Economics and market potential of power-to-gas

Workshop in Power to (the) molecules (Store & Go)
From technology to market uptake
Karlsruhe, 21 February 2020

Dr. David Parra

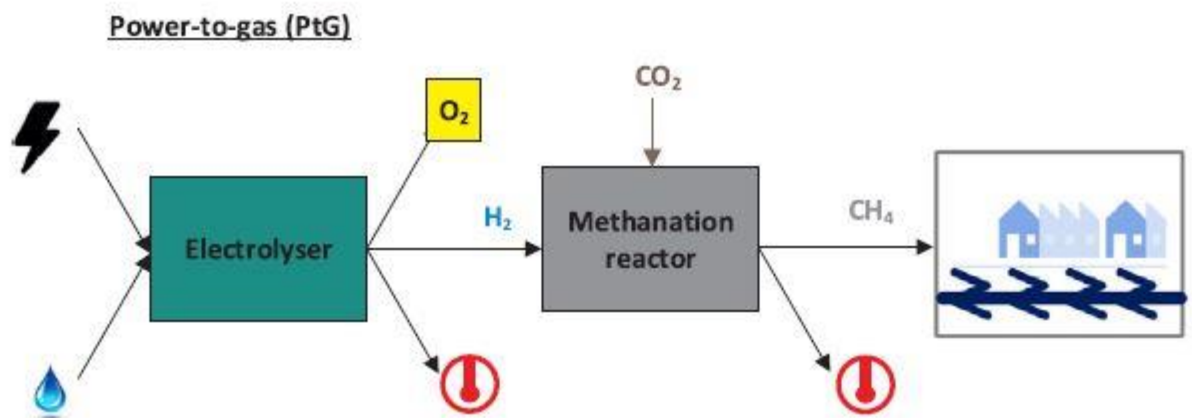
Senior researcher and teaching assistant
Institute for Environmental Sciences, University of Geneva

PI Swiss Competence Center for Energy Research in Energy Storage

Visiting researcher Institute for Data, Systems and Society (IDSS)
Massachusetts Institute of Technology


thermomix
VORWERK

Thermomix ®


Power-to-gas (PtG)
O₂
CO₂
H₂
Electrolyser
Methanation reactor
CH₄

Power-to-X

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P2X pathway	Conversion step	Carbon atoms	Inputs	Technology	Outputs
Hydrogen (H_2)	1	0	Electricity, water, heat (in case of SOEC)	Electrolyser, hydrogen storage	Hydrogen, oxygen, heat
Synthetic methane (CH_4)	1+2+3	1	Electricity, water, CO_2	Electrolyser, methanation reactor	Methane, oxygen, heat
Synthetic methanol (CH_3OH)	1+2+3	1	Electricity, water, CO_2	Electrolyser, methanol synthesis reactor	Methanol, oxygen, heat
Synthetic liquids (C_xH_yOH)	1+2+3	variable	Electricity, water, (heat), CO_2	Electrolyser, Fischer-Tropsch reactor	Liquid hydrocarbon fuels, oxygen, heat

Please give an estimate of the total production cost of:

- Power-to-hydrogen (electrolyser)
- Power-to-methane (+ methanation reactor)
- Power-to-power (+ hydrogen storage and fuel cell)
- Power-to-liquid (+ Fischer-Tropsch reactor)

Production cost

$$LCOX = \frac{CAPEX + \sum_{y=1}^{n} \frac{OPEX}{(1+r)^y}}{\sum_{y=1}^{n} \frac{E_{X_y}}{(1+r)^y}}$$

Parra et al. (2019) Perspective of Power-to-X technologies in Switzerland www.menti.com

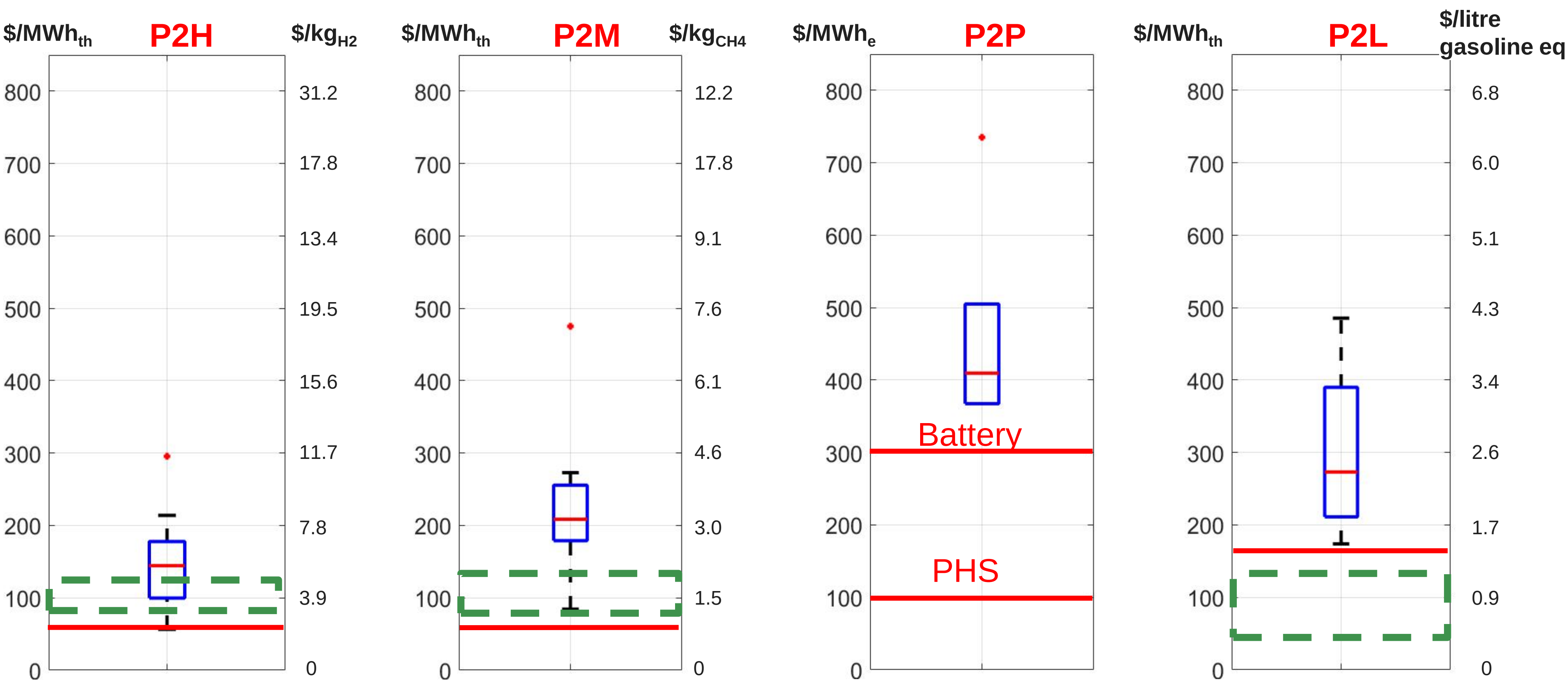
Introduce the code

40 50 6

Production costs of PtX systems

Cost of conventional technology or alternative

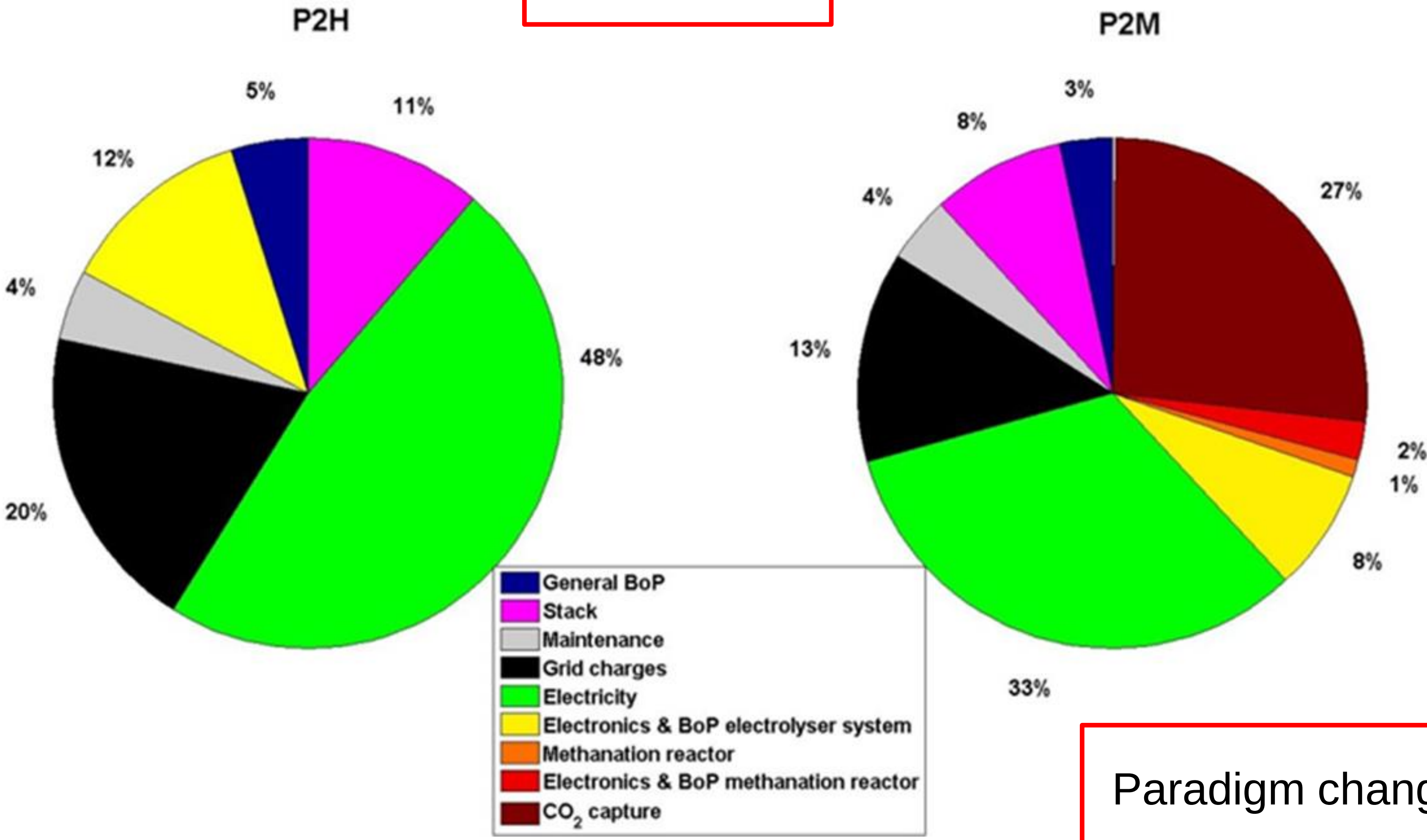
Projected levelised cost by 2050



Parra et al. (2019) White paper Power-to-X; Detz et al. (2019), Energy Environ Scie.

Electricity supply: levelised cost

Electricity!

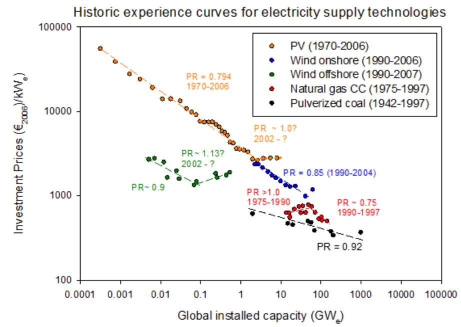


Paradigm change

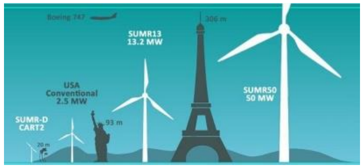
Source: D. Parra et al. (2017), Applied Energy

Cost and value gap

1 Technology progress

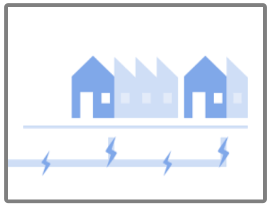


2 Scale

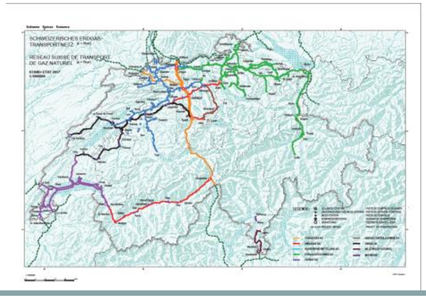


3 Smart electricity supply

4 Combination of applications

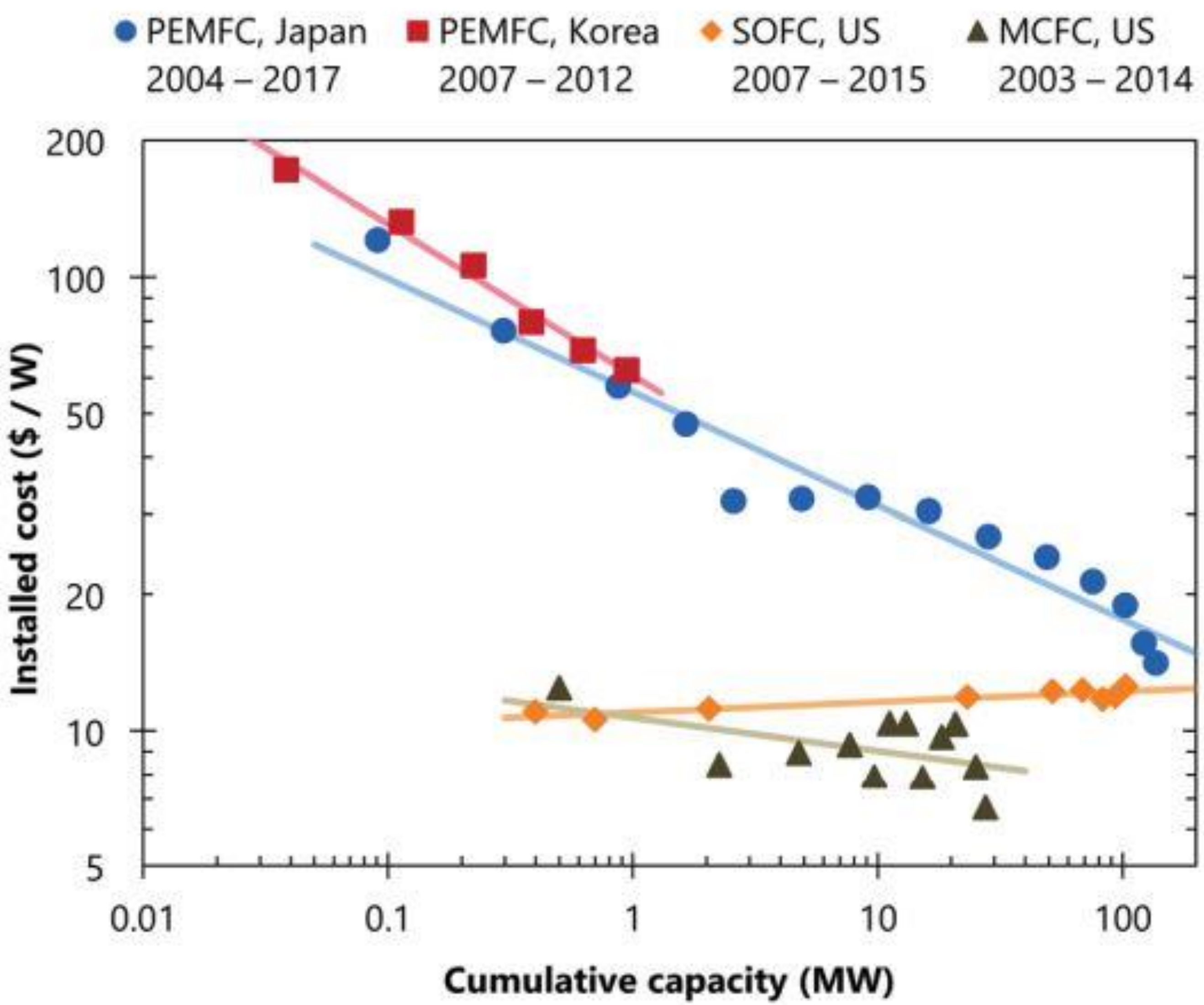


5 Energy system analysis



Source: D. Parra et al. (2019), Sustainable and Renewable Energy Reviews

Technology progress: Learning rate



Example for fuel cells

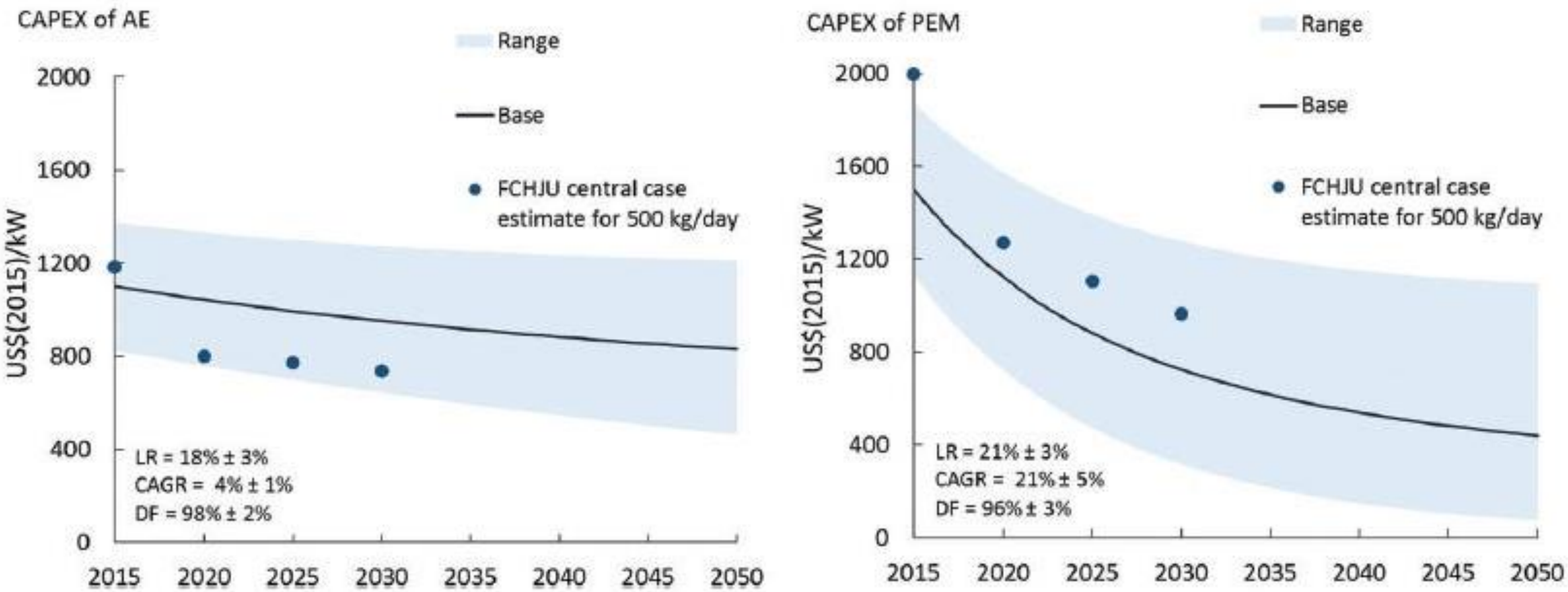
-Learning-by-doing
-Learning-by-searching
-Economies-of-scale
-Automation

Source: Staffel et al. (2019), Energy Environ Scie.

Technology progress

Alkaline electrolysis current installed capacity 21 GW

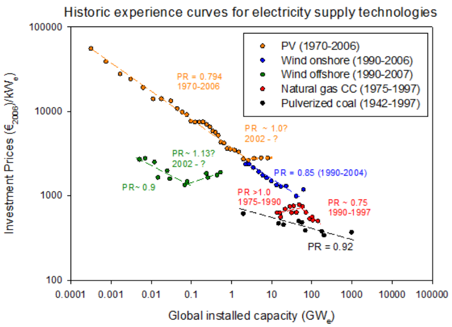
PEM electrolysis current installed capacity 0.8 GW



Learning rate (LR): Cost
Cumulative annual growth rate (CAGR)

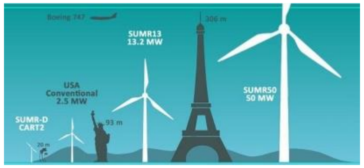
Detz et al. (2019), Energy Environ Scie.

Cost and value gap



1 Technology progress

2 Scale



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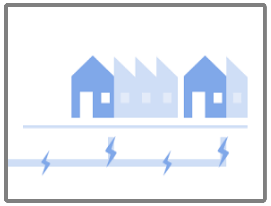
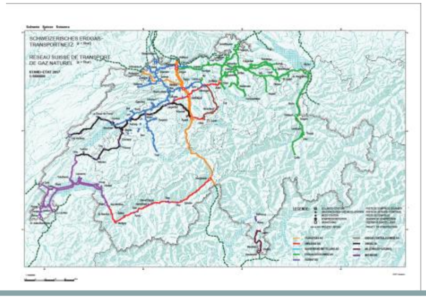


5 Energy system analysis



Source: D. Parra et al. (2019), Sustainable and Renewable Energy Reviews

Scale

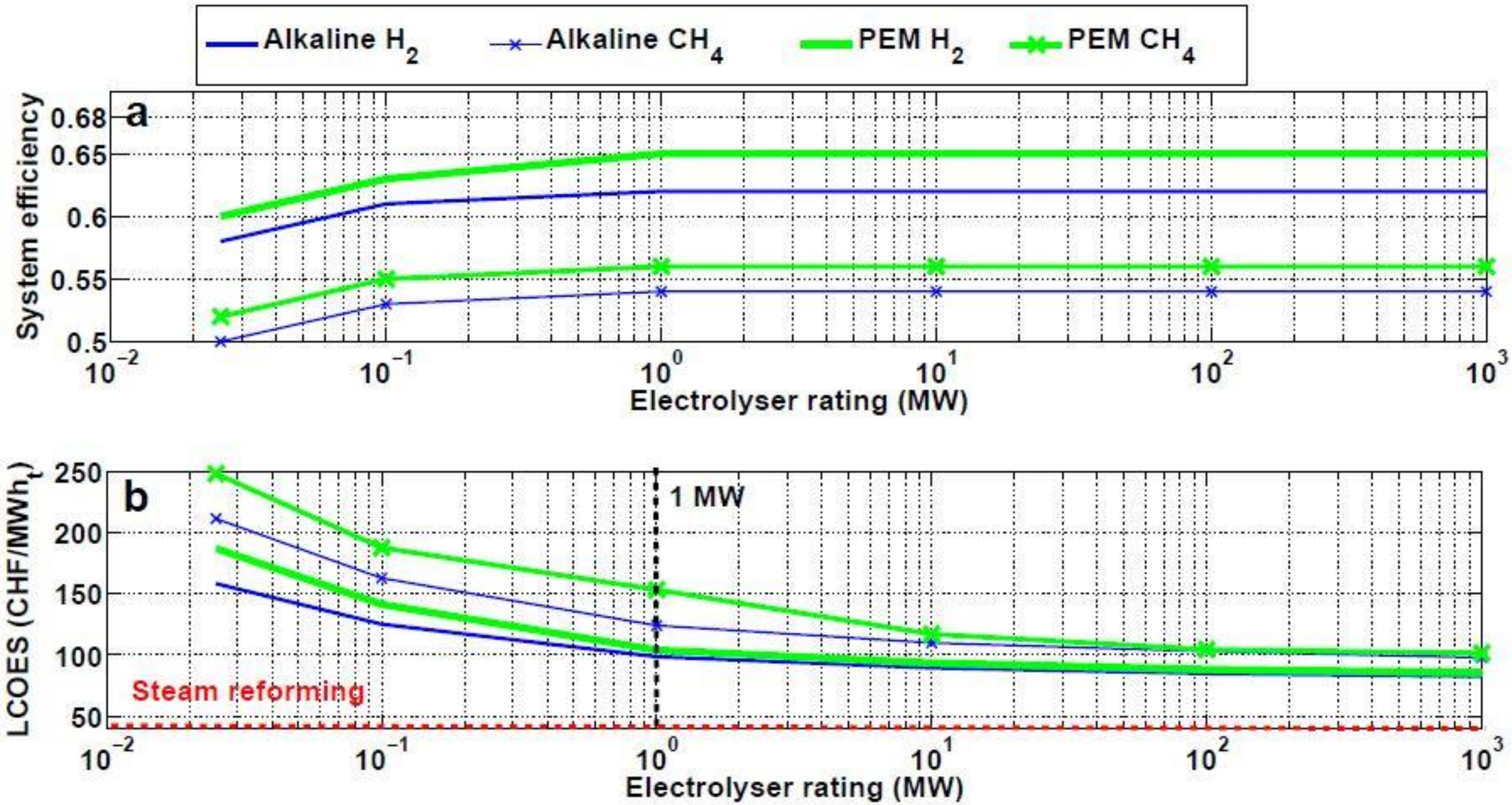
1kW

Scale matters

6 MW

Source: Parra et al. (2016), International Journal of Hydrogen Energy

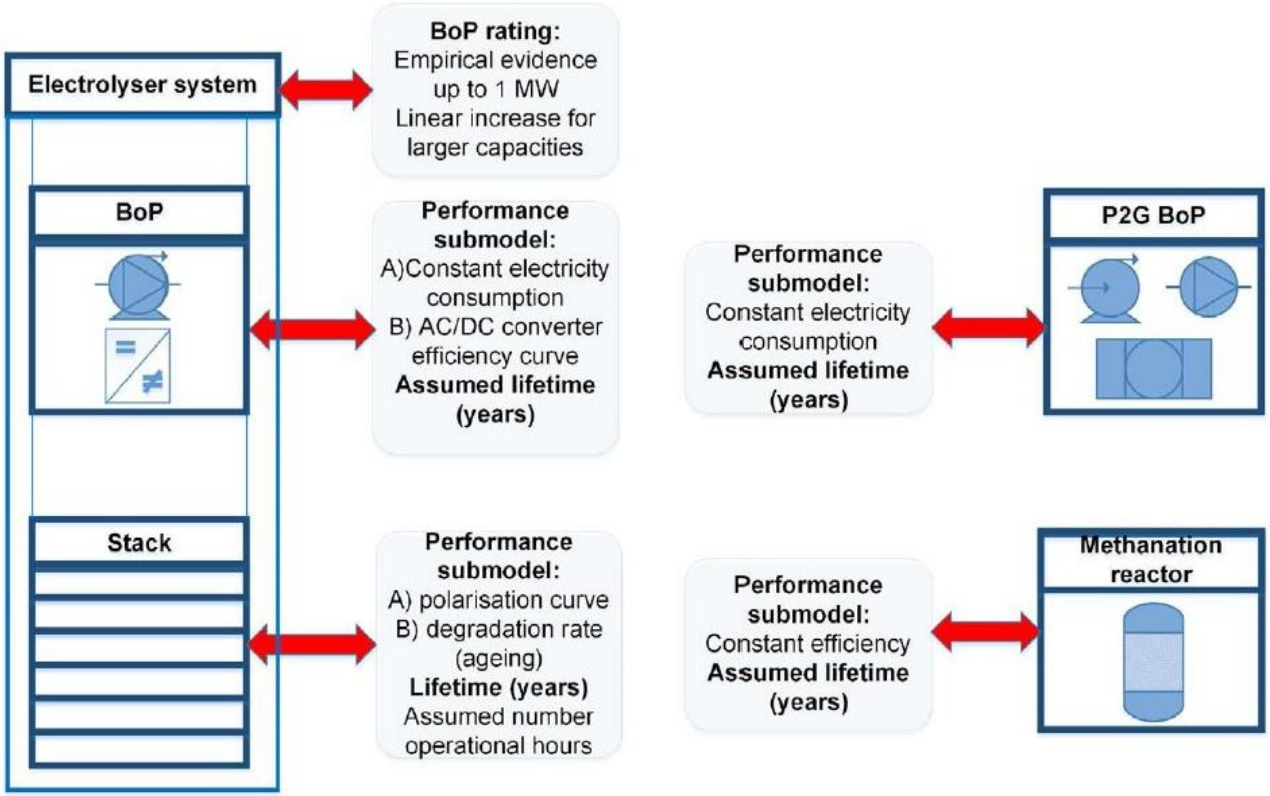
Scale



- The larger the plant, the better
- But improvement becomes smoother

Source: Parra et al. (2016), International Journal of Hydrogen Energy

Scale



$$Cost_{stack} = \left(\frac{Capacity_{plant}}{Capacity_{reference-plant}}\right)^{0.7} \times cost_{stack} \times Capacity_{reference-plant}$$

$$Cost_{BoP-inv} = \left(\frac{Capacity_{plant}}{Capacity_{reference-plant}}\right)^{0.7} \times cost_{BoP-invv} \times Capacity_{reference-plant}$$

$$Cost_{maint} = \left(\frac{Capacity_{plant}}{Capacity_{reference-plant}}\right)^{0.6} \times cost_{maint} \times Capacity_{reference-plant}$$

Source: Parra et al. (2016), International Journal of Hydrogen Energy

Cost and value gap

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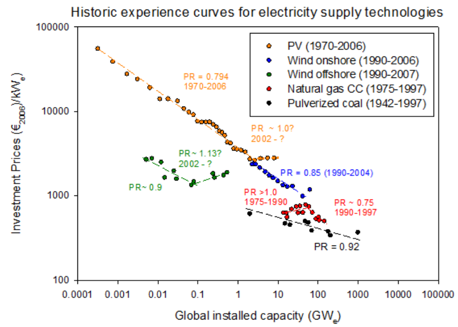
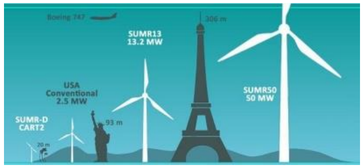
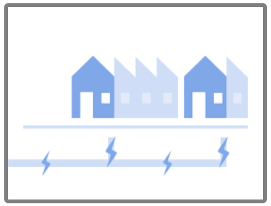


1 Technology progress

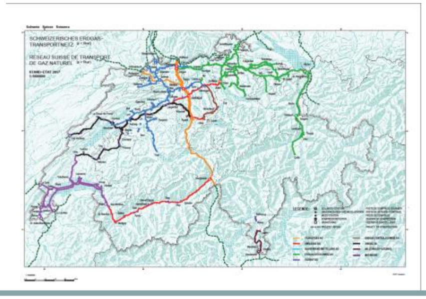


2 Scale

3 Smart electricity supply



4 Combination of applications



5 Energy system analysis

Source: D. Parra et al. (2019), Sustainable and Renewable Energy Reviews

Electricity supply

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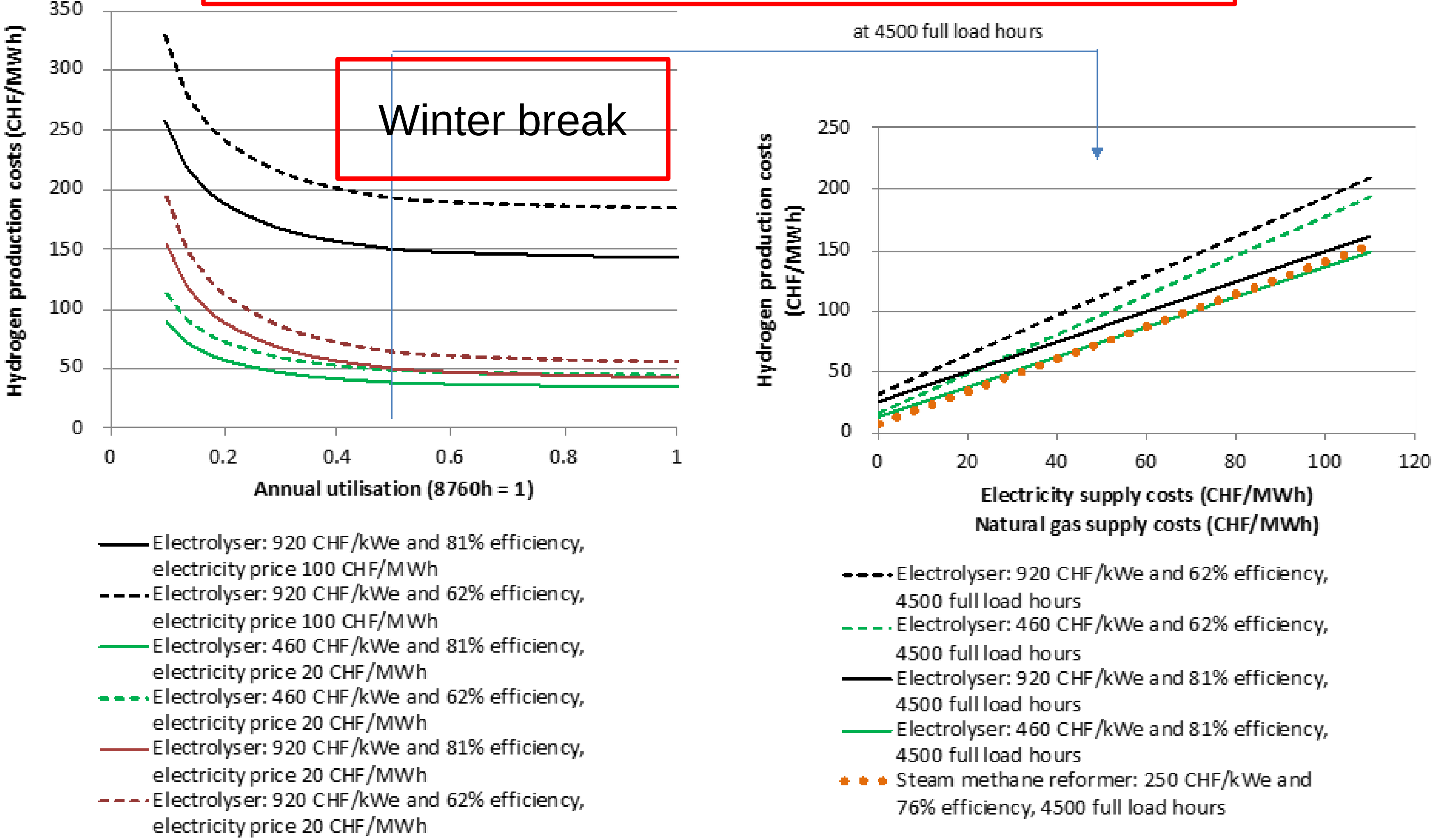
1) Electricity price; 2) efficiency; 3) CAPEX



Source: Kober et al. (2019) Perspective of Power-to-X in Switzerland

Electricity supply: available options

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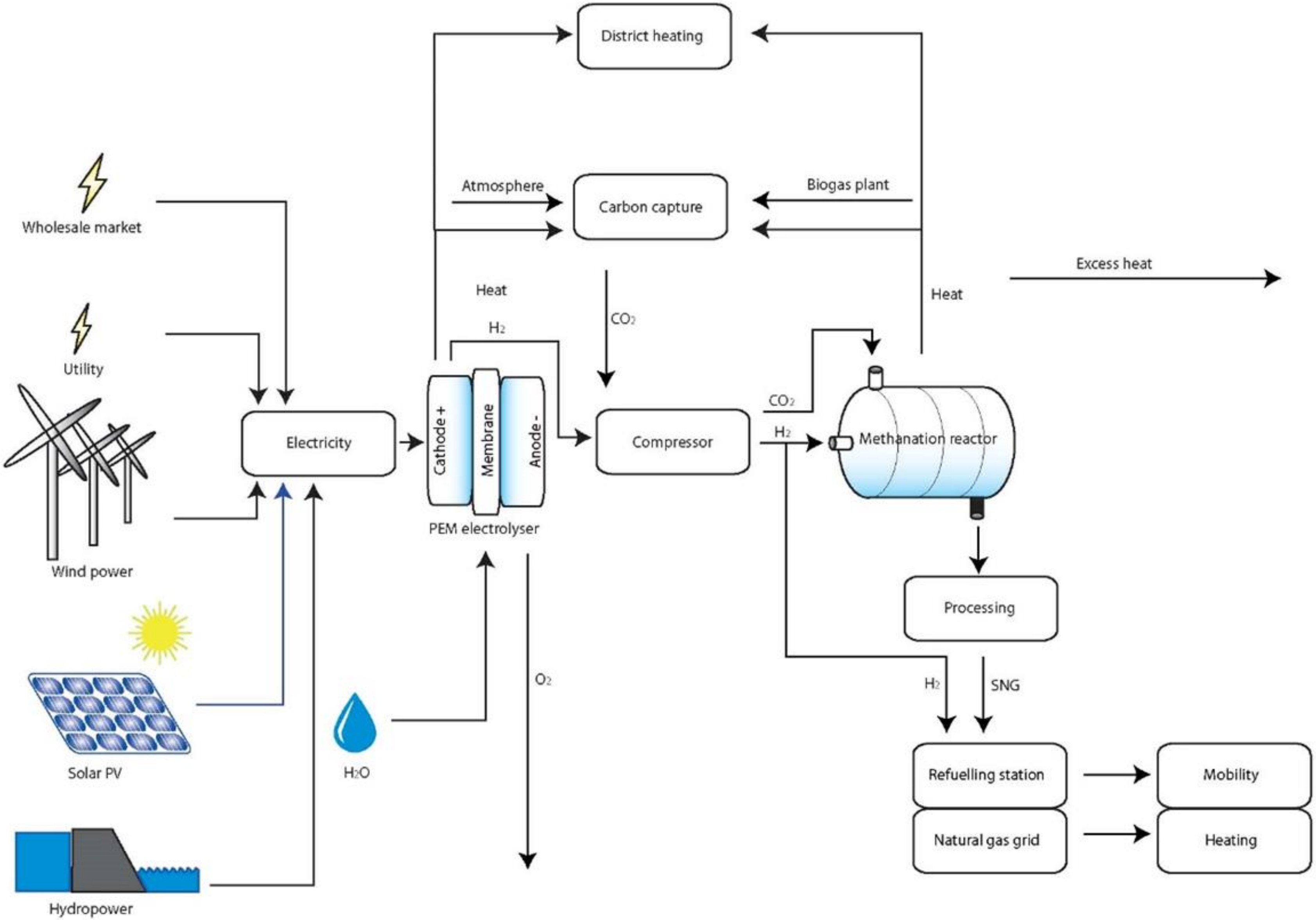
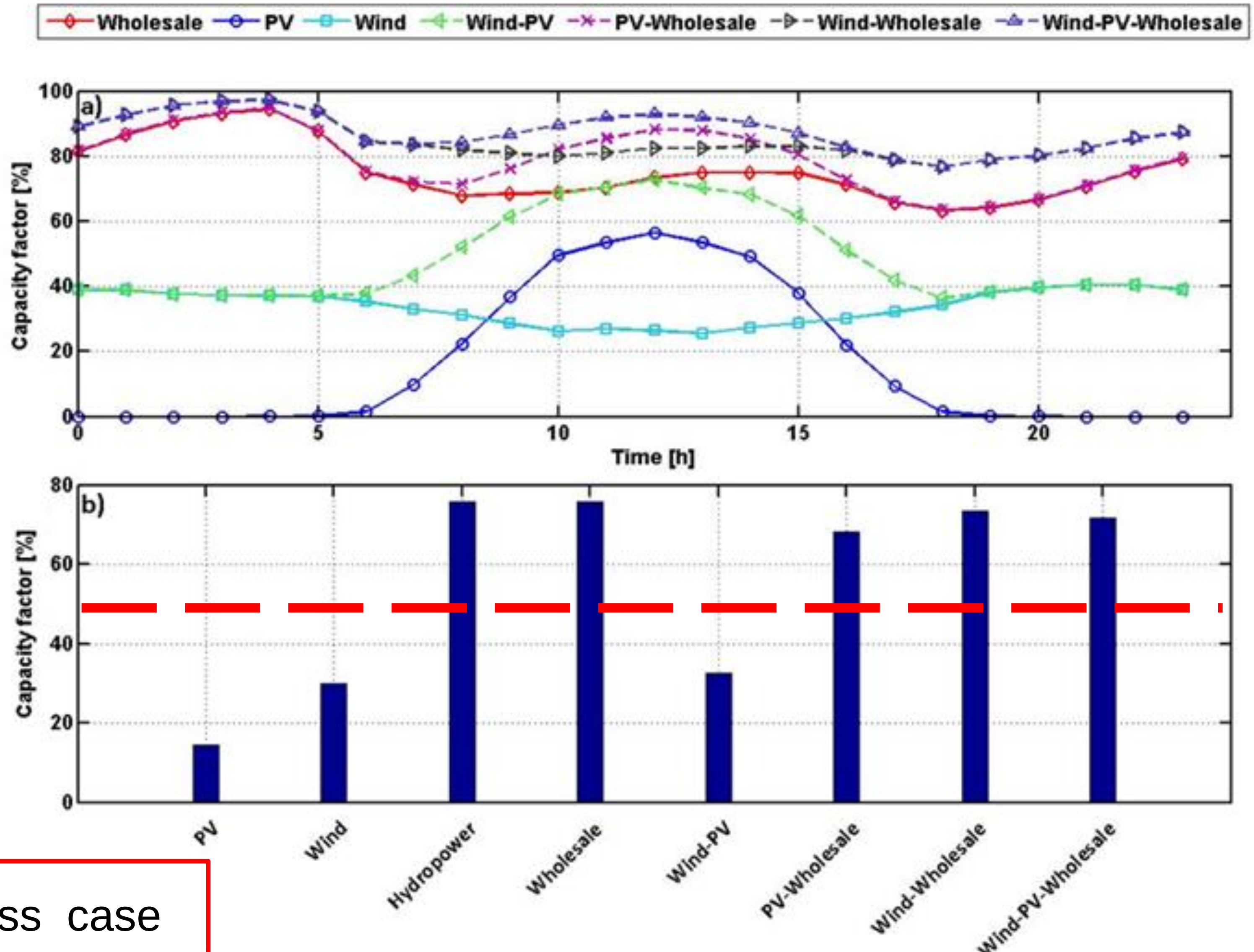


Source: H. Aymane et al. (2019), International Journal of Hydrogen Energy

Electricity supply: capacity factor



Swiss case

Source: H. Aymane et al. (2019), International Journal of Hydrogen Energy

Electricity supply: levelised cost

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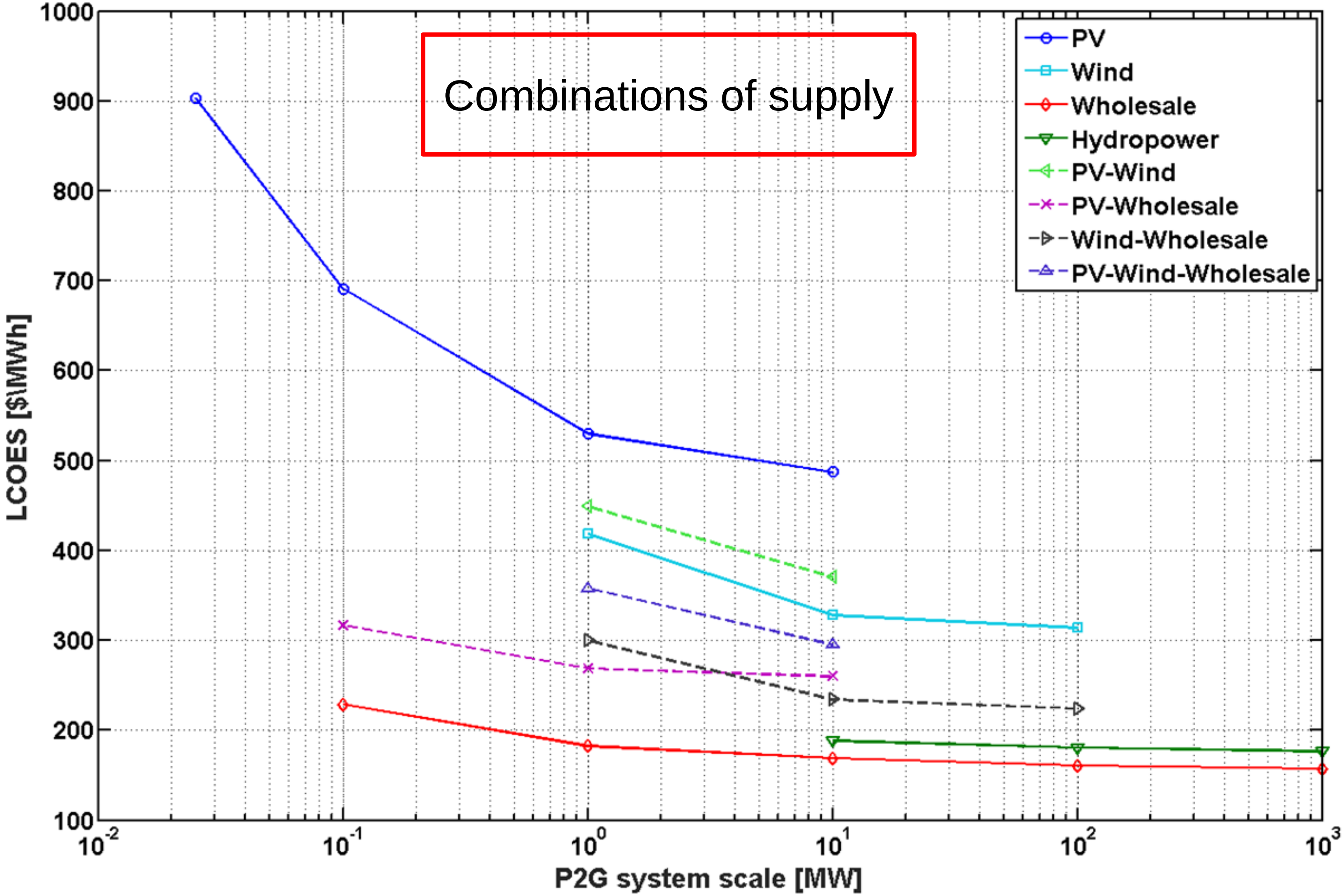
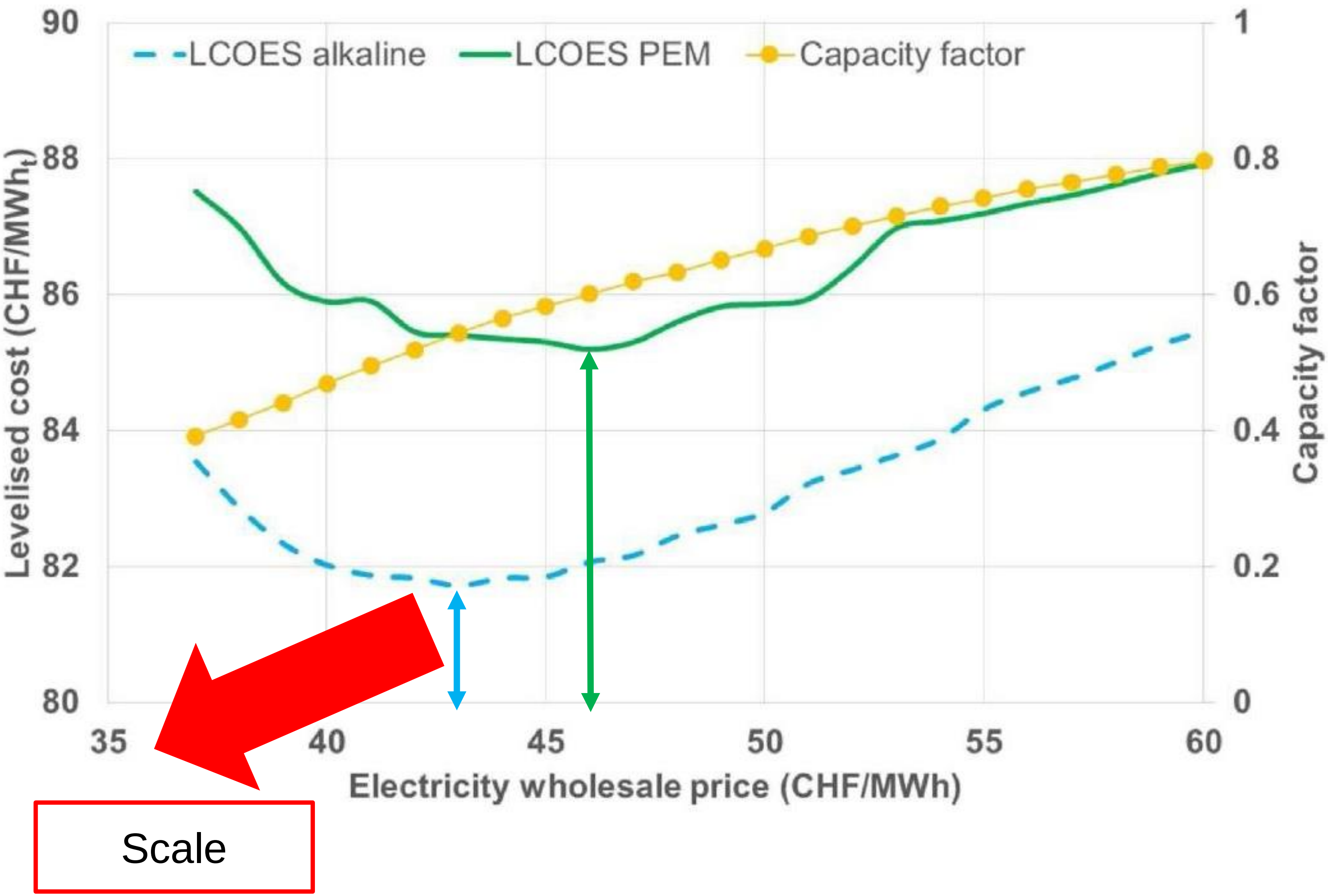


10 MW PtM plant with CO_2 captured from the air

Source: H. Aymane et al. (2019), International Journal of Hydrogen Energy

Electricity supply: wholesale market

10 MW PtH plant



Source: D. Parra & M. Patel (2016), International Journal of Hydrogen Energy

Electricity supply: NPV per CAPEX

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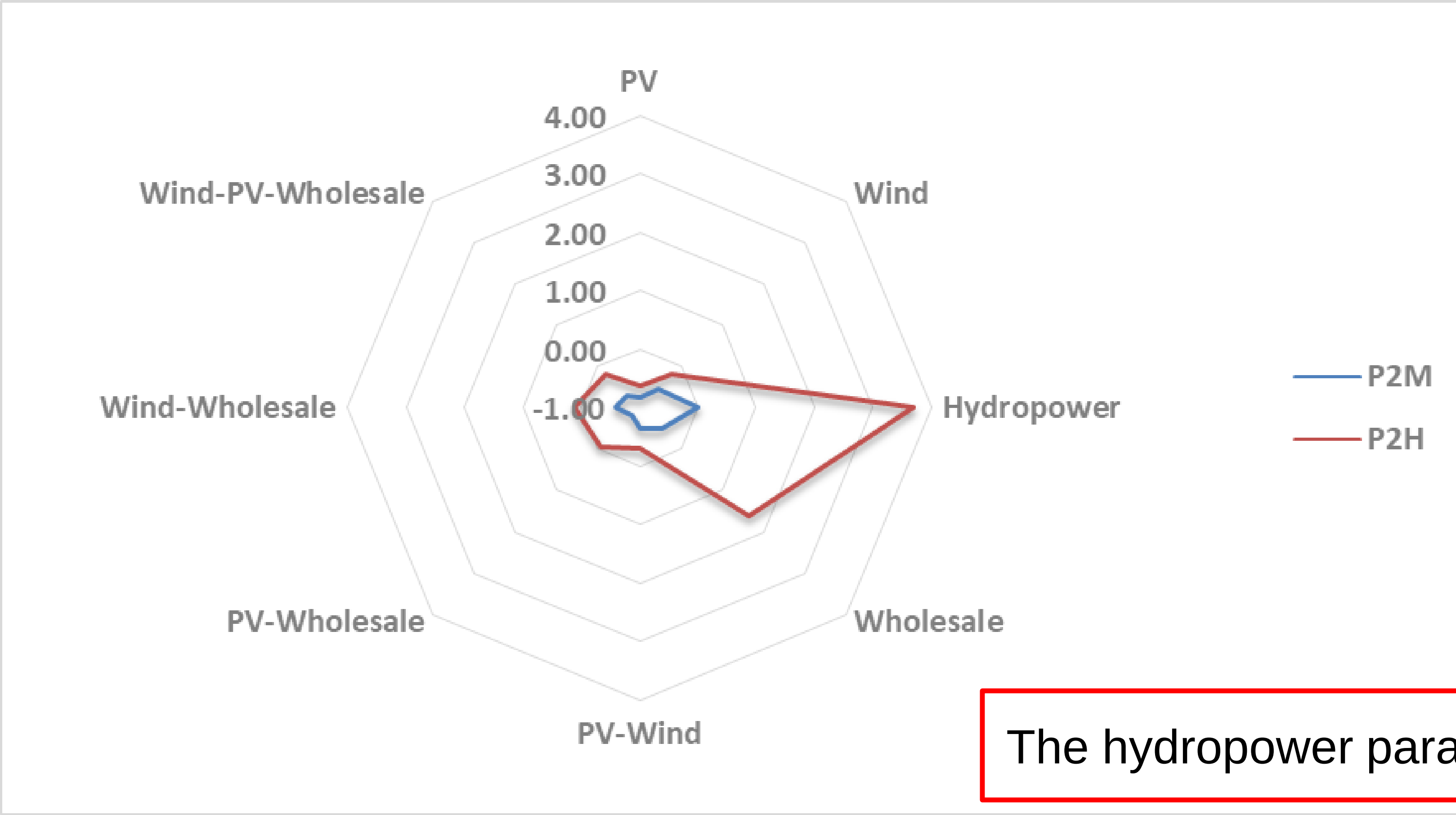
$$NPV_{per\ CAPEX} = \sum_{i=1}^{n} \frac{CF_i}{(1+r)^i \times CAPEX} - 1$$



The hydropower paradox

10 MW plant with CO_2 captured from the air

Source: H. Aymane et al. (2019), International Journal of Hydrogen Energy

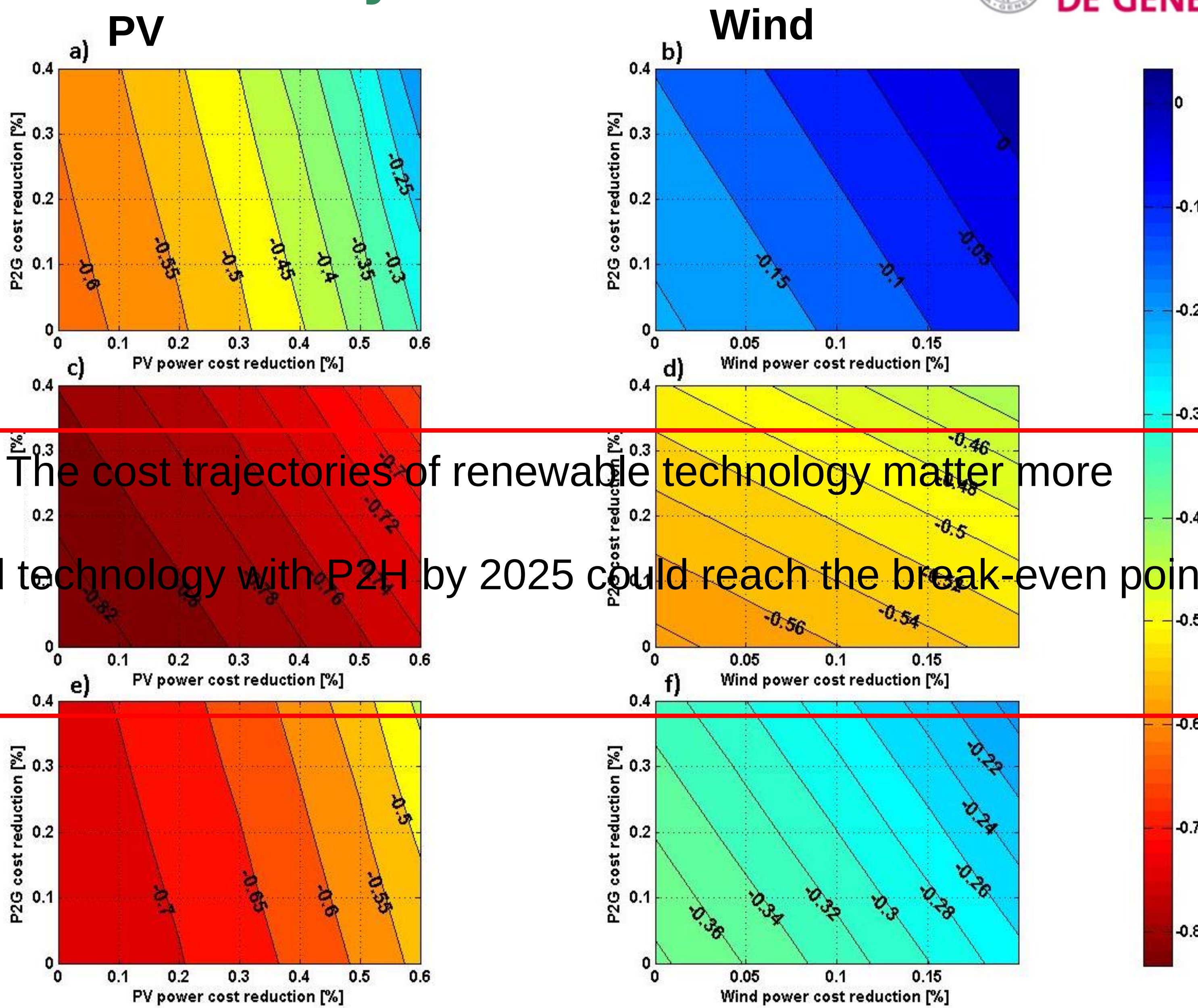
Renewable electricity outlook in 2025

10 MW

P2H

P2M (CO2 from air)

P2M (CO2 from biogas)



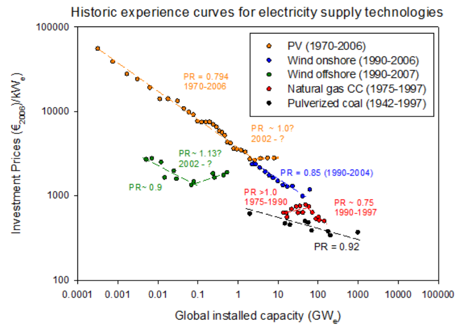
The cost trajectories of renewable technology matter more

Wind technology with P2H by 2025 could reach the break-even point

Source: H. Aymane et al. (2019), International Journal of Hydrogen Energy

Cost and value gap

1 Technology progress



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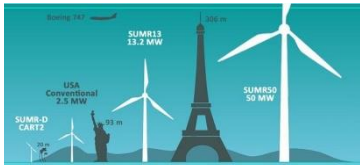
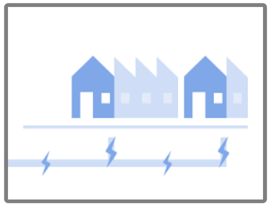
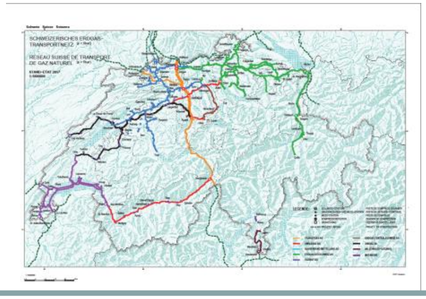


3 Smart electricity supply

4 Combination of applications



5 Energy system analysis



Source: D. Parra et al. (2019), Sustainable and Renewable Energy Reviews

Benefit stacking

Cost Value

Cost Value

Benefit stacking

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- Could you enumerate the revenue streams, i.e. products and services a PtG system can create?

www.menti.com

Use the code

40 50 6

Benefit stacking-key markets

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Key process step	Main output product	Potential markets
Electrolysis	*Hydrogen*	• Hydrogen market (industrial uses) • Natural gas market (H2 injection in natural gas grid) • Mobility fuel market (H2 as fuel) • Ancillary services market
Methanation	*Methane*	• Natural gas market • Biogas market • Mobility fuel market (CNG)
Fischer-Tropsch process	*Synthetic fuel*	• Mobility fuel market (synthetic fuel) • Industrial market for synthetic fuel
Methanol synthesis	*Methanol*	• Mobility fuel market (methanol) • Industrial market for methanol
Electrification (fuel cell)	*Electricity*	• Electricity market (future, spot market, intraday) • Ancillary services market

Source: B. Steffen and T. Schmidt (2019) Perspective of Power-to-X in Switzerland

Benefit stacking

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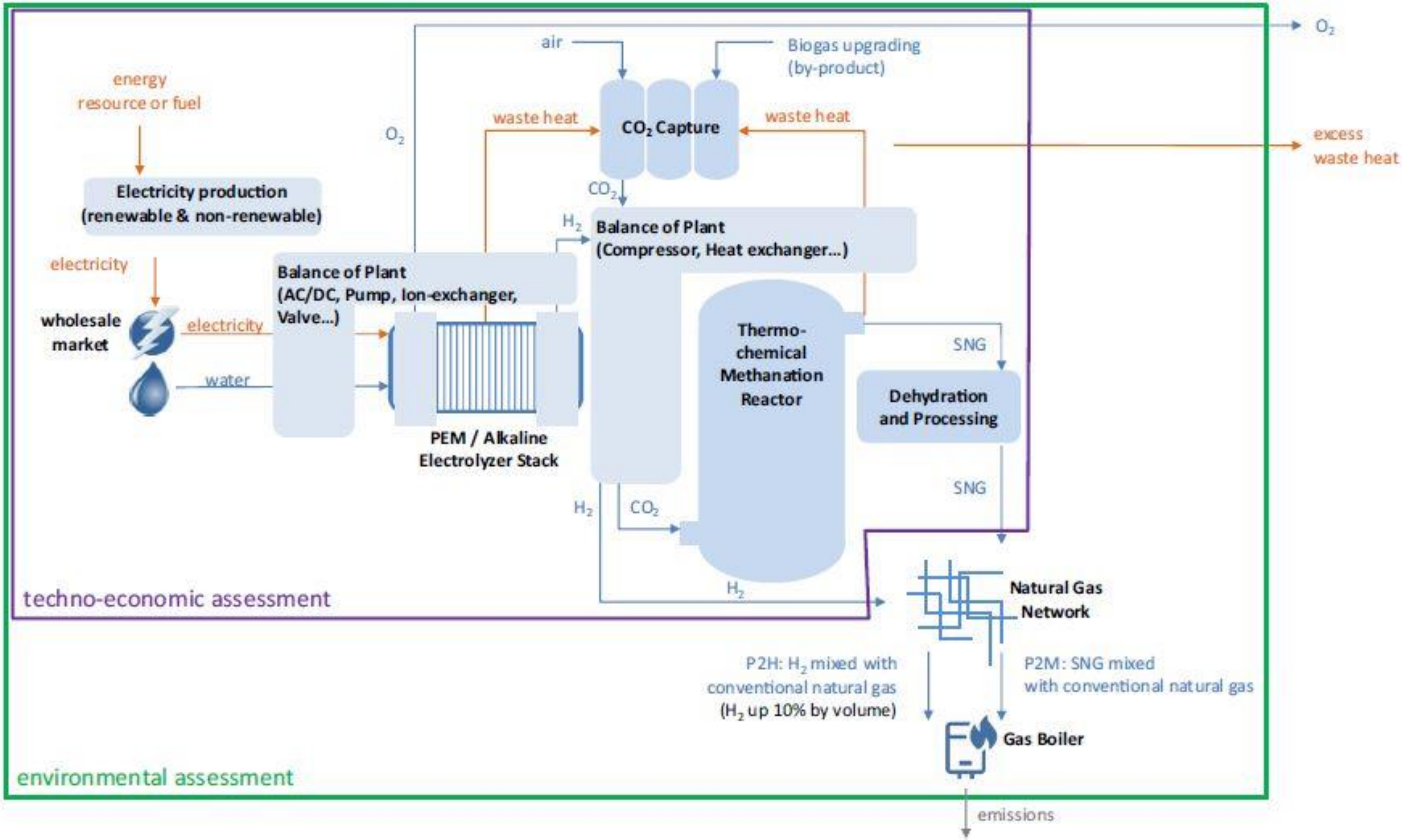

Source: Parra et al. (2017), Applied Energy

Benefit stacking

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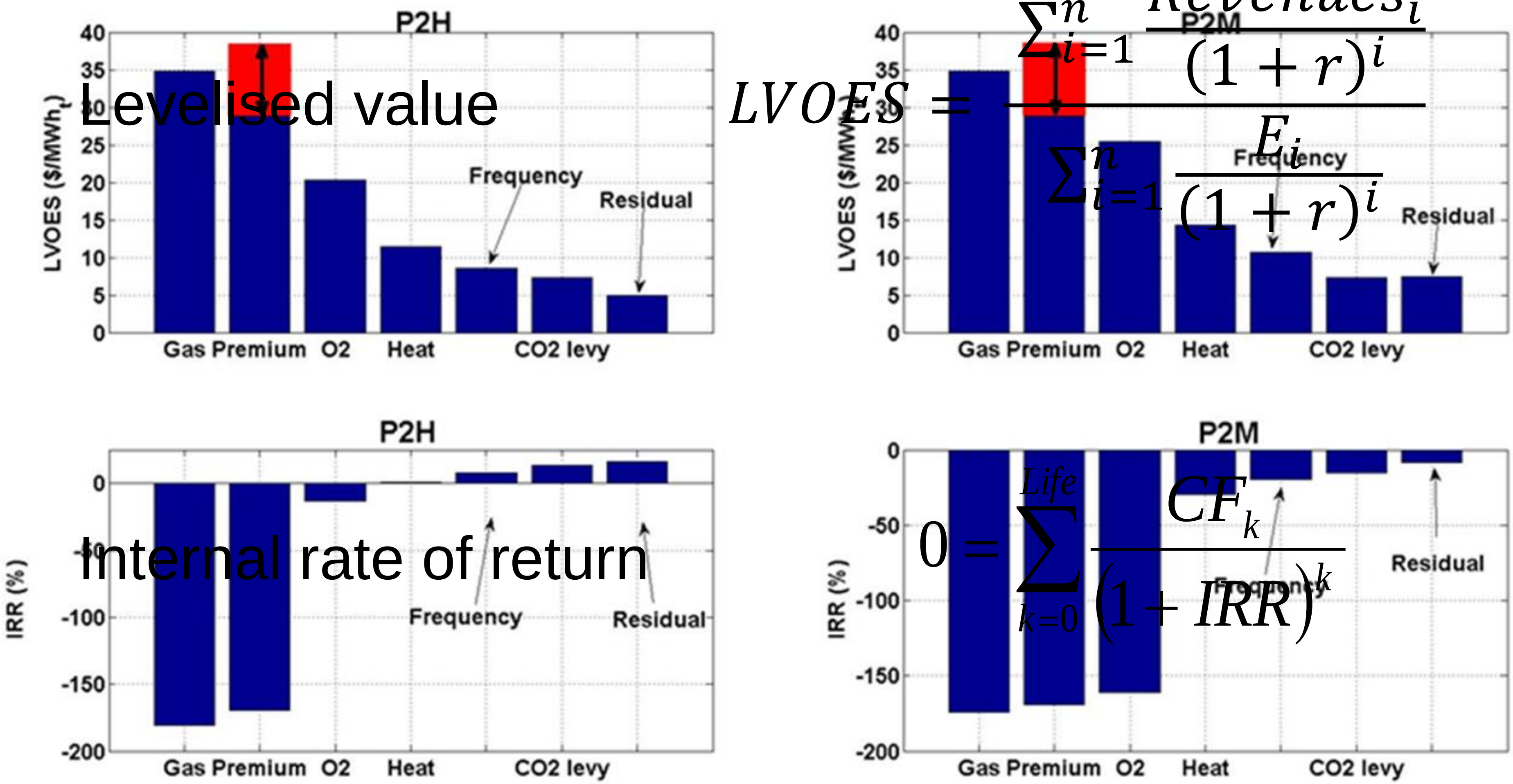
Levelised value

$$LVOES = \frac{\sum_{i=1}^{n} \frac{Revenues_i}{(1+r)^i}}{\sum_{i=1}^{n} \frac{E_i}{(1+r)^i}}$$

Internal rate of return

$$0 = \sum_{k=0}^{Life} \frac{CF_k}{(1+IRR)^k}$$



Source: D. Parra et al. (2017) Applied Energy

Benefit stacking-Heat

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System	Temperature range	Amount of heat generated	Potential heat applications and related heat price
PEM and alkaline Electrolysers	60 °C-100 °C	Up to 25% of electricity input	Residential (5-25 c€/kWh), 3rd and 4th district heating generation (40-80 €/MWh), and industrial (e.g., food)
Methanation reactor	250 °C-500 °C	Up to 20% of hydrogen input	Residential (5-25 c€/kWh), any district heating scheme (40-80 €/MWh) and industrial (e.g., chemical)
PEMFC system	60 °C-100 °C	Up to 60% of hydrogen input	Residential (5-25 c€/kWh), 3rd and 4th district heating generation (40-80 €/MWh) and industrial (e.g.,food)
SOFC system	600°C-800°C	Up to 40% of hydrogen input [11]	Residential (5-25 c€/kWh), any district heating scheme (40-80 €/MWh), and industrial (e.g., metal and mineral)

Source: D. Parra et al. (2019), International Journal of Hydrogen Energy

Benefit stacking-Heat

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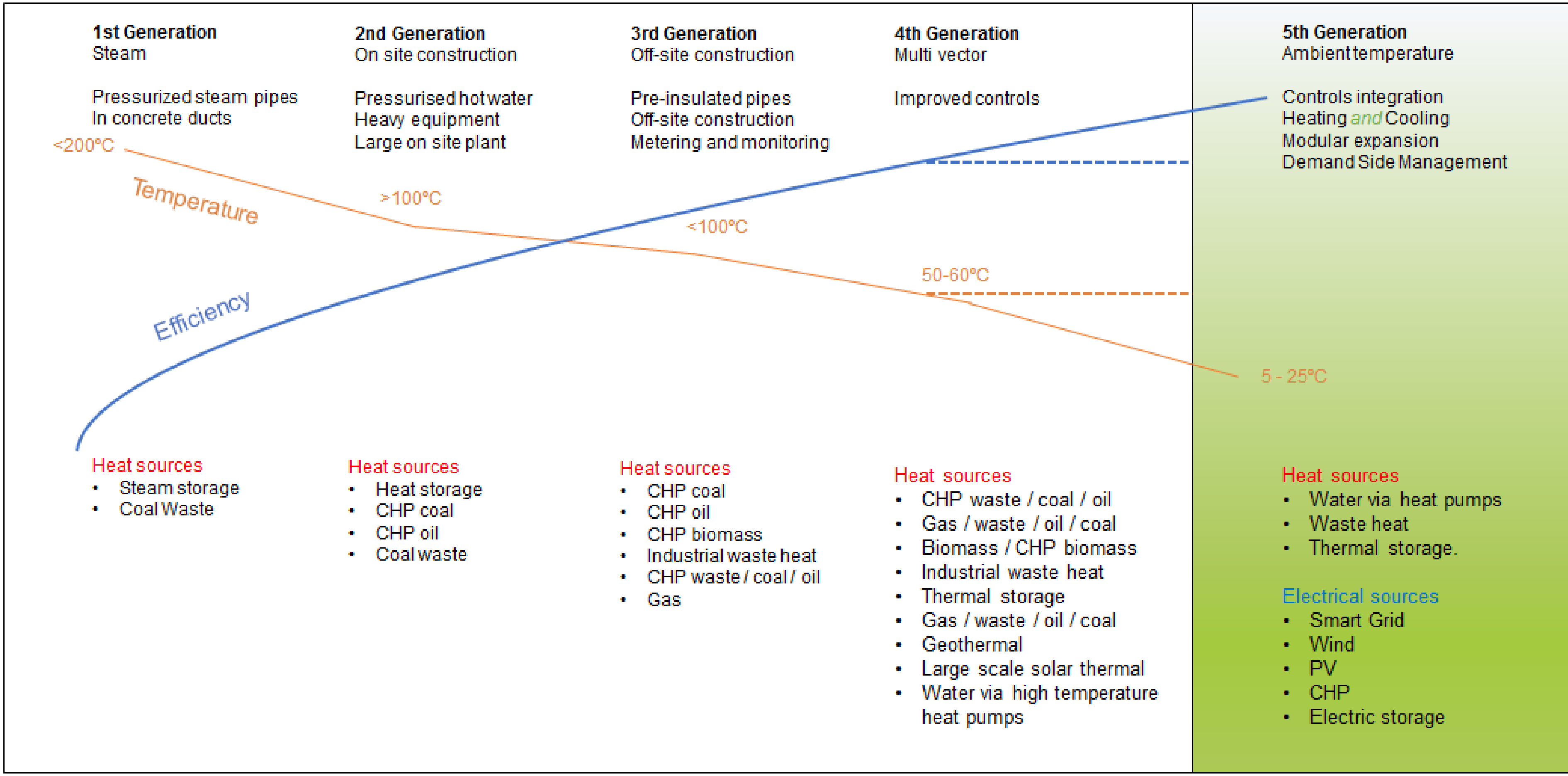


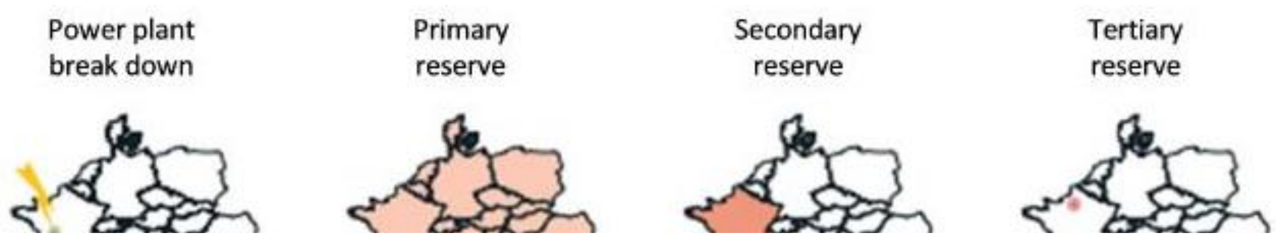
1880 → <200°C | 1930 → >100°C | 1980 → <100°C | 2010 → 50-60°C | 2017 → 5 - 25°C

Heat network trends to lower distribution temperatures and higher efficiency

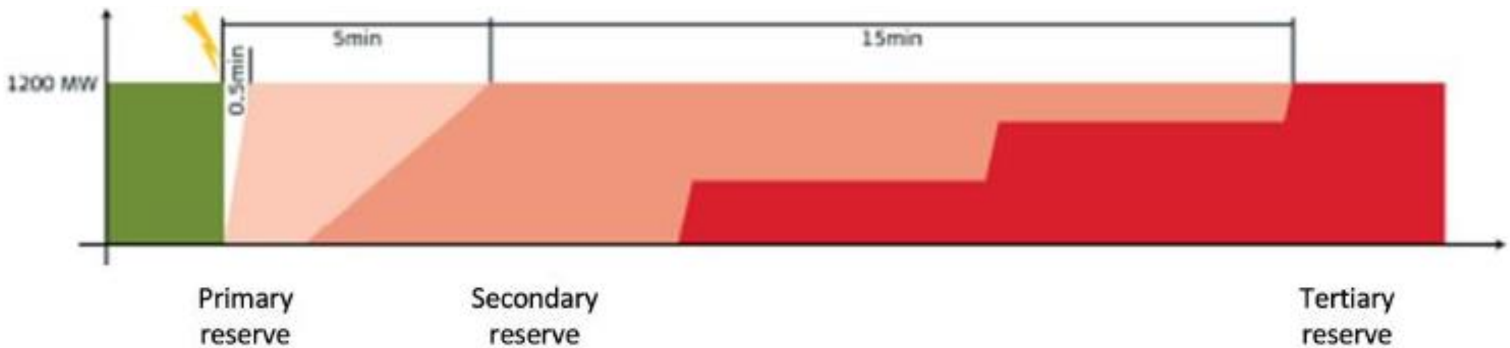
Source: ICAX (2019), www.icax.co.uk

Benefit stacking-frequency control

Frequency control markets in Switzerland



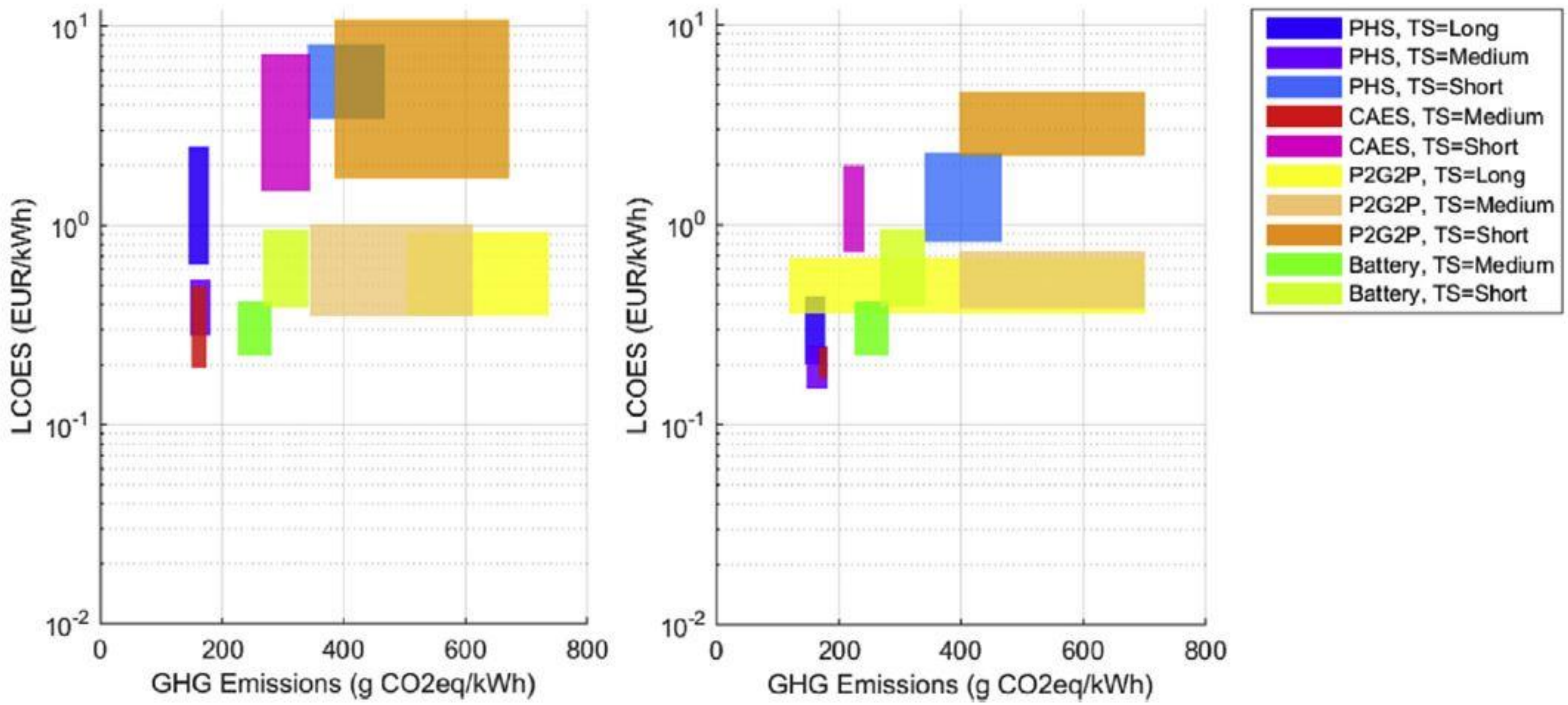
Ancillary Service Control reserves	Weekly average in 2017 [CHF/MW]	Size of reserve [MW]	Min bid size [MW]	Max bid size [MW]	Estimated market size [Mio CHF/Year]
Primary reserves	2466	±68	1	25	10
Secondary reserves	5535	±400	5	50	120
Tertiary reserves (–)	680	–300	5	100	10
Tertiary reserves (+)	450	+450	5	100	10

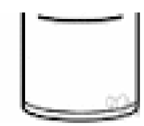


Source: Swissgrid

Benefit stacking-electricity storage

1 MW system	Short TS 0.01h	Medium TS 4.5h	100 MW system



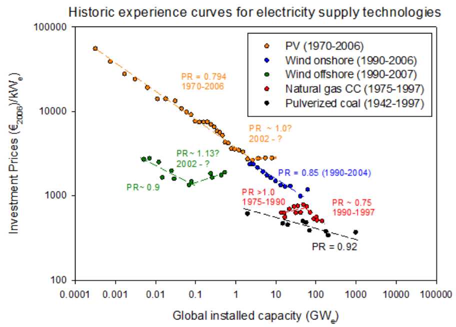


Seasonal storage

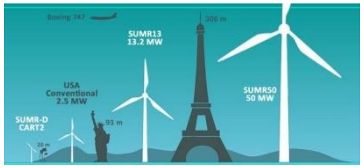
Source: Abdon et al. (2017), Energy

Cost and value gap

1 Technology progress

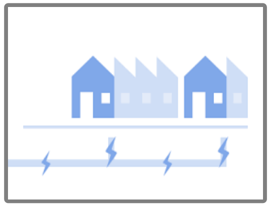


2 Scale

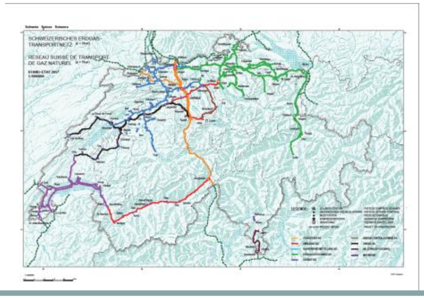


3 Smart electricity supply

4 Combination of applications

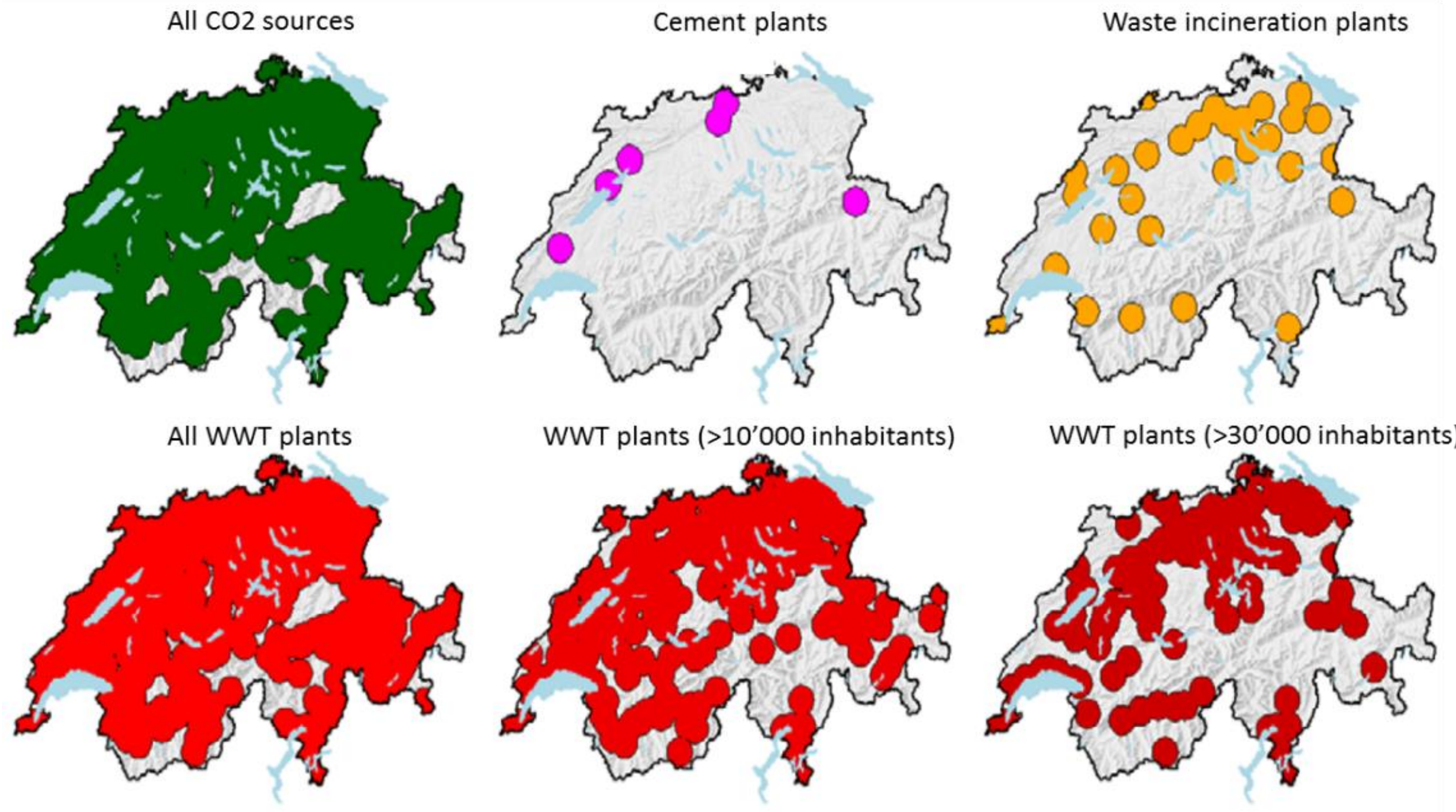


5 Energy system analysis



Source: D. Parra et al. (2019), Sustainable and Renewable Energy Reviews

Energy system analysis-Location



Source: Teske et al. (2019), Power-to-gas potential in Switzerland

Energy system analysis-Location

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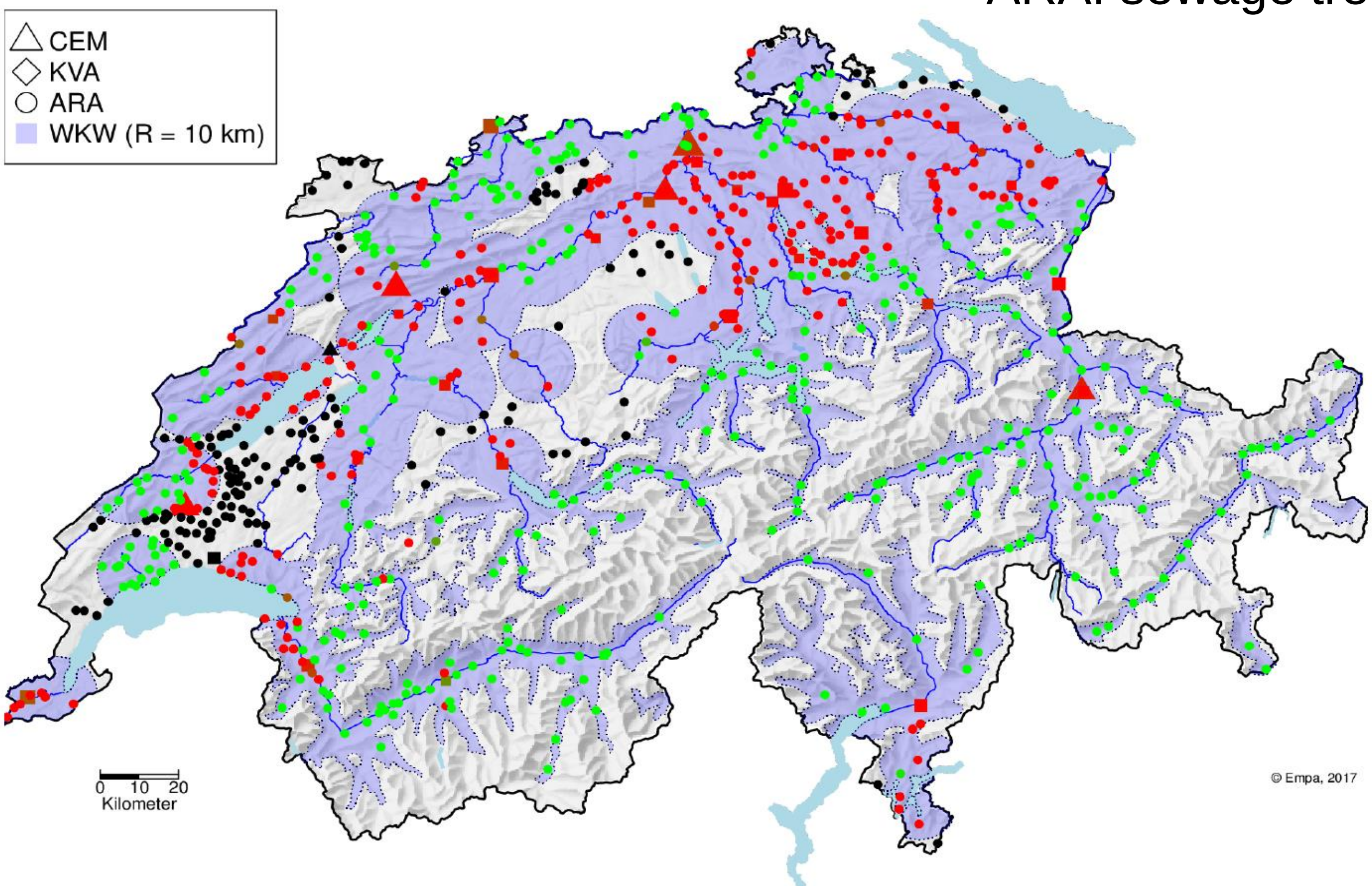
CO_2 perspective

CEM: cement plant
kVA: waste incineration plant
ARA: sewage treatment plant



Source: Teske et al. (2019), Power-to-gas potential in Switzerland

Energy system analysis-Location

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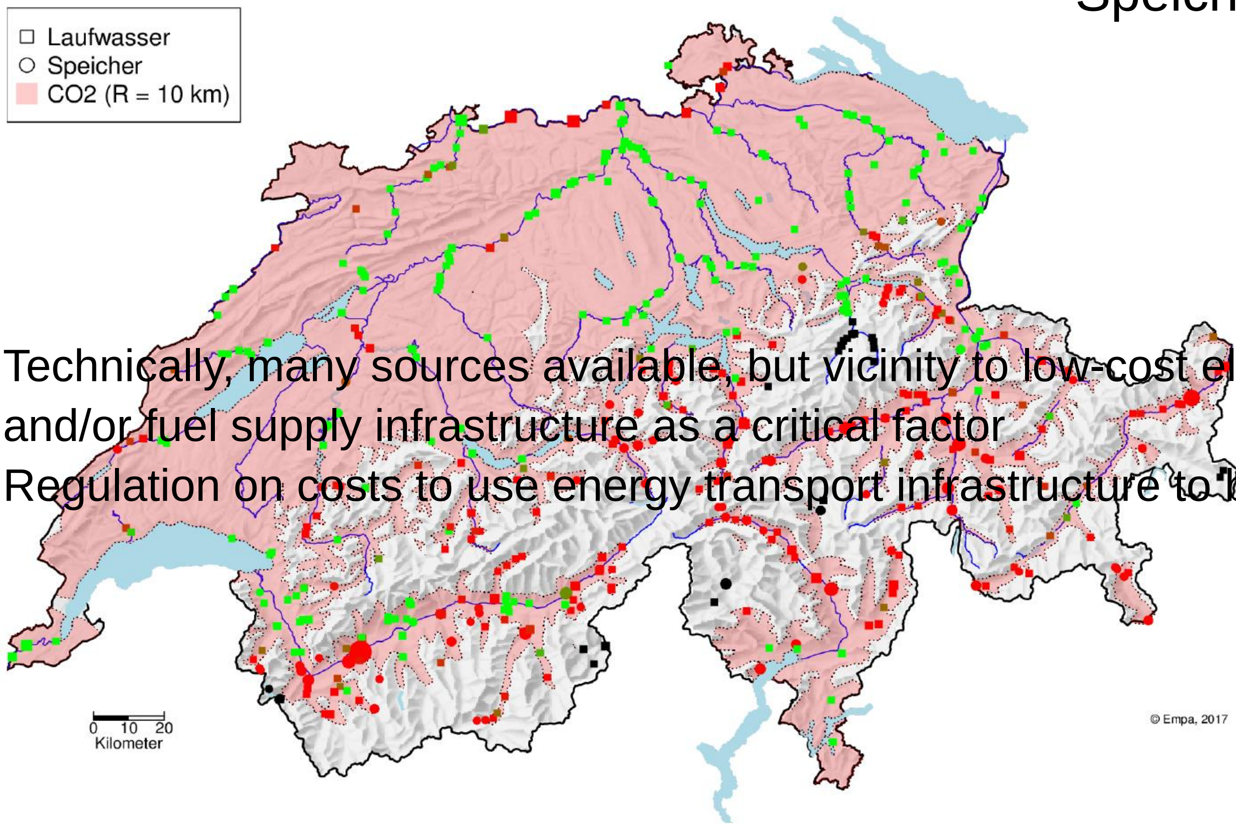
Hydro perspective

Laufwasser: running hydro
Speicher: hydro storage



- Technically, many sources available, but vicinity to low-cost electricity production and/or fuel supply infrastructure as a critical factor
- Regulation on costs to use energy transport infrastructure to become important

Trade-offs among resources

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Flow	Availability (p.a.)	Percentage
CO_2	**$1.90 \cdot 10^6$ ton**	**43% road transportation demand**
Electricity	57 TWh	97% demand
Water	$8.99 \cdot 10^6$ ton	1% demand

Electricity is the constraint

Source: B. Meier et al. (2017), Energy Technology

Important drivers for economic break-even

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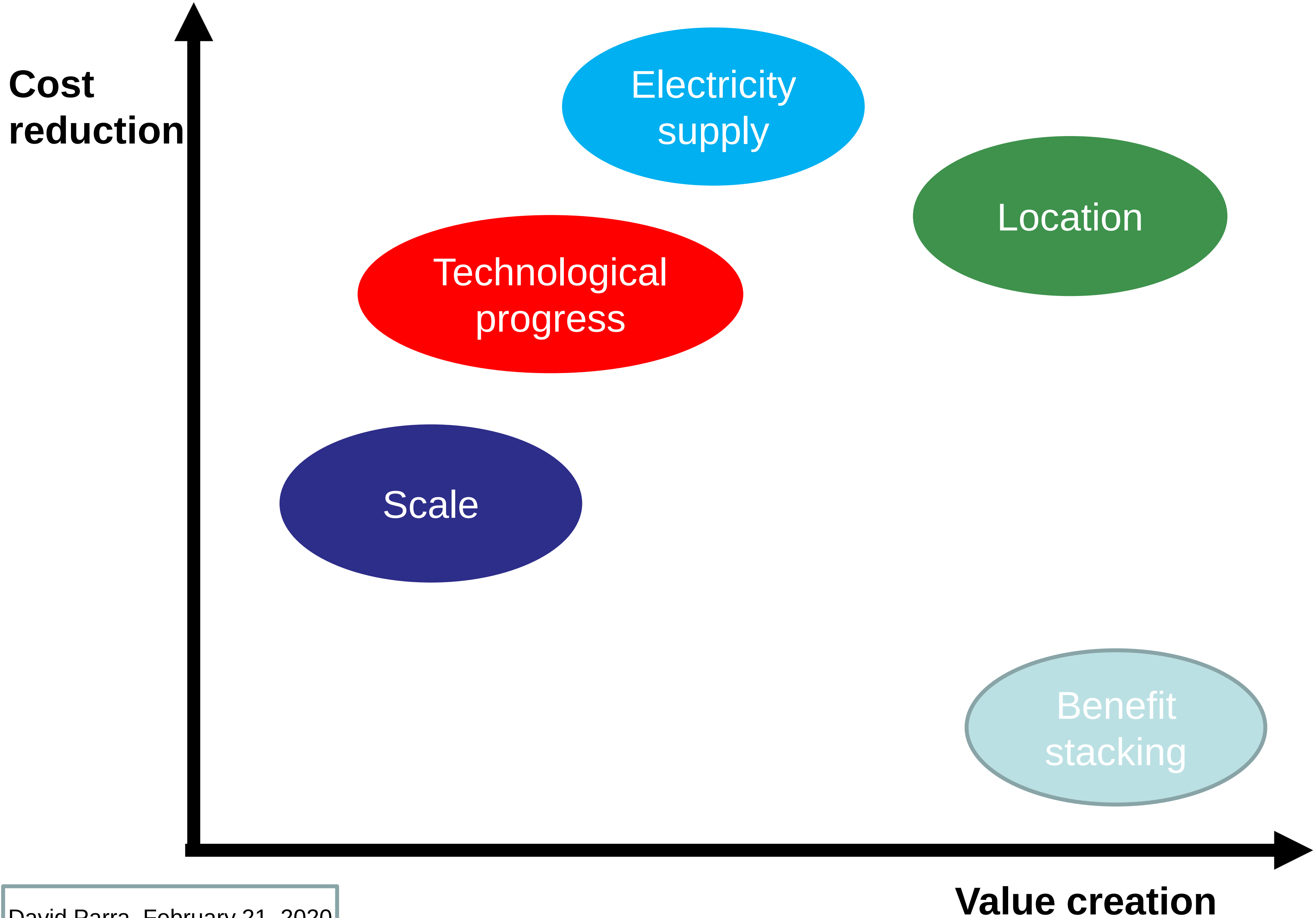

Discussion and conclusion remarks

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1. Power-to-gas (X) is an enabling and **cross-sector technology**
2. Value of P2X unfolds in its combination of **multiple benefits**
3. Potential solution for **seasonal storage**
4. **R&D** required for technology, e.g., electrolysis and methanation
5. Plant size, learning curves and market stimulating policies
6. Importance of **electricity** supply option and related strategy

Discussion and conclusion remarks

7. **Location:** proximity to CO_2 source; gas network; or implementation in refueling stations
8. **Utility companies** have a privilege position
9. **Legal framework**: further system integration with policy coordination to reduce uncertainty
10. **Interdisciplinary** research and teaching
11. **Stakeholder** involvement for accelerating acceptance
12. PtX can contribute to achieve **climate goals** with new competitive business models in selected market segments

Some publications

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D. Parra, L. Valverde, J. Pino, M. K. Patel (2019). A review on the role, cost and value of hydrogen energy systems for deep decarbonisation. Renewable & Sustainable Energy Reviews, 101, 279-294.

Hassan, M. K. Patel and **D. Parra** (2019). An assessment of the impacts of renewable and conventional electricity supply on the value and cost of power-to-gas. International Journal of Hydrogen Energy, 44, 9577-9593.

D. Parra, A. Abdon, X. Zhang, M. K. Patel, C. Bauer, J. Worlitschek. Techno-economic and environmental assessment of stationary electricity storage technologies for different time scales, 2017. Energy 139, 1173-1187.

D. Parra, S. Zhang, C. Bauer, M. K. Patel (2017). An integrated techno-economic and environmental assessment of power-to-gas systems. Applied Energy 193, 440-454.

D. Parra, M. K. Patel. Techno-economic implications of the electrolyser technology and size for power-to-gas, 2016. International Journal of Hydrogen Energy, 41 (6), 3748-3761.

D. Parra, M. Gillott and G. S. Walker (2016). Design, testing and evaluation of a community hydrogen storage system for end user applications. International Journal of Hydrogen Energy. 41 (10), 5215-5229.

Some publications

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david.parra@unige.ch
https://www.unige.ch/efficience/efficiency/team/parra/
Twitter: @david_parramen

Thank you and happy to take your questions