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TECHNICAL NOTE ARMENIA

Detailed calculations of the levelised cost of hydrogen electrolysis in Armenia

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Background

- The German Economic Team has analysed the potential of green hydrogen in Armenia (PS/01/2023) and performed calculations on its production costs
- Levelised costs in 2025 of hydrogen electrolysis in ARM using a newly-built solar PV plant were calculated at 3.4 USD/kg. Main assumptions:
  - Takes into account the construction of the solar PV plant and hydrogen electrolyser
  - Does not consider costs of water and transportation
  - Preferential interest rate of 2% p.a. (main scenario assumed in study)
- If the project was commissioned under commercial interest rates (~10%), production costs (~6.1 USD/kg) would increase significantly

In this Technical Note:

- Description of cost components
- Summary of main assumptions for each variable
- Detailed calculations for the two scenarios (interest rate of 2% and 10% p.a.)

Cost components and assumptions (1/2)

- Main components of the **levelised cost of hydrogen electrolysis** ($LCOHE$)
  - Capital expenditure ($CAPEX$)
  - Operational expenditure ($OPEX$)
  - Cost of electricity (C_ELC)
  - Quantity of hydrogen ($Q\_Hydrogen$)

Formulas used for the calculations:

$$CAPEX = investment * \frac{WACC * (1 + WACC)^y}{(1 + WACC)^y - 1}$$

$investment$ is the overnight capital investment cost, $WACC$ is the weighted average cost of capital, and y is the expected system lifetime in years, depending on the average capacity factor κ and the system lifetime in hours t:

$y = \frac{t}{\kappa * 8760}$ (note that $\kappa * 8760$ are the annual full load hours)

$$OPEX = investment * f_{OPEX}$$

f_{OPEX} is a constant factor expressing yearly $OPEX$ as a fraction of total investment cost

$$C_{ELC} = LCOE * \kappa * 8760$$

$LCOE$ is the levelised cost of electricity in USD$/kWh$ (note the difference to $LCOHE$)

$$Q_{Hydrogen} = \kappa * 8760 * \eta * \frac{1}{LHV}$$

η is the overall system efficiency of the electrolyser and LHV is the lower heating value of hydrogen in kWh/kg.

Cost components and assumptions (2/2)

» The variables and corresponding assumptions for the calculation of levelised cost of hydrogen electrolysis are classified into four general categories:

Physical constants	Assumed constants	Technology-specific variables	Electricity system variables
• Lower heating value of hydrogen $LHV = 33.33 \frac{kWh}{kg}$	• f_{OPEX} = 3% (Brynolf et al., 2017) • $WACC$ = 2%/10%	• Upfront investment $investment$ = 848 USD/kW • Efficiency of electrolyser system η = 67% • lifetime t = 60,000 h	• $LCOE_{solar}$ = 0.040 or 0.076 USD/kWh (2% or 10% WACC, respectively) • Capacity factor κ = 28 or 30% (2% or 10% WACC, respectively)

» Electricity cost for electrolysis is based on the cost of solar generation ($LCOE_{solar}$)

- Optimal installed capacity for solar changes to minimise the cost of H2 production

» Electrolysis technology used in the analysis is alkaline water (AW) electrolysis which requires **approx. 9 liters per kg of H2 produced**

Cost calculations for 2% WACC scenario

$$\mathbf{CAPEX} = investment * \frac{WACC * (1 + WACC)^y}{(1 + WACC)^y - 1} = 848\,\frac{\text{USD}}{\text{kW}} * \frac{2\% * (1 + 2\%)^{24}}{(1 + 2\%)^{24} - 1} = \boldsymbol{45\ USD/kW\ (annual)}$$

Expected system lifetime in years:

$$y = \frac{t}{\kappa * 8760} = \frac{60{,}000\ h}{28\% * 8760\ \text{h}} = 24\ \text{years}$$

$$\boldsymbol{OPEX} = investment * f_{OPEX} = 848\,\frac{\text{USD}}{\text{kW}} * 3\% = \mathbf{25\ USD/kW\ (annual)}$$

$$\boldsymbol{C_{ELC}} = LCOE * \kappa * 8760 = 0.04\ USD/kWh * 28\% * 8760\ h = \mathbf{100\ USD/kW\ (annual)}$$

$$LCOE^* = (OPEX_{fixed} + CAPEX_{annual}) * \frac{solar\ capacity\ size\ (in\ terms\ of\ electrolyser\ cap.)}{\kappa * 8760} +$$

$$OPEX_{var} * solar\ capacity\ size\ (in\ terms\ of\ electrolyser\ cap.) =$$

$$\left(19.23\,\frac{USD}{kW} + 55\,\frac{USD}{kW}\right) * \frac{1.35\ kW}{28\% * 8760\ h} + 0.0001\,\frac{USD}{kWh} * 1.35\ kW = 0.04\,\frac{USD}{kWh}$$

$$\boldsymbol{Q_{Hydrogen}} = \kappa * 8760 * \eta * \frac{1}{LHV} = 28\% * 8760\ \text{h} * 67\% * \frac{1}{33.33\,\frac{kWh}{kg}} = \mathbf{50\ kg/kW}$$

$$\boldsymbol{LCOHE = (CAPEX + OPEX + C_{ELC}) / Q_{Hydrogen}} = \frac{\mathbf{45+25+100}}{\mathbf{50}} = \boldsymbol{3.4\ USD/kg}$$

**Additional numbers are taken from the EU JRC database*

Cost calculations for 10% WACC scenario

$$\mathbf{CAPEX} = investment * \frac{WACC * (1 + WACC)^y}{(1 + WACC)^y - 1} = 848 \frac{\text{USD}}{\text{kW}} * \frac{10\% * (1 + 10\%)^{23}}{(1 + 10\%)^{23} - 1} = \boldsymbol{96\ USD/kW\ (annual)}$$

Expected system lifetime in years:

$$y = \frac{t}{\kappa * 8760} = \frac{60{,}000\ h}{30\% * 8760\ \text{h}} = 23 \text{ years}$$

$$\boldsymbol{OPEX} = investment * f_{OPEX} = 848 \frac{\text{USD}}{\text{kW}} * 3\% = \mathbf{25\ USD/kW\ (annual)}$$

$$\boldsymbol{C_{ELC}} = LCOE * \kappa * 8760 = 0.076\ USD/kWh * 30\% * 8760\ h = \mathbf{199\ USD/kW\ (annual)}$$

$$LCOE = (OPEX_{fixed} + CAPEX_{annual}) * \frac{solar\ capacity\ size\ (in\ terms\ of\ electrolyser\ cap.)}{\kappa * 8760} +$$

$$OPEX_{var} * solar\ capacity\ size\ (in\ terms\ of\ electrolyser\ cap.) =$$

$$\left(19.23 \frac{USD}{kW} + 118 \frac{USD}{kW}\right) * \frac{1.45\ kW}{30\% * 8760\ h} + 0.0001 \frac{USD}{kWh} * 1.45\ kW = 0.076 \frac{USD}{kWh}$$

$$\boldsymbol{Q_{Hydrogen}} = \kappa * 8760 * \eta * \frac{1}{LHV} = 30\% * 8760\ \text{h} * 67\% * \frac{1}{33.33 \frac{kWh}{kg}} = \mathbf{52\ kg/kW}$$

$$\boldsymbol{LCOHE = (CAPEX + OPEX + C_{ELC}) / Q_{Hydrogen}} = \frac{\mathbf{96+25+199}}{\mathbf{52}} = \boldsymbol{6.1\ USD/kg}$$

About the German Economic Team

Financed by the Federal Ministry for Economic Affairs and Climate Action, the German Economic Team (GET) advises the governments of Ukraine, Belarus*, Moldova, Kosovo, Armenia, Georgia and Uzbekistan on economic policy matters. Berlin Economics has been commissioned with the implementation of the consultancy.

**Advisory activities in Belarus are currently suspended.*

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