LATVIAN JOURNAL OF PHYSICS
AND TECHNICAL SCIENCES
2026, N 1

DOI: 10.2478/lpts-2026-0005

FROM ELECTRICITY PRICES TO HYDROGEN COSTS: EVALUATING GREEN HYDROGEN COMPETITIVENESS PATHWAYS

L. Zemite[1,2], L. Jansons[3], D. Kronkalns[1], A. Backurs[4], E. Dzelzitis[1], O. Slutins[2]

[1]Riga Nordic University,
1-5 Valerijas Seiles Str., Riga, LV-1019, LATVIA
[2]Riga Technical University,
Faculty of Computer Science, Information Technology and Energy,
12-1 Azenes Str., Riga, LV-1048, LATVIA
[3]Riga Technical University,
Faculty of Engineering Economics and Management,
6 Kalnciema Str., Riga, LV-1048, LATVIA
[4]Faculty of Engineering and Information Technologies,
Latvia University of Life Sciences and Technologies,
2 Liela Str., Jelgava, LV-3001, LATVIA
*e-pasts: laila.zemite@isma.lv

Green hydrogen produced via water electrolysis is a key pillar of the European Union's decarbonisation strategy for hard-to-abate sectors. However, its economic competitiveness remains highly uncertain in small, electricity-importing power systems characterised by volatile wholesale electricity prices. The study assesses the techno-economic viability of grid-connected green hydrogen production in Latvia under current and near-term electricity market conditions. A comparative analysis is conducted for alkaline water electrolysis (AWE), proton exchange membrane (PEM), anion exchange membrane (AEM), and solid oxide electrolysis (SOEC) using industry-standard performance parameters and European cost benchmarks for the 2023–2024 period. The levelized cost of hydrogen (LCOH) is calculated on an ex-plant basis using observed Latvian electricity prices for 2025, a uniform economic lifetime of 15 years, and a weighted average cost of capital of 10 %.

Results indicate that electricity prices are the dominant cost driver, accounting for more than two-thirds of total hydrogen production costs under high-price conditions. At electricity prices around EUR 85/MWh, the LCOH ranges from approximately EUR 6.1–6.6/kg for AWE and PEM, exceeding the cost of conventional hydrogen production via steam methane reforming (SMR) and SMR with carbon capture and storage (CCS). Sensitivity analysis confirms a near-linear relationship between electricity prices and hydrogen costs, with a reduction of EUR 1/MWh lowering LCOH by approximately EUR 0.052/kg for low-temperature electrolysis technologies. Competitiveness thresholds are derived analytically: achieving an LCOH of EUR 5/kg requires electricity prices below approximately EUR 50/MWh, while an LCOH of EUR 4/kg requires prices below approximately EUR 32/MWh, excluding compression. Additional electricity demand for hydrogen compression further tightens these thresholds.

Keywords: *Electricity price volatility, energy system decarbonisation, green hydrogen, LCOH, water electrolysis.*

1. INTRODUCTION

The decarbonisation of energy-intensive sectors has positioned hydrogen as a key energy carrier in the European Union's (EU) climate neutrality strategy [1]–[3]. Green hydrogen produced through water electrolysis using low-carbon electricity is widely regarded as essential for reducing emissions in hard-to-abate sectors, such as steelmaking, oil refining, chemical production, and heavy-duty transportation [4]–[7]. However, despite its strategic importance, green hydrogen remains significantly more expensive than conventional fossil-based hydrogen [8], raising concerns about its near-term economic viability without targeted support mechanisms.

Electricity cost is the dominant determinant of levelized cost of hydrogen (LCOH) from electrolysis [9]. In electricity-importing and relatively small power systems such as Latvia, wholesale electricity prices exhibit substantial volatility, influenced by seasonal demand, renewable generation availability, and regional market conditions [10].

As shown in Table 1, in 2025, Latvia's wholesale electricity prices ranged from approximately EUR 43/MWh to over EUR 80/MWh, creating highly variable cost conditions for grid-connected electrolysis [11].

Table 1. Electricity Prices in Latvia

Month	Avg price (EUR/MWh)	Min–Max (EUR/MWh)	Main drivers	Impact on H_2 cost
January	90	75–110	Winter demand, imports	High LCOH
May	67.88	55–80	Hydro, wind availability	Moderate
June	43.01	35–55	High-RES output	Low LCOH
August	80.20	65–100	Low wind, heat waves	High

At the same time, Table 2 provides a comparative overview of the main water electrolysis technologies currently considered for green hydrogen production, including alkaline water electrolysis (AWE), proton exchange membrane (PEM), anion exchange membrane (AEM), and solid oxide electrolysis (SOEC). It summarises key technical, economic, and operational characteristics that influence technology selection and cost performance. Parameters such as operating temperature and pressure, specific electricity consumption, capital and operational expenditures, and system flexibility are included to highlight fundamental differences between technologies. Special attention is paid to technology maturity and dynamic operating capabilities, which are critical under conditions of variable electricity prices and renewable generation. The comparison illustrates that while low-temperature electrolysis technologies exhibit similar electrical efficiencies, they differ significantly in capital costs and operational flexibility. High-temperature SOEC offers higher efficiency potential but faces greater system complexity and maturity constraints.

Table 2. Comparative Parameters of Water Electrolysis Technologies [12]–[15]

Parameter	AWE	PEM	AEM	SOEC
Technology maturity	Commercial, mature	Commercial, scaling	Pre-/early commercial	Pilot/early commercial
Electrolyte	Liquid alkaline	Polymer membrane	Polymer membrane	Ceramic oxide
Operating temperature (°C)	60–90	50–80	40–70	650–850
Operating pressure (bar)	1–30	30–70	1–30	Atmospheric–moderate
Specific electricity consumption (kWh/kg)	50–55	50–55	50–55	37–42
Electrical efficiency (LHV, %)	65–70	65–70	65–70	75–85
CAPEX (EUR/kW)	1,500–1,800	1,800–2,200	1,600–1,900	2,300–3,000
OPEX (EUR/kW·yr)	Low–moderate	Moderate	Moderate	High
Typical lifetime (years)	15–20	10–15	10–15	5–10 (stack)
Dynamic operation	Limited	Excellent	Good	Limited
Load flexibility	Moderate	Very high	High	Low
Critical materials	Nickel-based	Ir, Pt	Reduced precious metals	Ceramics, nickel
Main advantages	Low CAPEX, robust	Fast response, high pressure	Lower material cost	Highest efficiency
Main limitations	Slower dynamics	High cost, scarce metals	Durability risk	High temperature complexity

In addition, Table 3 indicates that four electrolysis technologies: AWE, PEM, AEM, and SOEC, differ in capital expenditure (CAPEX), operational expenditure (OPEX), and electricity efficiency, further complicating economic assessment [16]–[18], [4].

Table 3. Electrolyser Cost Parameters

Technology	CAPEX (EUR/kW)	OPEX (EUR/kW·yr)	Lifetime (years)	WACC (%)	Non-electric cost (EUR/kg)
AWE	1,666	43	15	10	≈1.7
PEM	1,970	64	15	10	≈2.1
AEM	1,700	45	15	10	≈1.8
SOEC	2,500	70	15	10	≈2.5

Against this background, the study examines whether green hydrogen production using grid-connected electrolysis can be economically competitive in Latvia under current and near-term electricity price conditions. It also identifies the electricity price thresholds required to achieve cost parity with conventional hydrogen production pathways. It is important as electrolysis using grid electricity currently contributes to a minority share of hydrogen produced in the EU, and this share is mainly linked to early-stage and demonstration projects [19]. Most electrolysis projects currently under development are designed to be powered by dedicated renewable generation, rather than relying solely on the grid, due to concerns about carbon intensity and electricity price volatility [20].

Therefore, the primary aim of the research is to evaluate the economic viability of green hydrogen production in Latvia using grid-connected electrolysis technologies, with a particular focus on the impact of electricity prices and operating conditions on the levelized cost of hydrogen.

The study hypothesises that at current electricity prices in Latvia, grid-connected green hydrogen production via electrolysis is not commercially competitive with conventional hydrogen production methods (steam methane reforming with and without carbon capture (SMR without CCS, SMR with CCS)) without subsidies; competitiveness can only be achieved at significantly lower electricity price levels or under high-utilisation, low-cost renewable electricity scenarios.

To address the research aim and test the hypothesis, the study is guided by the following research questions:

- What is LCOH for different electrolysis technologies (AWE, PEM, AEM, and SOEC) under current Latvian electricity price conditions?
- How sensitive is the LCOH to changes in electricity prices and electrolyser capacity factors?
- What electricity price thresholds are required for green hydrogen to reach target cost levels (EUR 5/kg and EUR 4/kg) associated with sectoral competitiveness?
- How do grid connection costs and hydrogen compression requirements affect the economic feasibility of electrolysis-based hydrogen production?
- Under what conditions could green hydrogen become cost-competitive with grey hydrogen and SMR with CCS in Latvia?

The study employs a techno-economic modelling approach to estimate the levelized cost of hydrogen production. The methodology is based on the following elements:

- the use of representative electricity price data for Latvia, reflecting observed market conditions;
- modelling of electrolysis technologies using industry-standard assumptions for specific electricity consumption, CAPEX, OPEX, financing parameters (15-year lifetime, 10 % Weighted Average Cost of Capital (WACC)), and capacity factors;
- calculation of LCOH using a simplified linear cost relationship that separates electricity-related costs from non-electric costs;
- scenario analysis to assess the impact of varying electricity prices, operating hours, grid mark-ups, and hydrogen compression levels;
- benchmarking results against conventional hydrogen production pathways and sector-specific hydrogen price acceptance ranges.

This approach allows for transparent identification of cost drivers and electricity price thresholds relevant for policy and investment decision-making.

Several limitations should be acknowledged:

- the analysis relies on assumed CAPEX and OPEX values based on European market benchmarks, which may change over time due to technological learning or supply chain effects;
- the study focuses on ex-plant hydrogen costs and does not account for downstream costs such as transport, storage, or distribution;
- electricity prices are treated as exogenous, and potential feedback effects from large-scale electrolysis deployment on power markets are not considered,
- the analysis does not incorporate policy instruments such as subsidies, contracts for difference, or carbon pricing, which could materially alter competitiveness outcomes.

Despite these limitations, the study provides a robust and transparent assessment of the economic conditions under which green hydrogen production in Latvia could become commercially viable.

2. METHODOLOGY

The study applies a techno-economic modelling methodology to assess the cost competitiveness of green hydrogen production via water electrolysis under Latvian electricity market conditions. The methodological framework is designed to isolate the impact of electricity prices, operating hours, and technology-specific cost parameters on LCOH, while maintaining transparency and reproducibility of results. The analysis focuses on grid-connected electrolysis and evaluates AWE, PEM, AEM, and SOEC as representative low-carbon hydrogen production technologies.

Electricity price inputs are derived from observed wholesale market outcomes for Latvia, reflecting monthly average prices and their seasonal variation. These prices are treated as exogenous inputs to the model and are adjusted to include an assumed grid connection and transmission markup representative of an industrial consumer. No long-term power purchase agreements or hedging strategies are assumed, as the objective is to evaluate hydrogen production economics under prevailing market price exposure. Electricity prices are expressed in real terms and applied consistently across all technology scenarios to ensure comparability.

Electrolyser performance parameters are defined using industry-standard assumptions. Specific electricity consumption values are assumed to be constant for each technology and reflect typical commercial performance levels. CAPEX and OPEX values are based on European market benchmarks from the 2023–2024 period. These parameters, as shown in Table 4, include stack costs, balance-of-plant components, fixed and variable operation and maintenance costs, and auxiliary consumption. A uniform economic lifetime and weighted average cost of capital are applied across all technologies to avoid bias in cost comparisons.

Table 4. Key Performance, Cost, and Economic Assumptions for Electrolyser Technologies

Parameter Category	Description	Assumption/Basis
Electrolyser Technologies	All major electrolyser technologies considered	Industry-standard performance assumptions
Specific Electricity Consumption	Electricity required per unit of hydrogen produced	Constant per technology; typical commercial performance
Capital Expenditure (CAPEX)	Investment costs for electrolyser systems	European market benchmarks (2023–2024)
Stack Costs	Cost of electrolyser stacks	Included in CAPEX; European benchmarks
Balance of Plant (BoP)	Non-stack system components	Included in CAPEX; European benchmarks
Operational Expenditure (OPEX)	Costs incurred during operation	European market benchmarks (2023–2024)
Fixed O&M Costs	Routine maintenance and fixed operating costs	Included in OPEX assumptions
Variable O&M Costs	Production-dependent operating costs	Included in OPEX assumptions
Auxiliary Consumption	Electricity consumption of supporting systems	Included in performance and cost calculations
Economic Lifetime	Operational lifetime of electrolyser systems	Uniform across all technologies
Weighted Average Cost of Capital (WACC)	Discount rate used in economic analysis	Uniform across all technologies to avoid bias
Cost Comparison Methodology	Treatment of economic assumptions	Harmonised assumptions for unbiased comparison

LCOH is calculated on an ex-plant basis using a simplified cost-accounting framework that separates electricity-related costs from non-electric costs. Electricity costs are calculated as the product of specific electricity consumption and the all-in electricity price faced by the electrolyser. Non-electric costs include annualized capital costs and OPEX allocated over the total hydrogen output. This separation allows for direct evaluation of cost sensitivity to electricity price changes and operating conditions.

Electrolyser utilisation is modelled through capacity factor assumptions that represent different operating strategies. High-utilisation scenarios correspond to near-continuous operation at prevailing electricity prices, while low-utilisation scenarios reflect operation limited to periods of low electricity prices. The resulting trade-off between lower electricity costs and higher capital cost allocation per unit of hydrogen is explicitly captured in the model. Capacity factor thresholds required for cost competitiveness are derived through comparative scenario analysis.

Additional scenarios incorporate hydrogen compression requirements to represent end-use applications such as industrial supply and transport. Incremental electricity consumption associated with compression is included in the total energy demand, and its effect on LCOH is evaluated across different pressure levels. This allows for the assessment of how downstream technical requirements influence upstream production economics.

Competitive benchmarks are established by comparing calculated LCOH values with reference costs for conventional hydrogen production pathways, including SMR with or without CCS. Sector-specific hydrogen price acceptance ranges are also used to contextualise the results in relation to potential demand from industrial and transport sectors. Electricity price thresholds required to achieve predefined LCOH targets are derived analytically and validated through scenario modelling.

The methodology emphasises transparency, comparability, and policy relevance. While simplified, the modelling approach captures the dominant economic drivers of green hydrogen production and provides robust insights into the conditions under which electrolysis-based hydrogen could become viable in Latvia.

3. RESULTS

According to data from Latvia's transmission system operator, the average electricity price in June 2025 was EUR 43.01/MWh, representing a sharp decline compared to May (EUR 67.88/MWh). In August, however, the average price reached EUR 80.20/MWh. Consequently, as shown in Table 5, electricity prices in Latvia in 2025 ranged approximately between EUR 43 and EUR 151/MWh, depending on the specific month and market situation [11].

Table 5. Average Electricity Price in Latvia (by month, 2025) [11]

Month	Average Price (EUR/MWh)
January	91.8
February	151.6
March	92.1
April	77.4
May	67.9
June	43.1
July	46.1
August	80.2
September	84.2
October	105.2
November	111.0
December	93.6

When modelling AWE and PEM electrolysis with a typical specific electricity consumption of approximately 52 kWh/kg of hydrogen and using industry-level CAPEX/OPEX parameters (AWE CAPEX – EUR 1,666/kW, OPEX – EUR 43/kW·year; PEM CAPEX – EUR 1,970/kW, OPEX – EUR 64/kW·year), a capitalisation period of 15 years and a WACC of 10 %, the resulting ex-plant break-even price ranges are as follows: AWE – EUR 6.10–6.20/kg and PEM – EUR 6.50–6.60/kg (at electricity prices of 84.6–86.5 EUR/MWh).

In this case, the electricity component accounts for EUR 4.40–4.50/kg, while the non-electric component (CAPEX and OPEX) amounts to EUR 1.70/kg for AWE and EUR 2.10/kg for PEM. For comparison, in 2023, typical grid-based electrolysis in Europe resulted in costs of EUR 7.94/kg, while electrolysis directly connected to renewable energy sources yielded EUR 6.61/kg. SMR costs averaged to EUR 3.76/kg, and SMR with CCS to EUR 4.41/kg. These cost differentials highlight the significant impact of electricity sourcing and carbon intensity on hydrogen production economics. Grid-connected electrolysis remains exposed to wholesale power price volatility and the prevailing emissions intensity of the European electricity mix [21], [22], which together contribute to higher LCOH.

In contrast, direct coupling of electrolysers with renewable energy sources benefits from lower marginal electricity costs and reduced exposure to carbon pricing, resulting in more competitive production costs [23]. Nevertheless, renewable-based electrolysis faces challenges related to variable capacity factors, increased capital utilization risks, and the need for oversized generation or storage solutions. Compared to electrolysis, SMR continues to exhibit lower production costs due to mature technology, high efficiency, and established supply chains. However, grey hydrogen production is associated with substantial greenhouse gas emissions [24], [25], which are increasingly subject to regulatory constraints and carbon pricing mechanisms. The integration of CCS significantly reduces lifecycle emissions but introduces additional CAPEX and OPEX costs, narrowing the cost gap with low-carbon hydrogen pathways. As carbon prices rise and renewable electricity costs continue to decline, the relative competitiveness of renewable-based electrolysis is expected to improve, reinforcing its role in long-term decarbonisation strategies [26], [27].

While the long-term cost decrease trend of renewable-based electrolysis appears favourable, its current competitiveness remains strongly constrained by prevailing electricity market conditions. When electrolysers are operated under grid-connected configurations and exposed to wholesale electricity prices, the theoretical advantages associated with declining renewable costs and rising carbon prices are not yet sufficient to offset higher production expenses. This gap between long-term expectations and short-term market realities becomes evident when evaluated against observed electricity price levels and sectoral hydrogen cost benchmarks [28].

For instance, at electricity prices of around EUR 85/MWh, none of the grid-connected green hydrogen electrolysis technologies (AWE, PEM, AEM, and SOEC) are commercially competitive without subsidies: the calculated EUR 6.1–6.6/kg exceeds SMR/SMR and CCS reference levels and often surpasses the hydrogen price limits acceptable in end-use sectors (oil refining – EUR 2.7–5.6/kg, steel – EUR 4.7/kg, heavy transport – EUR 2.4–5.8/kg). The hydrogen cost breakdown at an electricity price of 85 EUR/MWh is shown in Table 6.

Table 6. Hydrogen Cost Breakdown at an Electricity Price of 85 EUR/MWh

Technology	**Electricity price (EUR/MWh)**	**Espec (kWh/kg)**	**Electricity cost (EUR/kg)**	**CAPEX+OPEX (EUR/kg)**	**Compression included**	**LCOH (EUR/kg)**
AWE	85	52	4.42	1.73	No	6.15
PEM	85	52	4.42	2.10	No	6.55
SOEC	85	39	3.32	2.50	No	5.82

An exception may be off-grid or “captive renewable” scenarios (own wind/solar LCOE ≤ EUR 40–45/MWh with on-site consumption and no transmission/distribution charges), where the LCOH can decrease to approximately EUR 3.8–4.5/kg; however, this is no longer a case of “current prices including tariffs”, but a special case with cheaper local generation.

It shows that at electricity prices of

85 EUR/MWh including transmission, the ex-plant hydrogen sales price must be at least EUR 6.1–6.2/kg for AWE or EUR 6.5–6.6/kg for PEM to cover full costs, including CAPEX, without support.

Cheaper electricity and cheaper, more competitive green hydrogen become equal categories, where LCOH can be well approximated by:

$$\mathrm{LCOH} \approx E_{spec} \times P_{elek} + \mathrm{b},$$

where:

E_{spec} – 52 kWh/kg (typical specific consumption);

P_{elek} – the all-in electricity price (EUR/kWh or EUR/MWh);

b – non-electric costs (electrolyser CAPEX amortization and OPEX, water, compression, etc.).

This relationship implies cost sensitivity: each reduction of electricity price by 1 EUR/MWh lowers the LCOH by EUR 0.052/kg. For example, a drop from 85 to 60 EUR/MWh results in approximately EUR 1.3/kg cheaper hydrogen, all else being equal.

AWE example with realistic CAPEX/OPEX and E_{spec} – 52 kWh/kg and changeable P_{elek} shows the following trends:

- *almost 24/7 operation*: P_{elek} = 85 EUR/MWh, capacity factor CF – 0.90, electricity cost EUR 4.42/kg, CAPEX and OPEX – EUR 1.73/kg, LCOH – EUR 6.15/kg;
- *very cheap but rare*: P_{elek} = 30 EUR/MWh, CF – 0.25 (2,200 h/year), electricity cost – EUR 1.56/kg, but sum of CAPEX and OPEX increases to EUR 6.22/kg and LCOH to EUR 7.78/kg (worse than expensive 24/7 operation);
- *cheap and sufficiently frequent*: P_{elek} = 30 EUR/MWh, CF = 0.60, electricity cost ≈ EUR 1.56/kg, CAPEX and OPEX = EUR 2.59/kg, LCOH = EUR 4.15/kg (Fig. 1).

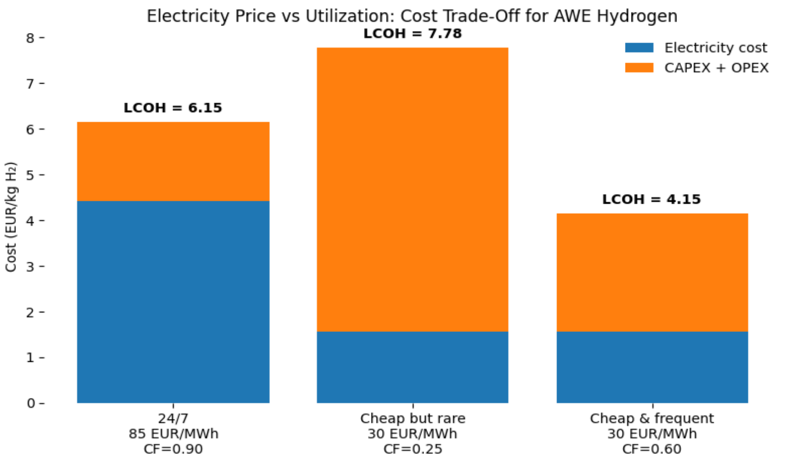

Fig. 1. Impact of electricity price and electrolyser capacity factor on LCOH for AWE.

This example illustrates the following trade-off: cheaper electricity reduces LCOH, but if the low price is "purchased" with too few operating hours, CAPEX/kg can offset the benefit. A practical rule-of-thumb: at 30 EUR/MWh electricity prices, at least 35 % annual utilisation (around 3,000 h/year) is required to outperform 24/7 operation at 85 EUR/MWh.

The relationship is linear: lower P_{elek}

directly reduces LCOH by EUR 0.052/kg for each 1 EUR/MWh. Practical economics also depends on the number of operating hours; too few hours increase unit CAPEX costs. An optimal real-world solution is to combine low electricity prices with a sufficiently high-capacity factor, ensuring both low P_{elek} and adequate CF.

The thresholds below are derived from the linear relationship:

$$LCOH \approx E_{spec} \times (P_{exchange} + \tau) + b,$$

where:
E_{spec} – the specific electricity consumption (assumed 52 kWh/kg for AWE/PEM/AEM and 39 kWh/kg for SOEC);
τ – the grid markup (assumed ≈ 5 EUR/MWh for an industrial connection);
b – non-electric costs (CAPEX amortisation and OPEX).

Parameter references used are as follows:

- AWE CAPEX – EUR 1,666/kW, OPEX – EUR 43/kW·year;
- PEM CAPEX – EUR 1,970/kW, OPEX – EUR 64/kW·year, yielding approximately bAWE – EUR 1.7/kg and bPEM – EUR 2.1/kg;
- AEM has a cost profile like AWE, while SOEC currently features lower E_{spec} and higher b (for example, bSOEC – EUR 2.5/kg).

Thresholds for all electrolysis technologies (with grid markup $\tau \approx 5$ EUR/MWh) are as follows:

- target LCOH – EUR 5.0/kg (minimum competitiveness). For AWE, PEM, AEM, and SOEC to be economically viable, electricity exchange prices must be ≤ 51 EUR/MWh (PEM with P_{max} – 50.8 EUR/MWh; AWE – 58.5, AEM – 56.5; SOEC – 59.1). If compression to 350 bar is required (+/- 2.5 kWh/kg), the PEM threshold falls to 48.2 EUR/MWh; at 700 bar (+/-7.5 kWh/kg) to 43.7 EUR/MWh;
- target LCOH – EUR 4.0/kg (borderline competitiveness). For all technologies to be viable, exchange electricity prices must be ≤ 31.5 EUR/MWh (PEM with P_{max} – 31.5 EUR/MWh; AWE – 39.2; AEM – 37.3; SOEC – 33.5). With 350 bar compression, this becomes 29.1 EUR/MWh; with 700 bar, 24.6 EUR/MWh.

Table 7. Electricity Price Thresholds for Competitiveness

Target LCOH (EUR/kg)	Technology	Max $P_{exchange}$ (EUR/MWh)	Grid fee (EUR/MWh)	Compression 350 bar	Compression 700 bar
5.0	PEM	50.8	51	48.2	43.7
5.0	AWE	58.5	59	56	51
4.0	PEM	31.5	31.5	29.1	24.6
4.0	SOEC	33.5	34	31	26

With grid connection (around 5 EUR/MWh markup) and a target LCOH of EUR 5/kg, simultaneous commercial viability of all major green electrolysis technologies in Latvia would require electricity prices ≤ 51 EUR/MWh (without compression) or ≤ 48/44 EUR/MWh (with ~350/700 bar compression). For LCOH of EUR 4/kg, the corresponding thresholds are ≤ 31.5 EUR/MWh (without compression) and ≤ 29/25 EUR/MWh (with 350/700 bar compression).

4. DISCUSSION AND CONCLUSIONS

The results demonstrate that electricity price levels and operating conditions are the dominant determinants of green hydrogen competitiveness in Latvia. Under current grid-based electricity prices, which frequently exceed EUR 80/MWh and exhibit strong seasonal volatility, electrolysis-based hydrogen production remains structurally disadvantaged relative to conventional fossil-based pathways. Even under favourable assumptions regarding CAPEX and electrolyser efficiency, the electricity cost component alone accounts for more than two-thirds of total hydrogen production costs in high-price periods. This confirms the central hypothesis of the study that grid-connected green hydrogen production is not commercially viable in Latvia at prevailing market prices without targeted policy support or access to significantly cheaper electricity.

The comparative analysis across electrolysis technologies indicates that differences in CAPEX and efficiency, while relevant, are secondary to electricity price exposure. AWE and PEM electrolysis show broadly similar cost outcomes under identical electricity prices, with PEM remaining slightly more expensive due to higher CAPEX and OPEX. SOEC benefits from lower specific electricity consumption but is offset by higher non-electric costs, resulting in comparable or only marginally lower LCOH under grid-connected operation. These findings suggest that technology choice alone cannot overcome unfavourable electricity market conditions and that systemic cost reductions must primarily originate from the power supply side.

The sensitivity analysis further illustrates the linear relationship between electricity prices and LCOH, highlighting the strong leverage effect of electricity cost reductions. A decrease of EUR 1/MWh in electricity price reduces hydrogen production costs by approximately EUR 0.052/kg for conventional low-temperature electrolysis technologies. Consequently, even moderate reductions in electricity prices can yield substantial improvements in competitiveness. However, the analysis also reveals a critical trade-off between electricity price minimisation and electrolyser utilisation.

Operating electrolysers exclusively during low-price periods can significantly increase CAPEX allocation per unit of hydrogen, thereby offsetting the benefits of cheap electricity. This underscores the importance of achieving a sufficiently high-capacity factor alongside low electricity prices.

The results indicate that cost parity with SMR and SMR with CCS can only be achieved under electricity prices well below historical Latvian averages. For a target LCOH of EUR 5/kg, electricity prices must fall below approximately EUR 50/MWh, even before accounting for compression or downstream requirements. Achieving a more ambitious target of EUR 4/kg, which would enable broader sectoral adoption, requires electricity prices below EUR 32/MWh, a level that is rarely observed in the Latvian wholesale market on a sustained basis. These thresholds highlight the structural challenge faced by grid-connected electrolysis in small, import-dependent electricity systems.

The comparison with off-grid or captive renewable scenarios illustrates a potential pathway toward competitiveness. When electrolysers are directly coupled with low-cost renewable generation and shielded from transmission charges and wholesale price volatility, hydrogen production costs can approach or even undercut EUR 4.5/kg. However, such configurations represent a fundamentally different system architecture and are not representative of general grid-connected operation. Moreover, captive renewable systems introduce additional challenges related to land availability, intermittency management, and investment risk, which must be carefully considered in policy and planning contexts.

From a policy perspective, the findings suggest that relying solely on market-driven deployment of grid-connected electrolysis is unlikely to deliver cost-competitive green hydrogen in Latvia in the near term. Without intervention, hydrogen production will remain confined to niche applications or demonstration projects. Policy instruments such as contracts for difference, electricity price support mechanisms, reduced grid tariffs for electrolysers, or direct capital subsidies could materially alter the cost balance. Alternatively, prioritising the development of dedicated renewable generation for hydrogen production may offer a more structurally robust pathway to competitiveness.

The study also highlights the importance of aligning hydrogen policy with electricity market design. As electrolysis deployment scales, interactions with the power system will become increasingly important. While this analysis treats electricity prices as exogenous, large-scale hydrogen production could influence wholesale prices, system flexibility, and renewable curtailment dynamics. Future research should therefore integrate hydrogen production into broader energy system models to capture these feedback effects.

The study has provided a comprehensive techno-economic assessment of grid-connected green hydrogen production in Latvia under current and near-term electricity market conditions. The results clearly indicate that, at prevailing electricity prices, green hydrogen produced via electrolysis is not commercially competitive with conventional hydrogen production pathways such as SMR or SMR with CCS. Electricity costs dominate the levelized cost of hydrogen, and even modest price volatility translates into significant cost uncertainty for producers.

The analysis confirms that achieving competitiveness requires electricity prices substantially below historical averages, alongside sufficiently high electrolyser utilisation rates. Technology-specific differences between alkaline, PEM, AEM, and SOEC electrolysis are of secondary importance relative to electricity price exposure. Without access to low-cost electricity, no currently available electrolysis technology can achieve sustained cost parity with fossil-based hydrogen in Latvia.

The findings underscore the necessity of targeted policy intervention if green hydrogen is to play a meaningful role in Latvia's decarbonisation strategy. Support mechanisms that reduce effective electricity costs, mitigate price volatility, or de-risk capital investment are essential to bridge the current cost gap. Alternatively, the development of captive renewable hydrogen systems may provide a viable pathway, albeit with distinct system and investment challenges.

ACKNOWLEDGEMENT

The research has been funded by the Latvian Council of Science, project "Mitigating Energy Poverty through Innovative Solutions", No. lzp-2023/1-0214.

REFERENCES

1. Buonomenna, M. G., & Patonia, A. (2025). Green hydrogen in Europe: Where are we now? *Hydrogen*, *6*(4), 105. doi: 10.3390/hydrogen6040105
2. Kronkalns, D., Zemite, L., Jansons, L., & Backurs, A. (2025). Pursuing opportunity: A multi-dimensional analysis of green hydrogen production technologies. *Latvian Journal of Physics and Technical Sciences*, *62*(5), 87–108. doi: 10.2478/lpts-2025-0039
3. Jansons, L., Zemite, L., Zeltins, N., Geipele, I., & Backurs, A. (2023). Green and sustainable hydrogen in emerging European smart energy framework. *Latvian Journal of Physics and Technical Sciences*, *60*(1), 24–38. doi: 10.2478/lpts-2023-0003
4. Backurs, A., Jansons, L., & Laizans, A. (2025). Water electrolysis technologies: comparison of maturity, operational and cost efficiency. In: *24th International Scientific Conference "Engineering for Rural Development": Proceedings* (pp. 275–285), 21–23 May 2025. Jelgava, Latvia: Latvia University of Life Sciences and Technologies. doi: 10.22616/ERDev.2025.24.TF061
5. Du, L., Yang, Y., Zhou, L., & Liu, M. (2024). Greenhouse gas reduction potential and economics of green hydrogen via water electrolysis: A systematic review of value-chain-wide decarbonization. *Sustainability*, *16*(11), 4602. doi: 10.3390/su16114602
6. Louli, R., Giurgea, S., Salhi, I., Laghrouche, S., & Djerdir, A. (2026). A critical review of green hydrogen production by electrolysis: From technology and modeling to performance and cost. *Energies*, *19*(1), 59. doi: 10.3390/en19010059
7. Innovation News Network. (2025). *Decarbonising heavy industries with green hydrogen*. Available at: https://www.innovationnewsnetwork.com/decarbonising-heavy-industries-with-green-hydrogen/58321/
8. Ammar, M., Oyewale, B. O., Elseragy, A., Albayati, I. M., & Aliyu, A. M. (2025). A global review of blue and green hydrogen fuel production technologies, trends and future outlook to 2050. *Fuels*, *6*(4), 88. doi: 10.3390/fuels6040088
9. Barros Souza Riedel, A. B., Feitosa Riedel, V., Souza Filho, H. N. d., da Silva, E. P., Marques Cabral, R., de Brito Silva, L., & de Castro Pereira, A. (2024). Technical–economic analysis of renewable hydrogen production from solar photovoltaic and hydro synergy in a pilot plant in Brazil. *Energies*, *17*(17), 4521. doi: 10.3390/en17174521
10. Wattstor. (n.a.). *What is electricity price volatility & how it impacts businesses?* Available at: https://wattstor.com/insight/what-is-electricity-price-volatility/
11. AST. (2025). *Latvian electricity market overview*. Available at: https://www.ast.lv/en/electricity-market-review?year=2025&month=11
12. Vedrtnam, A., Kalauni, K., & Pahwa, R. (2025). Water electrolysis technologies and their modeling approaches: A comprehensive review. *Eng.*, *6*(4), 81. doi: 10.3390/eng6040081
13. Abudureyimu, A., Tuluhong, A., Chang, Q., Wang, F., & Luo, B. (2025). A comprehensive review of green hydrogen technology: Electrolysis methods, topologies and control strategies, applications. *Materials*, *18*(21), 4826. doi: 10.3390/ma18214826
14. Khalil, Y. F. (2025). A comparative science-based viability assessment among current and emerging hydrogen production technologies. *Applied Sciences*, *15*(2), 497. doi: 10.3390/app15020497
15. Shaya, N., & Glöser-Chahoud, S. (2024). A review of life cycle assessment (LCA) studies for hydrogen production technologies through water electrolysis: Recent advances. *Energies*, *17*(16), 3968. doi: 10.3390/en17163968
16. Bora, D. K. (2025). Green hydrogen production with 25 kW alkaline electrolyzer pilot plant shows hydrogen flow rate exponential asymptotic behavior with the stack current. *Hydrogen*, *6*(4), 75. doi: 10.3390/hydrogen6040075

17. Riester, C. M., García, G., Alayo, N., Tarancón, A., Santos, D. M. F., & Torrell, M. (2022). Business model development for a high-temperature (co-)electrolyser system. *Fuels*, *3*(3), 392–407. doi: 10.3390/fuels3030025
18. Remboll. (2025). *Cost-competitive green H_2: CAPEX and OPEX insights for industrial integration.* Available at: https://hydrogentechworld.com/wp-content/uploads/sites/22/2025/05/02-19.pdf
19. Bellona Europa. (2021). *Electrolysis hydrogen production in Europe*. Available at: https://bellona.org/assets/sites/3/2021/04/Electrolysis-Hydrogen-Production-In-Europe-1.pdf
20. LCP Delta. (2025). *European Green Hydrogen Market – 2025 update hydrogen intelligence* (Report sample). Available at: https://insights.lcp.com/rs/032-PAO-331/images/LCP-Delta-Green-Hydrogen-Market-Update-2025.pdf
21. Pavlík, M., Kurimský, F., & Ševc, K. (2025). Renewable energy and price stability: An analysis of volatility and market shifts in the European electricity sector (2015–2025). *Applied Sciences*, *15*(12), 6397. doi: 10.3390/app15126397
22. Pavlík, M., & Bereš, M. (2025). Effects of electricity price volatility, energy mix and training interval on prediction accuracy: An investigation of adaptive and static regression models for Germany, France and the Czech Republic. *Energies*, *18*(15), 3893. doi: 10.3390/en18153893
23. Pastore, L. M. (2026). Sector coupling and flexibility measures in distributed renewable energy systems: A comprehensive review. *Sustainability*, *18*(1), 437. doi: 10.3390/su18010437
24. Beigi Kheradmand, A., Heidari Soureshjani, M., Jahangiri, M., & Hamawandi, B. (2025). Comparative techno-economic analysis of gray hydrogen production costs: A case study. *Sustainability*, *17*(2), 547. doi: 10.3390/su17020547
25. Ingale, G. U., Kwon, H.-M., Jeong, S., Park, D., Kim, W., Bang, B., … & Lee, U. (2022). Assessment of greenhouse gas emissions from hydrogen production processes: Turquoise hydrogen vs. steam methane reforming. *Energies*, *15*(22), 8679. doi: 10.3390/en15228679
26. Elegbeleye, I., Oguntona, O., & Elegbeleye, F. (2025). Green hydrogen: Pathway to net zero greenhouse gas emission and global climate change mitigation. *Hydrogen*, *6*(2), 29. doi: 10.3390/hydrogen6020029
27. Curcio, E. (2025). Techno-economic analysis of hydrogen production: Costs, policies, and scalability in the transition to net-zero. *International Journal of Hydrogen Energy*, *128*, 473–487. doi: 10.1016/j.ijhydene.2025.04.013
28. Green Skills for Hydrogen. (2024). *Green hydrogen cost and reduction potential.* Available at: https://greenskillsforhydrogen.eu/wp-content/uploads/2024/07/2024-Juni-4-V03-Masterclass-WHB_-Greenskill4h2_Green-Hydrogen-Cost-and-reduction.pdf