LCM 2021

Prospective LCA and LCC applied on different Power-to-Gas technologies

Jan Koj, Freia Harzendorf & Petra Zapp – September 6 2021

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1. Introduction

Power-to-Gas (PtG) is seen as an important instrument for decarbonizing the industry, energy & transport sectors.

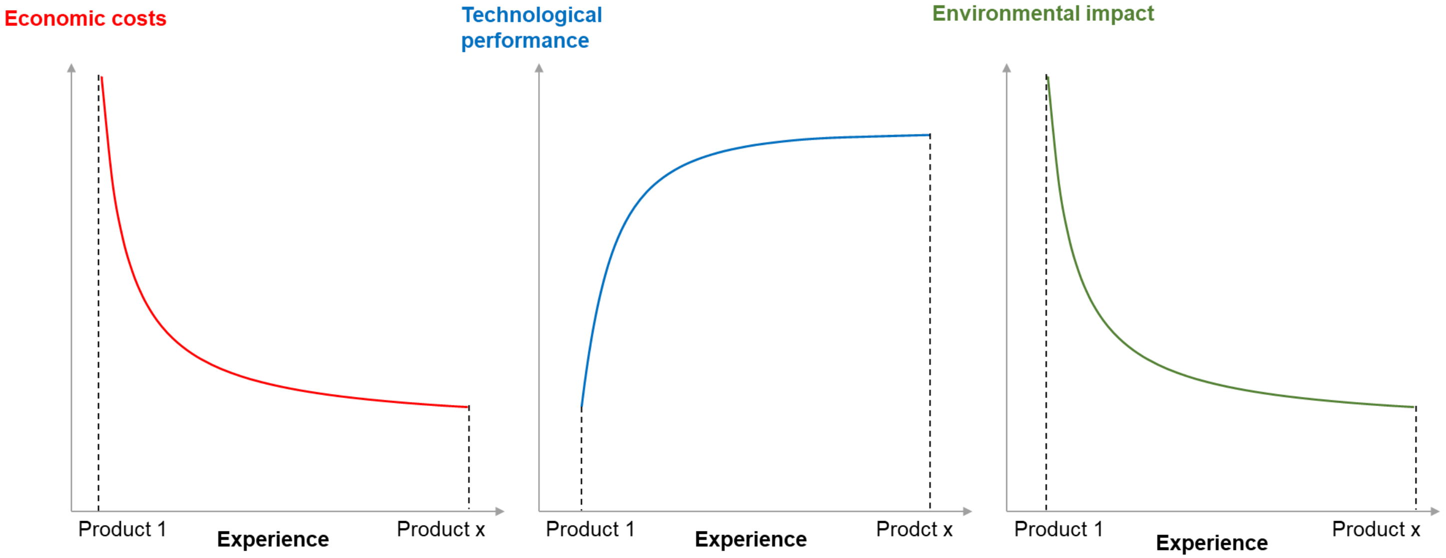
Studies and roadmaps expect significant increases of produced & installed PtG systems.

Research questions (RQ)

RQ 1	RQ 2
Will the production/capacity increase affect the environmental impact of these technologies?	**How can I quantify the prospective environmental performance and life cycle cost development?**

1. Introduction
Prospectivity and learning

Manufacturing processes & practices develop over time based on learning effects.



Source: Own illustration based on Thomassen et al. (2020)

Method to estimate this prospective economic, technological & environmental progress:

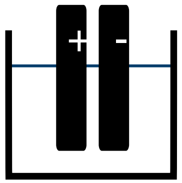
Learning curves

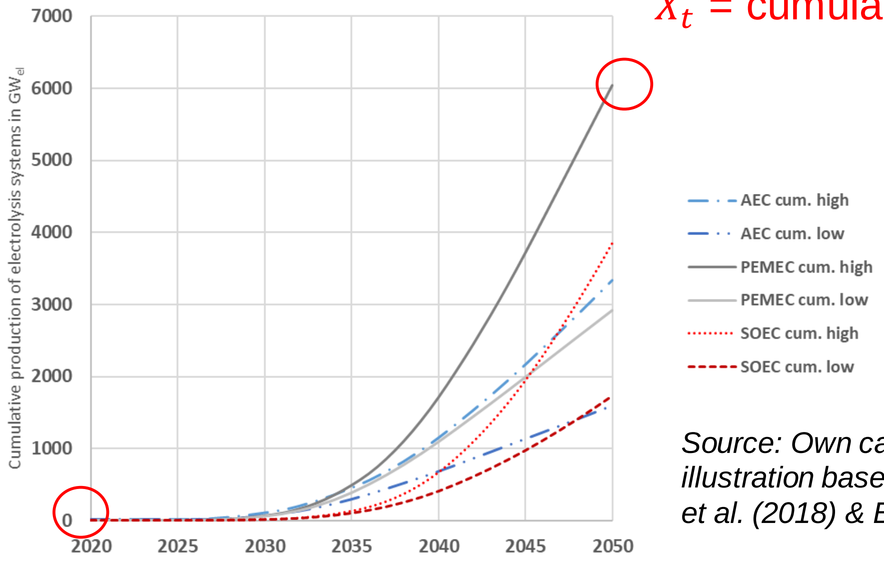
A case study of combined prospective LCA & LCC applied on different PtG technologies is presented – incorporating learning curves

2. Methods

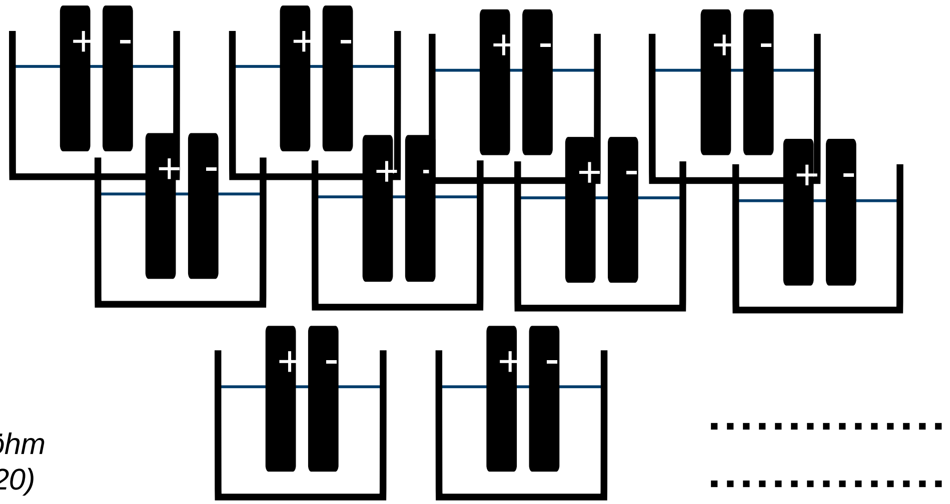
Economic learning curve concept – Example

X_t = cumulative installed capacity at time t





Source: Own calculation and illustration based on data in Böhm et al. (2018) & Böhm et al. (2020)



X_0 = installed capacity at time t=0

Capacity values for 2020-2050 are given – what more do I need for prospective cost assessment?

C_0 = costs (unit costs, investment costs or labour costs) at time t=0

C_t= costs at time t

$$C_t = C_0 \boxed{\left(\frac{X_t}{X_0}\right)}^{-\beta}$$

***β*= learning parameter or degradation factor**

$\beta = \log(\frac{1}{1-lr}) \,/\, \log 2$ (lr: learning rate)

2. Methods
Environmental learning curve concepts

E.g. Caduff et al. (2012), Arnold (2015) and Bergesen & Suh (2016) apply the economic learning approach on environmental assessments.

They replace costs by material or energy inputs or environmental impacts

Prospective material input, energy input or environmental impact

$$I_t = I_0 \left(\frac{X_t}{X_0}\right)^{-\beta}$$

Specific learning paramters and underlying learning rates have to be obtained

Material input, energy input or environmental impact at time t=0

3. Power-to-Gas case study description

Scope & data

Technology

- Alkaline water electrolysis cell (<u>AEC</u>; PtH_2)
- Environmental assessment: 5 MW_{el} in 2020 & 2050
- Economic assessment: 5 MW_{el} in 2020 & 50 MW in 2050

Scope & data

- Temporal scope: 2020 – 2050
- Spatial scope: Germany
- Electricity input: Wind onshore
- Start values: Preliminary results of the project „*Virtual Institute Power-to-Gas and heat*“ (s. acknowledgements)
- Prospective capacities were derived from Böhm et al. (2018 & 2020)

Technology

- Polymer electrolyte membrane electrolysis cell (<u>PEMEC</u>, PtH_2)
- Environmental: 5 MW_{el} in 2020 & 2050
- Economic assessment: 5 MW_{el} in 2020 & 50 MW_{el} in 2050

- Catalytic methanation (<u>CM</u>; $PtCH_4$)
- Environmental assessment: 5 MW_{th} in 2020 & 2050
- Economic assessment: 5 MW_{th} in 2020 & 50 MW_{th} in 2050

Technology

3. Power-to-Gas case study description

Scope & data – learning rate assumptions

Learning rates for electrolysis & methanation for prospective LCA & LCC were based on literature.

Following approach of Arnold (2015) & Simon et al. (2020) was applied:
(economic) learning rates of an established technology can be applied for environmental learning curves.

Overview on learning rates of whole PtG systems in literature

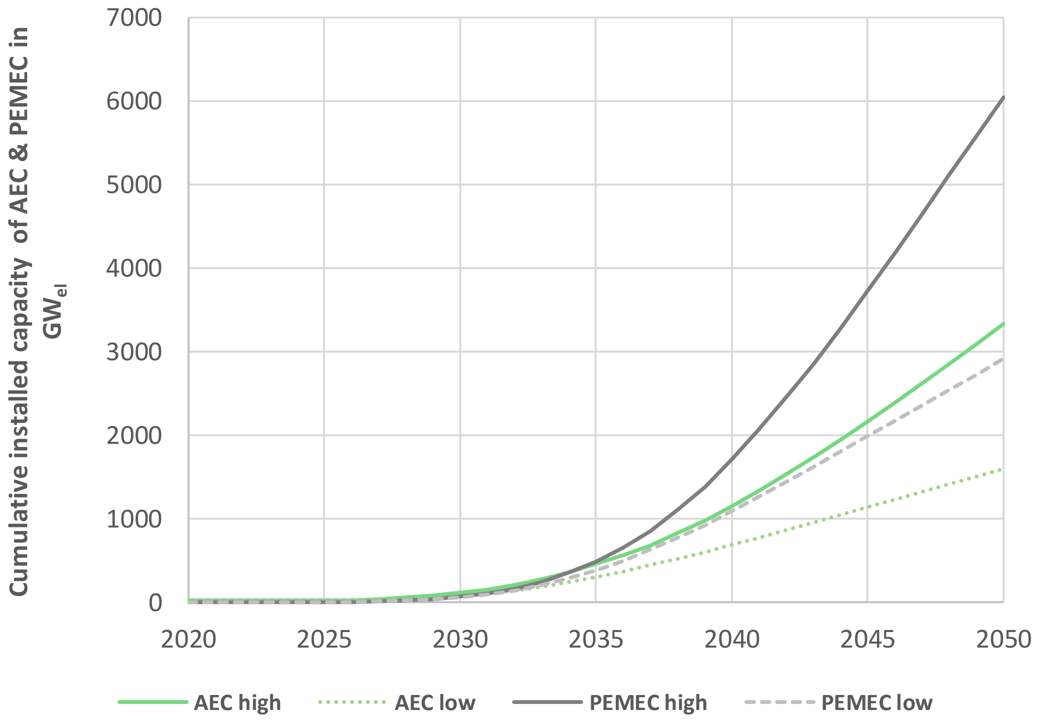
Learning rate in %	Technology	Notes	Reference
8	AEC		Gül et al. (2009)
9	AEC	2020-2030	Hydrogen Council, 2020
9.6 +/-5.5	Electrolysis		Böhm et al. (2018)
12	Electrolysis	No calculations - judged as conservative lr	Alverà (2019)
13	PEMEC	2020-2030	Hydrogen Council (2020)
13	Electrolysis & Methanation		Thema et al. (2016)
18 +/-6	AEC	1956-2014	Schmidt et al. (2017)
18 +/-13	Electrolysis	1972-2004	Schoots et al. (2008)

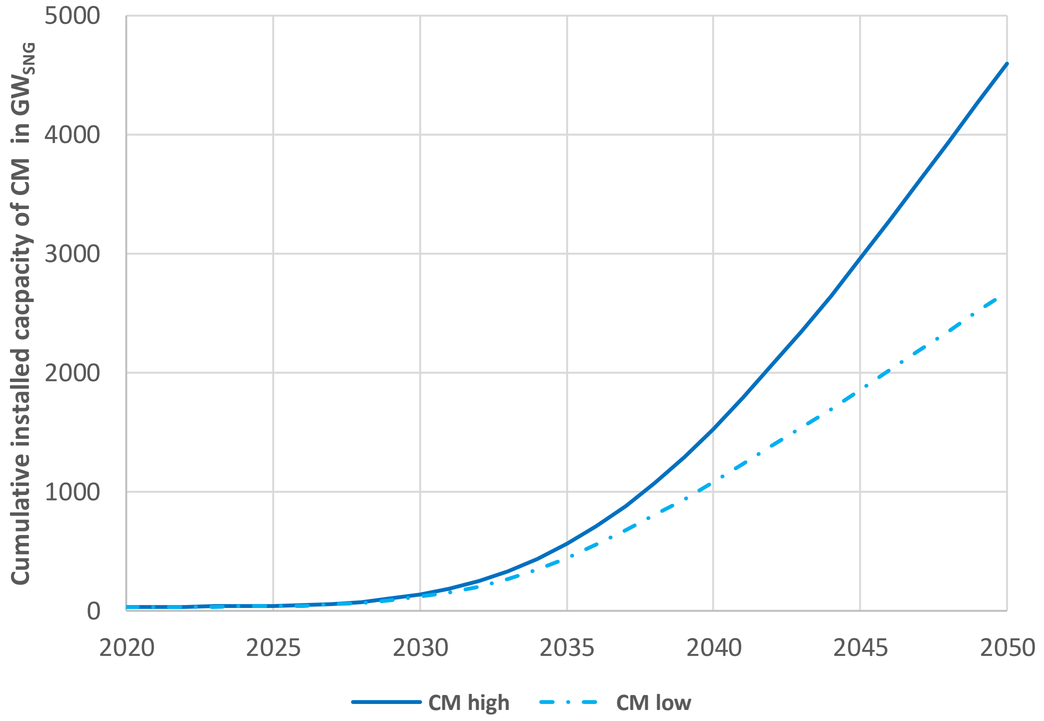
Assessment of environmental learning effects: 8 %, 9.6 & 12 % were chosen as range for learning rates (lr) for electrolysis & methanation.

Assesment of economic learning effects: values from Böhm et al. (2020) considering learning effects from 7 – 13 % for different components were chosen.

3. Power-to-Gas case study description

Scope & data – assumed installed capacity development





Source: Own calculation and illustration based on data in Böhm et al. (2018) & Böhm et al. (2020)

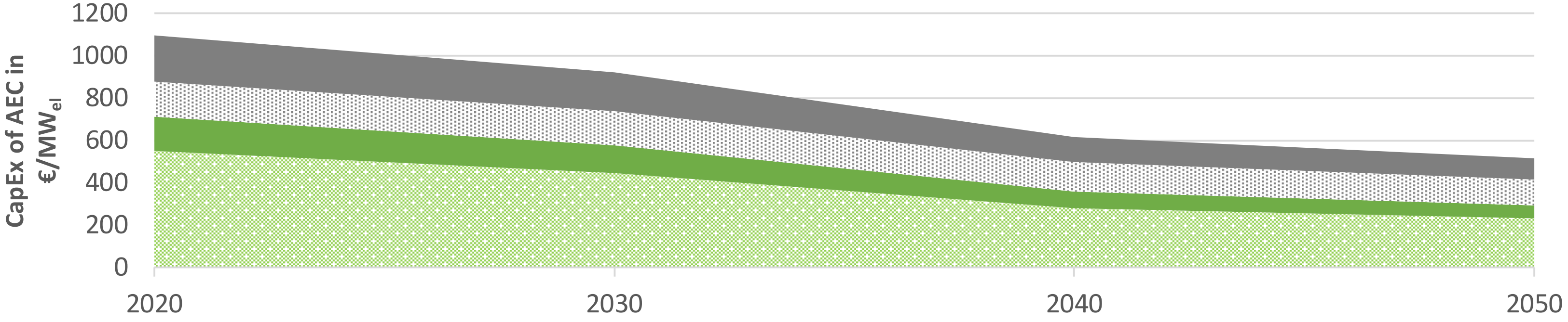
4. Results
Prospective LCA: learning curve based environmental impact reduction

Highest multplication rate occures between 2025 and 2030 – provoking highest decrease between periods

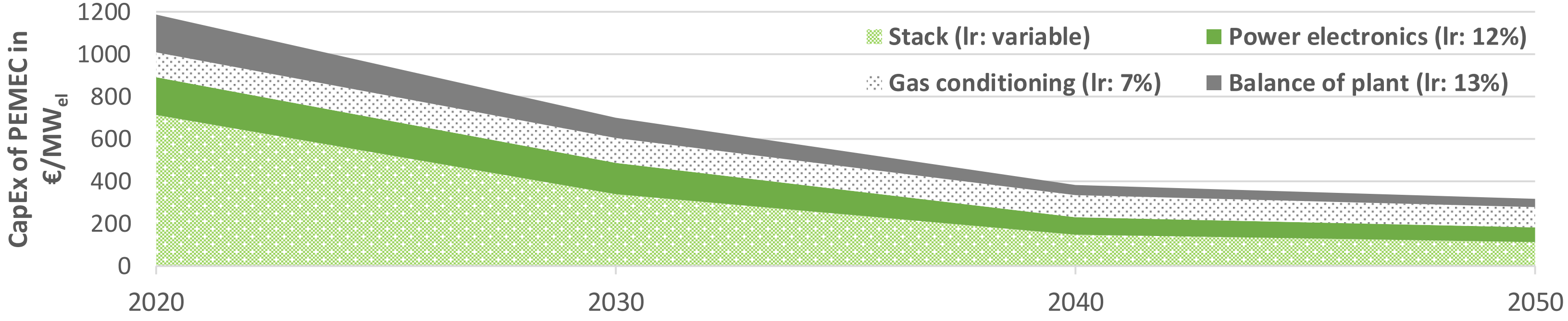
Highest capacity increase assumed for PEMEC – Leading to highest relative impact reductions of the assessed PtG-technologies

4. Results

Prospective LCC: CapEx development for AEC, PEMEC and CM

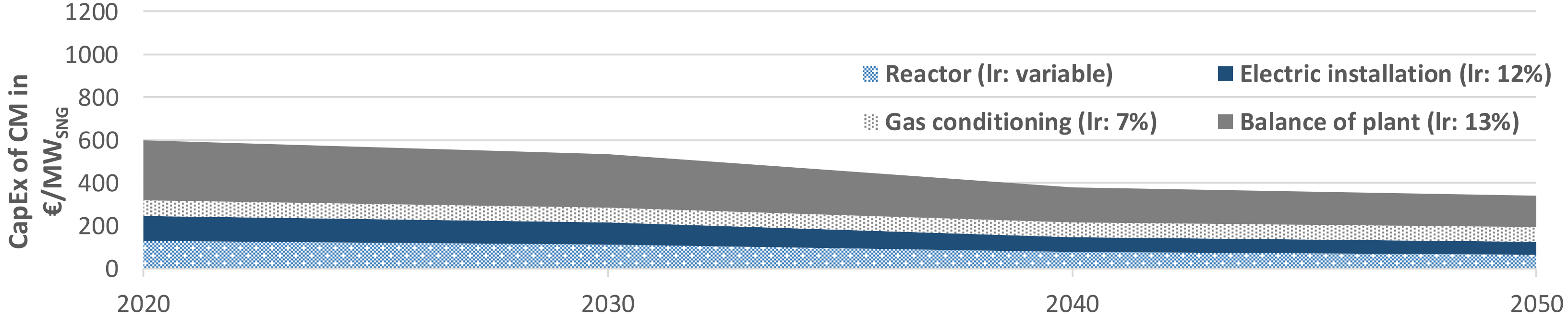


- **Costs decrease** due to learning and scaling
- Stack with highest CapEx contribitions



PEMEC with lower costs in 2050 due to:

- higher learning rates of the stack &
- higher capacity multplication rate between 2025 and 2030



- **Costs decrease** due to learning and scaling
- BOP with highest CapEx contributions
- Comparative reductions due to lower capacity multiplication rates

Source: Own calculation and illustration based on data in Böhm et al. (2018) & Böhm et al. (2020)

5. Discussion & conclusion

- Answer to RQ 1:

→ Capacity increase affects the environmental impact of all considered technologies

- Answer to RQ 2:

→ Learning curves can be used to quantify the prospectively changing environmental performance and development of life cycle costs

- Decreases of environmental impacts and life cycle costs can be expected till 2050 – due to significant capacity increase and accompanying learning effects

- Requirements:

- detailed data about prospective capacity/production increase
- learning rates or historic data to calculate them

5. Discussion & conclusion

- Ways to reduce uncertainties:

- many points in time should be considered (better one-year steps as ten-year steps)
- ranges of learning rate & prospective capacities help to show ranges of possible developments

- The environmental learning curve approach of Arnold (2015) and Simon et al. (2012) helps to give an idea of prospective environmental impacts based on learning curves. However, this is a simplified approach.

- Learning curves of prospective material use for construction and energy requirements are more appropriate.

→ More detailed insights about environmental contributions & developments of different life cycle stages.

- Our work on learning curve concepts for prospective LCA curves continues – especially for electrolysis & methanation – aiming on further develop better solutions.

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Contact data and acknowledgement

Dipl.-Ing. Jan Christian Koj
Tel.: +49-2461-61 4540
E-Mail: j.koj@fz-juelich.de

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KoVI SGW Project description on IEK-STE website:
https://www.fz-juelich.de/iek/iek-ste/DE/Forschung/Projekte/KoVI_SGW/KoVI_SGW_node.html

Official project website:
http://strom-zu-gas-und-waerme.de/