Imperial College London

Experience Curves for Electricity Storage

Oliver Schmidt, Adam Hawkes, Ajay Gambhir, Iain Staffell

REFLEX-Workshop: "Technological Learning in the Energy Sector"
08 November 2017 | Karlsruhe

Grantham Institute

Atmospheric CO_2 concentration is rising at record levels

Last week's news

Global atmospheric CO2 levels hit record high

UN warns that drastic action is needed to meet climate targets set in the Paris agreement

The Guardian (30 October 2017)

UNO: CO2-Konzentration in der Atmosphäre stieg 2016 mit Rekordgeschwindigkeit an

30. Oktober 2017, 11:52 Uhr / Quelle: afp

Genf (AFP) Die Konzentration des klimaschädlichen Kohlendioxid (CO2) in der Atmosphäre hat im vergangenen Jahr einen neuen Rekordwert erreicht. Noch nie sei dieser Wert so schnell angestiegen wie 2016, erklärte die Weltorganisation für Meteorologie (WMO) am Montag in Genf. Im weltweiten Durchschnitt lag sie demnach bei 403,3 ppm (Teilchen pro eine Million Teilchen), nach 400 ppm im Jahr 2015.

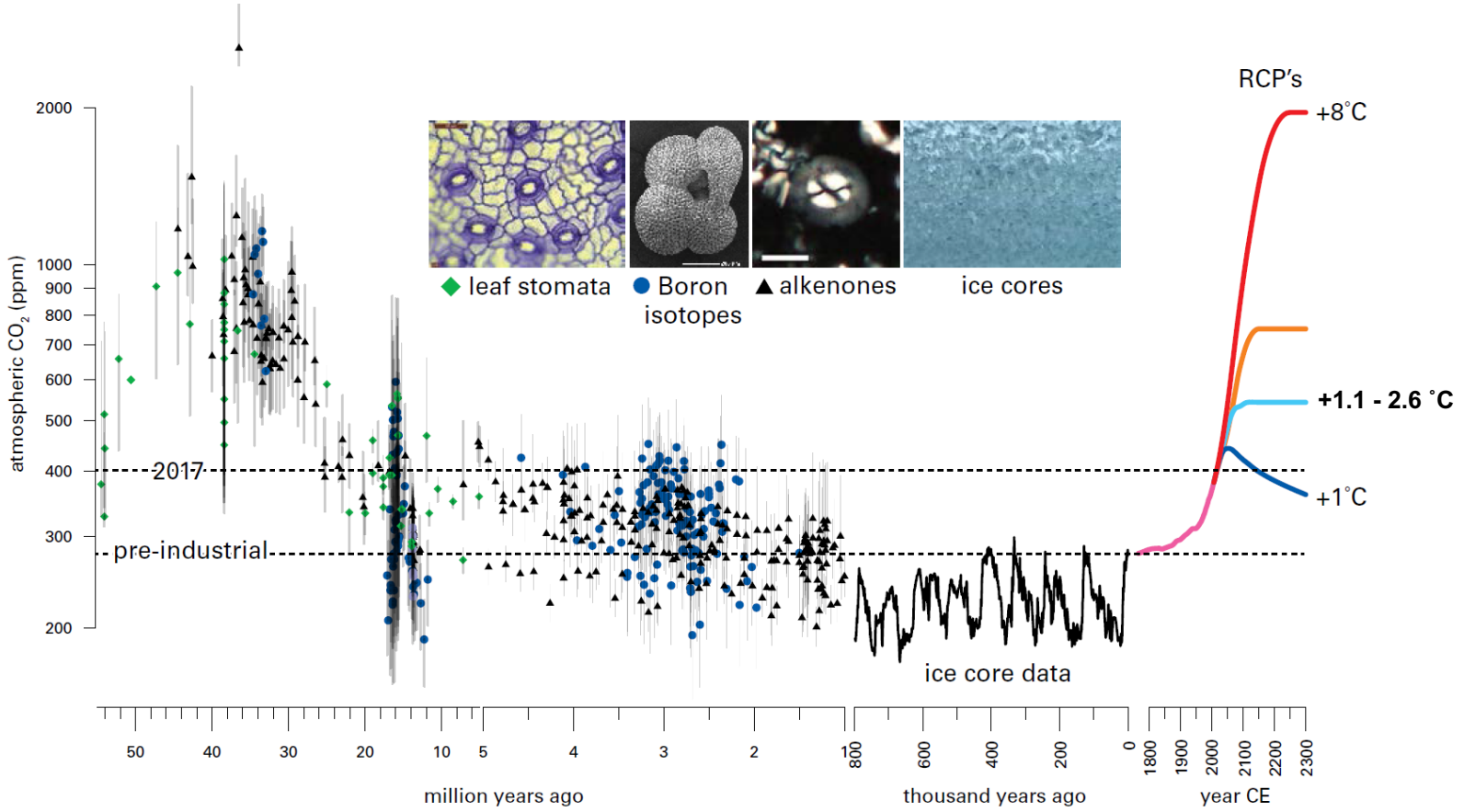
Zeit Online (30 October 2017)

Carbon dioxide levels grew at record pace in 2016, U.N. says

Reuters (30 October 2017)

CO_2 levels must stay below 500 ppm to limit temperature rise to 1.1-2.6 ˚C

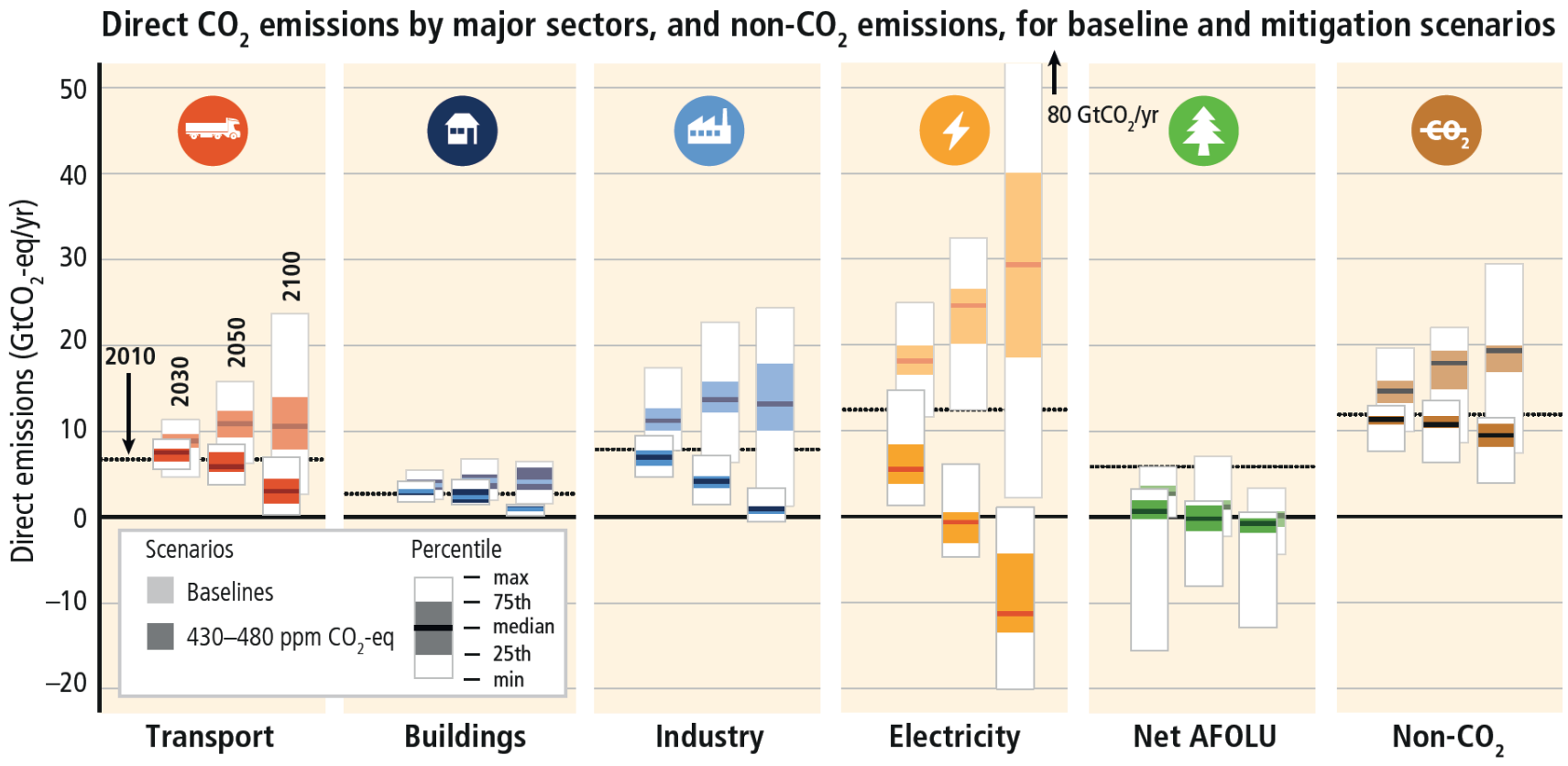
Atmospheric CO_2 concentration



Source: WMO Greenhouse Gas Bulletin No. 13. The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2016. World Meteorological Organisation. (30 October 2017)

For that to happen, global electricity generation must be carbon-free by 2050

Decarbonisation of electricity generation



Source: IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

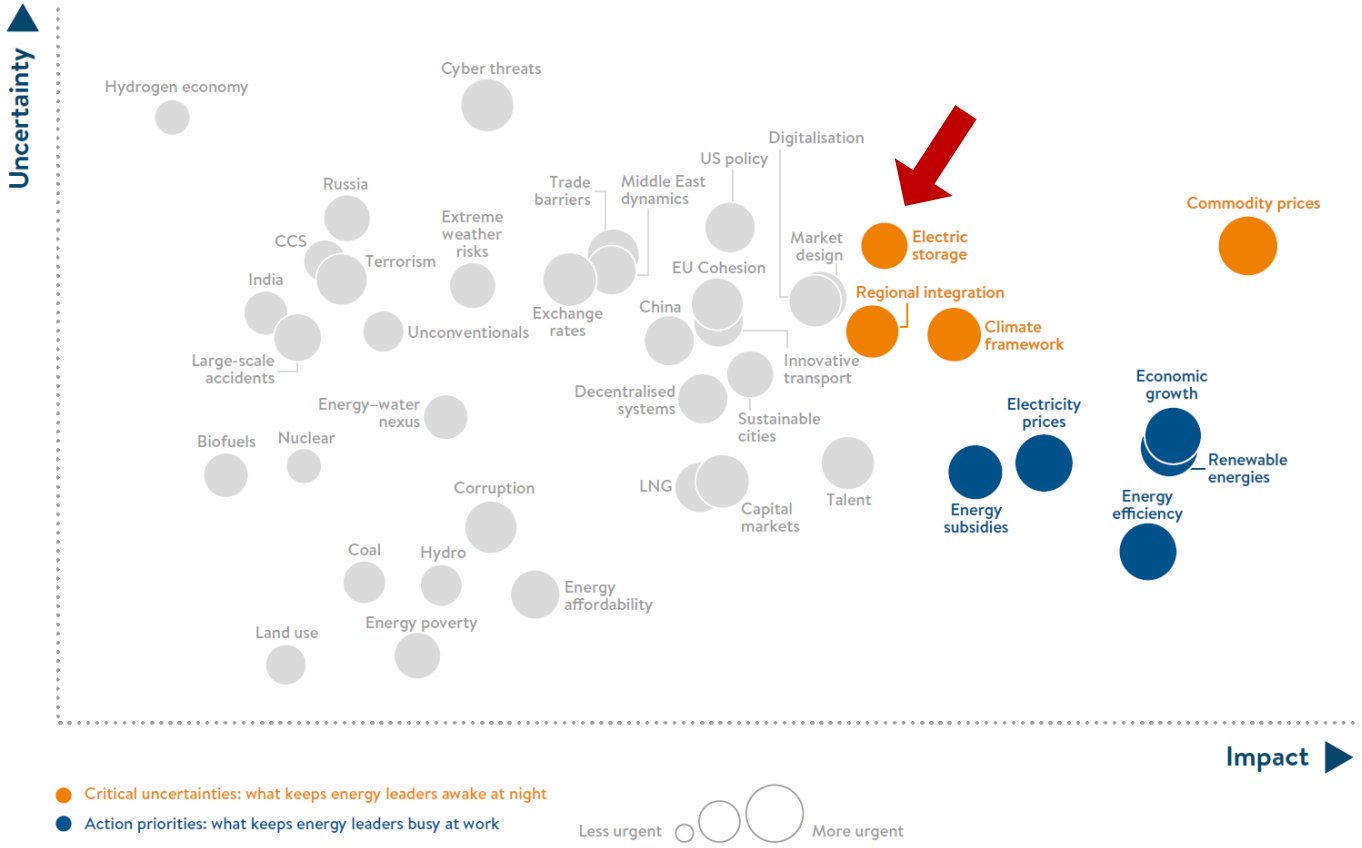
Electricity storage could play a critical role in low-carbon energy systems

Role of storage

Source: Icons made by Freepik from www.flaticon.com

But, the future role of electricity storage is still perceived as highly uncertain

Uncertainty on role of storage



Source: World Energy Issues Monitor 2017 | Exposing the new energy realities. World Energy Council; 2017.

Although costs for lithium-ion batteries have fallen dramatically in recent years

Recent cost developments

Average: 3,000 $/kWh

Powerwall 1: 1,100 $/kWh

Powerwall 2: 500 $/kWh

October 2013 — April 2015 — October 2016

Sources: Tepper, M. Solarstromspeicher-Preismonitor Deutschland 2016. (Bundesverband Solarwirtschaft e.V. und Intersolar Europe, 2016); www.solarfixni.co.uk/solarpanelsystems/tesla/; www.tesla.com/powerwall

A consistent method to project cost for multiple technologies is needed

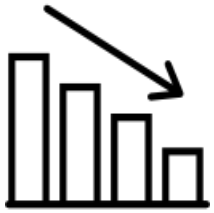
Approach

Technology

- Cost analyses are focussed on lithium-ion
- A holistic assessment should cover multiple technologies

Scope

- Cost quotes refer to different technology components
- A transparent analysis should clarify reference scope



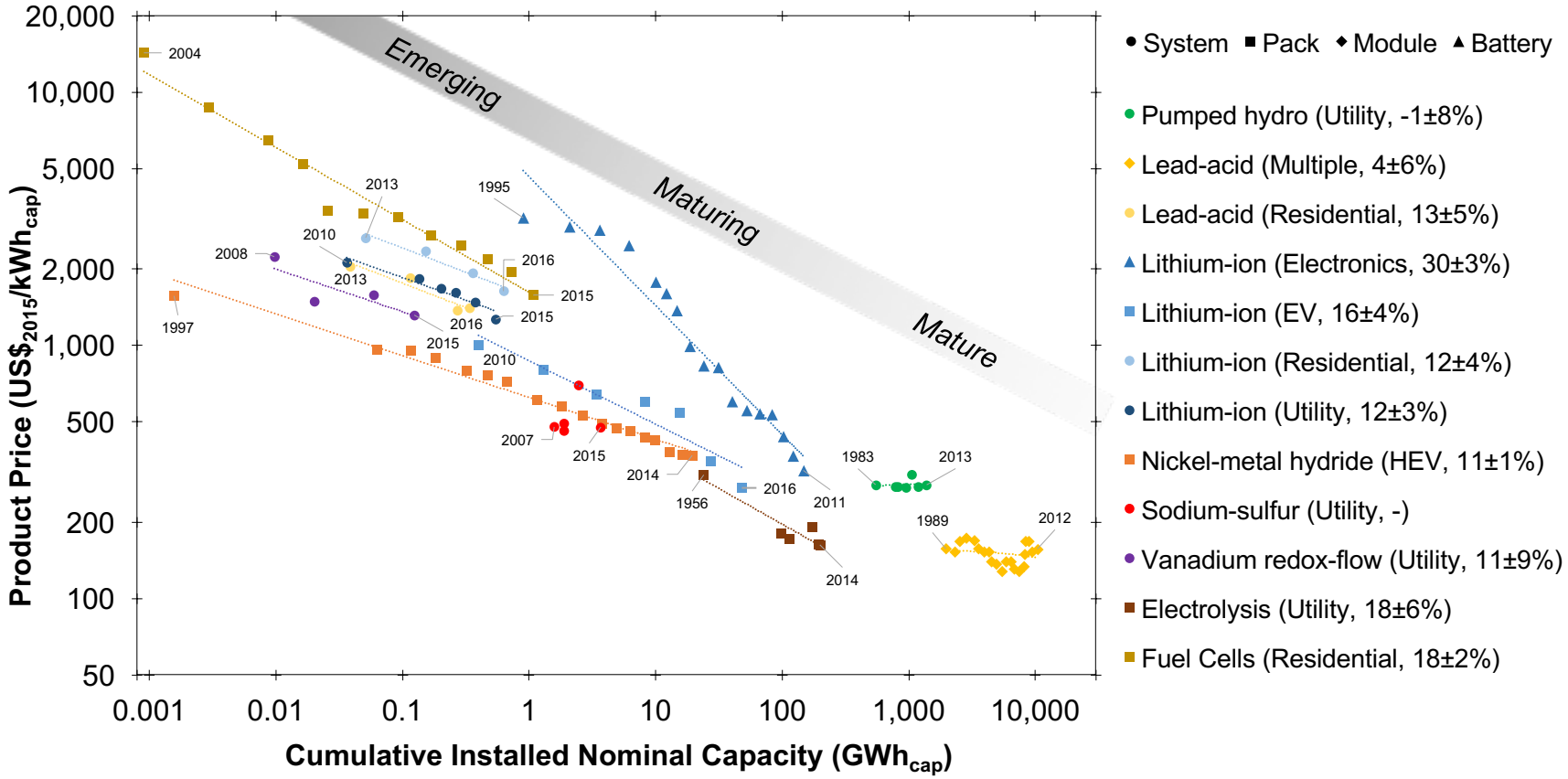
Method

- Cost projections are made with varying methods
- An objective and consistent method should be chosen

Source: www.flaticon.com

We derive a 1st-of-its-kind experience curve dataset for storage technologies...

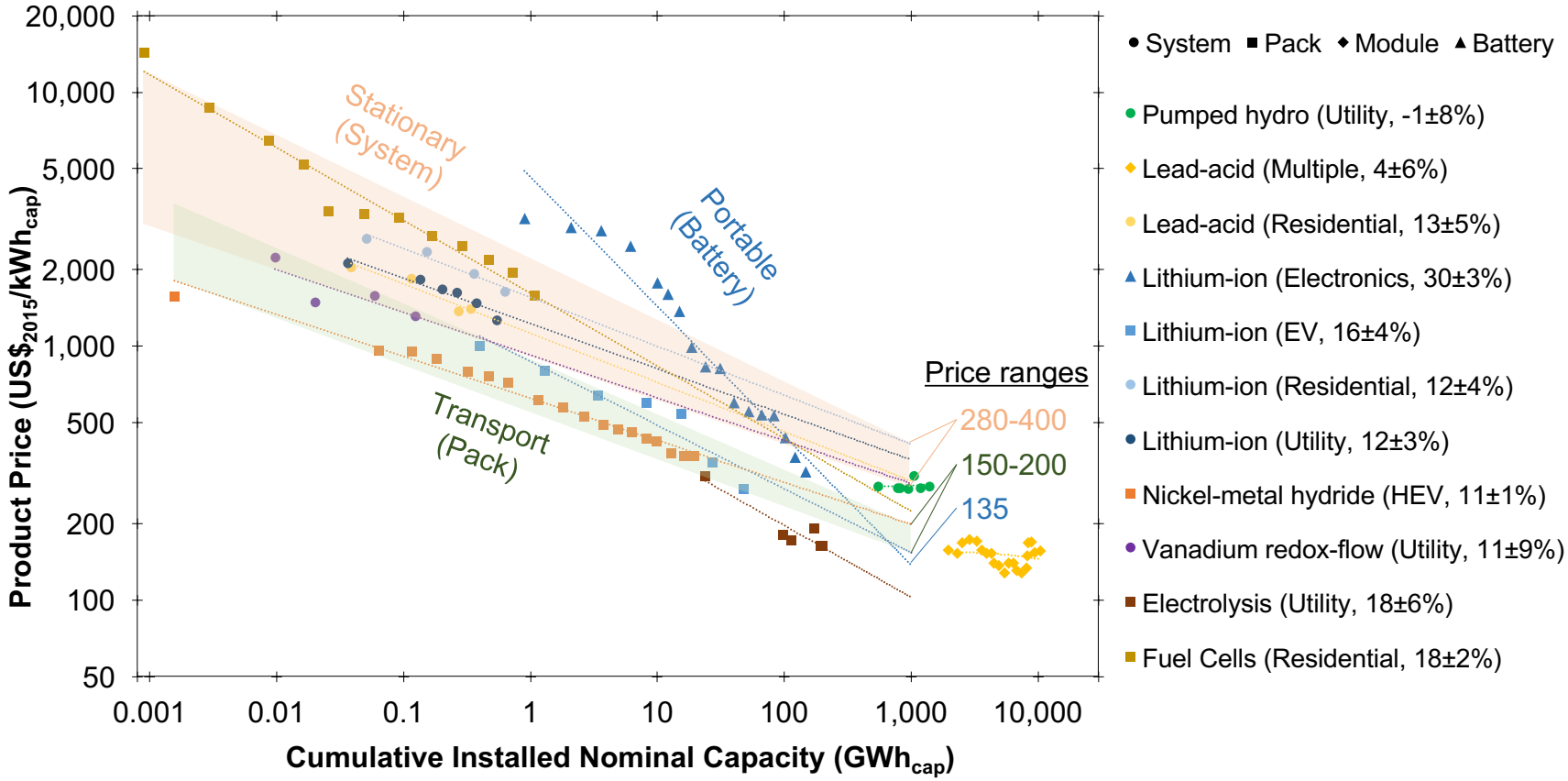
Dataset



Source: O. Schmidt, A. Hawkes, A. Gambhir & I. Staffell. The future cost of electrical energy storage based on experience rates. Nat. Energy 2, 17110 (2017)

... that enables evidence-based cost projections

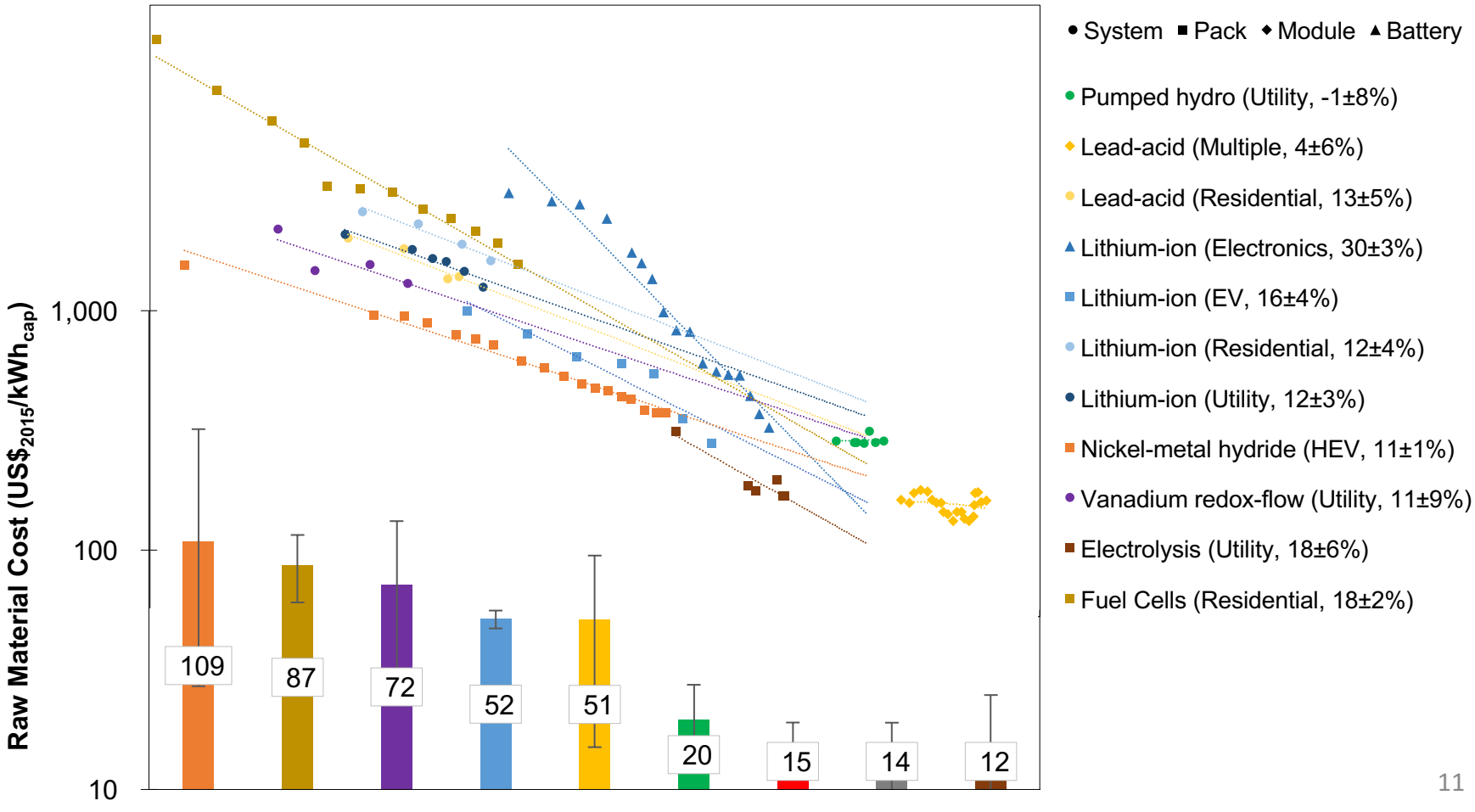
Result



Source: O. Schmidt, A. Hawkes, A. Gambhir & I. Staffell. The future cost of electrical energy storage based on experience rates. Nat. Energy 2, 17110 (2017)

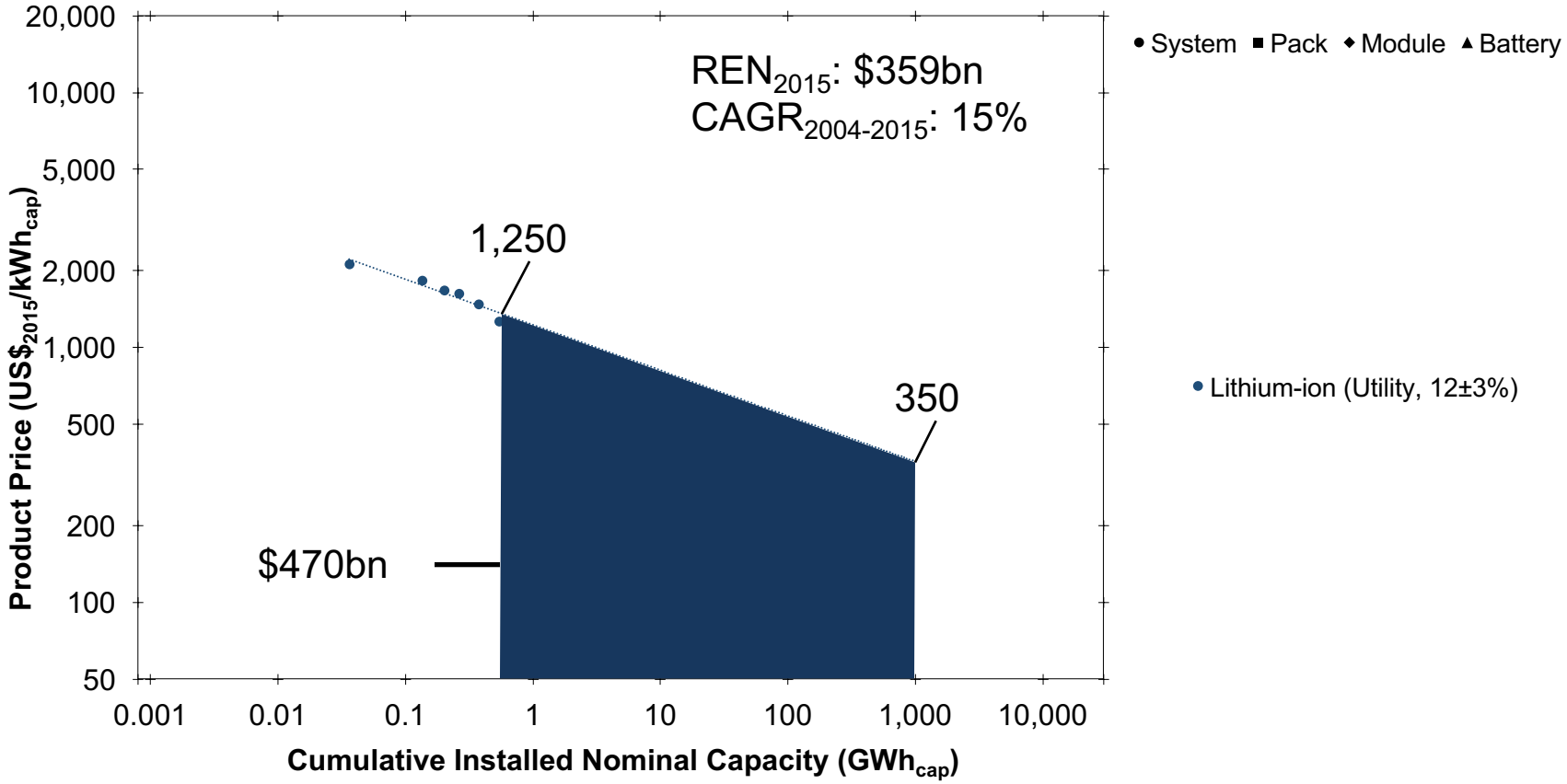
Raw material costs suggest that these cost projections are not infeasible

Sanity Check – Raw material cost



Required investments in deployment to achieve projected costs appear sensible

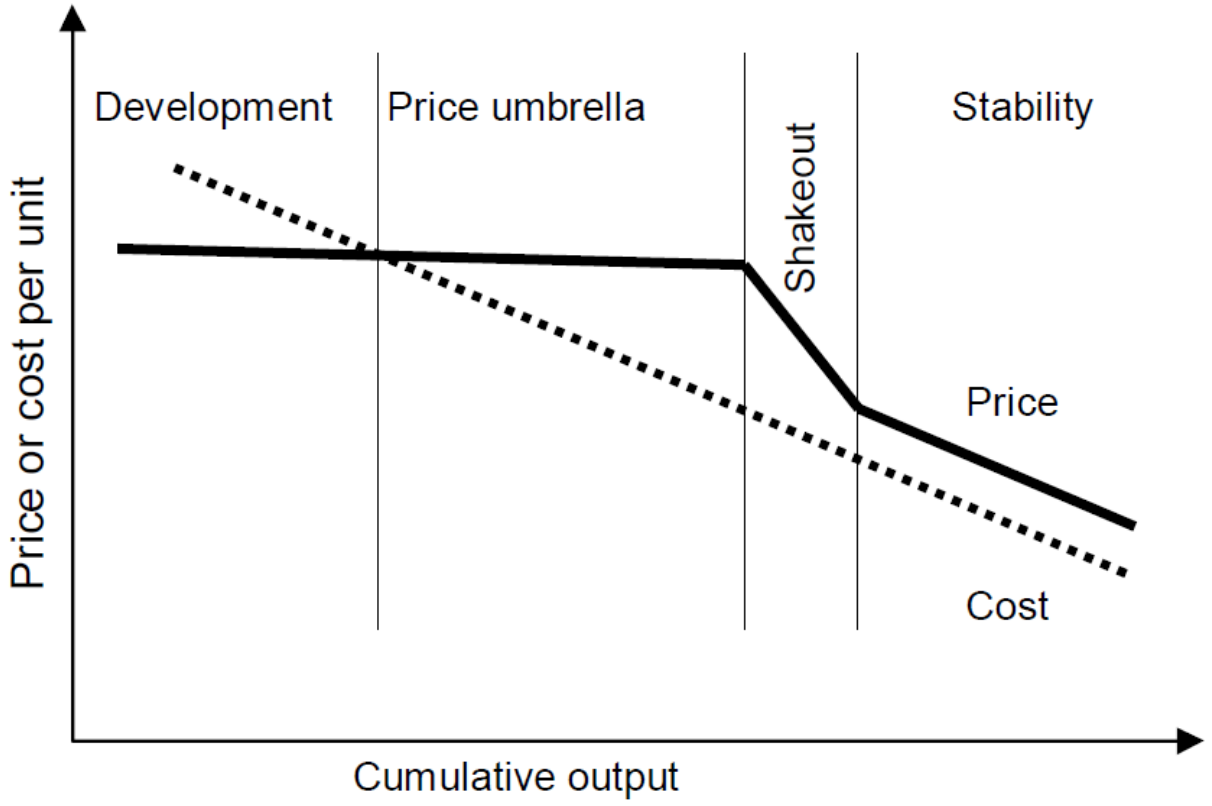
Sanity Check – Investment requirement



Source: O. Schmidt, A. Hawkes, A. Gambhir & I. Staffell. The future cost of electrical energy storage based on experience rates. Nat. Energy 2, 17110 (2017)

However, experience rates of immature technologies can be highly uncertain

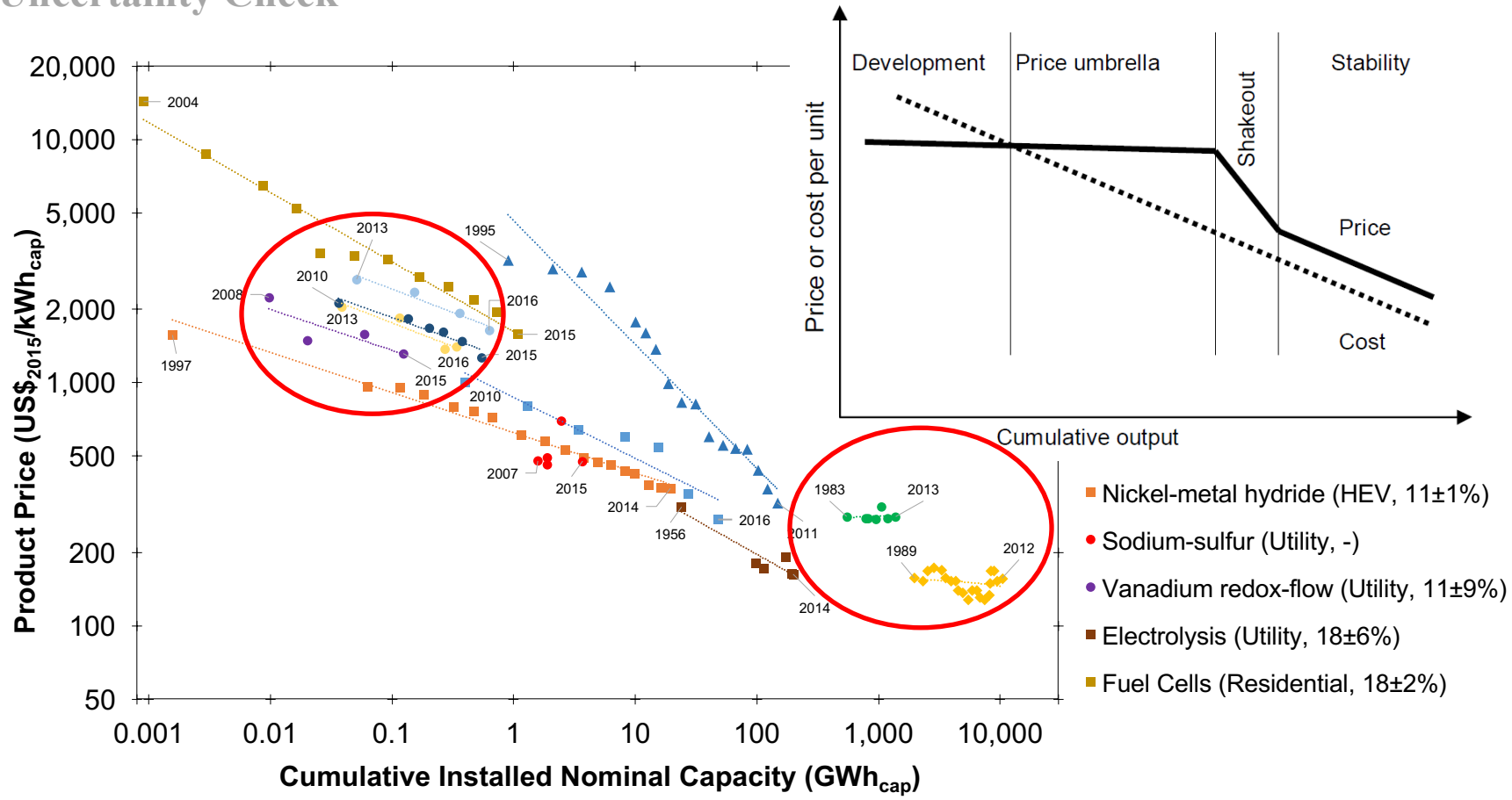
Uncertainty Check



Source: Junginger M, van Sark W, Faaij A. Technological learning in the energy sector: Lessons for policy, industry and science. Cheltenham: Edward Elgar Publishing; 2010.

However, experience rates of immature technologies can be highly uncertain

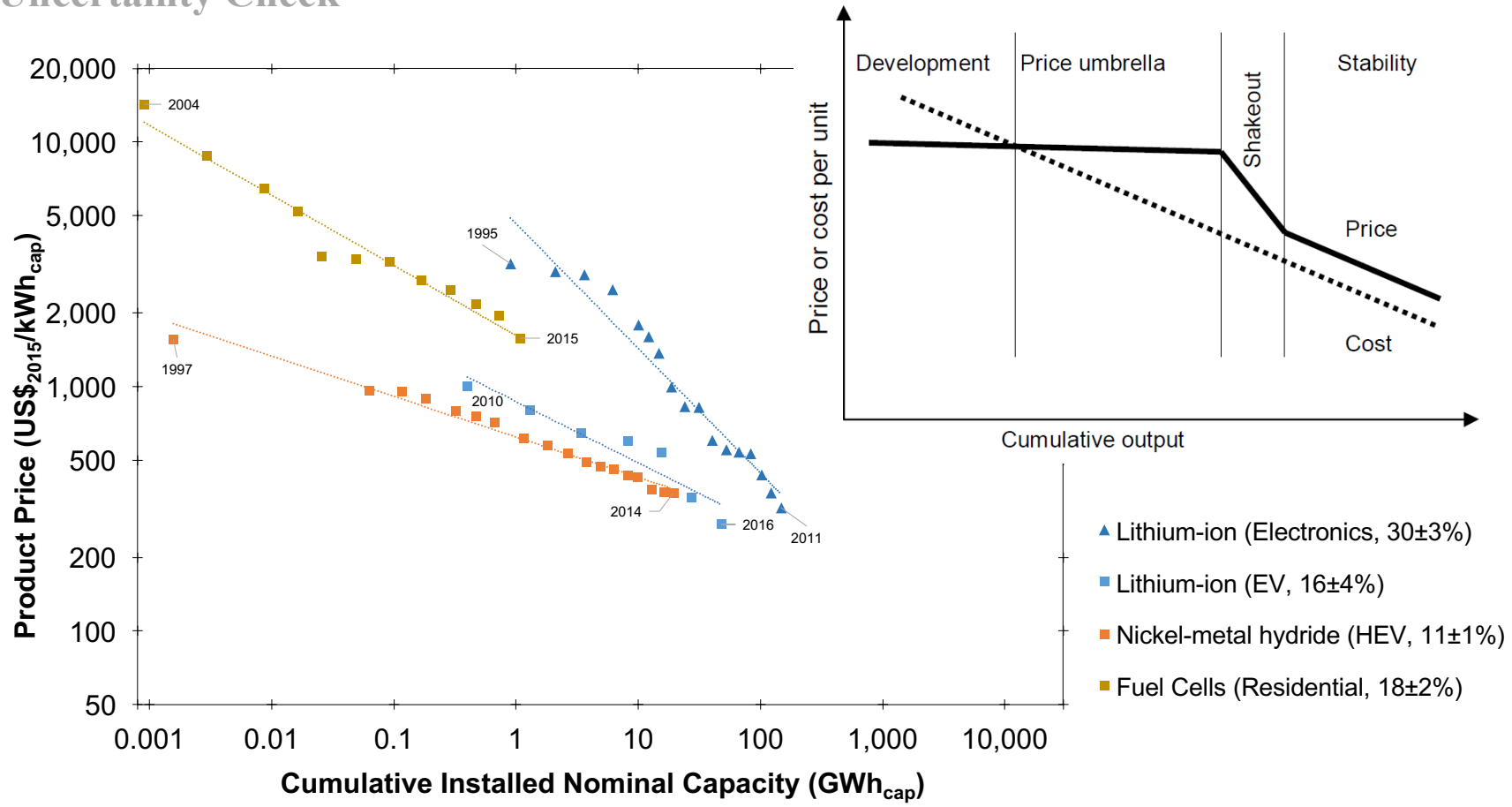
Uncertainty Check



Source: O. Schmidt, A. Hawkes, A. Gambhir & I. Staffell. The future cost of electrical energy storage based on experience rates. Nat. Energy 2, 17110 (2017)

However, experience rates of immature technologies can be highly uncertain

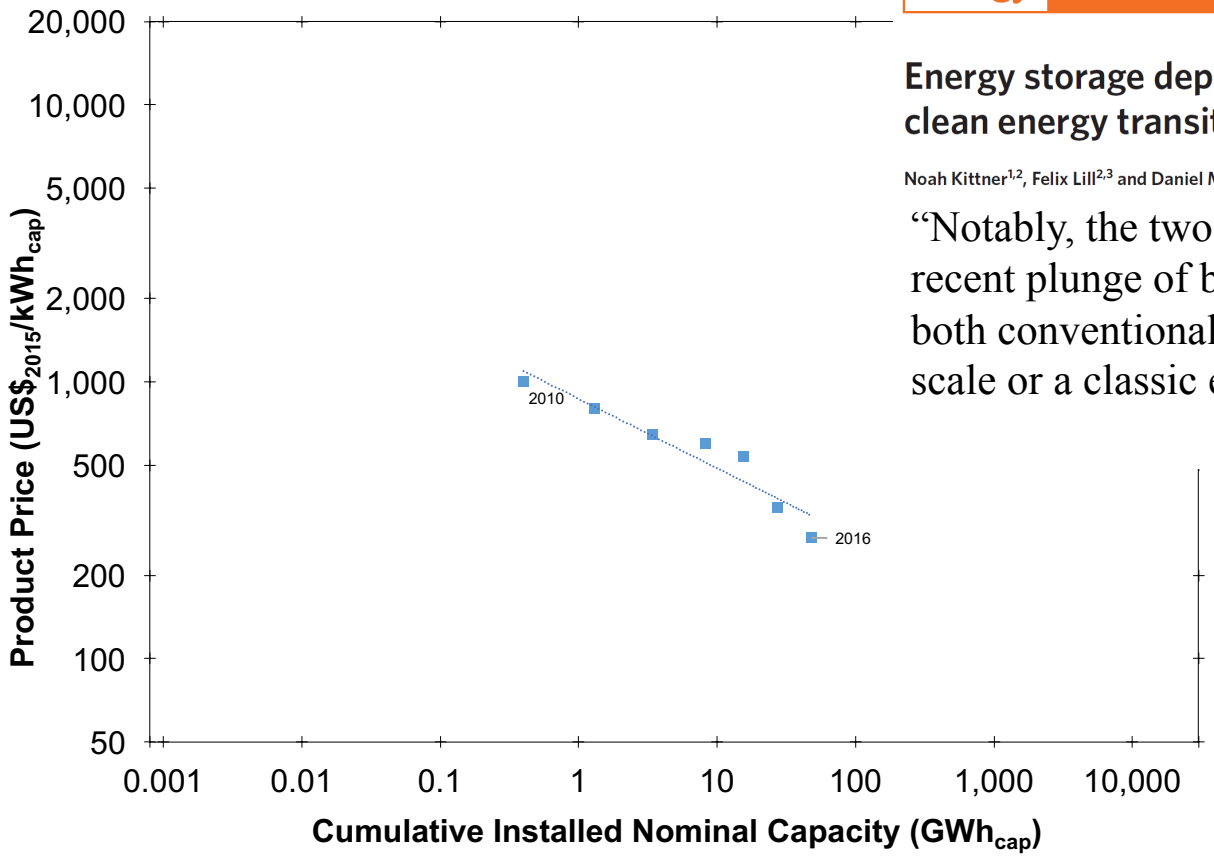
Uncertainty Check



Source: O. Schmidt, A. Hawkes, A. Gambhir & I. Staffell. The future cost of electrical energy storage based on experience rates. Nat. Energy 2, 17110 (2017)

However, experience rates of immature technologies can be highly uncertain

Uncertainty Check



nature energy
ARTICLES
PUBLISHED: 31 JULY 2017 | VOLUME: 2 | ARTICLE NUMBER: 17125

Energy storage deployment and innovation for the clean energy transition

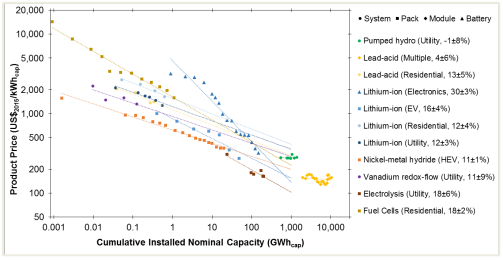
Noah Kittner[1,2], Felix Lill[2,3] and Daniel M. Kammen[1,2,4]*

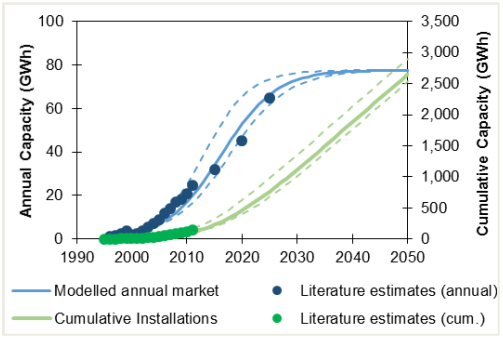
"Notably, the two-factor model explains the recent plunge of battery prices better than both conventional models using economies of scale or a classic experience curve approach."

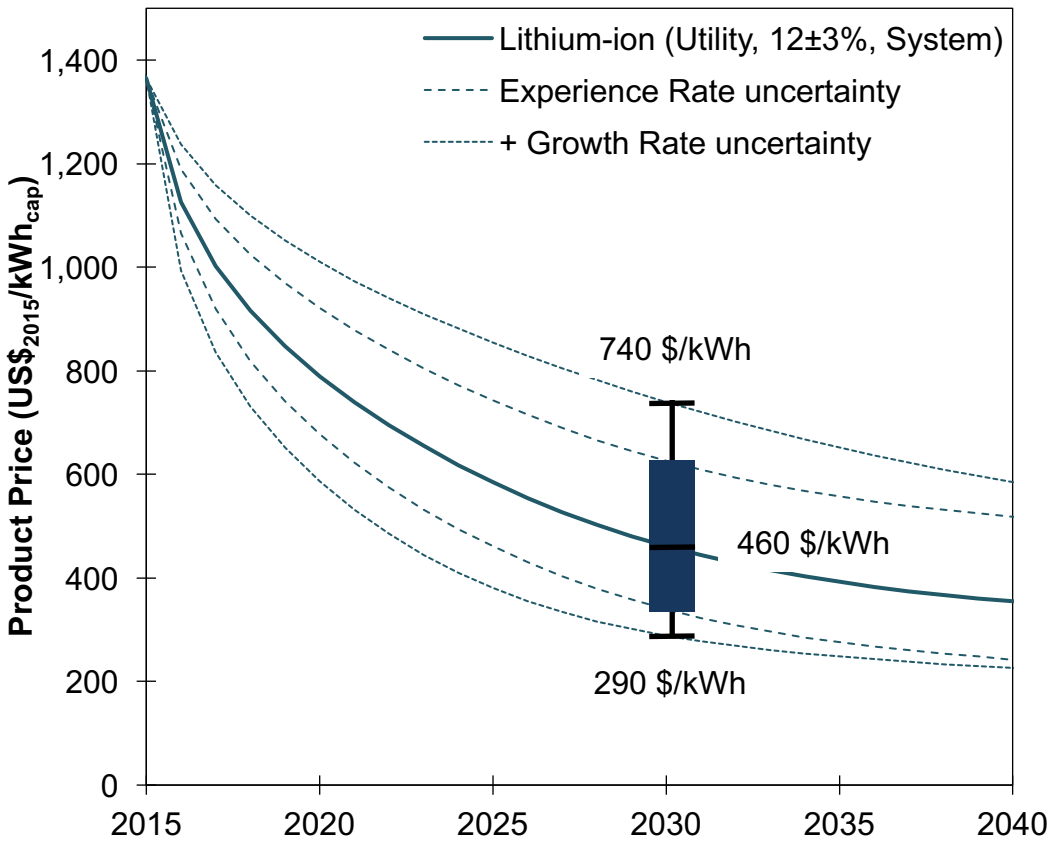
Source: O. Schmidt, A. Hawkes, A. Gambhir & I. Staffell. The future cost of electrical energy storage based on experience rates. Nat. Energy 2, 17110 (2017)

The cost of installed utility-scale lithium-ion systems fall to 290-740 $/kWh by 2030

Analysis 1 – Capital cost projection







Source: Own Analysis

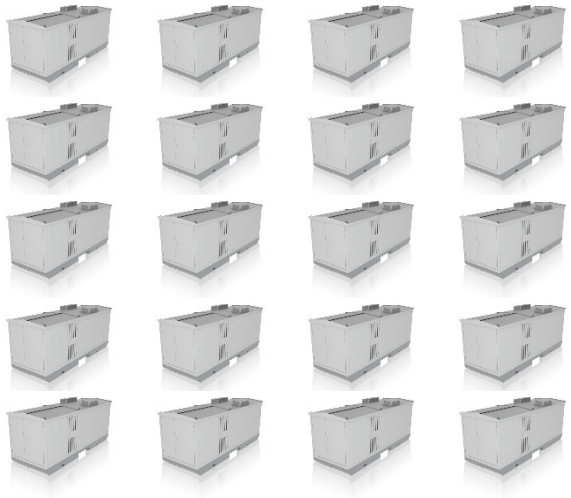
Instead of a nuclear plant, the UK could have doubled its existing storage capacity

Analysis 2 – Investment comparison

Cost: US$24 billion

Completion: 2025

OR



3.2 GW baseload capacity

"*Meet 5-10% of UK demand*"

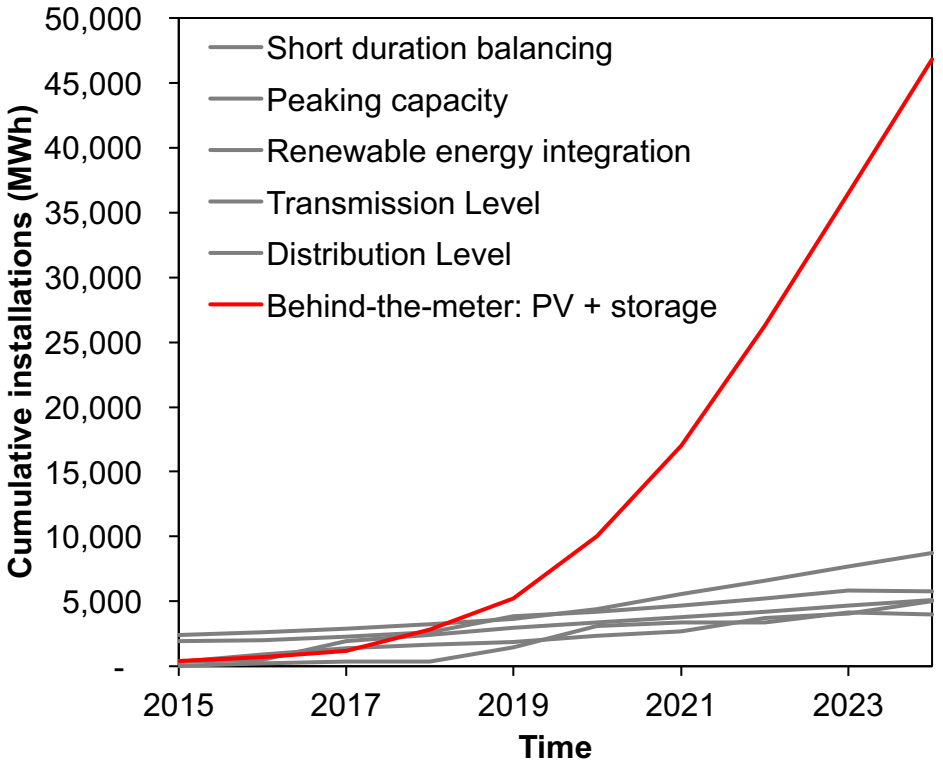
35 GWh storage capacity

"*Double UK's storage capacity*"

Source: Own Analysis

The market for home storage appears poised for growth...

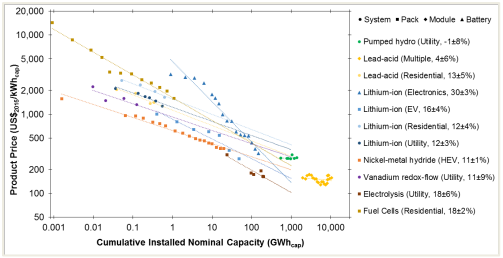
Analysis 3 – Competitiveness (Home storage)

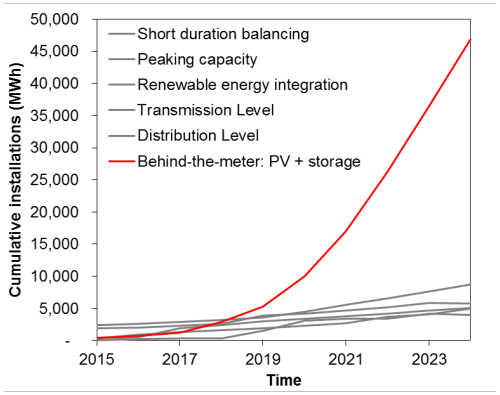


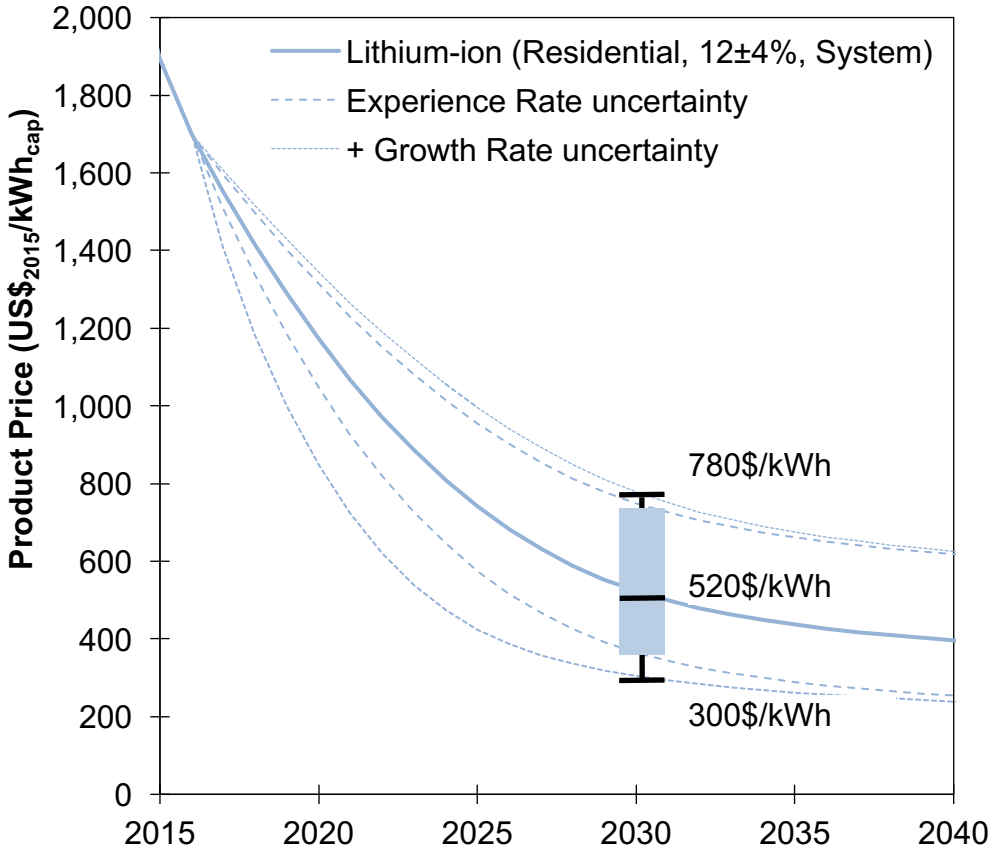
Source: www.tesla.com/powerwall; L. Goldie-Scot, Global Energy Storage Forecast 2016-24, Bloomberg New Energy Finance, 2016.

with cost of installed residential li-ion systems falling to 300-780 $/kWh by 2030

Analysis 3 – Competitiveness (Home storage)



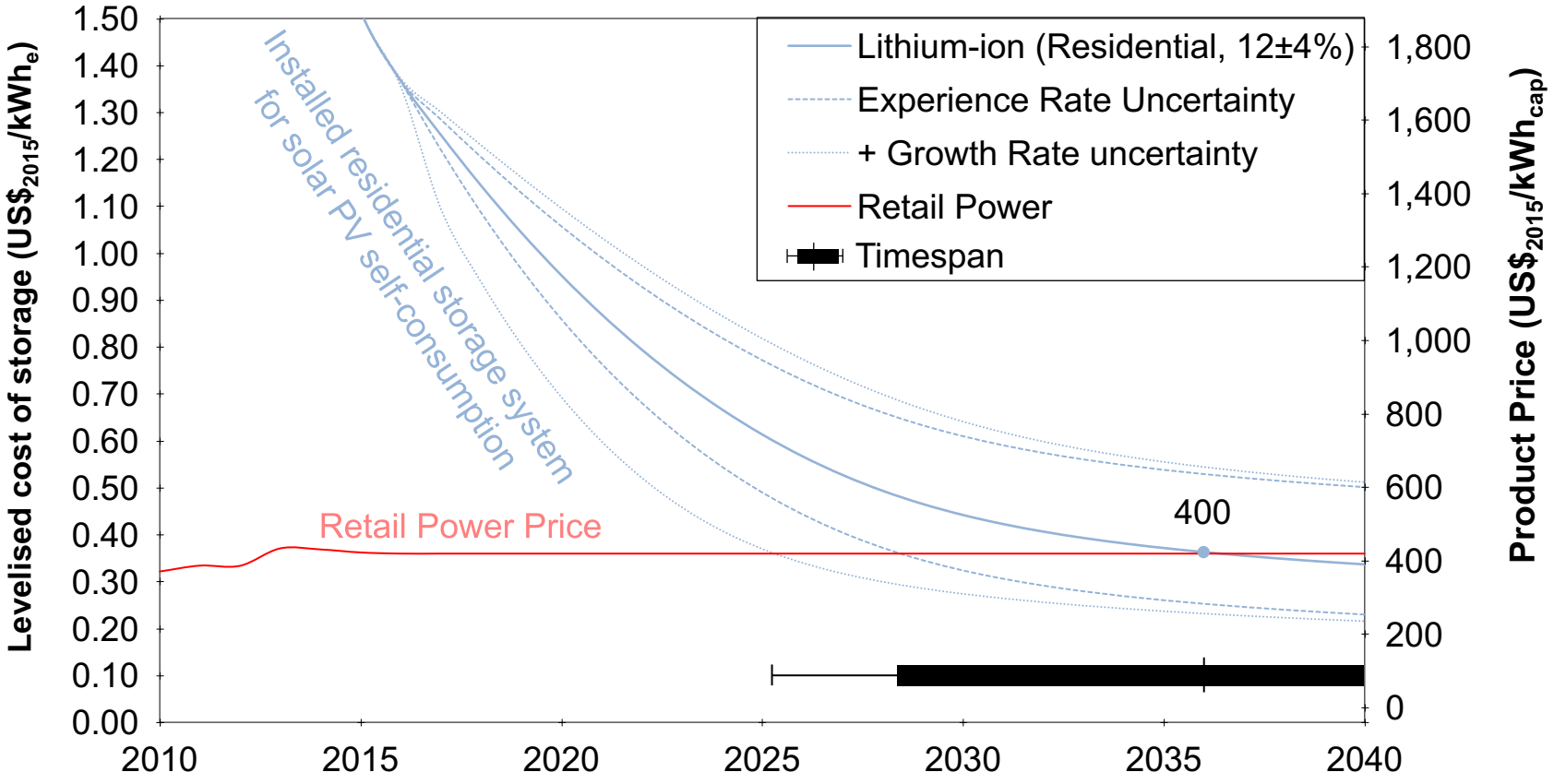




Source: Own Analysis

Still, residential batteries are unlikely to make economic sense in GER before 2030

Analysis 3 – Competitiveness (Home storage)

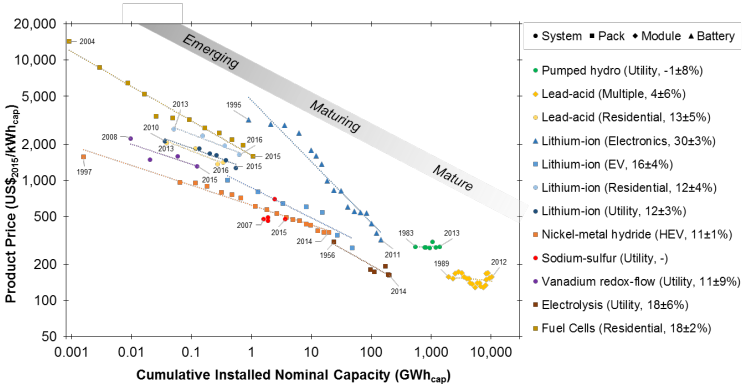


Source: Own Analysis

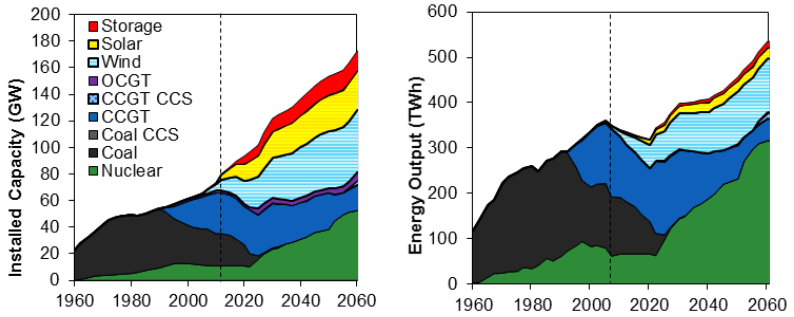
Including storage cost forecasts in power system models informs on abatement cost

Analysis 4 – Power system models (Approach)

Experience Curves



Power System Model (UK)



Future cost for three storage technologies:

	P2G	Flow	Li-ion
Duration	20h	6h	3h
Efficiency	30%	75%	85%
Lifetime	15y	15y	15y

1. Baseline scenario
2. Storage scenario
3. Marginal abatement cost

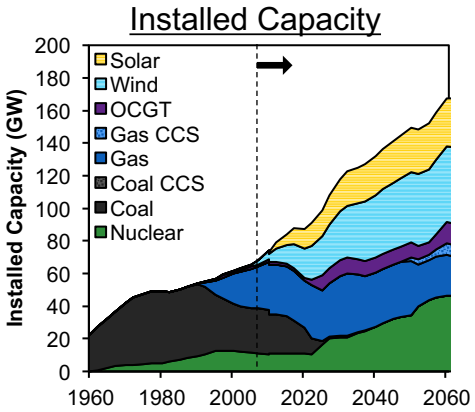
We model storage in the power system where it reduces CO_2 emissions at a cost

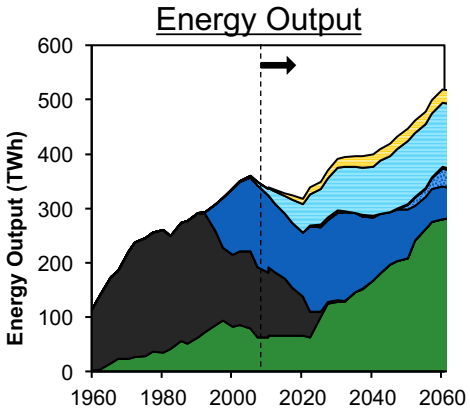
Analysis 4 – Power system models (Impact of storage)

Baseline

2050
- Carbon Price: 200 £/ton
- Strike Price: 89.5 £/MWh
- Renewables: 70 GW

2010 - 2060
- Curtailed: 159 TWh
- Emissions: 3.14 GT_{CO2}
- Net Spend: £113 bn

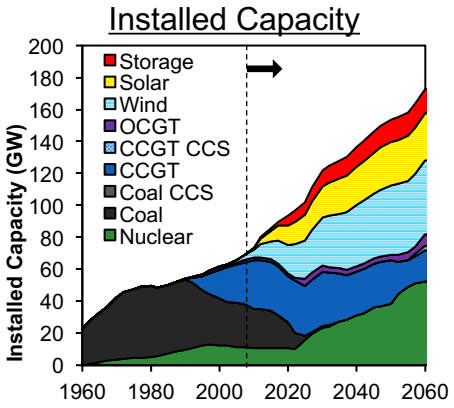


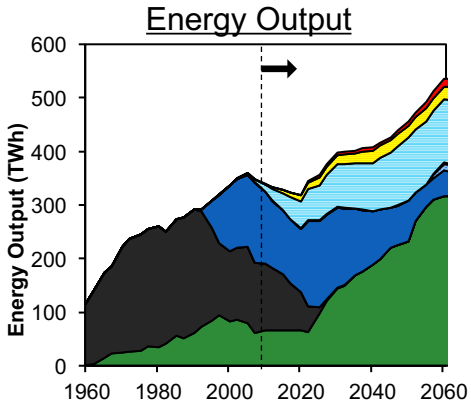


Storage

2050
- Storage capacity: 14 GW (20%)
- Storage duration: 6 hours
- Storage efficiency: 75%

2010 - 2060
- Curtailed: 117 TWh (-25%)
- Emissions: 2.94 GT_{CO2} (-6%)
- Net Spend: £130 bn (+15%)

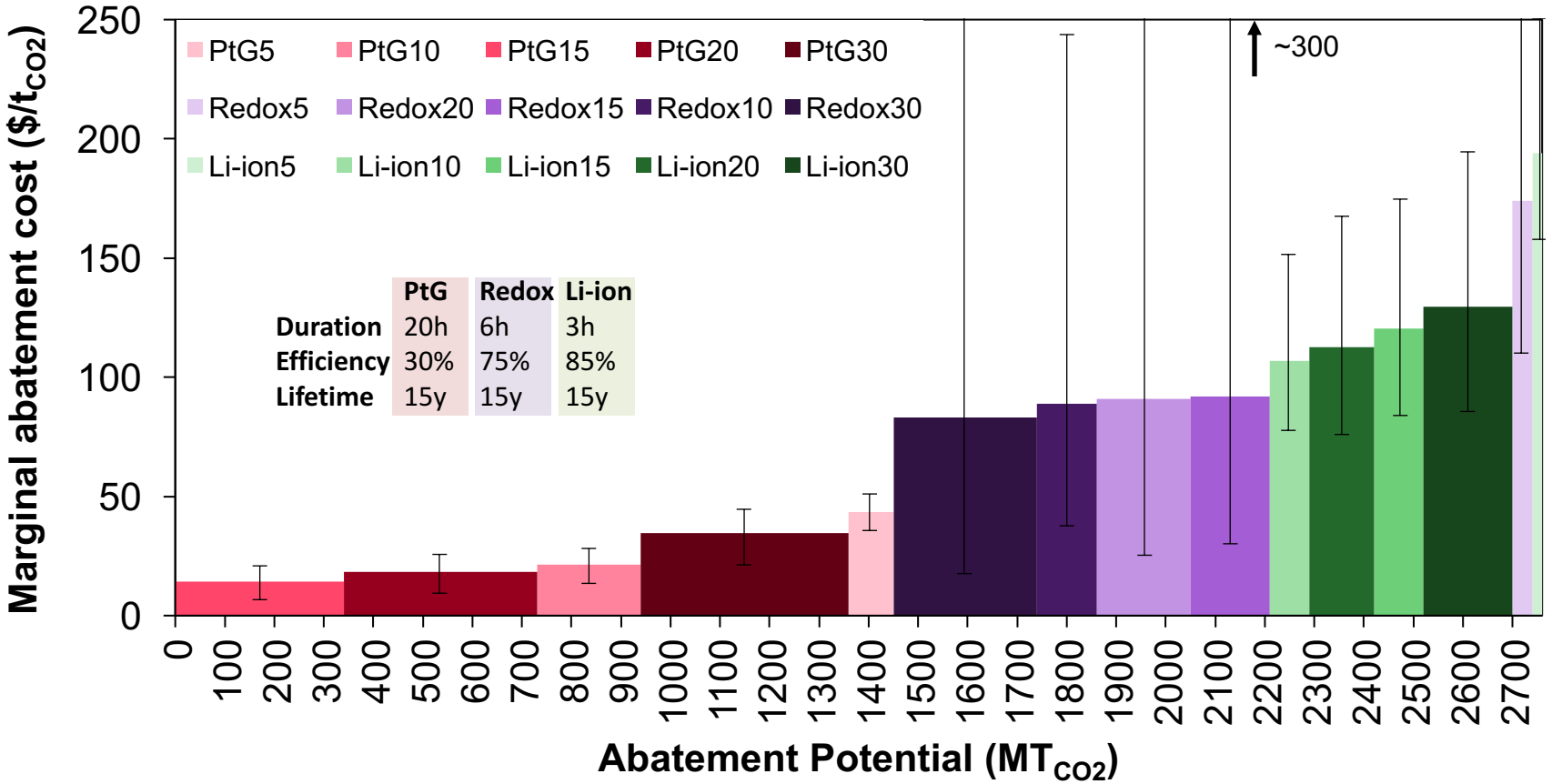




Source: Own analysis

... the marginal abatement cost of storage

Analysis 4 – Power system models (MACC for storage)



Source: Own analysis

Imperial College London

NERC SCIENCE OF THE ENVIRONMENT

Questions?

Oliver Schmidt | PhD Researcher in Energy Storage
Grantham Institute - Climate Change and the Environment
Imperial College London, Exhibition Road, London SW7 2AZ
Tel: +44 (0) 7934548736
Email: o.schmidt15@imperial.ac.uk
Website: www.storage-lab.com

Grantham Institute

This has implications on the profitability of storage in various business cases

Analysis 3 – Competitiveness

Home storage

Electric vehicles

The electrification of transport attracts most attention, because ...

Analysis 3 – Competitiveness (Electric Vehicles)

Tesla's Model 3 could be the car that makes electrics mainstream

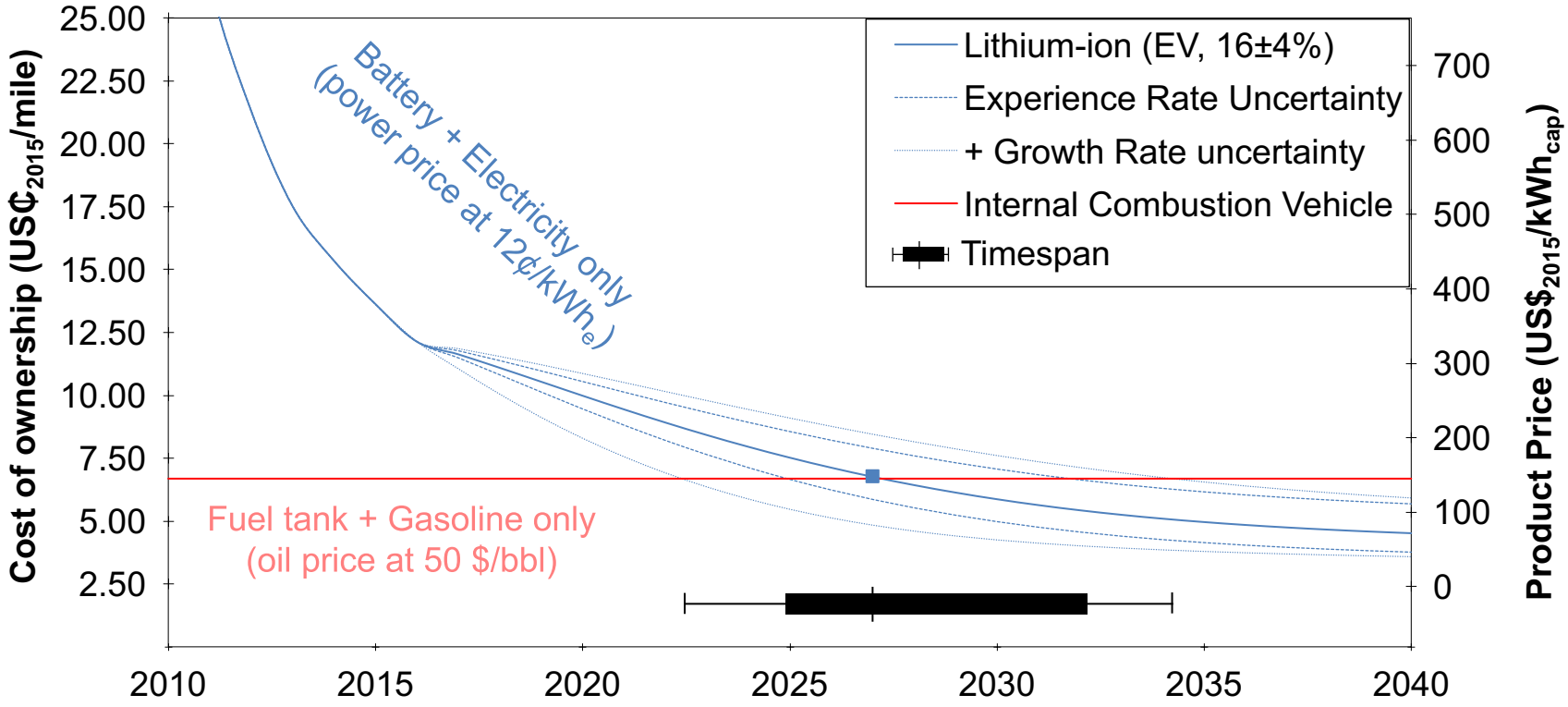
60,000 GWh

(annual demand for EV batteries if 1.2bn passenger cars are electric)

Source: https://www.thestar.com/business/2016/04/01/teslas-model-3-could-be-the-car-that-makes-electrics-mainstream.html; https://www.evoto.ca

... electric cars will beat conventional ones between 2022 and 2034

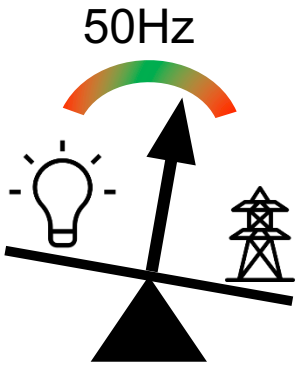
Analysis 3 – Competitiveness (Electric Vehicles)



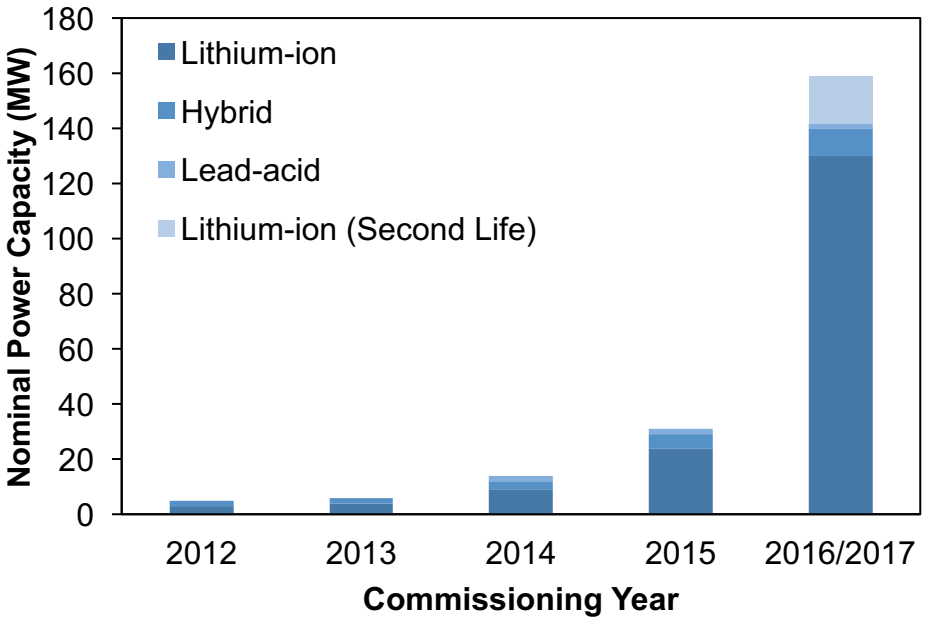
Source: O. Schmidt, A. Hawkes, A. Gambhir & I. Staffell. The future cost of electrical energy storage based on experience rates. Nat. Energy 2, 17110 (2017)

Recent investments in storage to provide balancing services show that...

Analysis 3 – Profitability (Frequency control)



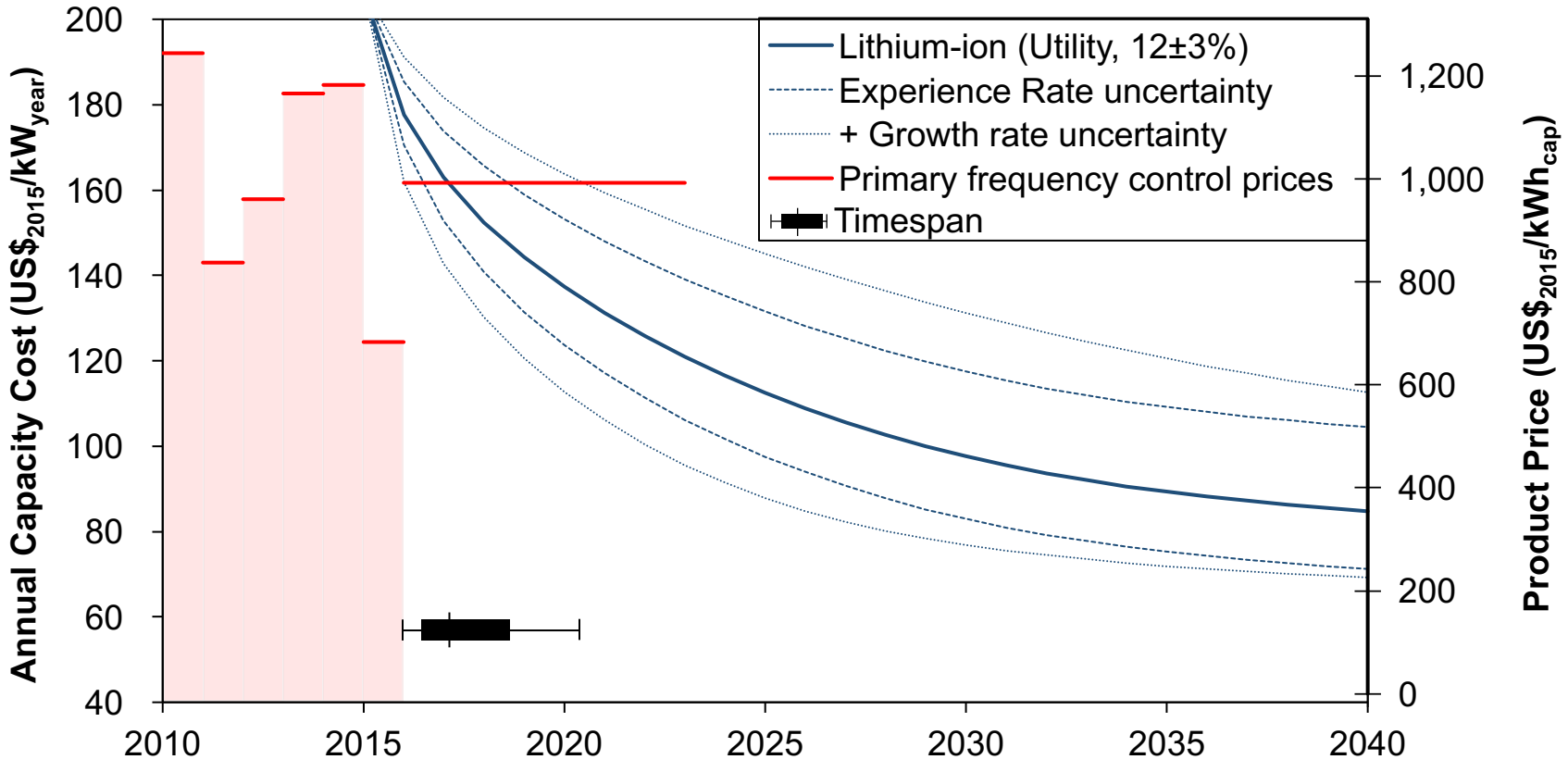
Siemens to deploy market-based grid balancing battery for German utility



Source: https://www.energy-storage.news/news/siemens-to-deploy-market-based-grid-balancing-battery-for-german-utility
P. Stenzel, Bereitstellung von Primärregelleistung durch stationäre Großbatteriespeicher, Forschungszentrum Jülich, Institut für Energie- und Klimaforschung – Systemforschung und Technologische Entwicklung (IEK-STE), 2016.

... primary frequency response is a business case for storage

Analysis 3 – Profitability (Frequency control)

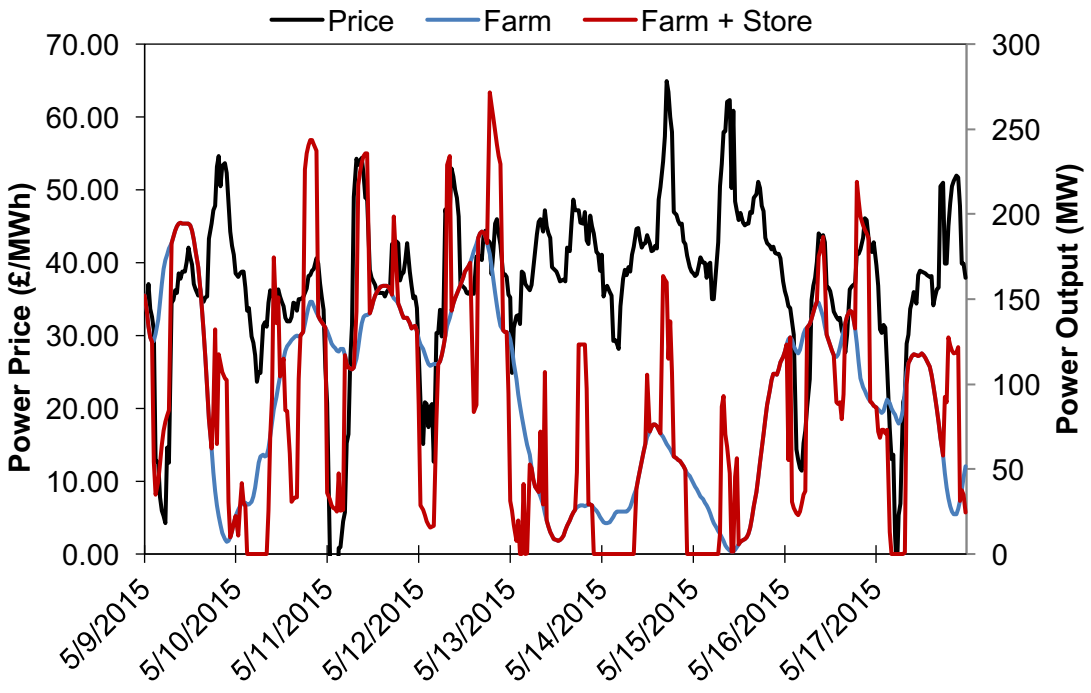


Source: Own Analysis
D.P. Svoboda, D.R. Schemm, M. Bartelt, Aufbruch in den Regelenergiemarkt?, Energ. Manag. (August 2015) 28.

Using batteries to optimise renewable power output for profit...

Analysis 3 – Profitability (Wind farm)

Vattenfall plans 22MW battery storage facility at South Wales wind farm

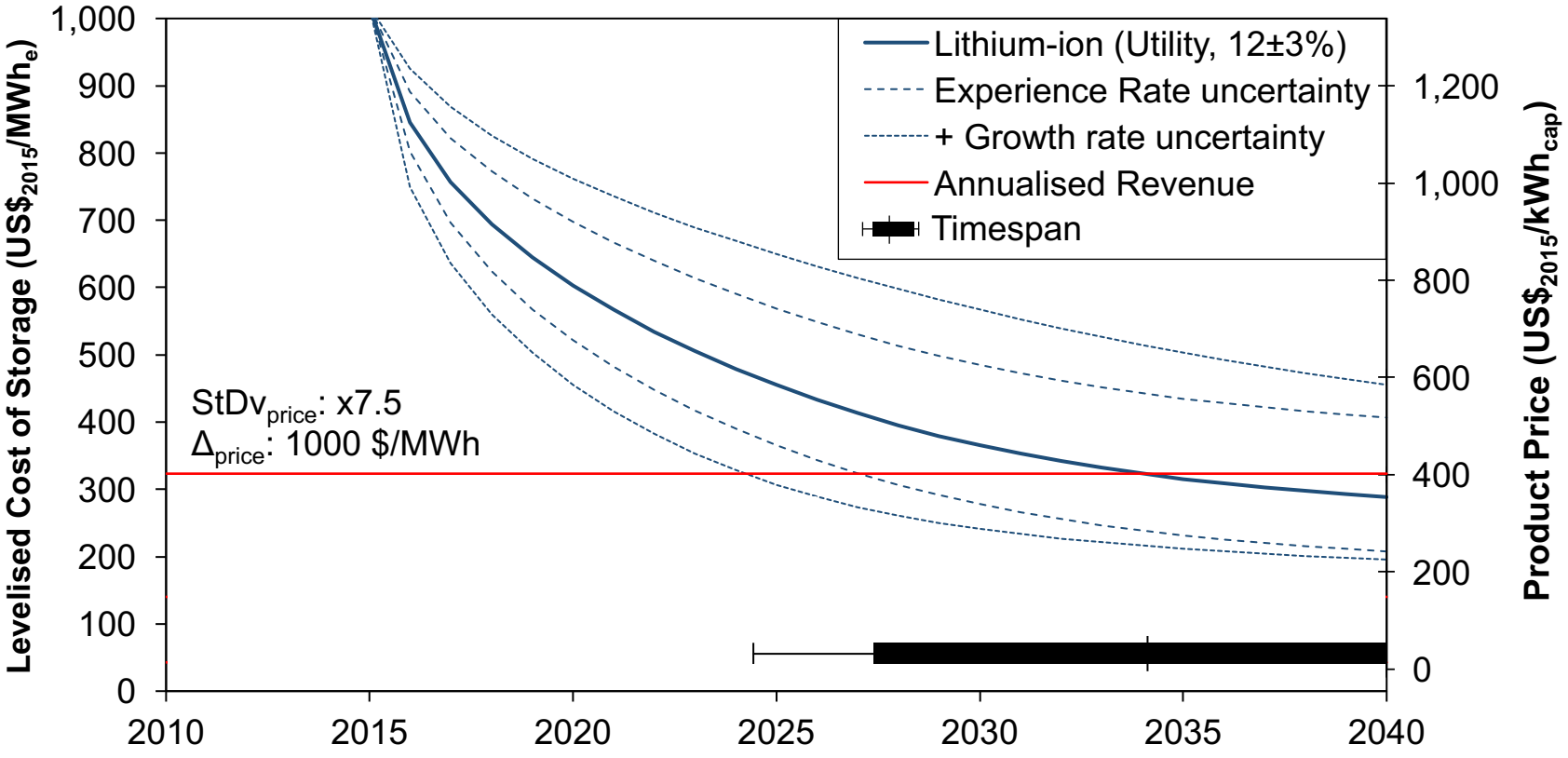


Source: https://theenergyst.com/vattenfall-plans-22mw-battery-storage-facility-at-south-wales-wind-farm/
Own analysis

... is only viable when the variability of power prices increases by a factor of 7.5

Analysis 3 – Profitability (Wind farm)

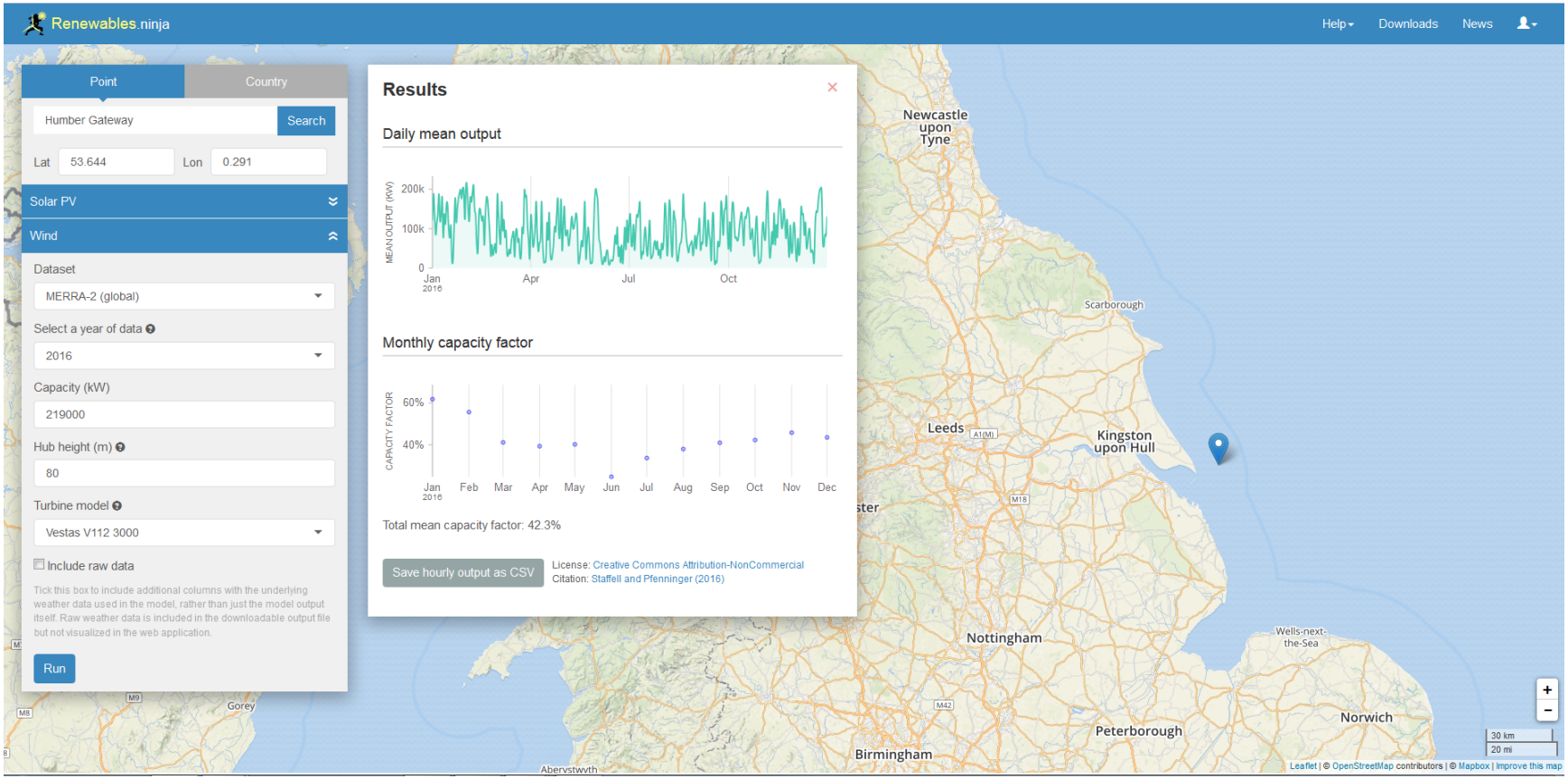
Wind farm: 219 MW
Battery: 95 MW / 330 MWh



Source: www.renewables.ninja
Own analysis

Wind farm output from Renewables.Ninja

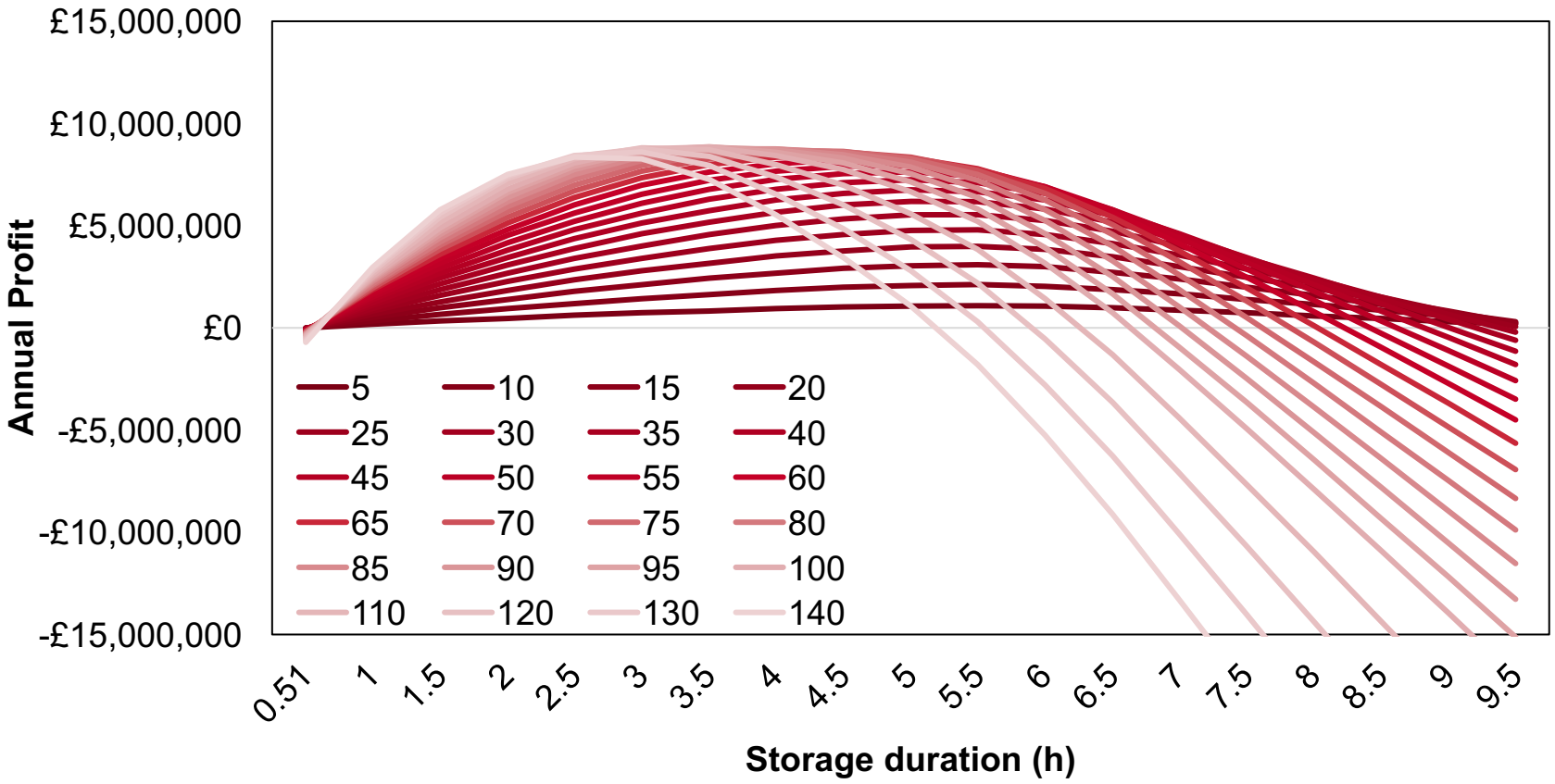
Analysis 4 – Profitability (Wind farm)



Source: https://theenergyst.com/vattenfall-plans-22mw-battery-storage-facility-at-south-wales-wind-farm/

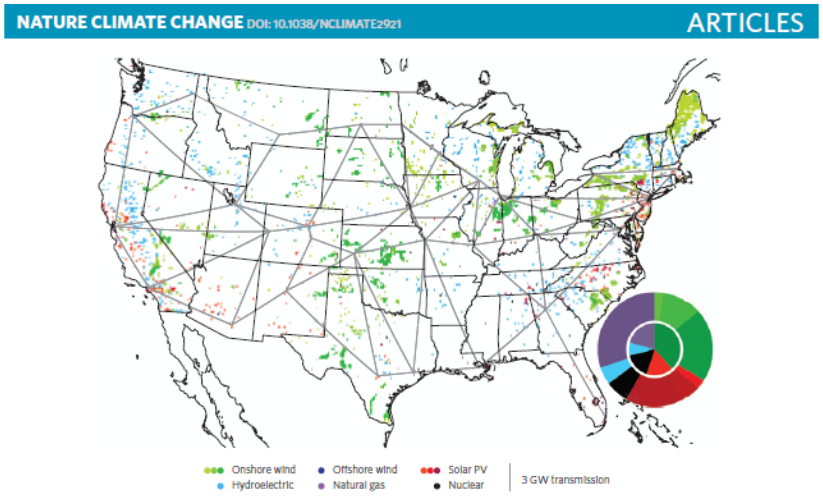
Annual profit for battery of different sizes coupled to 219MW wind farm

Analysis 4 – Profitability (Wind farm)



… affecting insights gained from energy system models

Problem



"Our results show that [...] CO_2 emissions [...] can be reduced by up to 80% [...], **without electrical storage."**

Source: MacDonald AE, Clack CTM, Alexander A, Dunbar A, Wilczak J, Xie Y. Future cost-competitive electricity systems and their impact on US CO2 emissions. Nat Clim Chang. 2016:4–7.

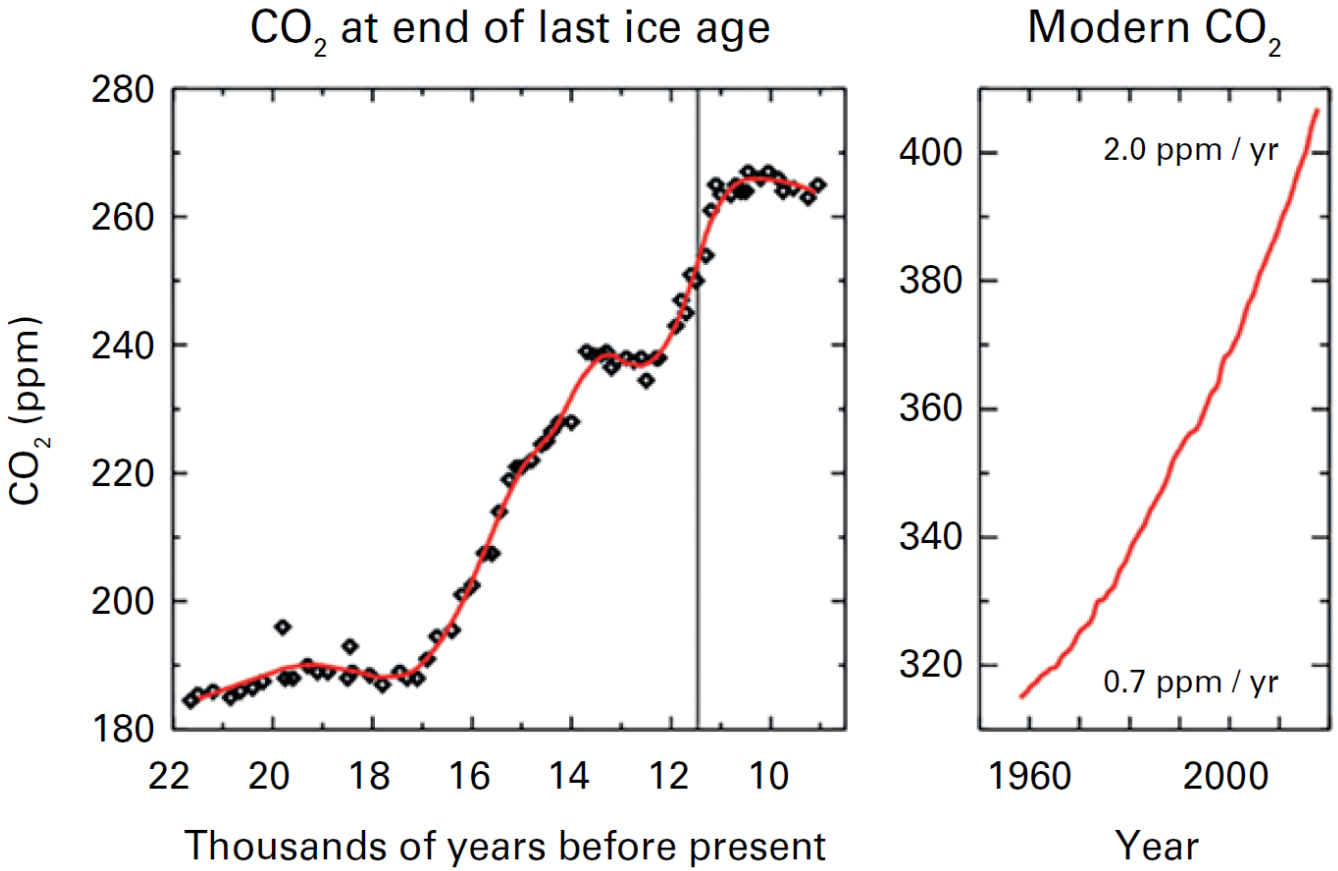
vs.

"Production of Powerwall 2 started on **January 4th 2017**."

Source: www.tesla.com/blog/battery-cell-production-begins-gigafactory
www.youtube.com/watch?v=4F9ON-8rSnM

from <0.2 (ice age end) to 0.7 (mid 20th) to 2.0 ppm/yr (2006-16)

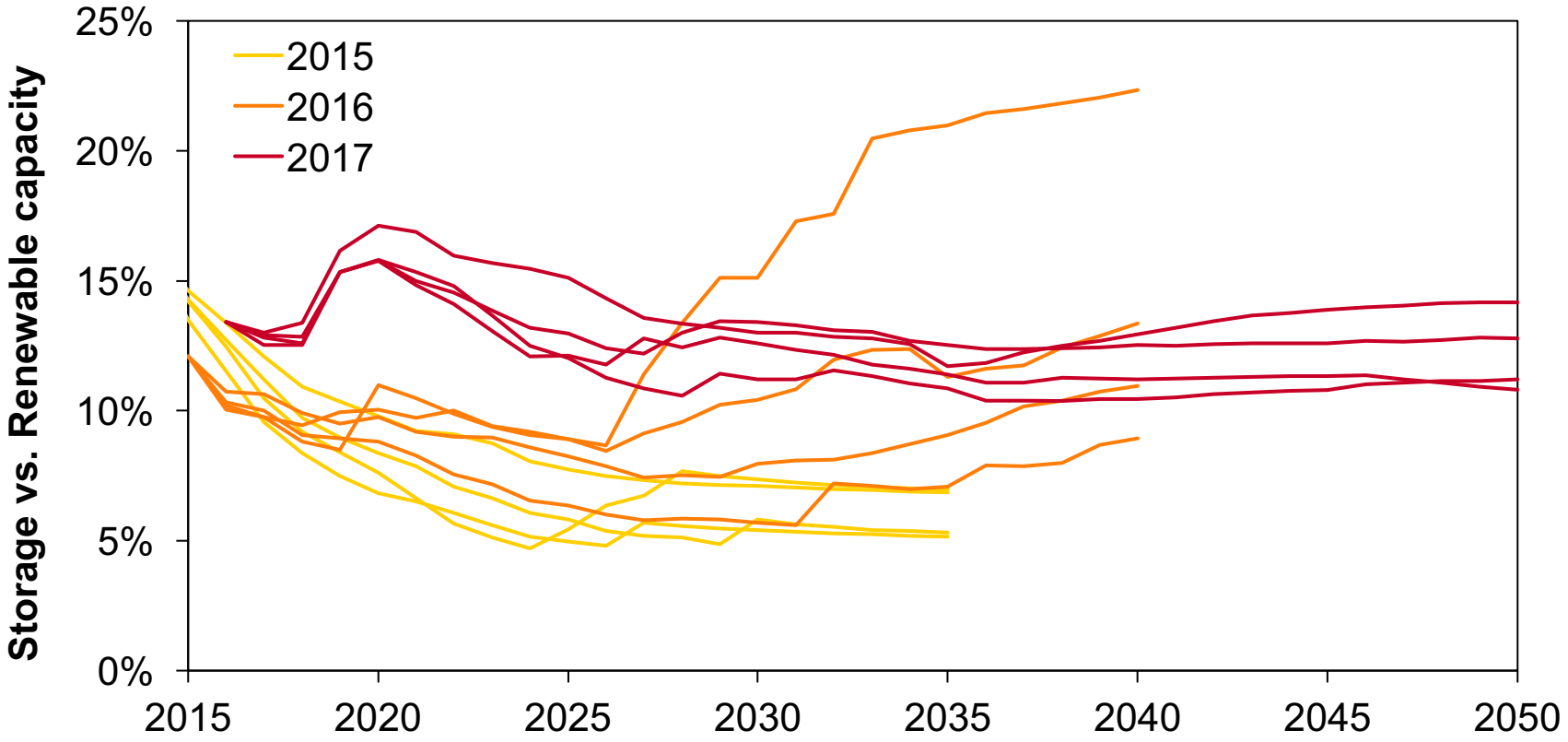
Atmospheric CO_2 growth



Source: WMO Greenhouse Gas Bulletin No. 13. The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2016. World Meteorological Organisation. (30 October 2017)

In the UK, electricity storage is projected to be 5%-20% of Renewable capacity

Electricity storage & Renewables



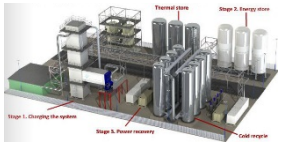
Source: Future Energy Scenarios, National Grid, 2015, 2016, 2017. Analysis by Dr Iain Staffell.

Electricity can be stored in multiple ways

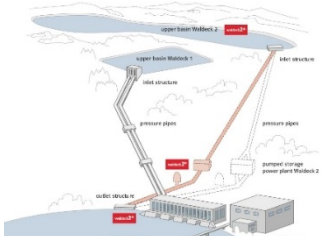
Technologies

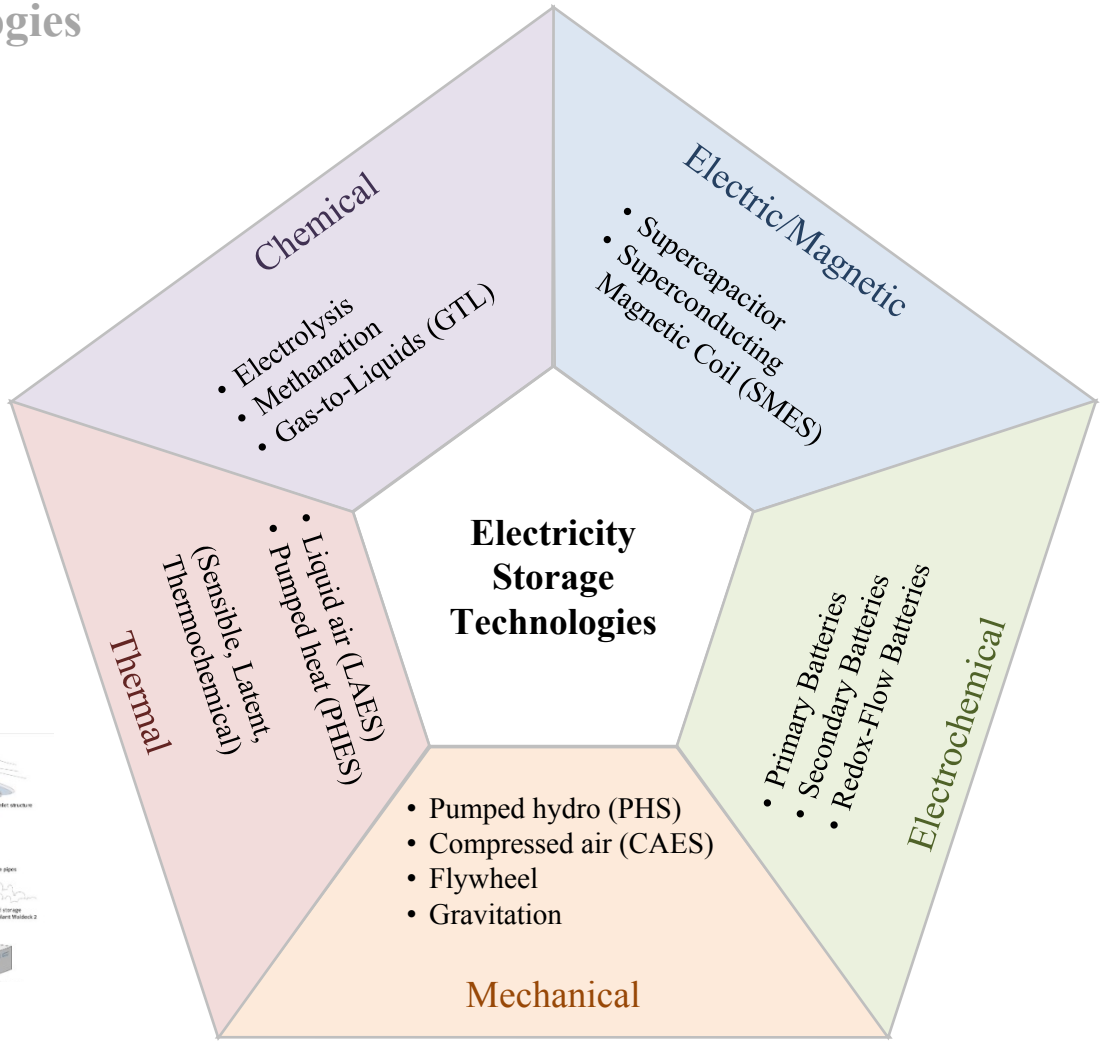
Electrolysis

Liquid air

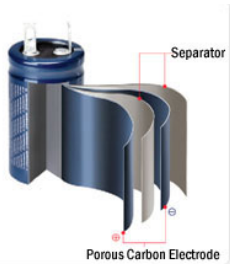


Pumped hydro





Supercapacitor



Lithium-ion

Redox-Flow

Cost figures often refer to different technology scopes

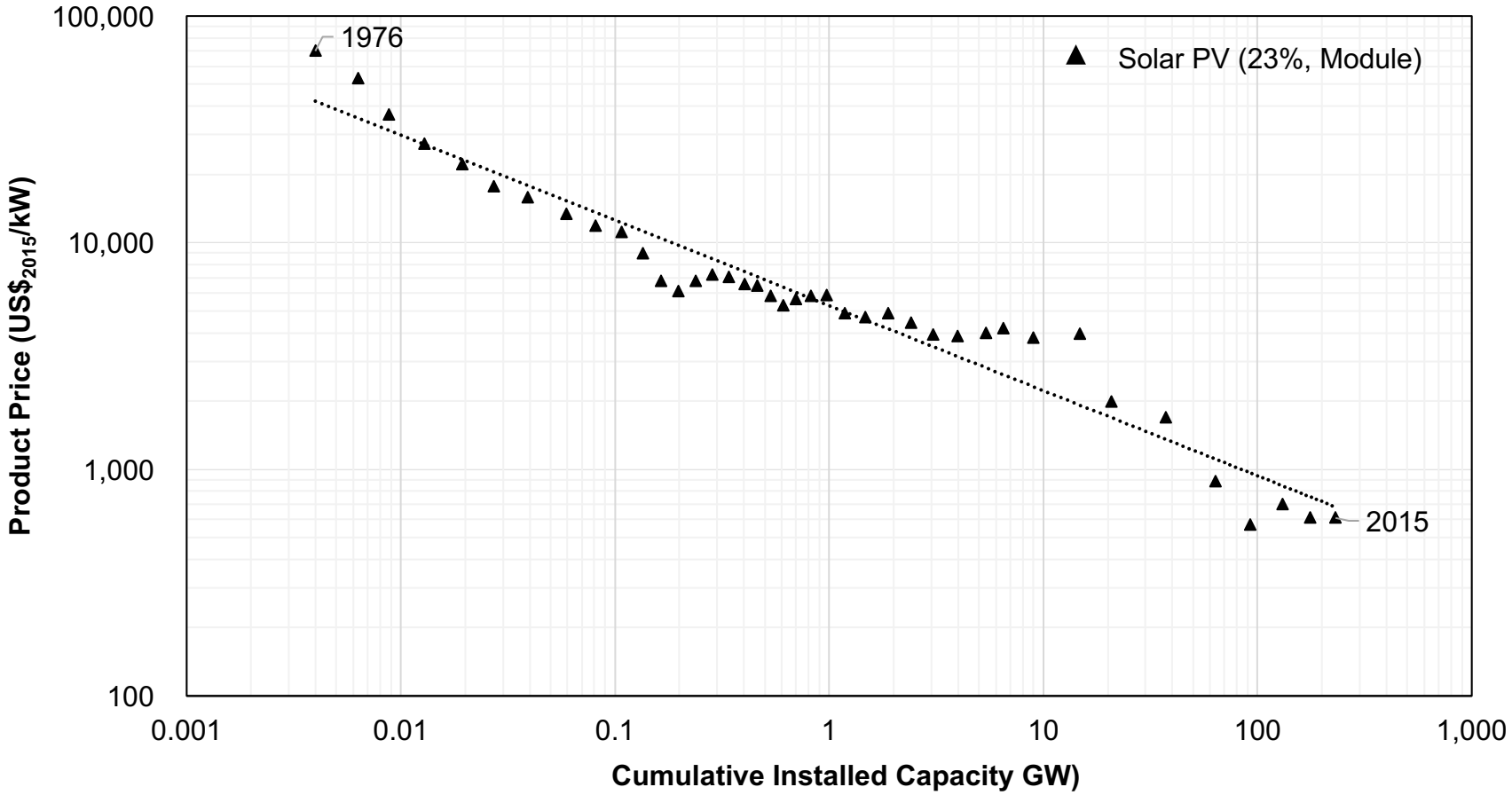
Technology Scope

Cell	Pack	System	Installed System
20%	30%	65%	100%

Source: O. Schmidt, A. Hawkes, A. Gambhir & I. Staffell. The future cost of electrical energy storage based on experience rates. Nat. Energy 2, 17110 (2017)

Experience curves are an objective tool to model cost reductions for technologies

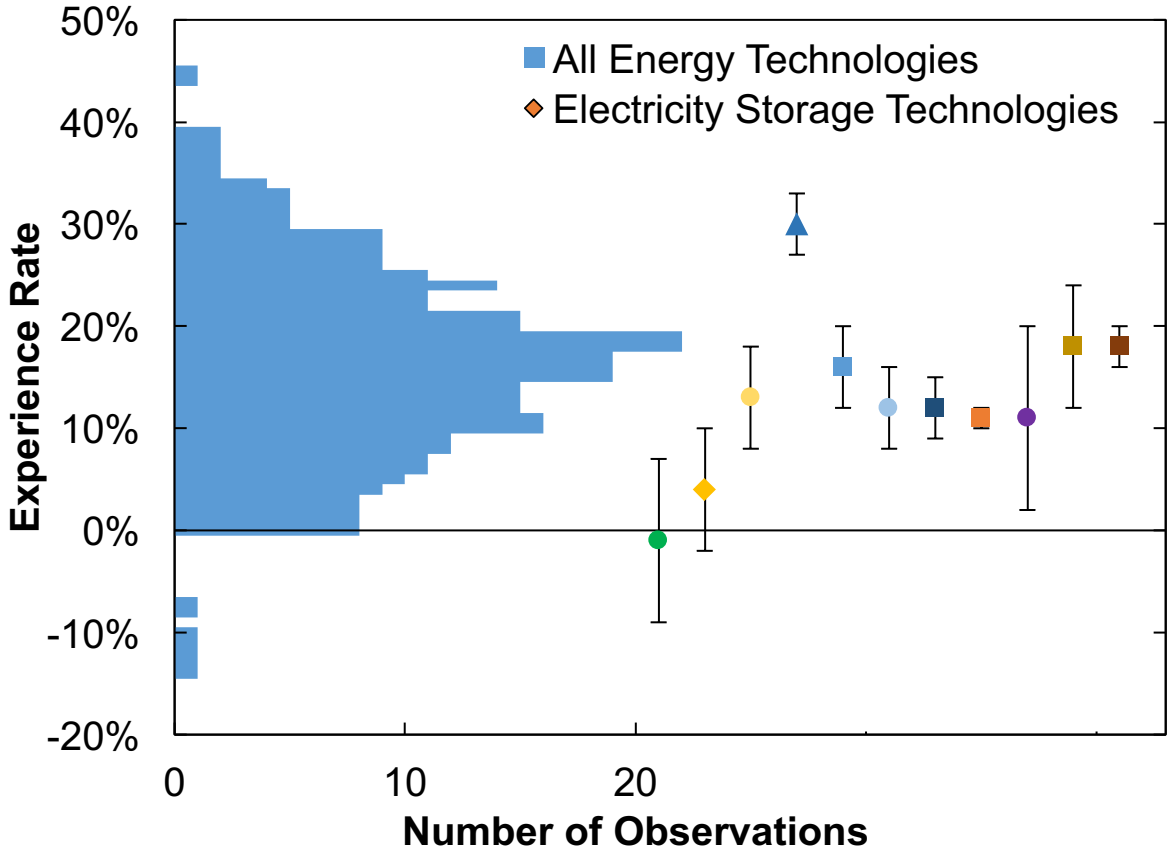
Method



Source: Liebreich, M. Keynote - Bloomberg New Energy Finance Summit 2016. (Bloomberg New Energy Finance, 2016).

The identified experience rates are within the range of other energy technologies

Sanity Check – Energy technologies



Source: Adapted from Staffell I, Green R. The cost of domestic fuel cell micro-CHP systems. Int J Hydrogen Energy 2013;38:1088–102. doi:10.1016/j.ijhydene.2012.10.090.