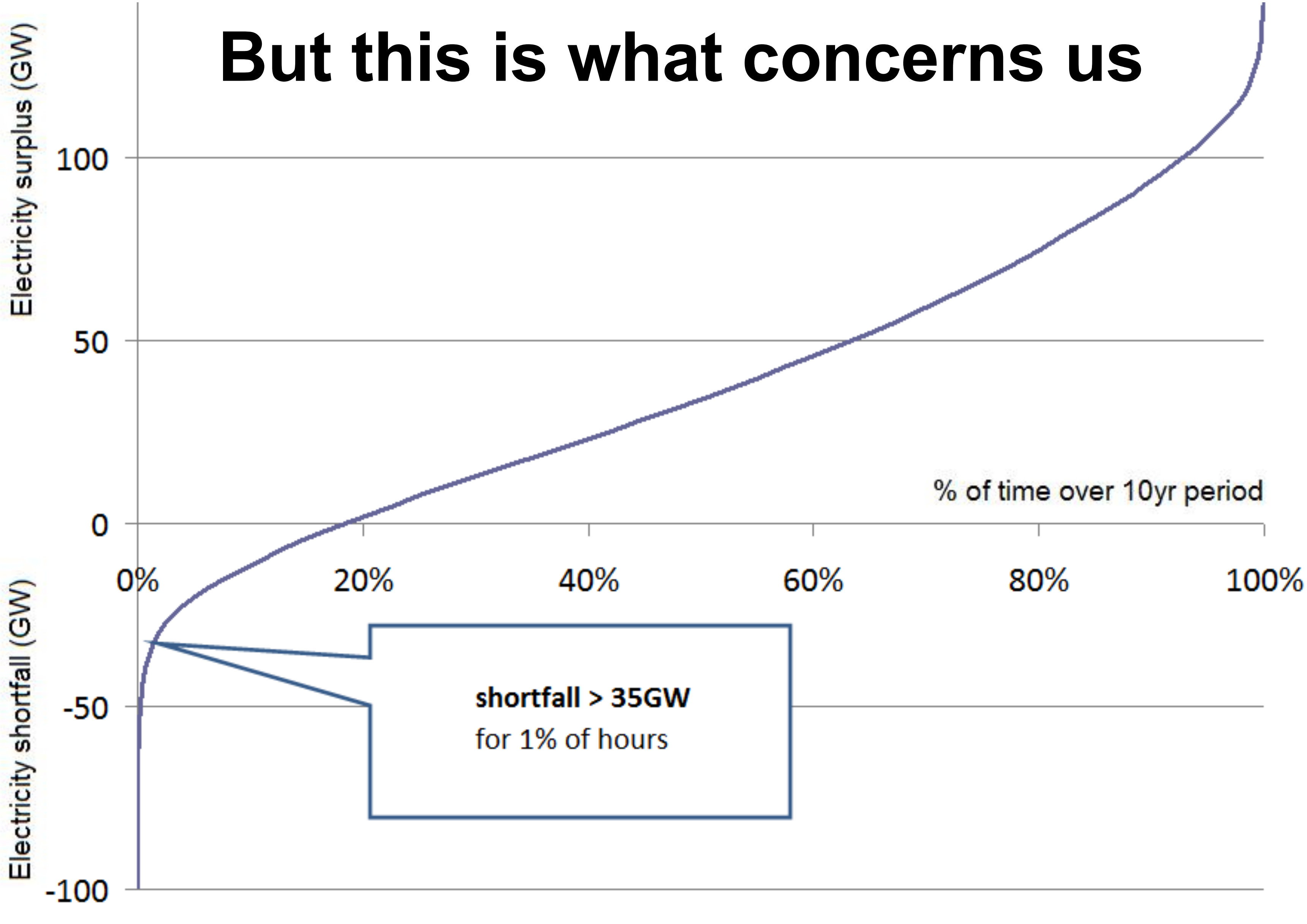
But this is what concerns us



Short-term fluctuations

Demand Side Management (DSM) can help
e.g. 'smart charging‘ of electric cars ~25GWh

Storage of energy – short term
Pumped hydro storage ~25GWh;
Heat storage via thermal mass ~100GWh

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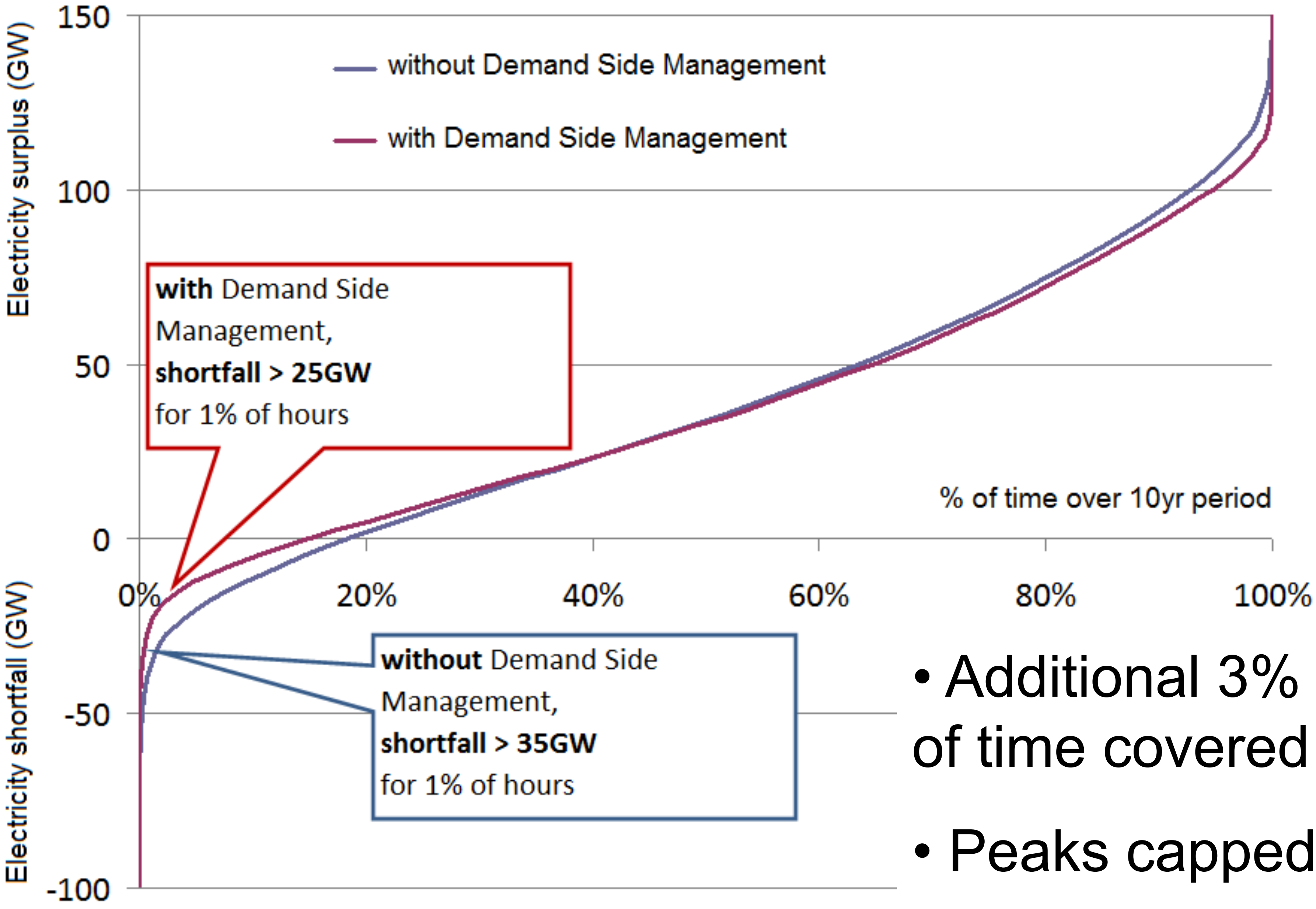

- Additional 3% of time covered
- Peaks capped

Longer-term fluctuations

Required:

- Capacity to store many TWh (1,000 GWh) over long periods
  ➔ not realistic with batteries, pumped storage, compressed air, fly wheels...
- Capacity to “withdraw” (dispatch) energy rapidly & flexibly

Modern **Combined Cycle Gas Turbine (CCGT)** plant:

- 60% efficiency
- >1h cold start time
- Very flexible ramping up/down of output

Renewable gas options

Hydrogen (H_2)

- can be produced from surplus renewable electricity (through electrolysis)
- very hard to transport & store
- we‘d need expensive new infrastructure

Renewable gas options

Methane (CH_4)

- vast existing infrastructure (natural gas = 90% methane), easy to store vast amounts of energy
- But only *climate neutral* if CO_2 is non-fossil & no gas leaks
- But how can we achieve this?

Renewable gas options

Synthetic methane gas

- Upgrades hydrogen to methane
- Sabatier reaction:

$$4H_2 + CO_2 = CH_4 + 2H_2O$$

Renewable transport fuels

- most transport is electrified in ZCB...
- ... but some vehicles need higher energy densities (more energy per weight)

The ZCB Scenario demonstrates

- 82% of the time, the supply of renewable electricity exceeds demand (inc. electricity for heating and transport).
- 18% of the time, electricity supply does not fully meet demand.
- Short-term storage & load shifting can reduce this from 18% to 15%.
- Biogas and carbon neutral synthetic gas are burned in gas power stations to cover this.

Management of supply and demand with a 100% renewable energy system is possible with existing technology

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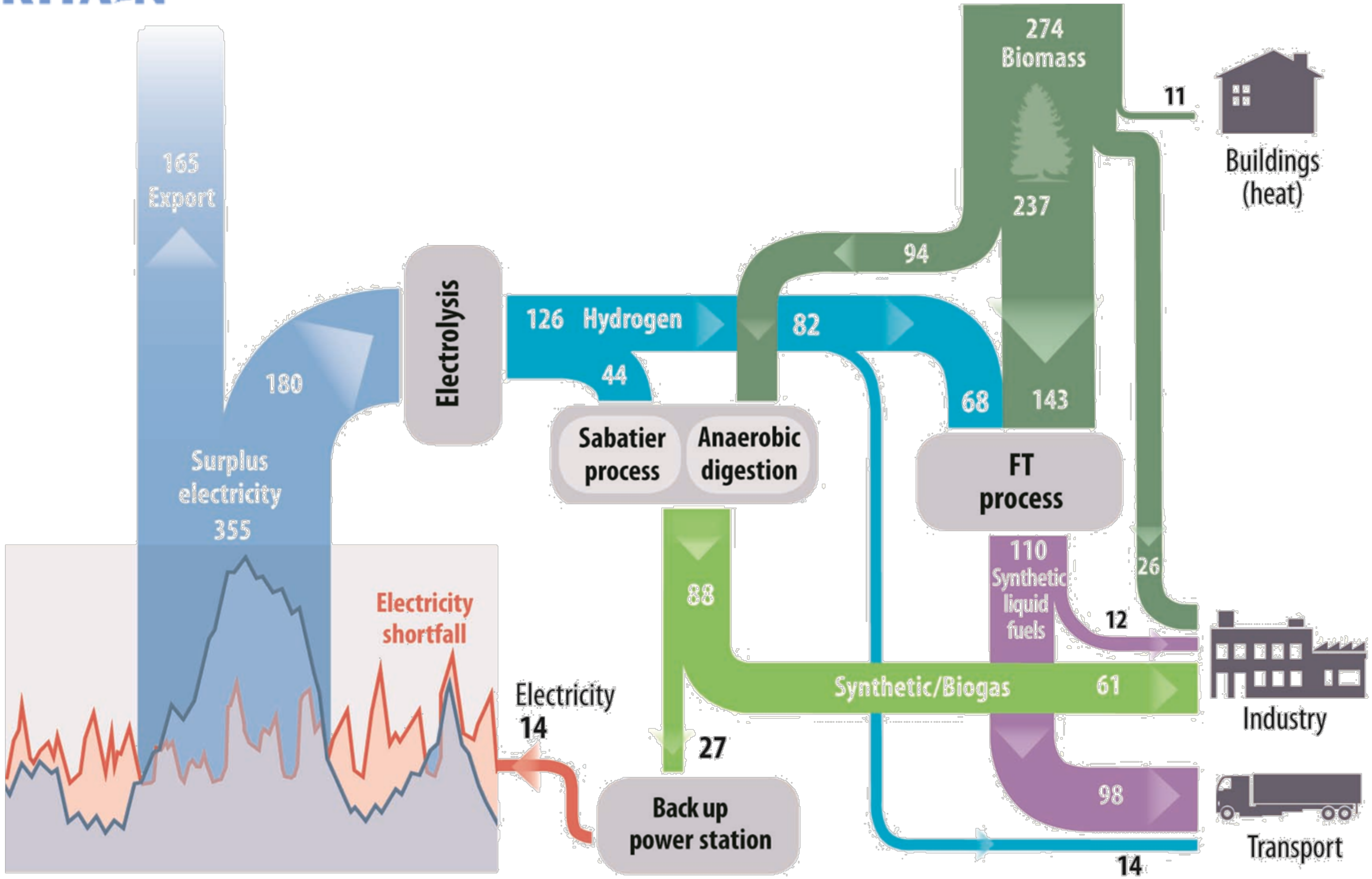

Carbon Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tcmt20

Toward understanding the challenges and opportunities in managing hourly variability in a 100% renewable energy system for the UK

Alice Hooker-Stroud[a], Philip James[a], Tobi Kellner[a] & Paul Allen[a]
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Published online: 22 Apr 2015.

Toward understanding the challenges and opportunities in managing hourly variability in a 100% renewable energy system for the UK

Carbon Management (2014)

Alice Hooker-Stroud*, Philip James, Tobi Kellner & Paul Allen
One hundred percent renewable energy systems have the potential to mitigate climate change, but large fluctuations in energy supply and demand make ensuring reliability a key challenge. A hypothetical future energy system developed for the UK features reduced total energy demand, increased electrification and 100% renewable and carbon-neutral energy sources. Hourly modelling of this system over a 10-year period shows that even in an integrated energy system there will be significant electricity surpluses and shortfalls. Flexible demand and conventional electricity and heat stores reduced the extremes but could not provide the capacity required. Carbon-neutral synthetic gaseous fuel could provide a flexible and quickly dispatchable back up system, with large storage and generation capacities comparable with those in the UK today.

So we can shift from this..

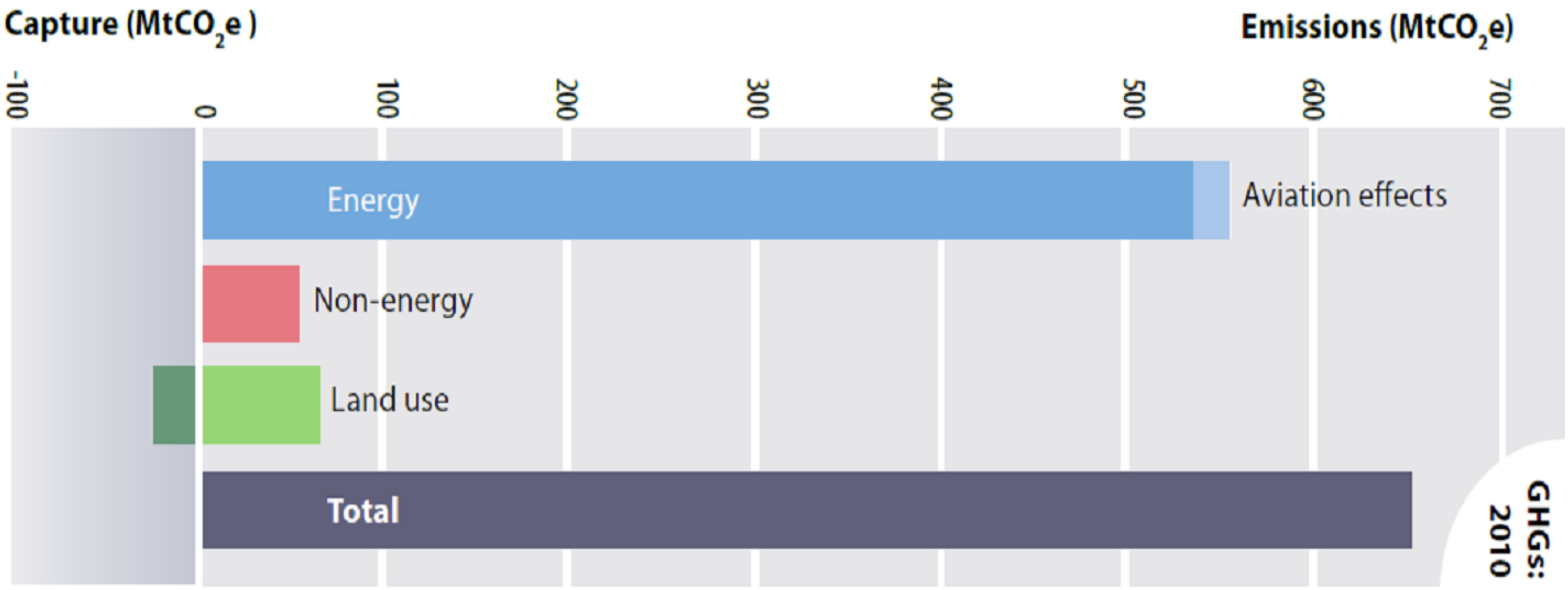

Figure 3.1: UK Greenhouse gas emissions in 2010, including international aviation and shipping, and the enhanced effect of emissions from aviation (DECC, 2013).

To reach "net zero"

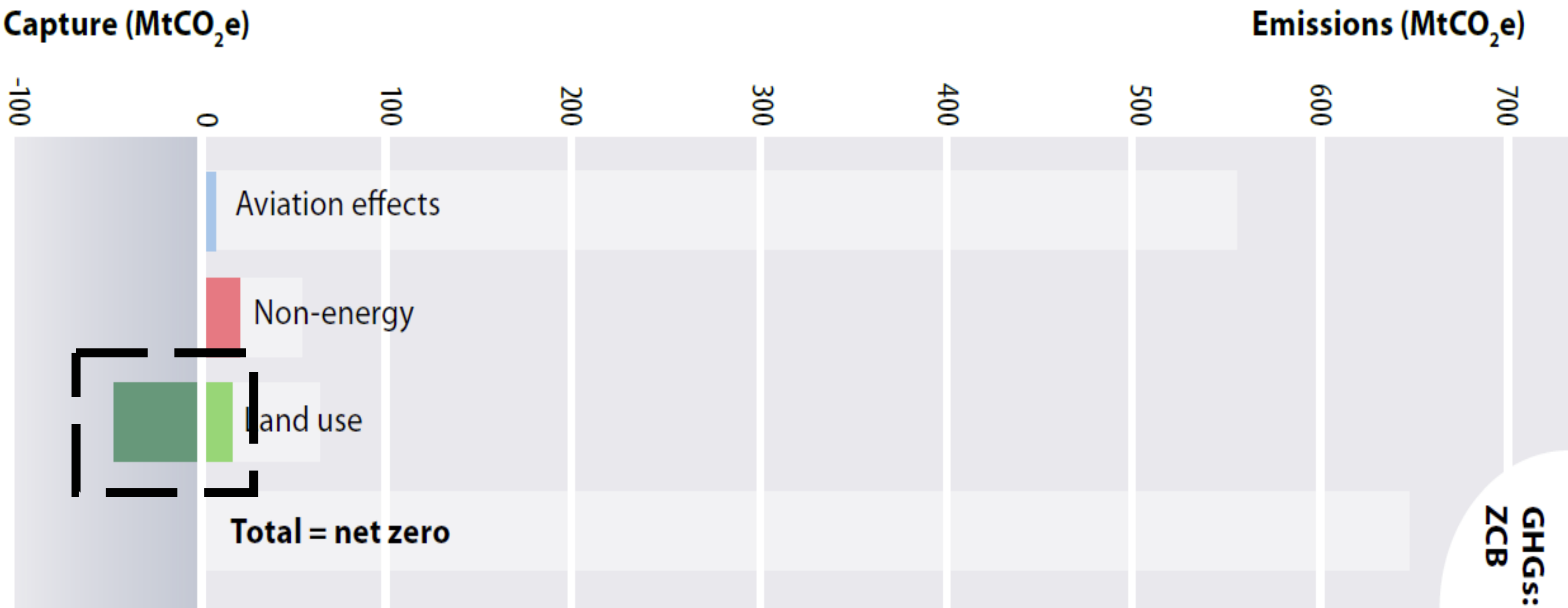

Figure 3.35: Carbon captured and greenhouse gas emissions for the UK in our scenario relative to 2010, including international aviation and shipping and the enhanced effect of emissions from aviation. Total emissions sum to net zero.

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WHO'S GETTING READY FOR ZERO?

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TRACK

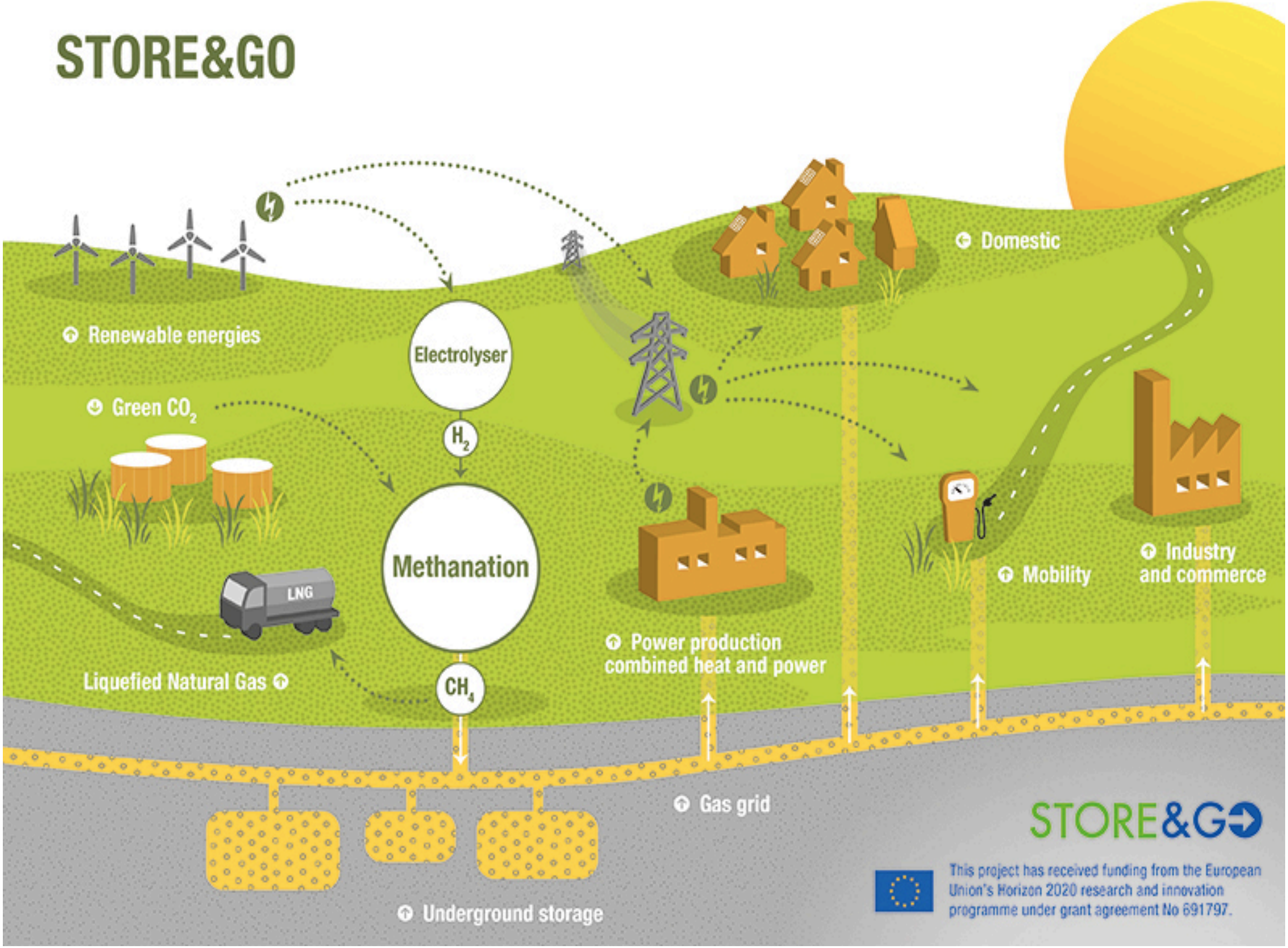
Power to Gas is growing

- In 2013, Audi announced its opening of a 6-MW PtG facility in Germany making it the first automaker to develop a chain of sustainable energy carriers. The Audi e-gas project demonstrates how large amounts of green electricity can be stored efficiently and independent of location by transforming it into methane gas and storing it in the natural gas network, the largest German public storage system.
- Construction of Japan's first PtG plant was initiated in July 2017 as a key part of its efforts to reduce CO2 emissions. It is the objective of this test facility to prove the feasibility of large scale PtG plants."
- Navigant Research indicates that a key inflection point for PtG is anticipated beginning around 2020 "as costs reach parity in more areas."

https://www.renewableenergyworld.com/articles/2018/02/the-future-of-power-to-gas-couldn-t-be-brighter.html

www.storeandgo.info/about-the-project/

- Generating gas from renewable electrical power using Power-to-Gas processes is by far the most promising way to store large amounts of energy and to reach the targets of the Paris agreement for 2030 and beyond. Power-to-Gas diminishes the need for power grid expansion and reduces the associated CAPEX and OPEX costs as well.
- These technologies will be demonstrated at a considerable scale between 200 kW and 1 MW in three different demonstration environments for a runtime of about two years. The resulting product – synthetic natural gas (SNG) – will be injected into the existing grid and delivered to customers.
- The consortium is built of 27 partners from six European countries having expertise in the energy sector, process engineering, economics, law and social science.


STORE&GO
Renewable energies
Electrolyser
Green CO2
H2
Methanation
LNG
Liquefied Natural Gas
CH4
Domestic
Power production
combined heat and power
Mobility
Industry
and commerce
Gas grid
Underground storage
STORE&GO
This project has received funding from the European
Union's Horizon 2020 research and innovation
programme under grant agreement No 691797.