01 | Apr 2023

POLICY STUDY ARMENIA

Assessment of green hydrogen potential in Armenia

by Julian Grinschgl, Dinara Saparova, Pavel Bilek, Rouven Stubbe and Dr Ricardo Giucci

Executive summary

- ARM possesses **significant renewable energy potential** and **green hydrogen production** could – in principle - be one of the options to utilise it

Solar potential and hydrogen production costs

- **Solar PV** is the main technology **for large-scale renewable expansion in ARM**
- ARM has a levelized cost of green hydrogen production of ~**3.4 USD/kg at preferential interest rates (~2%)** making it internationally competitive

Domestic use

- As of today, **no clear domestic use cases** for green hydrogen exist in ARM
- However, applications could be possible in the future if the **copper smelting sector restarted** or if ARM began **producing ammonia-based fertilisers**

Exports

- Exports to the EU are **unlikely** in the medium term due to **landlocked position, small production capacity and high CAPEX for pipeline construction**
- **Participation** in a **broader regional hydrogen export project** would lower costs of transportation, but would require improvement in regional relationships

➢ **Limited perspective for green hydrogen in ARM in medium term, despite competitive production costs**

Outline

1. Introduction and rationale
2. Solar potential and development
3. Production costs: 2025 results and cross-country comparison
4. Domestic use
    i. Copper smelting
    ii. Ammonia and fertilisers
    iii. Transportation
5. Exports
6. Conclusions and policy recommendations

Annex

1. Introduction and rationale

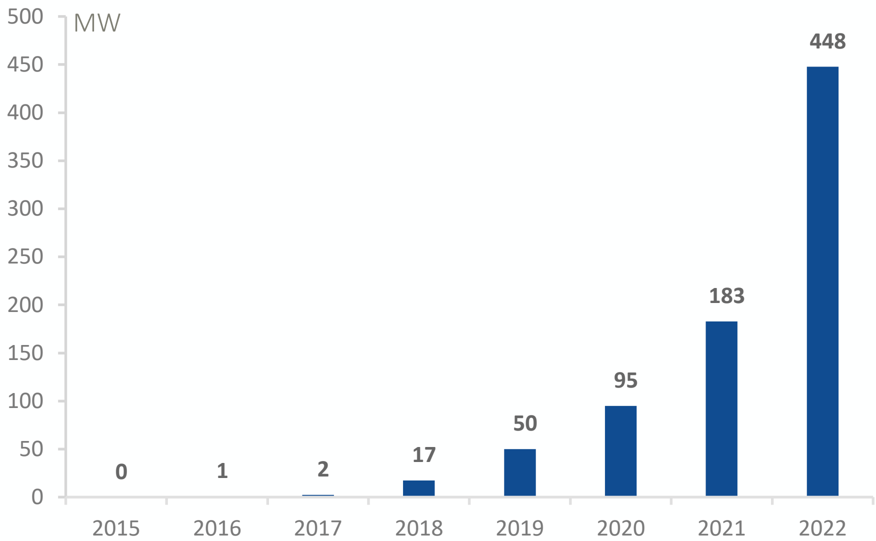
- ARM possesses **significant renewable energy potential** that can be used to decarbonise and diversify its economy and reduce its energy import dependency in different sectors
- Currently, ARM's electricity production relies on natural gas, nuclear and hydro power, but the government aims to **increase the share of renewables (solar PV) significantly**
- **Green hydrogen production from renewable electricity** could potentially be **one of the options to utilise ARM's solar potential** for domestic use as well as exports
  - Domestically: **decarbonise hard-to-abate industrial sectors** (e.g. metal smelting and fertilizer usage in agriculture), and **unlock new economic opportunities**
  - Exports: the EU announced an **import target of 10 m tonnes of green hydrogen per year** by 2030, presenting **new potential commercial opportunities**

Goal of this study

- Analysis of possible green hydrogen **production costs** in ARM as well as **applications** for **domestic use and exports potential**

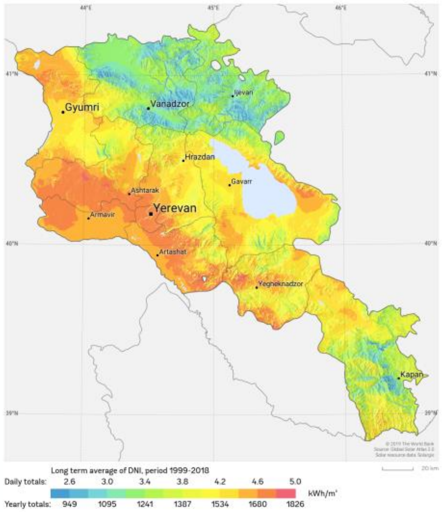
2. Solar potential and development

Installed solar PV capacity in Armenia



Source: IRENA and IEA

Solar resource map of Armenia



Source: Global Solar Atlas

Average daily theoretical potential (GHI):

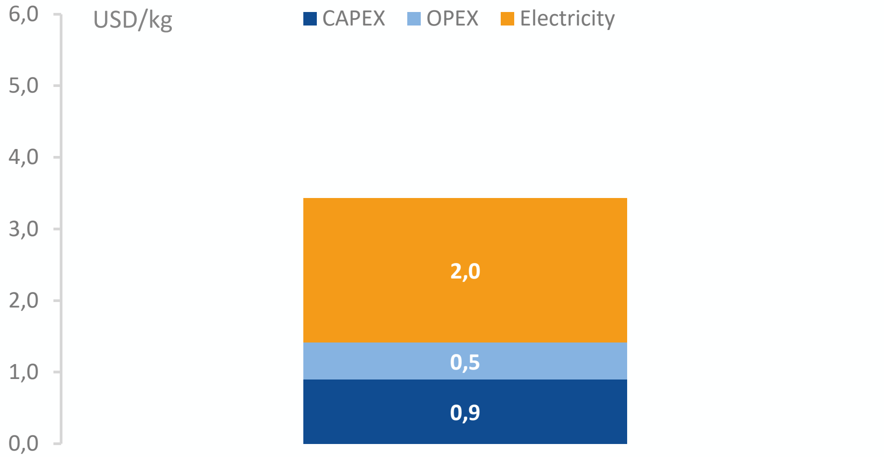
- Armenia **4.224 kWh/m²**
- Germany: **2.978 kWh/m²**

- Armenia has **very high solar potential** close to economic activity around Yerevan and other large cities
- The 2021 Energy Strategy envisions a scale-up of solar PV capacity to **1,000 MW by 2030** (~15% of total electricity generation)
- In 2022, 265 MW were commissioned, including a 55 MW utility-scale plant "Masrik-1“
  - Significant cost competitiveness compared to other electricity sources
- In 2023, the construction of the 200 MW “Ayg-1” PV plant is planned to start
- However, possible solar capacity expansion has limits due to country size and land availability in the sunniest parts

- **Solar PV is the envisioned technology for large-scale renewable expansion**
- **Electrification should remain the priority**

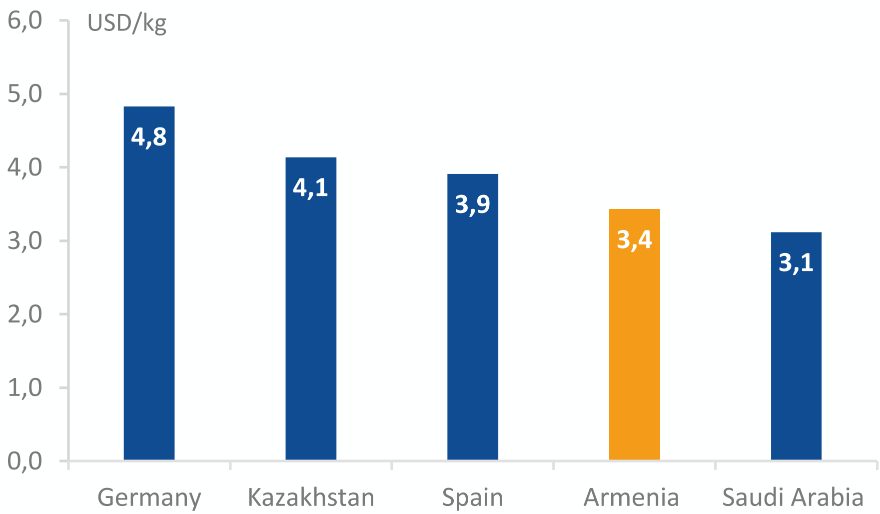
3. Production costs: 2025 results

Levelised cost of hydrogen electrolysis in Armenia (2%)



Source: own calculations

Cross-country comparison (2%)



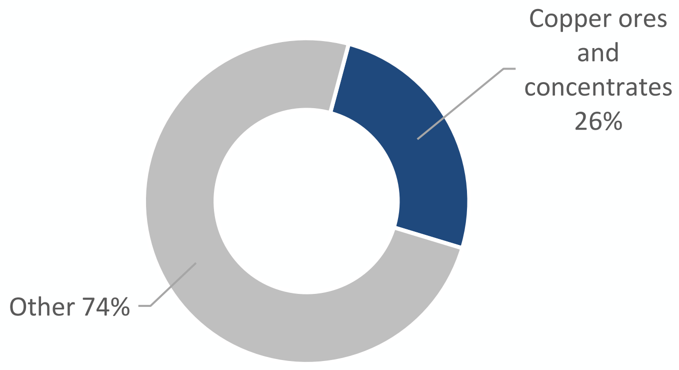
Source: own calculations

- Levelised costs in 2025 of hydrogen electrolysis in ARM using a newly-built solar PV plant are **3.4 USD/kg**
  - Assuming **2% interest rate;** requires to secure preferential loans
  - Costs take into account the construction of the solar PV plant and the hydrogen electrolyser
  - Does not consider transportation costs
- **If the project was commissioned under commercial interest rates (~10%),** production costs (**~6.1 USD/kg**) increase significantly
  - High level of capital investment
- High solar capacity factors facilitate the competitiveness of green hydrogen in ARM

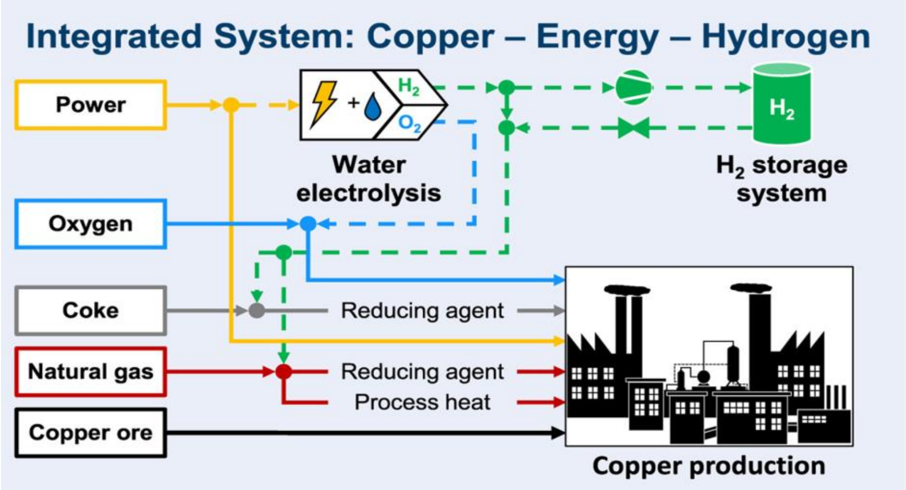
- **Green hydrogen could be produced in ARM at internationally competitive costs**
- **Securing preferential interest rates with the assistance of IFIs or bilateral donors is essential to achieve this**

4.i. Domestic use: copper smelting

Exports of Armenia in 2021



Source: Armstat



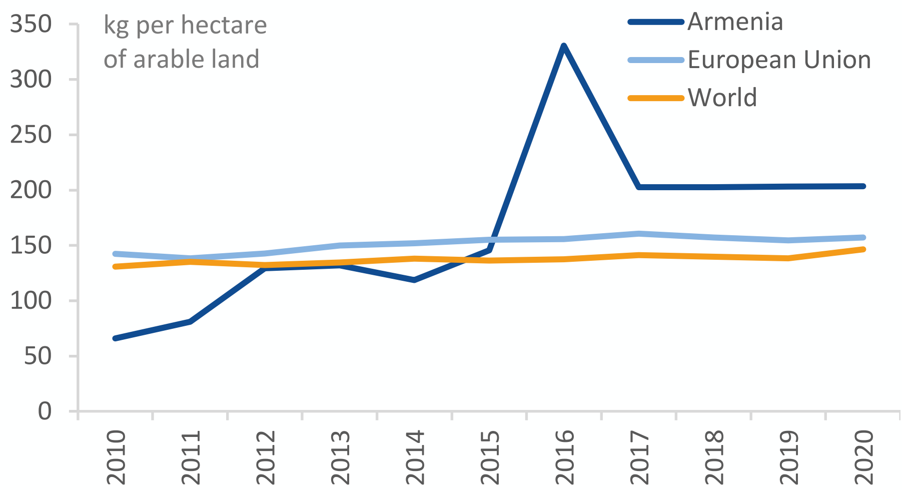
Source: Röben et al (2021), Decarbonizing copper production by power-to-hydrogen: A techno-economic analysis, Journal of Cleaner Production (306)

- ARM unrefined copper ore exports restricted since the closure of the Alaverdi copper smelter for environmental reasons
- A return of **copper smelting capacities would be a potential domestic use case for green hydrogen in ARM**
- Decarbonisation/improvement of environmental aspects would be key:
  - Hydrogen can (1) generate process heat instead of burning fossil fuels and (2) serve as a reducing agent
  - Copper production also requires oxygen which is a by-product of hydrogen production via electrolysis
  - Use of green hydrogen can eliminate air pollution and reduce emissions
  - EU potentially adding copper products to the Carbon Border Adjustment Mechanism (CBAM) would have impact

➢ **Re-start of copper smelting capacities presents potential domestic use case of green hydrogen in Armenia**

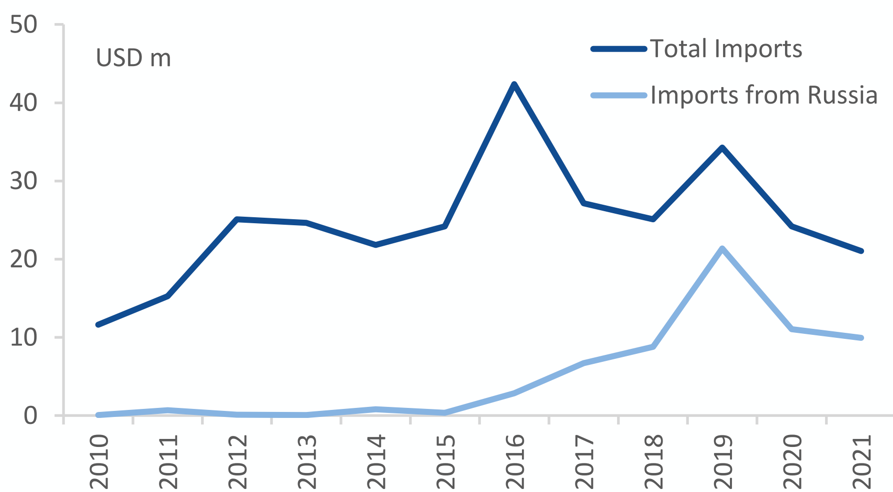
4.ii. Domestic use: ammonia and fertilisers

Fertiliser consumption



Source: World Bank Development Indicators

Fertiliser imports



Source: UN Comtrade (HS-31)

Fertiliser production

- Hydrogen, sourced from natural gas is the main input of ammonia-based fertilisers which are commonly used worldwide
- Heat and pressure are used to combine hydrogen with nitrogen separated from the air to create ammonia
- **Ammonia can also be sourced from green hydrogen** that is obtained using water electrolysis

Agricultural sector

- The **agricultural** sector is important for the ARM economy and **heavily relies on fertilisers** which are mostly imported from RUS
- ARM could explore the option of producing its fertiliser domestically using green hydrogen

➢ **Domestic green hydrogen production could reduce reliance on fertilisers imports**

➢ **Moreover, it would also support the decarbonisation of the agricultural sector**

4.iii. Domestic use: transportation

Fuel prices in ARM

Fuel prices	USD/MWh
Petrol*	110-123
Diesel*	93
LPG (Autogas)*	76
Production cost green hydrogen**	103
Avg. residential electricity price in 2021	77

Source: own calculations, Global Climate Scope,
**Current prices for final customer, not import prices*
***Assuming 2% preferential interest rate; not taking into account the distribution network*

Well-to-wheel efficiency (%)

Type	%
Electric vehicles	Up to ~72%*
Hydrogen fuel cell engine	~35%
Hydrogen combustion engine	~30%
Gasoline combustion engine	11-27%
Compressed natural gas cars	12-22%

Source: Albatayneh et al (2020), McKinsey
**depends on electricity mix, grid losses, and location of production*

- Imports of natural gas at rather low prices facilitate the use of compressed natural gas engines (at low cost) in Armenia

Existing vehicle fleet

- Green hydrogen produced in ARM could potentially replace gas
- However, this would entail **higher fuel costs compared to gas**

New vehicle fleet

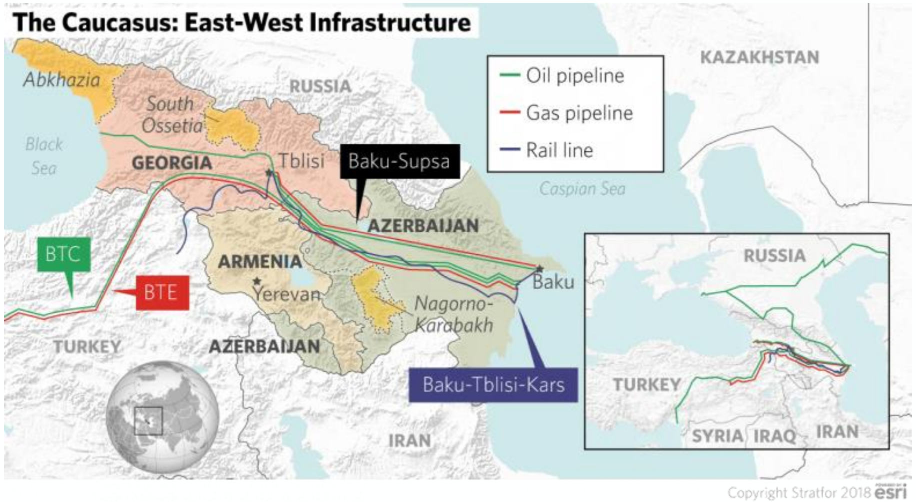
- For most transport use cases **electric vehicles are generally the better choice**
- Electric vehicles have **higher efficiency** as well as **lower operating costs**

Mining and long-haul heavy-duty trucking

- Grid constraints, fast refuelling requirements and long-distance transportation favour **hydrogen use instead of electric vehicles**
  - E.g., off-road **vehicles like graders used in mining** and road works, cranes and construction machinery, forestry vehicles

➢ **Use of hydrogen instead of electric vehicles only makes sense for niche segments**

5. Exports



Source: Stratfor

Source: The Economist

Transportation

- The most **energy-efficient and cost-effective way** to transport hydrogen from ARM to EU would be in a **compressed state via pipeline**
- However, the feasibility of producing green hydrogen for export is questionable
  - Landlocked position would require **high CAPEX for building a pipeline**
  - At the same time: **overall small production capacity** due to physical limitations for solar expansion
- Seaborne exports via a GEO black sea port would be technically possible, yet less efficient due to significant conversion losses

Regional export initiative

- Exports would be more realistic in the framework of a **regional export project**
- EU has already expressed interest to import green hydrogen from AZE, TUR and KAZ

➢ **Hydrogen exports from ARM to the EU would only be economically feasible as part of a regional hydrogen export initiative**

6. Conclusions and policy recommendations

- Based on its strong solar potential - and assuming preferential interest rates are secured – Armenia could produce **green hydrogen** at an internationally competitive price of ~**3.4 USD/kg.**
- Nonetheless, both export potential and domestic use cases are currently rather limited, but could be improved with regional cooperation and the usage of green hydrogen in domestic industries, including copper smelting and fertilizers.

- Several important policy considerations and conclusions emerge:
  - Pursue regional dialogue to tap into possible synergies in creating hydrogen exporting infrastructure
  - Assess economic feasibility and competitiveness of restarting and upgrading copper smelter in Alaverdi, and refurbishing operations to run on green hydrogen
  - Further explore and conduct feasibility on ammonia-based fertilizer production potential in Armenia, including through the use of green hydrogen
  - Continue and expand cooperation between government, academia, research institutes and private sector, including matching producers and consumers of green hydrogen

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.

CONTACT

Dmitry Chervyakov, Project Manager Armenia
chervyakov@berlin-economics.com

German Economic Team
c/o BE Berlin Economics GmbH
Schillerstraße 59 | 10627 Berlin
Tel: +49 30 / 20 61 34 64 0
info@german-economic-team.com
www.german-economic-team.com

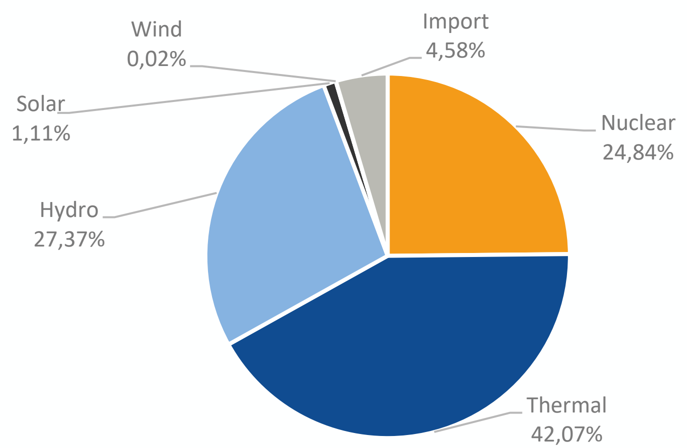
Our publications are available under
https://www.german-economic-team.com/

Implemented by

Berlin Economics

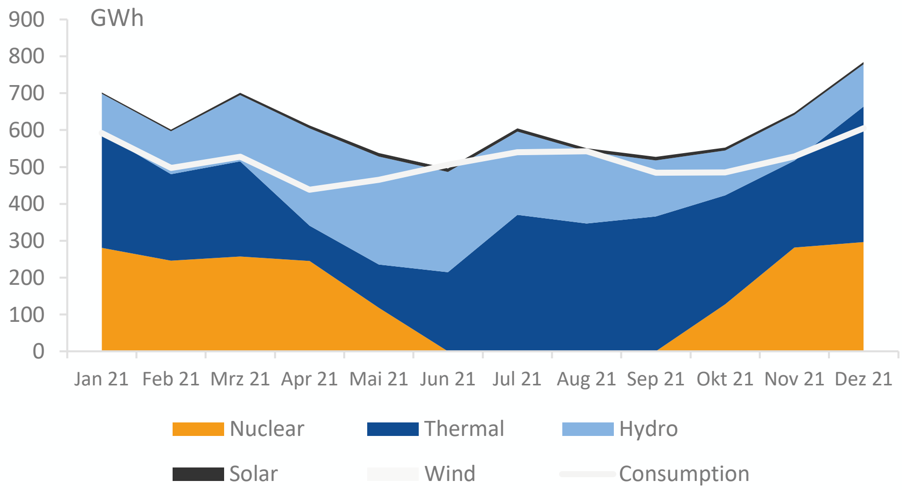
Annex: electricity sector overview

Electricity supply Armenia 2021 (8 TWh)



Source: Public Services Regulatory Commission of Armenia (2022)

Electricity balance Armenia 2021



Source: Public Services Regulatory Commission of Armenia (2022)

- » Electricity production of ARM relies on natural gas, nuclear and hydro power
  - Production from natural gas is fully dependent on imports from RUS via Gazprom Armenia
  - Gazprom Armenia controls all import, transportation and distribution infrastructure
- » The lifetime of the aging nuclear power plant was extended beyond 2026
  - Plans for a new plant exist, but are yet uncertain
- » Wind and solar power do not yet play a significant role in the electricity mix
  - But: government is tendering numerous new projects to increase it’s role
- » Seasonality does not pose a significant challenge to the system due to high proportion of thermal, hydro and nuclear power

➢ **Large share of flexible gas generation allows for rather unproblematic integration of variable renewables like wind and solar**

Annex: cost components and assumptions (1/2)

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

$investment$ 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.

Annex: cost components and assumptions (2/2)

» The variables for the LCOHE calculation are classified into four categories

Physical constants	Assumed constants	Technology-specific variables	Electricity system variables
• Atomic molar masses of hydrogen $M_{Hydrogen}$ • Lower heating value of hydrogen LHV	• f_{OPEX} = 3% (Brynolf et al., 2017) • $WACC$ = 2%/10%	• Upfront investment $investment$ • efficiency of the electrolyser system η • lifetime t	• $LCOE_{solar}$ = 0.040 - 0.076 USD /kWh for 2% and 10%, respectively • κ = 29%