TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät für Wirtschaftswissenschaften, Lehrstuhl für Energiewirtschaft, Prof. Dr. Möst

Will the experience curve of PV repeat for Batteries and Electrolysis?

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www.ee2.biz

Energieforschungsgespräche Disentis 2019

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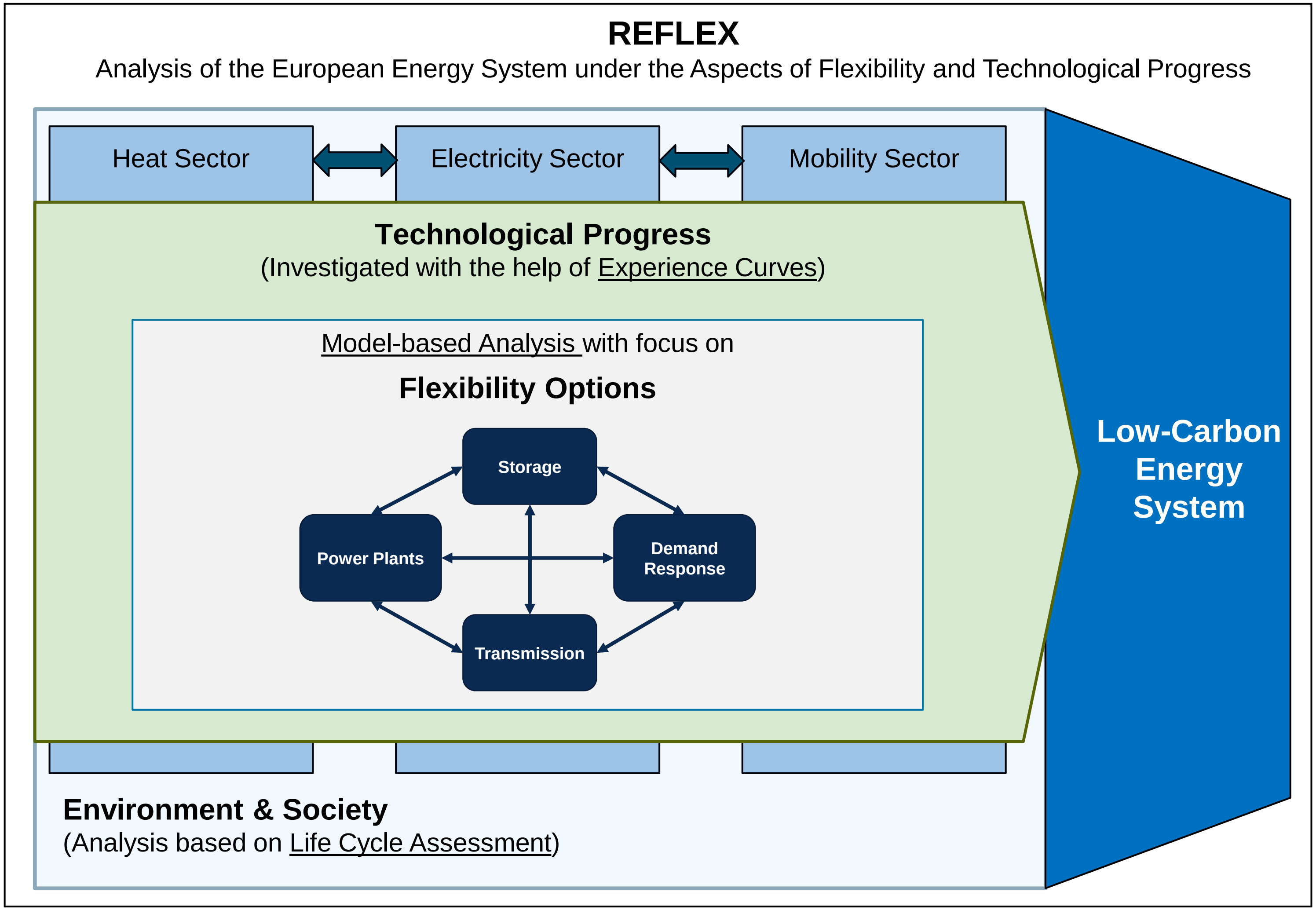
Prof. Dr. Dominik Möst

Objective of the talk

- What are experience curves and what can we learn from them?
- How do experience curves look like for PV systems and what can we learn from it for the future?
- And how will prices for battery electric vehicles (BEV), fuel cell electric vehicles (FCEV) and electrolysis develop?

REFLEX: Project Scope and Applied Approaches



Partners of the REFLEX-Project

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Scenarios in REFLEX for shaping the European energy system

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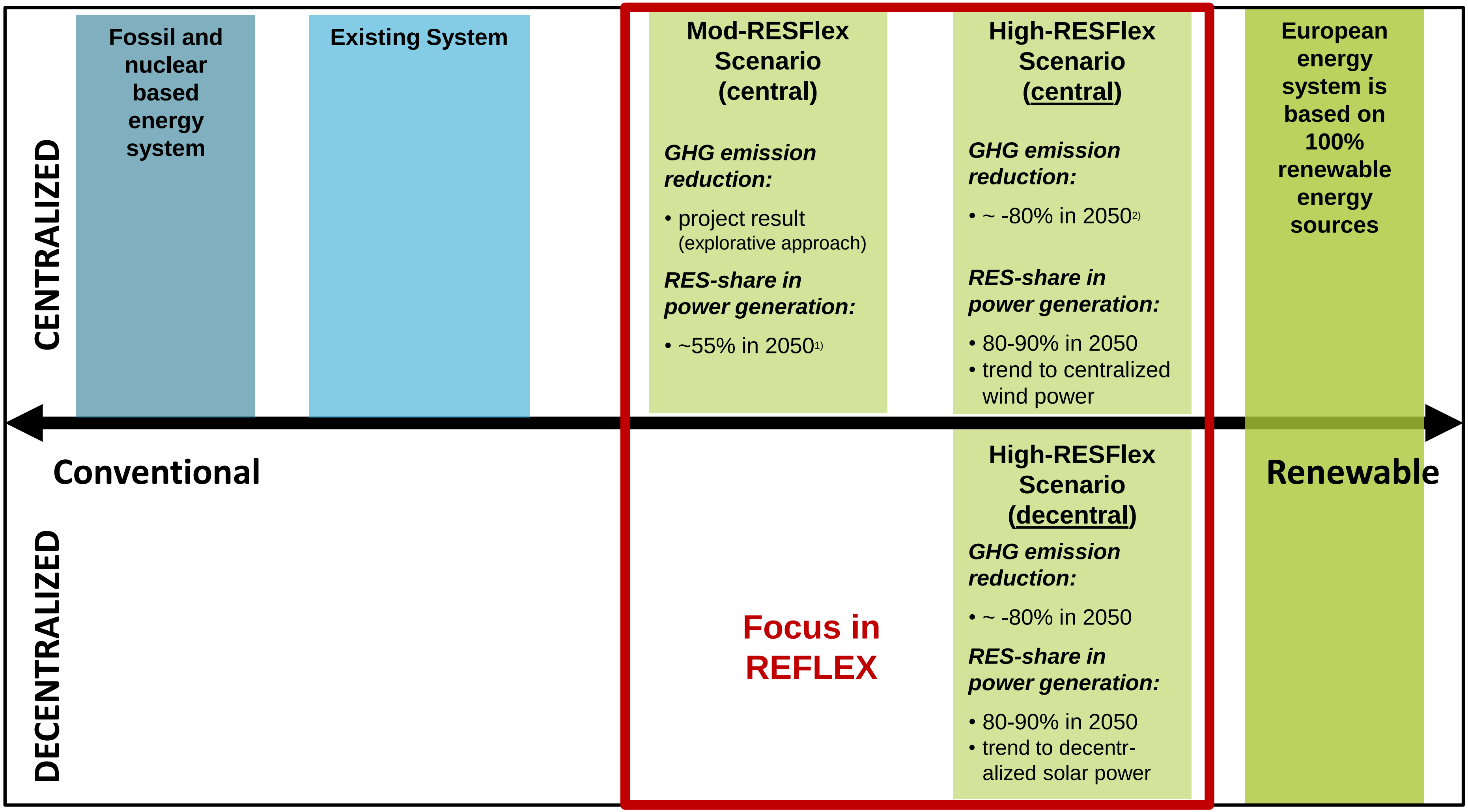
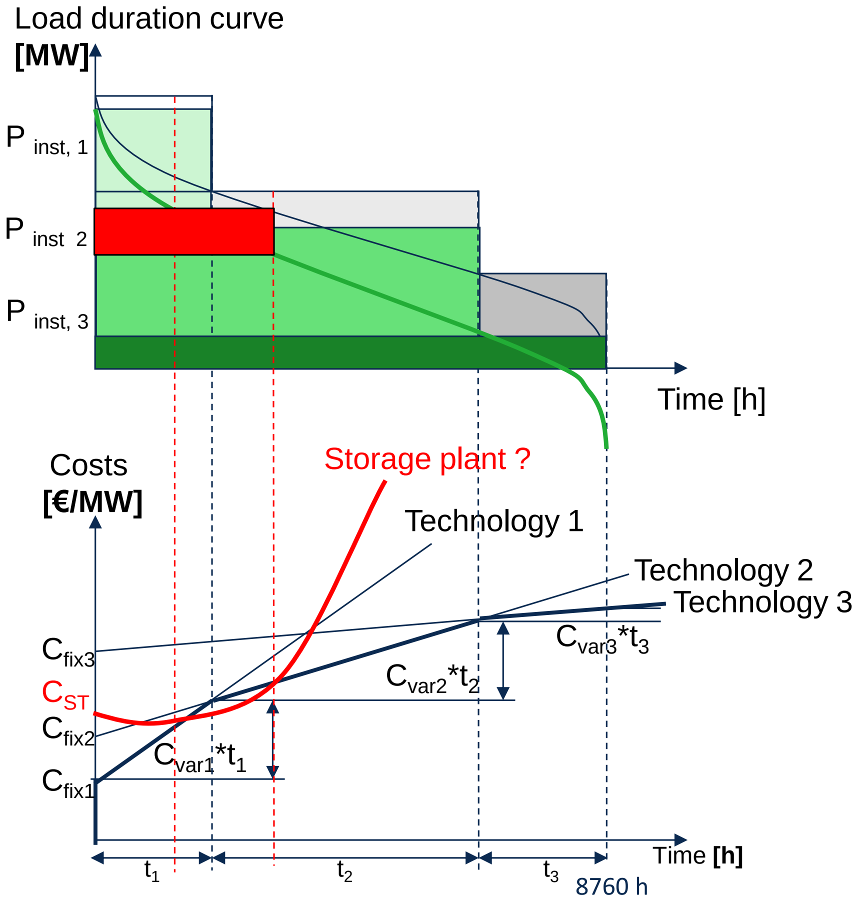


1) EU Reference Scenario 2016 (Capros et al. 2016) 2) EC Roadmap for moving to a competitive low carbon economy in 2050 (COM 2011/0112)

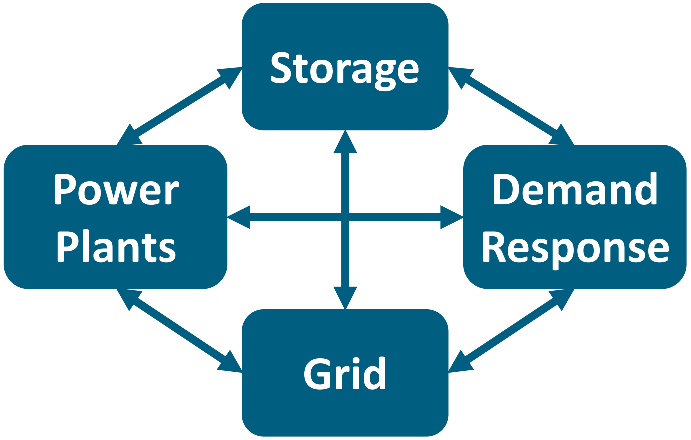
System perspective
Adaptation of „optimal“ capacity?



Necessary generation portfolio – what will change?

- Reduction of base-load and mid-load
- Increase of peak-load
- Increase of storage power plants

What to do with the surplus?



1 Background information of the REFLEX project

2 Basics of experience curves

3 The cases of photovoltaic and wind: what can be learned?

4 What can we learn about batteries, fuel cells and electrolysis?

5 Some final remarks

Theory of learning curves

- Classical learning effect: „*learning by doing*“ (Wright, 1936; Arrow, 1962)
- Basic idea: increased realisation of a technology leads to a higher production efficiency and reduced production costs
- Learning effects can be described by learning curves (or experience curves) and are used as a rough estimation of long-term costs developments
- Amount of cumulative production is often used as „*proxy*“ for learning, but other factors also influence product prices and learning effects
  - size of factories (see debates about Giga-factories)
  - spend R&D subsidies
  - resource prices
  - …

Reasons for learning effects

Multiple purposes

- insight into and amount of new knowledge for the use of the new technology
- continuous improvement in the manufacturing process
- standardization and automation
- economies of scale
- Know-how pool
- Benefits in purchase (e.g. driven by market power)
- ..

=> However: cumulative capacity is often used as a proxy for learning effects

Cost driver	Characteristics	Example
Market-push	Competition, R & D investment	Computer
Demand-pull	Government policies, demonstration project, consumer adaptation	Flue gas desulfurisation (FGD)
Process advancement	Economies-of-scale, infrastructure, industry integration, components	Photovoltaic (PV) panels
Technological change	Functionality improvement, material, design, application	Wind turbines

Source: Heuberger et al. (2017)

Experience curves allow to estimate future cost reductions

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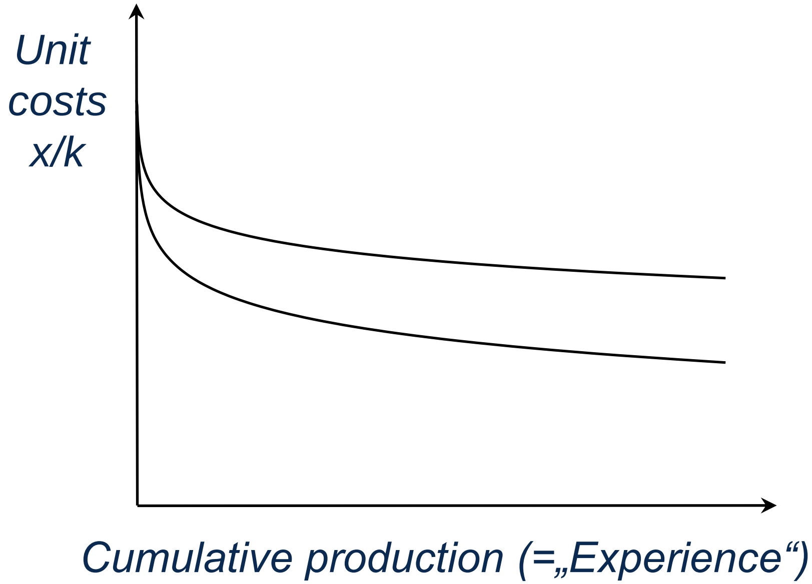
Concept

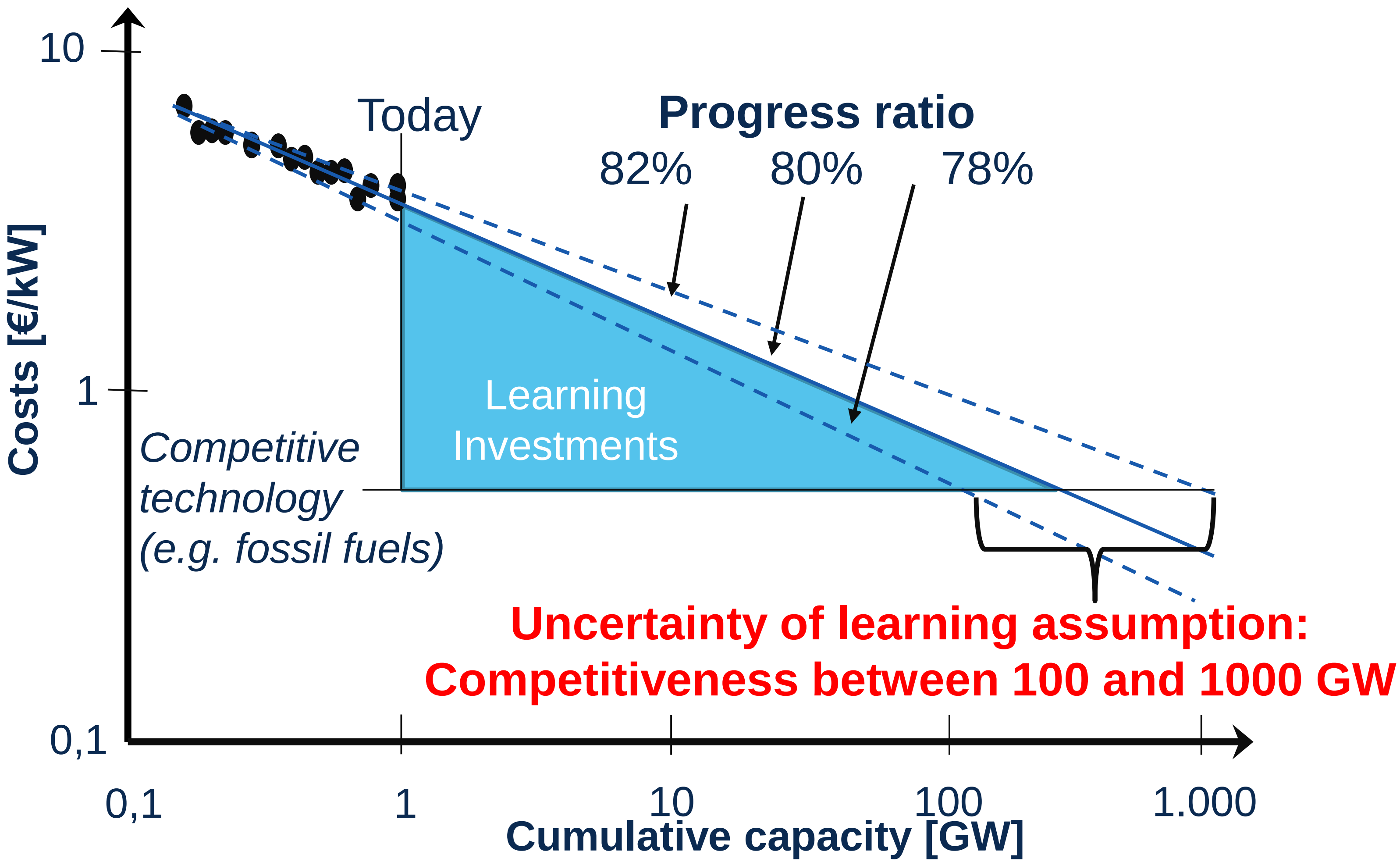
- Experience curve describe a functional interrelation between the cumulative production and the (real) costs per unit
- Core message: Increase of production, decreases marginal costs.
  E.g. a doubling of the cumulative production reduces unit costs by 20 to 30%

- But what is the “right” unit?
  - kW versus kWh
- And is data available?
- And learning also refers to other parameters (not only costs), which are relevant for market success
  - Weight (e.g. for batteries)
  - Storage capacity
  - Increase in production (e.g. wind)
  - …



Competitiveness of new technologies and their needed investment volumes?

Uncertainty of learning factor (and expected capacity) has significant impact on reached competitiveness and may result in “delay” by decades (here: factor of capacity between 100 and 1000 GW)



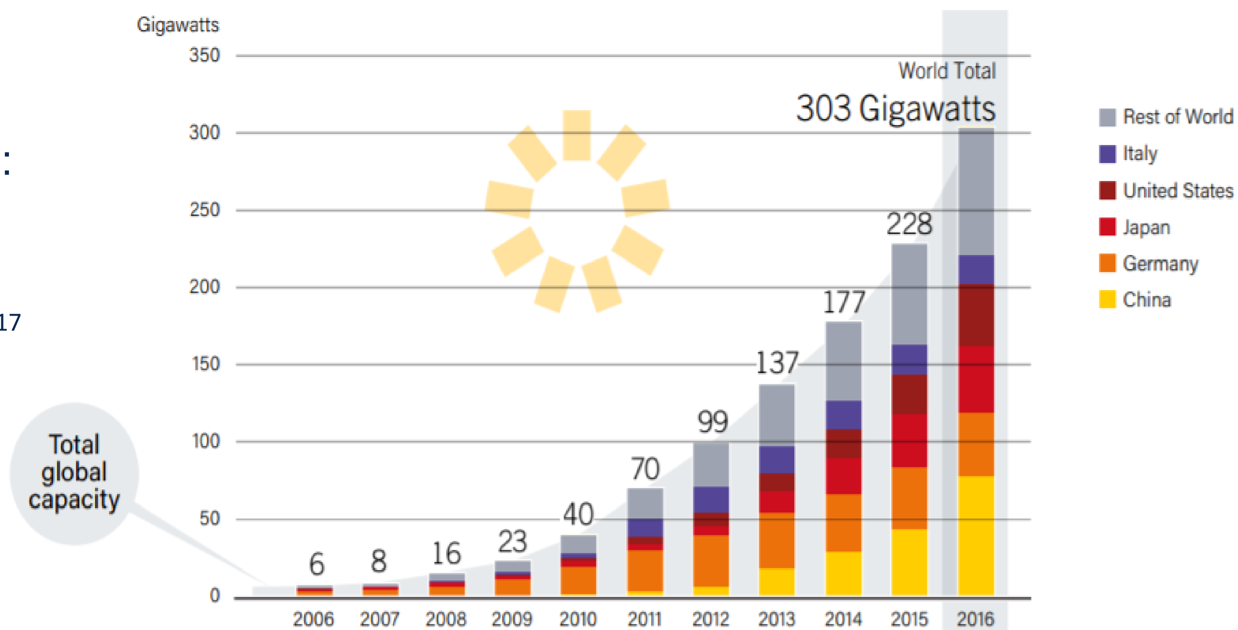
Source: Own illustration based on : Experience Curves for Energy Technology Policy; IEA

Global installed solar PV capacity

Strong growth of installed PV capacity

- Main technology: silicon PV with approx. 95% share (multicristalline 70% and 25% monocrystalline)
- Prices for modules lowest in China and India (0,43 USD/W) and highest in California (0,61 USD/W)
- Expectations:
    - ~ 950 GW in 2025
    - >2.000 GW in 2040
    - Two degree scenario: >7.100 GW in 2050 (currently on track)

Source IEA WEO 2017



Source: Renewables 2017 Global Status report

Experience curves for PV modules, systems and BOS components

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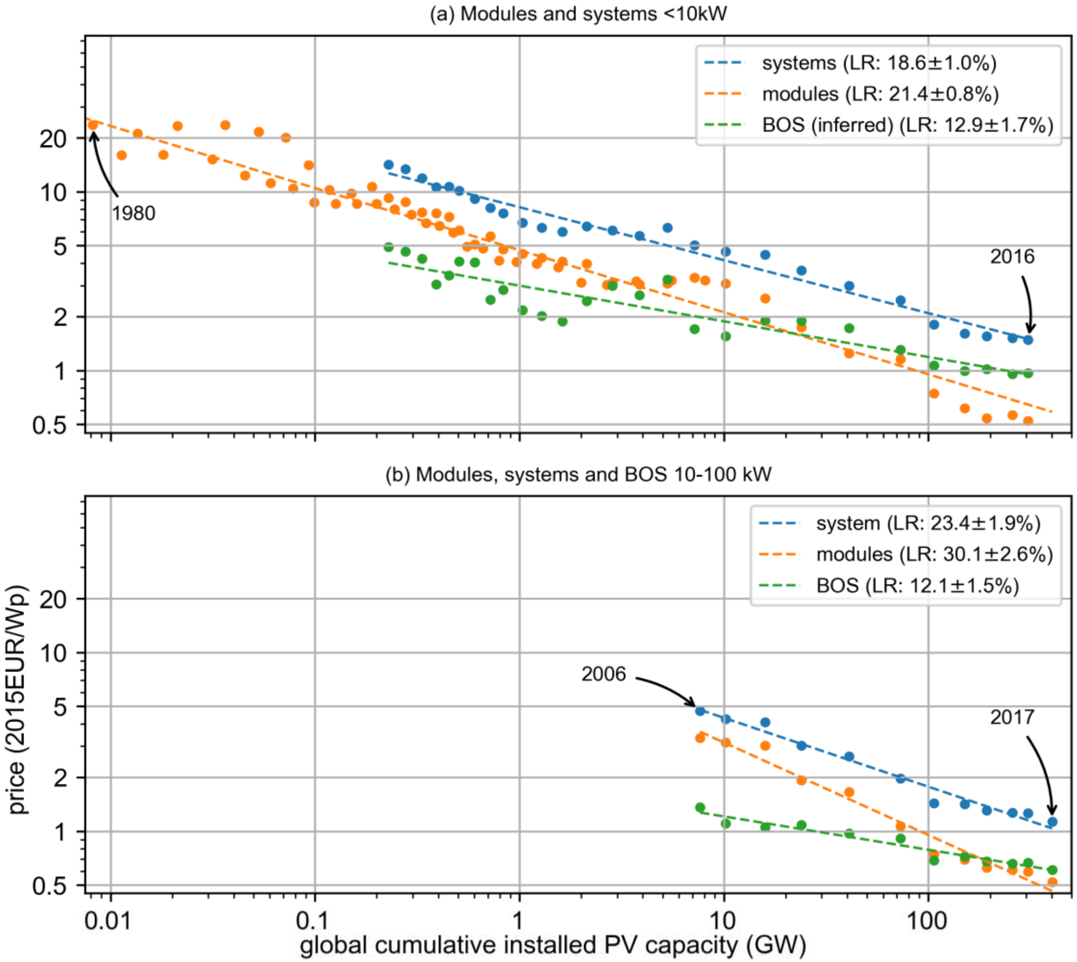

Source: REFLEX: Experience curve report (not published yet)

Learning rate of

- 21% for modules
- 19% for systems
- and considerably lower for BOS components (wiring, switches, mounting system, solar inverters, …) with just 13%
- Contribution of BOS has increased to around 50% of system costs now (from ~20% 10 years ago)

Quite rapid decline between 2012 and 2015

- Fast decline is likely to be related to market dynamics rather than only being a result of technological progress

=> *Cost extrapolation*

- 2025: 0,28 – 0,33 EUR/W
- 2040: 0,21 – 0,27 EUR/W

Experience curve for wind energy

Strong growth of installed wind capacity

- 74 GW in 2006 to ~500 GW in 2016, dominated by China with approx. 175 GW
- Expectations:
  - ~ 1200 GW (~ 1700 GW) in 2030 and
  - ~ 1700 GW (~ 2600 GW) in 2040 (in brackets: climate change lower than 2 degrees) Source IEA WEO 2017

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Onshore system not behaving according to theory

- Price increase between 2004 and 2008 ?
- "Long-term" LR of ~ 6%
- "Short-term" LR of ~25%

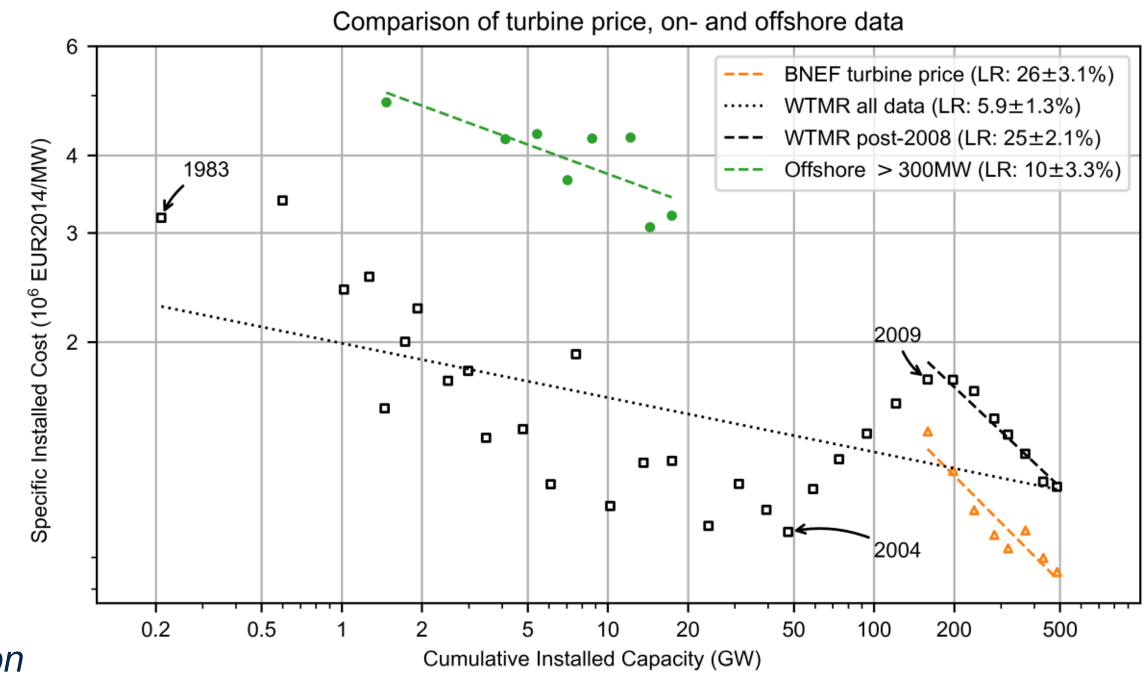
Offshore:

- Less mature
- Learning rate of ~10%

=> Cost extrapolation:

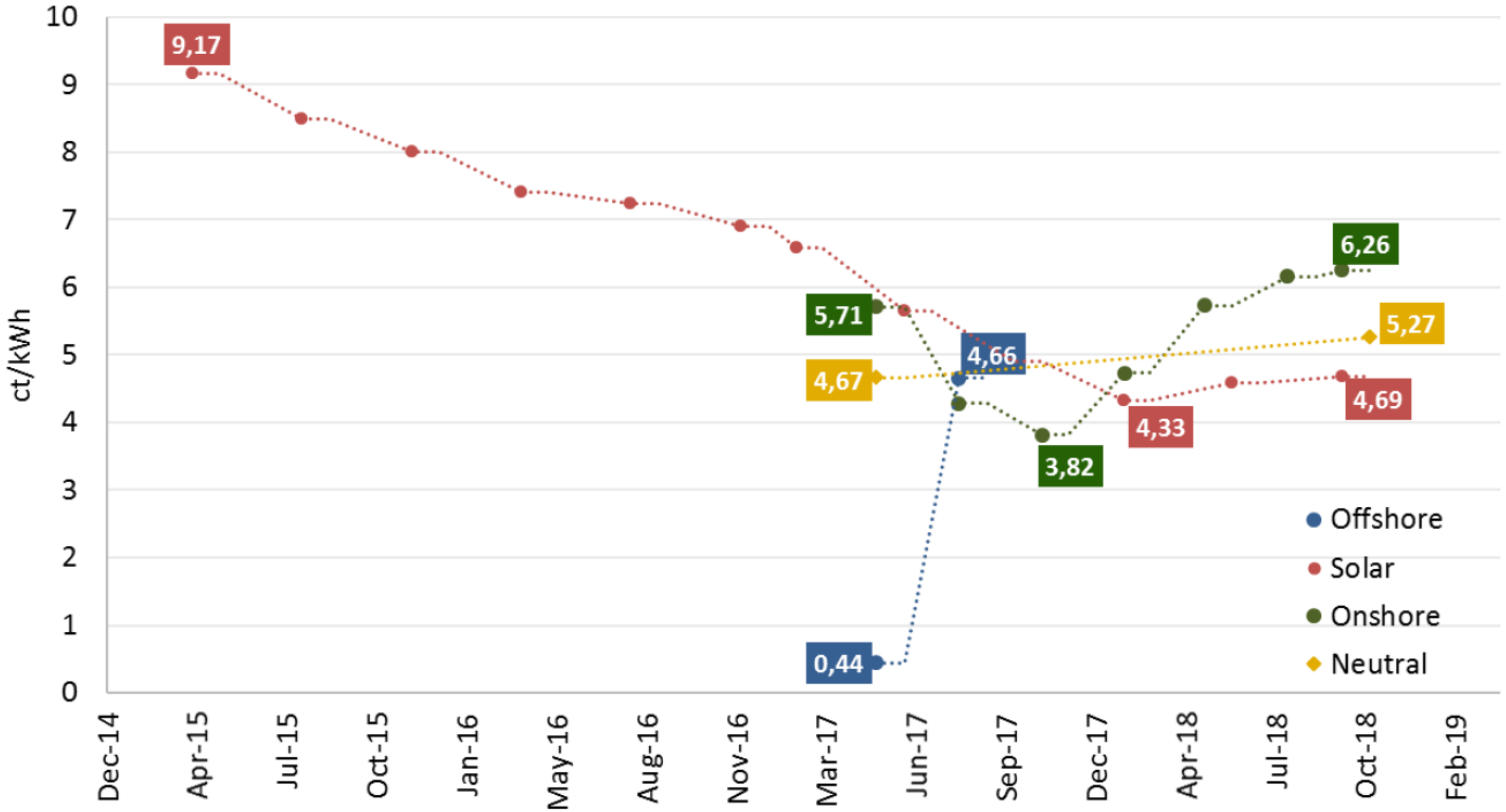
- 2030: ~ 0,95 -1,1 k€/kW
- 2040: ~ 0,8 - 1 k€/kW

=> However, increase of generation (higher full load hours) => lower generation costs!



Source: REFLEX: Experience curve report (not published yet)

Auction results for RES-E in Germany



Source: Müsgens 2019

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Dominant markets for EV:
China and US with high growth rates

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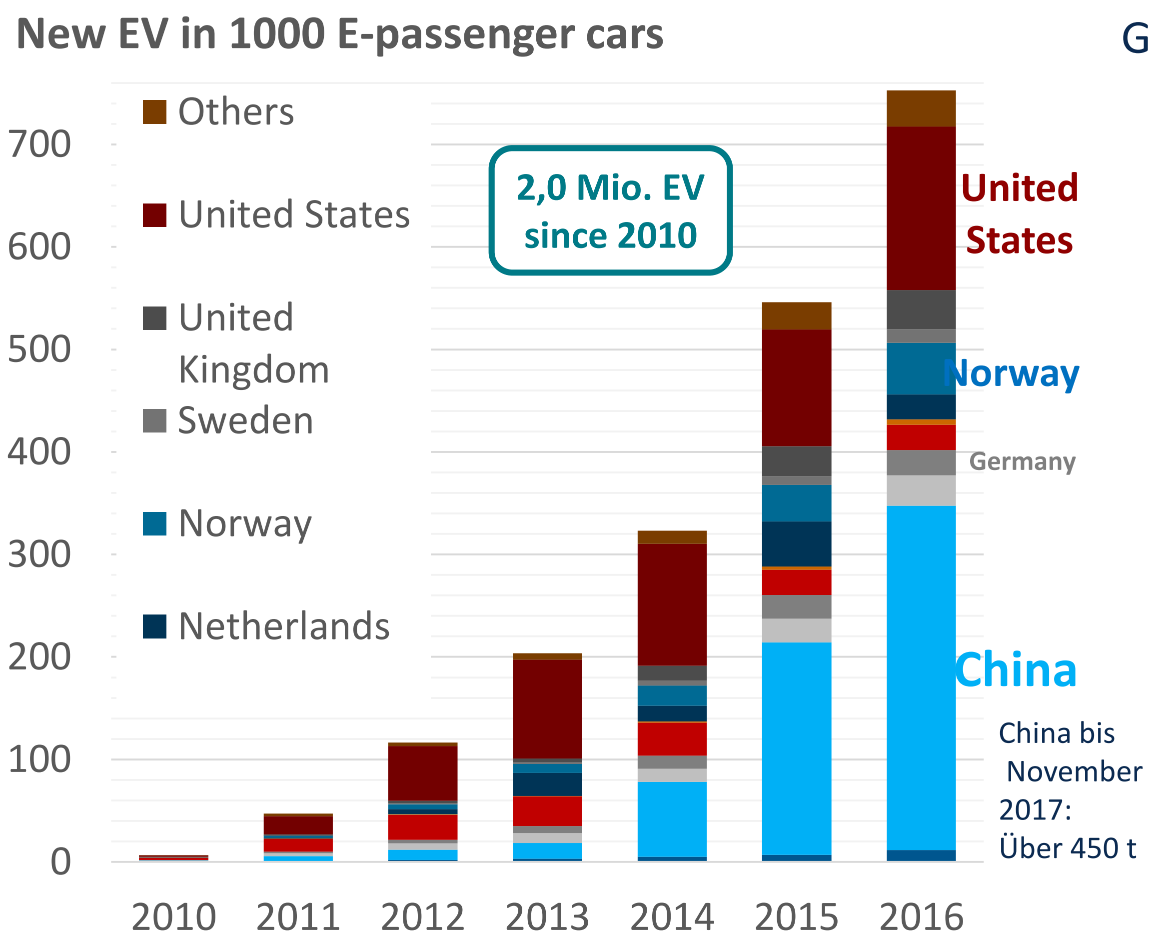
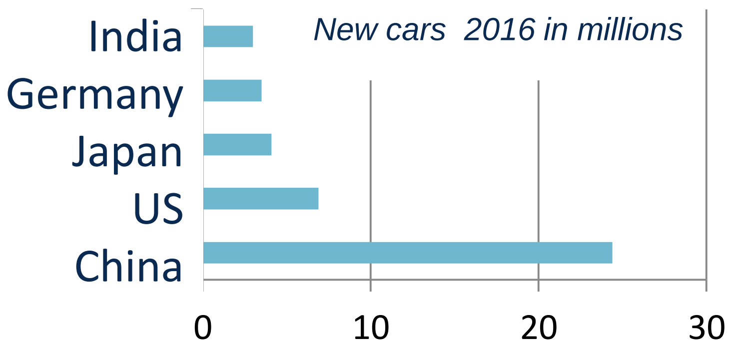




China has clear focus on EV-strategy

- China dominates passenger car demand and EV-production
- Reasons of China's policies
  - Key market E-mobility
  - Clean air in mega-cities
  - Independence from oil
  - Climate protection
- Regulation:
  - Quota for EV-cars from 2019

Source: Fraunhofer ISI and IEA (2017): Global EV Outlook 2017.

Experience curve for vehicle battery packs and fuel cell stacks

Prices for batteries have declined rapidly

- ~ 200 USD/kWh for BEVs (+components), competitive with combustion around 150 USD/kWh (incl. components)
- Learning rate for BEVs around 15% and HEVs around 11%
- Learning rate for FCEV around 18%
- Expectations for BEV/HEV market development
  - 106 millions in 2030
  - 277 millions in 2040 (corresponding to 14% market share (MS))
  - 243 in 2030 and 873 millions in 2040 (~40% MS) under two degree scenario

Source IEA WEO 2017

Extrapolation depends on assumptions about

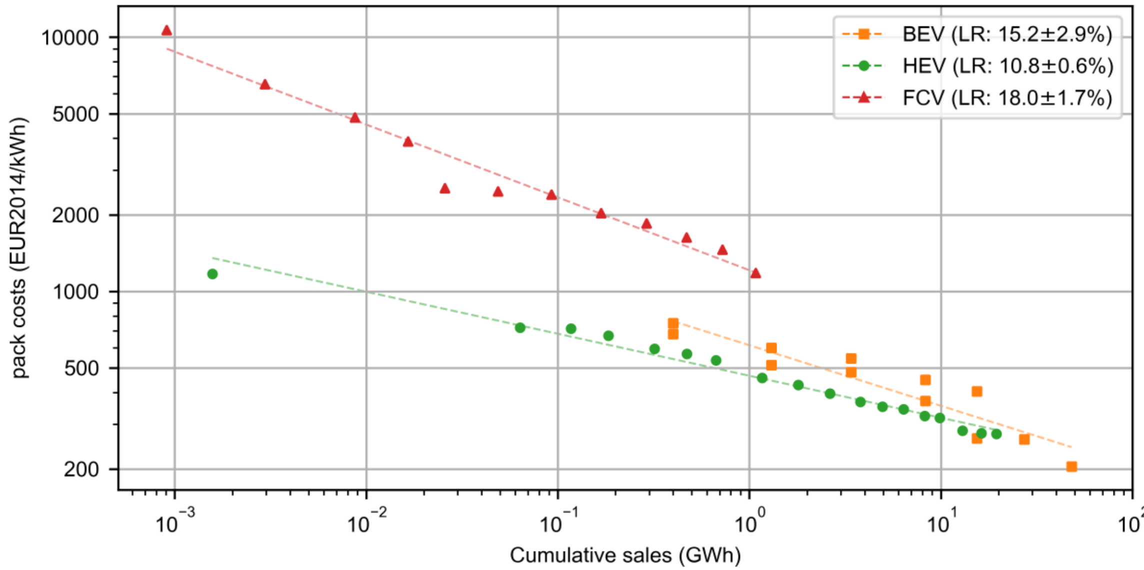
- Battery pack size per EV

=> Larger packs resulting in larger declines

=> Cost extrapolation:

- 2030: ~ 50– 90 USD/kWh
- 2040: ~ 30 – 70 USD/kWh

=> Fuel cell depletion difficult to extrapolate



Source: REFLEX: Experience curve report (not published yet)

Learning will not only decrease costs, but also increase storage capacity and density

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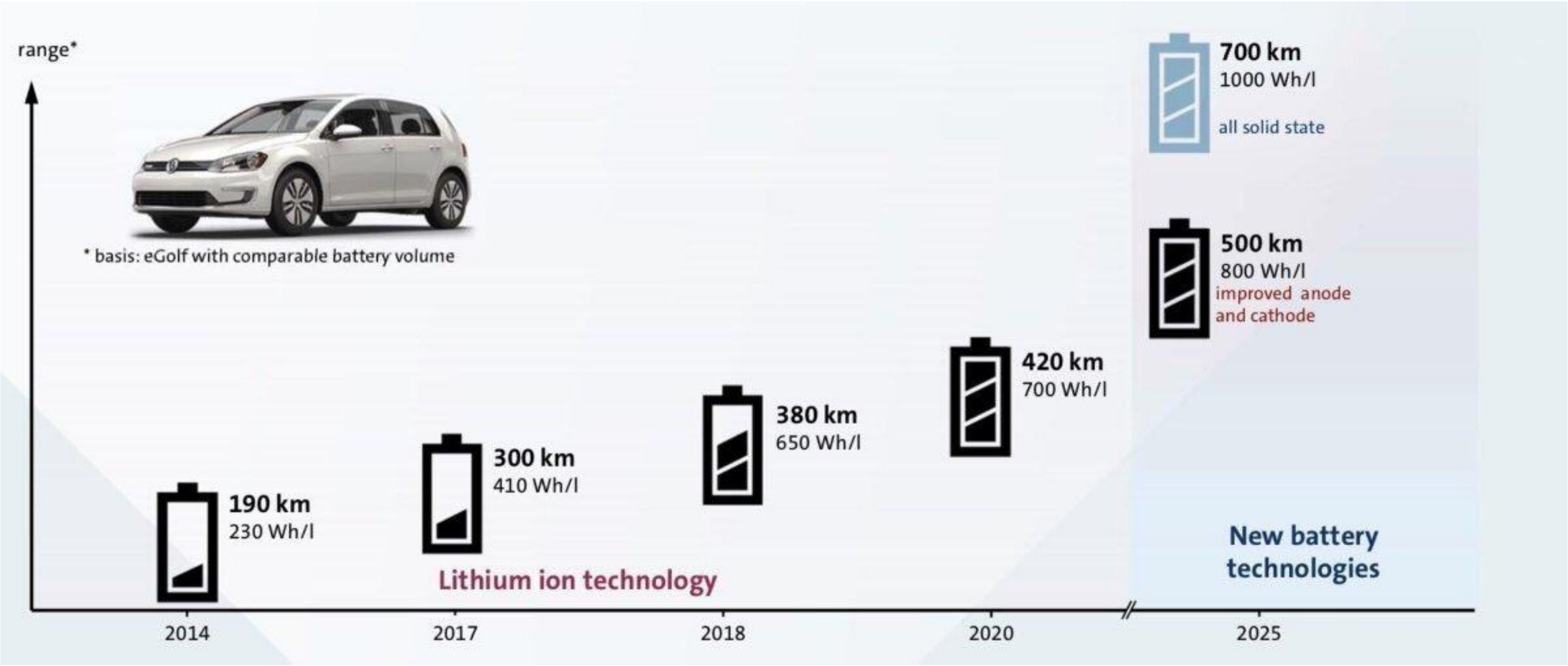
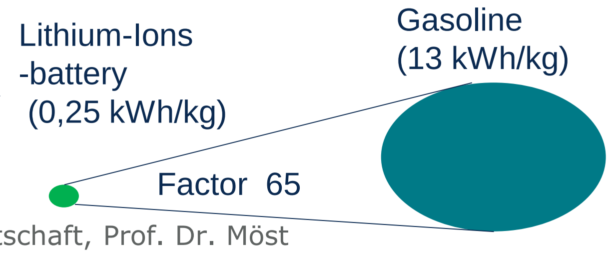
New batteries will increase possible driving distances, costs and weight!

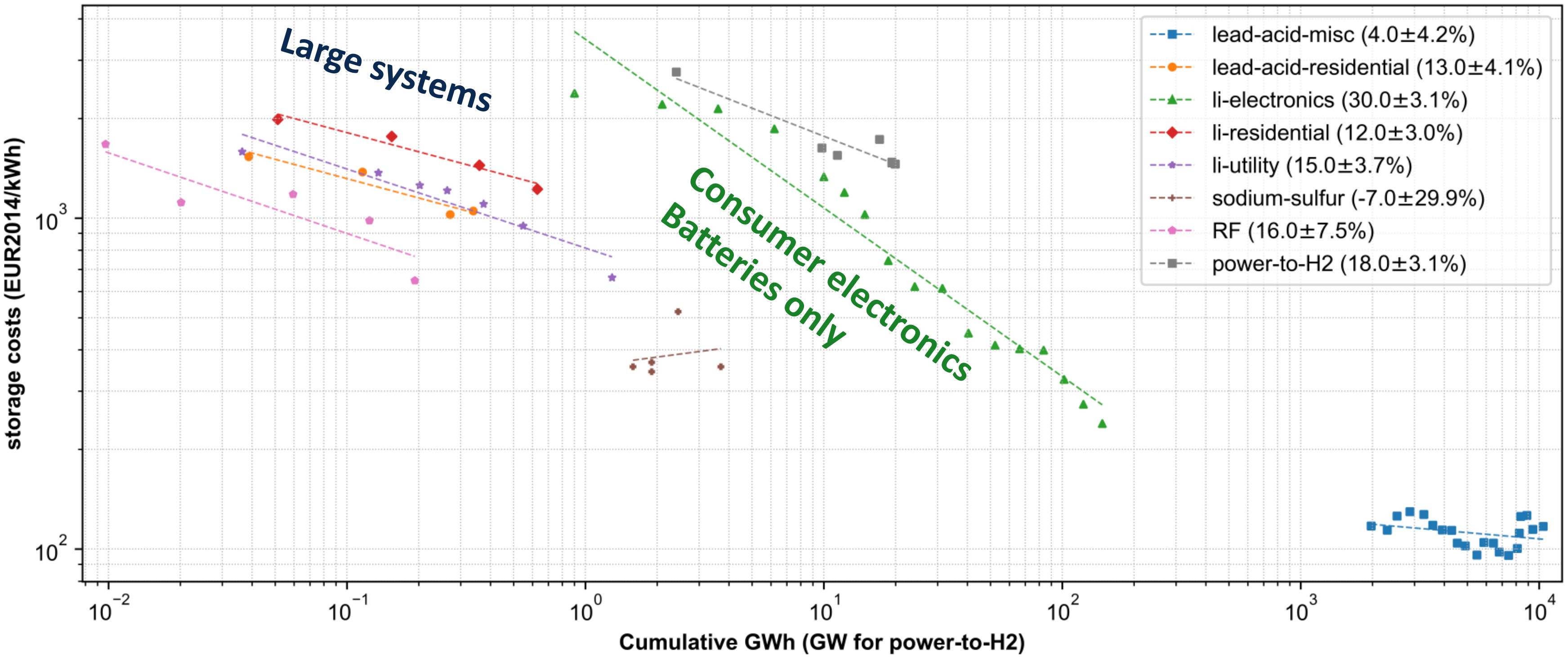


Source: Volkswagen : https://twitter.com/ddiazpilas/status/947837052934082560

Comparison of energy density



Experience curves of electricity storage

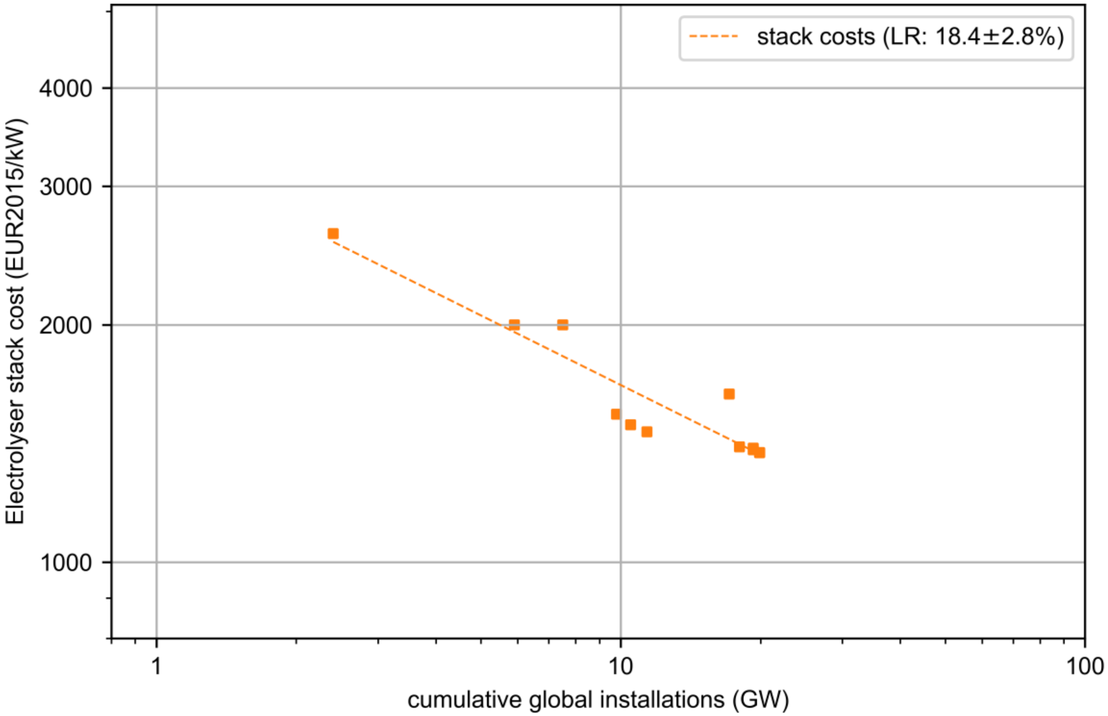


Source: REFLEX: Experience curve report (not published yet)

Experience curve for Power-to-hydrogen (alkaline electrolysis)

Hydrogen up to now mainly produced from fossil resources

- 95% of global production
- Proton exchange membrane (PEM) cells and solide oxid cells more on demonstrating scale and yet no large deployments, but more suitable for intermittent operation
- Alkaline electrolyser is considered as more mature and economically attractive technology
- Learning rate of ~18%, but with a relatively high parameter error
- … and first data point strongly determines slope of the curve
- Future penetration levels at current state difficult to predict



Source: REFLEX: Experience curve report (not published yet)

Experience curves as mean for long-term analysis in scenarios?

- Experience curve: a macroscopic model
  - Based on ex-post realisations => empirical data
  - no reliable basis for short-term decisions
- Experience curves can be an important tool in deriving long-term strategies and can be used in scenario development (see IEA (2000))
- Biggest challenge in using experience curves for the ex-ante analysis is that:
  - that an exact theoretical prediction of the course of the cost reduction curve for a new product is not possible / underlies high uncertainties
  - to make assumptions for starting point and amount of cost degression
- At least experience curves give some indications of the expected cost degression rates

Will the learning curve of PV repeat for Batteries and Electrolysis?

Learning will take place for the different technologies,

- but learning rates are different
  - PV systems ~ 18% (~21% for modules and ~13% for BOS)
  - BEV ~15%
  - FCEV ~ 18%
  - $P2H_2$ ~ 18%, but high uncertainty from learning factor and expected capacity development

Will costs also drop similar to PV?

- BEV: in the short-term: probable (2020), in the long-term (>2030): very likely (other restrictions may play a larger role)
- Electrolysis: in the short-term (2020): hard to expect, in the long-term: difficult to predict, but can not be excluded

⇒ Will the learning of PV repeat for Batteries and electrolysis?

- BEV: very likely (or even certain)
- $P2H_2$: depends, today seriously not predictable, but very likely under emission reduction scenarios

»Wissen schafft Brücken.«