SH2E Spring School (20-24 May 2024)

Life Cycle Costing of hydrogen systems – SH2E LCC guidelines

Christina Wulf (Forschungszentrum Jülich)

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LIFE CYCLE COSTING OF HYDROGEN SYSTEMS – SH2E LCC GUIDELINES

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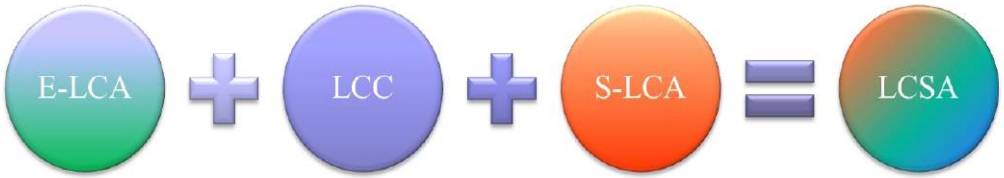
INTRODUCTION – WHAT IS LIFE CYCLE SUSTAINABILITY ASSESSMENT (LCSA)?

KEEPING THE LIFE CYCLE APPROACH BY COMBINING ENVIRONMENTAL ASSESSMENT (E-LCA), LIFE CYCLE COSTING (LCC) AND SOCIAL ASSESSMENT (S-LCA)



Environmental Evaluation

Economic Evaluation

Social Evaluation

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INTRODUCTION – WHAT IS LIFE CYCLE SUSTAINABILITY ASSESSMENT (LCSA)?

TYPICAL LCC INDICATORS:

- Investment costs
- Variable operation and maintenance costs
- Fixed operation and maintenance costs (wages, taxes, heating, lighting)
- Levelized costs of electricity (Σ Invest, fix & variable O&M)
- Internalized external effects (CO_2 taxes)

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COST BREAKDOWN OF ELECTRICITY PRICE FOR HOUSEHOLD CUSTOMERS IN GERMANY 2023

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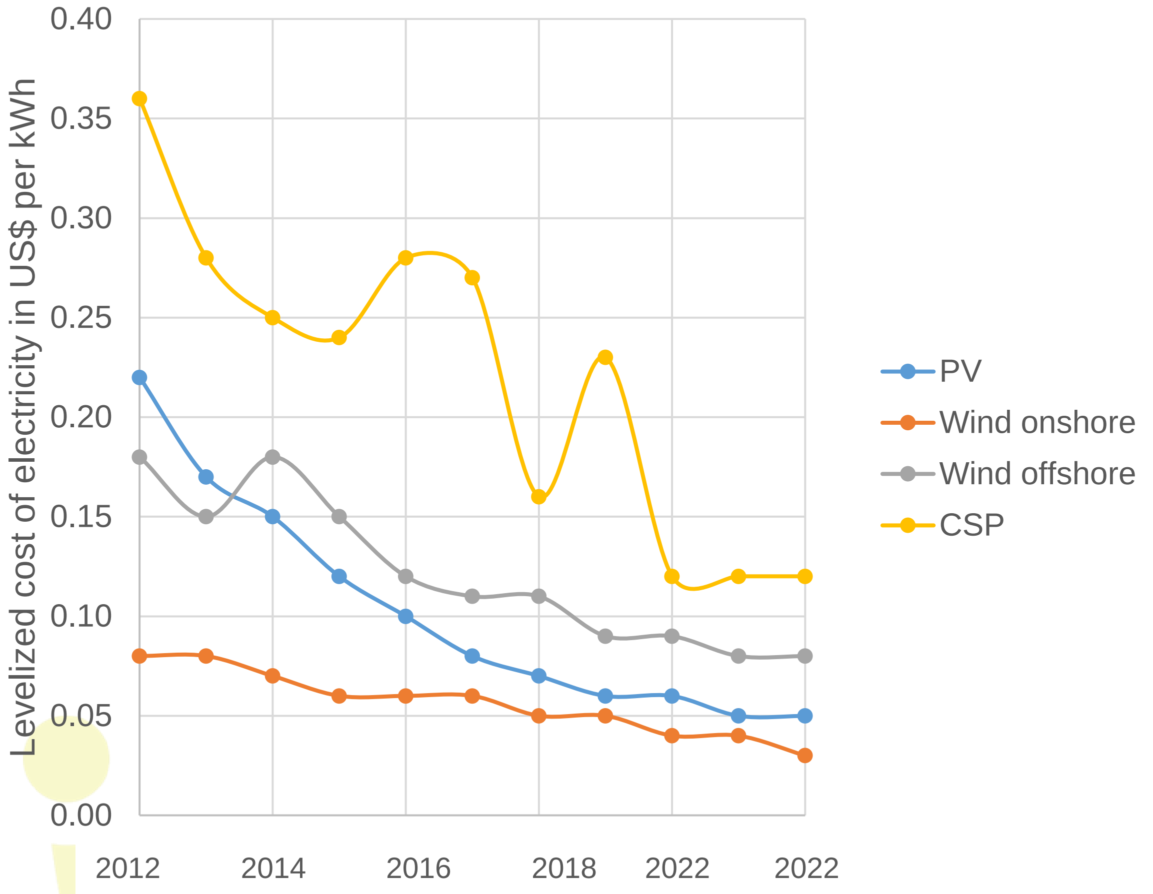
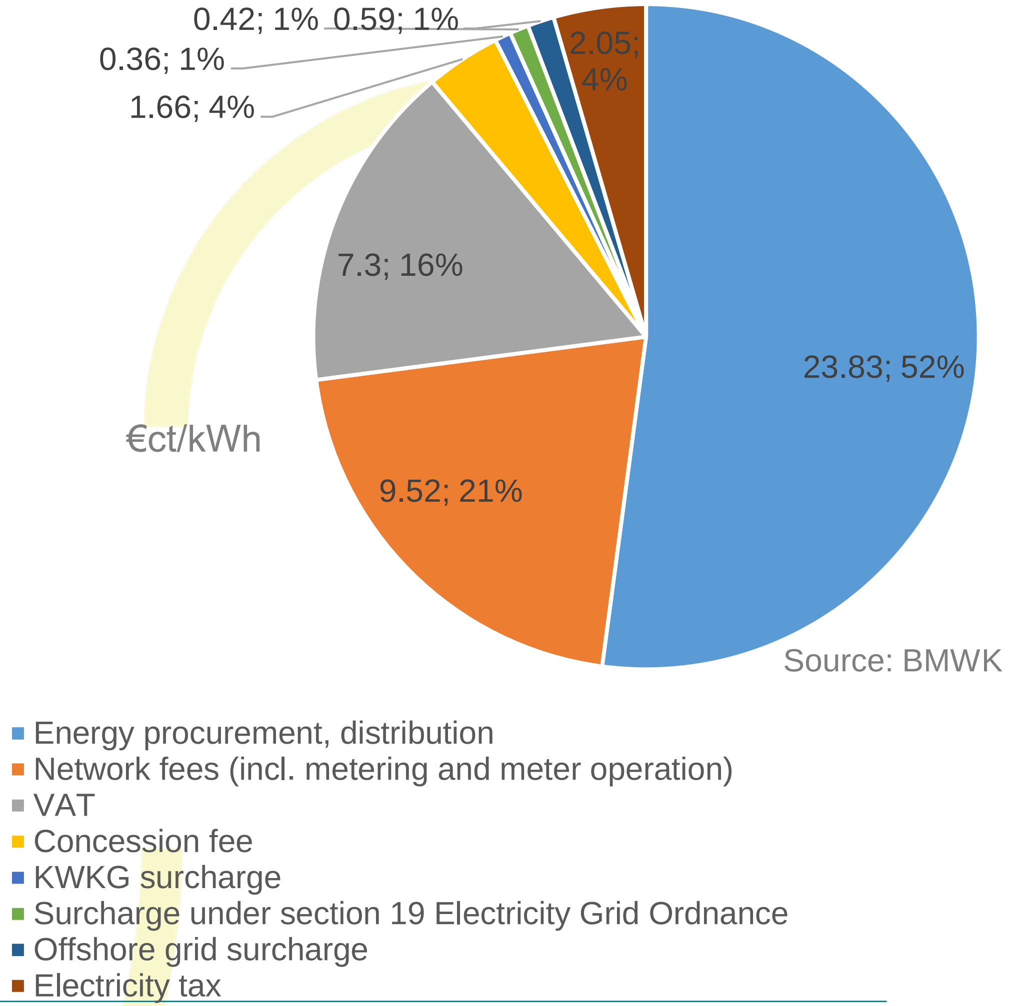
COSTS VS. PRICES





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UP-SCALING IN LCC

- Economies of scale
- Estimation of equipment capital costs
- Power-law relationship
- Rule of thumb, α is set to 0.6 in engineering (Triebe et al. 1986), more specific factors in Peters et al. 2003

$$C_t = C_0 \left(\frac{X_t}{X_0}\right)^{\alpha}$$

C_0 : Capital cost at a known capacity
X_0 : Capacity at initial point 0
C_t : Wanted capital cost
X_t : Target capacity
α : Scaling factor

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LEARNING PHENOMENA AND ECONOMIES OF SCALE

- Learning-by-searching and learning-by-doing + economies of scale
- Experience curves
- Power-law relationship
- Empirically observed phenomenon: unit costs tend to decline by a constant percentage for each doubling of cumulative production volume (Wright 1936)

$$C_t = C_0 \left(\frac{Q_t}{Q_0}\right)^{-b}$$

$$LR = 1 - 2^{-b}$$

C_0 : Initial capital cost at point 0
Q_0 : Cumulated installed capacity or production rate at initial point 0
C_t : Wanted capital cost at point t in time
Q_t : Cumulated installed capacity or production rate at point t
b : Scaling factor or experience index

LR : Learning rate

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LIFE CYCLE INVENTORY – COST BREAKDOWN STRUCTURE

	Cost items	Production	Transport and storage	Utilization
CAPEX **Captial Expenditure**	Investment	EPC cost, land, interests, subsidy, R&D, engineering, design, and planning	EPC cost, land, interests, subsidy procurement cost of tankers, R&D, engineering, design, and planning	EPC cost, land, interests, subsidy procurement cost of equipment, R&D, engineering, design, and planning
	End of life	Decommissioning and salvage value	Recycle cost, resale value	Decommissioning and salvage value
OPEX **Operational Expenditure**	Labour	Operational labour	Wages for drivers	
	Maintenance	Maintenance labour and parts	Maintenance parts and service cost	Maintenance labour and parts
	Feedstock	Natural gas, biomass, electricity	N/A	N/A
	Utilities	Fuel, electricity, cooling water, steam etc.	–	–
	Consumables	Chemicals, lubricant	–	–
	Insurance and taxes	–	–	–
	Administration	Costs for management and headquarters, etc.	–	–

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PRICE YEAR ADJUSTMENTS

- Consideration of price increases over the years
- Chemical Engineering Plant Cost Index (CEPCI), production indices of local organizations, e.g. Processnet Chemieanlagen-Index Deutschland
- Consumer price indices or GDP deflators are not suitable for the adjustments

$$C_{2020} = C_{2018}\left(\frac{PCI_{2020}}{PCI_{2018}}\right)$$

C_{2022}: cost in 2022
C_{2018}: cost in 2018,
PCI_{2022}: plant cost index in 2022
PCI_{2018}: plant cost index in 2018

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COST CALCULATIONS PRODUCERS

- Levelized cost of hydrogen
- Discounted cost
- If investment cost occur only in year 0

$$LCOH = \frac{\sum_n \frac{I_t + M_n + O_n - R_n}{(1+r)^n}}{\sum_n \frac{E_n}{(1+r)^n}} = \frac{I_0 + \sum_n \frac{M_n + O_n - R_n}{(1+r)^n}}{\sum_n \frac{E_n}{(1+r)^n}}$$

I_i : Investment in year i (currency units)
M_i : Maintenance and service cost in year i (currency units)
O_i : Operational cost in year i (currency units)
E_i : Hydrogen output in year i (mass units)
R_i : Revenue income (from additional products) in year i (currency units)
r : Cost of capital (rate).

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- If you are including inflation

$$r^* = \frac{i - f}{1 + f}$$

f: inflation rate
i: nominal interest rate
r*: real discount rate, an interest rate adjusted to remove the effect of actual or expected inflation

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EXAMPLE MULLEN ET AL. 2023

Table 2
Economic model parameters.

Parameter	Unit	Value
Discount rate (Review of next generation 2022)	%	7.8
Interest Rate (Elliott, 2022)	%	4.0
Productive lifetime (Collodi et al., 2017)	Years	25
Base year	–	2023
Year operational	–	2026
Build Time (Collodi et al., 2017)	Years	3 Years
CAPEX expenditure curve (Collodi et al., 2017)	%	20/45/35
Load Factor (Collodi et al., 2017)	%	95%
Transport and storage cost (Assessing the Cost 2018)	£/tCO_2	19
Natural Gas Fuel price (Review of next generation 2022)	£/MWh	28
Electricity selling price (Mullen and Lucquiaud, 2022)	£/MWh	105
Chemical Engineering Plant Index (CEPCI) (THE CHEMICAL ENGINEERING 2022)	–	816.3
International Construction Cost Index [Netherlands/UK/Texas] (Arcadis 2020)	–	100/138/97
USD to GBP exchange rate (2020) (Rates, 2023)	£/$	0.82
Equipment Tax/Insurance/Freight (Elliott, 2022; Donald, 2007)	%	10
Civil Works factorial cost (Elliott, 2022; Bechtel 2019; Bechtel 2018)	%	21
Utilities factorial cost (Elliott, 2022; Bechtel 2019; Bechtel 2018)	%	18
Electrical factorial cost (Elliott, 2022; Bechtel 2019; Bechtel 2018)	%	30
Project management (Elliott, 2022; Bechtel 2019; Bechtel 2018)	%	21
Contractor Fee (Donald, 2007)	%	3
Project Contingency (Elliott, 2022; Bechtel 2018)	%	10
Owners Costs (Review of next generation 2022)	%	7
Start-up & Spares (Review of next generation 2022)	%	5
Utility Connections (Review of next generation 2022)	%	1
Consulting Fee (Review of next generation 2022)	%	1
Maintenance (CCS) (Assessing the Cost 2018)	%/Year	1.5
Maintenance (SMR) (Assessing the Cost 2018)	%/Year	3.0
Labour (Assessing the Cost 2018)	£/Employee/Year	69,810
Insurance/Tax/Admin (Review of next generation 2022)	%/Year	1.5
Regulatory (Review of next generation 2022)	%	2.0
MEA (Michailos and Gibbins, 2022)	£/t	940
Caustic (Evaluating the Costs of Retrofitting 2017)	£/t	34
Reclaimer disposal (Michailos and Gibbins, 2022)	£/t	500
Working Capital (Assessing the Cost 2018)	–	1 Months Consumables

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CASE STUDY HYDROGEN PRODUCTION ASSUMPTIONS

- Steam methane reforming
- 800 MW in 2023
- Scaling factor 0.79 (Sinnott and Towler, 2020)
- Capacity factor 90 %
- To ensure this capacity factor you need 40 people full time (devided in three shifts)
- 25 years of operation

Given values		
Capacity	MW	500
Reformer (2020)	Mio. €	400
Connections	% of invest	1
Commissioning	% of invest	5
Consultation	% of invest	3
Owner‘s cost	% of invest	7
Electricity costs	€/kWh$_{el}$	0.23
Natural gas costs	€/kWh$_{NG}$	0.00818
Water costs	€/kg$_{H2O}$	0.00066
Electricity demand	kWh$_{el}$/kg$_{H2}$	3.13
Natural gas demand	kWh$_{NG}$/kg$_{H2}$	36.43
Water demand	kg/kWh$_{H2}$	13.12
Maintanance	% of CAPEX	4.5

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CASE STUDY HYDROGEN PRODUCTION QUESTIONS

1. What is the efficiency of the SMR process?
2. How would you set the interest rate/cost of capital rate? Why?
3. What adjustments do you need to make for the year diffrence?
4. What full load hours do you get?
5. What labour costs do you assume in Spain?
6. What are the levelized cost of hydrogen?

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CASE STUDY HYDROGEN PRODUCTION RESULTS

1. $\eta_{SMR} = \frac{LHV_{H2}}{electricty\ demand + natural\ gas\ demand} = \frac{33.33\ kWh_{H2}/kg}{3.13\ kWh_{el}/kg + 36.43 kWh_{NG}/kg} = 84.3\ \%$
2. Defining the interest rate in LCC is a very decisive step. Depending on the perspective of the assessment and the risk of the endeavor it might differ. In the SH2E guidelines we distinguish between two private perspectives (industrial producers and private consumers) and a social perspective by policy makers and civil society. Policy makers would only consider the discount rate that is needed to finance projects by sovereign bonds, e.g. Spain currently 3.3 %. A private consumer has a higher interest rate to pay, e.g. 8.5 % in Germany for a consumer credit in 2023. Industrial producers might get their money cheaper, but they also including their profit in there. Furthermore, for higher risk endeavors a higher interest rate is chosen because the risk of loosing the money is included.

   As building an SMR plant in Spain is not as risky as building it, e.g. in Iran, and the general inflation has become moderate an 8 % rate would be reasonable.

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CASE STUDY HYDROGEN PRODUCTION RESULTS

3. If you have outdated values for investment cost you can adjust them to the required year by a (chemical) plant cost index. An internationally used index is the CEPCI published by Chemical Engineering a monthly publication.

$$C_{2023} = C_{2020}\left(\frac{CEPCI_{2023}}{CEPCI_{2020}}\right) = 400\ Mio.€\ \left(\frac{800}{596}\right) = 537\ Mio.€$$

Further adjustments include an upscaling from 500 MW installed capacity to 800 MW

$$C_t = C_0\left(\frac{X_t}{X_0}\right)^{\alpha} = 537\ Mio.€\left(\frac{800}{500}\right)^{0.79} = 778\ Mio.€$$

Including the other components besides the reformer the total investment costs amount to 903 Mio. €.

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CASE STUDY HYDROGEN PRODUCTION RESULTS

4. You have 8760 hours a year and this plant is running 90 % of the year (capacity factor). Thus, you have 7884 full load hours a year. Furthermore, with a capacity of 800 MW you will produce 6,307,000 MWh_{H2}/year transforming to ca. 189,000,000 kg/a.
5. In 2022 labour costs were 39,557.41 €/year in industries with a 5.6 % increase from 2022 to 2023 (Source: Instituto Nacional de Estadística).

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CASE STUDY HYDROGEN PRODUCTION RESULTS

6.

(1+r)^n	n		(M_n+O_n)/(1+r)^n	E_n/(1+r)^n	I_0	I_0+∑(M_n+O_n)/(1+r)^n	LCOH
1.08	1		224,243,072	175217522			
1.17	2		207,632,474	162238446			
1.26	3		192,252,290	150220783			
1.36	4		178,011,380	139093318			
1.47	5		164,825,352	128790109			
1.59	6		152,616,067	119250101			
1.71	7		141,311,173	110416760			
1.85	8		130,843,678	102237741			
2.00	9		121,151,554	94664575			
2.16	10		112,177,365	87652384			
2.33	11		103,867,930	81159615			
2.52	12		96,174,010	75147792			
2.72	13		89,050,009	69581289			
2.94	14		82,453,712	64427119			
3.17	15		76,346,030	59654740			
3.43	16		70,690,768	55235870			
3.70	17		65,454,415	51144324			
4.00	18		60,605,940	47355856			
4.32	19		56,116,611	43848015			
4.66	20		51,959,825	40600014			
5.03	21		48,110,949	37592605			
5.44	22		44,547,175	34807968			
5.87	23		41,247,384	32229600			
6.34	24		38,192,022	29842222			
6.85	25		35,362,984	27631687			
		Sum	2,585,244,169	2,020,040,455			
					902,851,854		
						3,488,096,022	
							1.73

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SH2E

SUSTAINABILITY ASSESSMENT OF HARMONISED HYDROGEN ENERGY SYSTEMS

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