Gréoux Research

Enabling the transition to a low-carbon future

Methodological Note

# Beyond LCOH:
# Assessing the *Value* of Green Hydrogen

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# Contents

# Introduction

Green hydrogen, produced by splitting water with electricity from renewable sources, is a key player in the clean energy transition. However, assessing its production cost is challenging.

A common method for assessing the economics of hydrogen production is the Levelized Cost of Hydrogen (LCOH) approach, which considers factors like the upfront cost of the electrolyser, operation expenses (including electricity price), and the average load factor. While relatively simple to implement, this methodology often uses the Levelized Cost of Electricity (LCOE) of a single source (e.g., solar) as a proxy for electricity price, assuming electrolysers are tied to a specific generator. In reality, electrolysers are not linked to a specific energy source but to the power grid, which is built around a mix of generation technologies. The actual cost of electricity varies depending on the source being used at a given time, which is determined by "the merit order". Moreover, hydrogen production and storage can act as a flexibility means, harnessing surplus renewable energy during periods of high production and low prices. The added value associated with this flexible character is usually not factored into the LCOH.

A more rigorous approach involves modelling how hydrogen production interacts with the broader energy system, considering the electricity mix and its variable pricing. This alternative provides a more accurate picture of green hydrogen's economic viability.

However, this process requires substantial effort, describing different components of the energy system and their interactions, and accounting for real-world constraints determining their behaviour. Several tools can help with this process: GenX [1], MESSAGE [2], OSeMOSYS [3], and PLEXOS [4]. These tools typically rely on Mixed-integer Linear Programming (MILP) techniques and powerful commercial solvers, making the optimisation process computationally demanding, and limiting its accessibility to experienced energy modellers and planners with access to such resources. Moreover, running many simulations to explore different options can be very time-consuming.

To address these challenges, an open-source tool called IESO has been developed and made available on GitHub [1]. IESO (Integrated Energy Systems Optimiser) is a linear optimisation-based energy system modelling environment designed to support initial investigations such as options evaluation and trend analysis [5]. The tool allows users to optimise an energy system — including generators, flexibility means, and PtX processes —, meeting final demands for electricity, water, hydrogen, heat, and other byproducts, at the lowest costs and emissions.

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[1] IESO is freely available on Gréoux Research's GitHub repository: https://github.com/greoux-research/ieso

IESO adopts a simplified linear structure solved by the open-source Google Linear Optimization Package (GLOP) [6]. While it fully accounts for key inputs — annual demand, demand curves, and the technical-economic attributes of various energy system components (fixed and variable costs, emissions, and output profiles) —, it intentionally avoids representing individual power plants, transmission and distribution networks, and real-world constraints such as ramping limits and reserve requirements. This makes it easier to use compared to more established software tools in the energy modelling field, and suitable for getting a preliminary assessment of the economics of electricity generation and X production, where X can be desalinated water, hydrogen, or heat.

This note presents a practical example illustrating the application of the model. The example assesses the economics of green hydrogen supply within a low-carbon energy mix, primarily reliant on solar and wind power.

## Illustrative Simulation

In this simulation, we consider a fictitious country with an annual electricity demand of 50 terawatt-hours (TWh). This demand is met by a low-carbon energy mix, utilising solar, wind, battery storage, and open-cycle gas turbines (OCGT) for peak power generation. Additionally, the country produces 35 million kg of hydrogen per year using alkaline electrolysers. The complete set of assumptions is described in the Appendix [2].

Table 1 presents the optimal energy system identified by IESO under carbon constraint (an upper limit of 100 kg$CO_2$eq per MWh was set).

| Technology | Installed capacity | Annual output |
|---|---|---|
| Solar | 11,559 MW | 23,565 GWh |
| Wind | 9,440 MW | 19,228 GWh |
| Battery storage | 13,427 MWh | — |
| OCGT | 6,842 MW | 9,560 GWh |
| Electrolyser | 13,731 kg per hour | 35 million kg |
| Hydrogen storage | 174,740 kg [3] | — |

Table 1: Optimal energy system identified by IESO.

[2] This set of assumptions is also available as an IESO input dataset at https://greoux.re/blog/index.php/beyond-lcoh-value-of-green-hydrogen/

[3] This storage volume represents about 15 hours of production at maximum capacity.

To minimise the cost function, IESO solves both the primal problem (the original optimisation problem) and its corresponding dual problem. The dual problem associated with the demand constraints reveals the shadow price — and the value — of electricity and hydrogen.

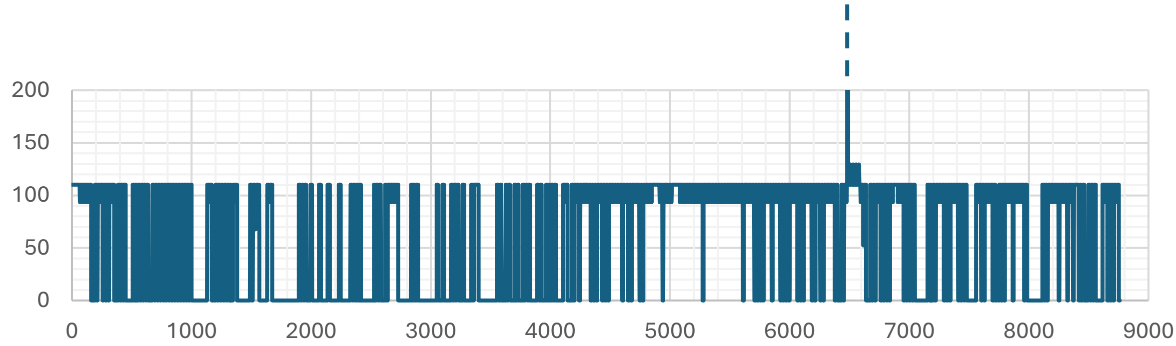


Figure 1: Electricity prices ($ per MWh) at different hours of the year.

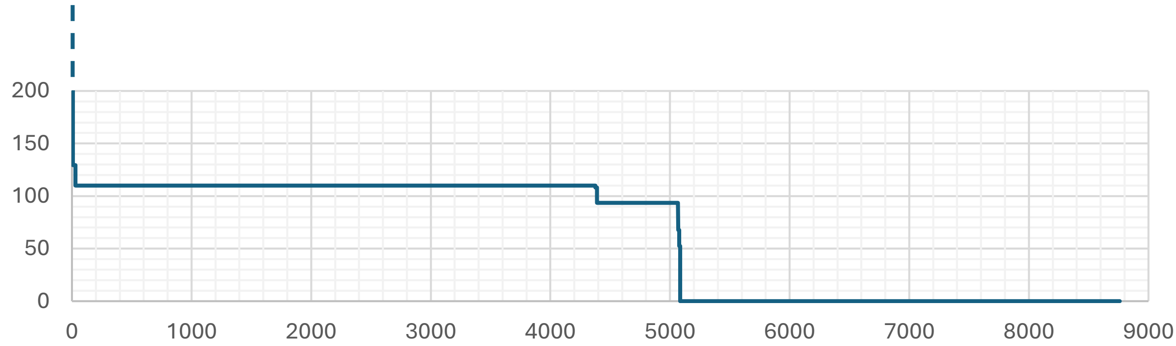


Figure 2: Electricity price ($ per MWh) duration curve.

Figures 1-4 illustrate the shadow price profiles for both commodities. Figures 1 and 3 depict the price evolution over the course of a year (8,760 hours), while Figures 2 and 4 present the price duration curve.

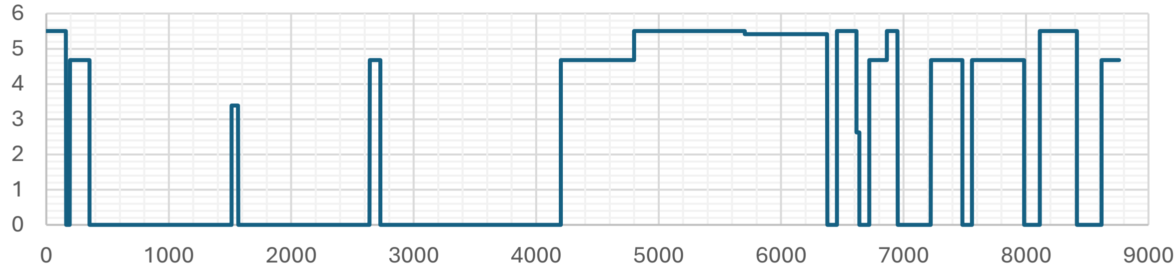


Figure 3: Hydrogen prices ($ per kg) at different hours of the year.

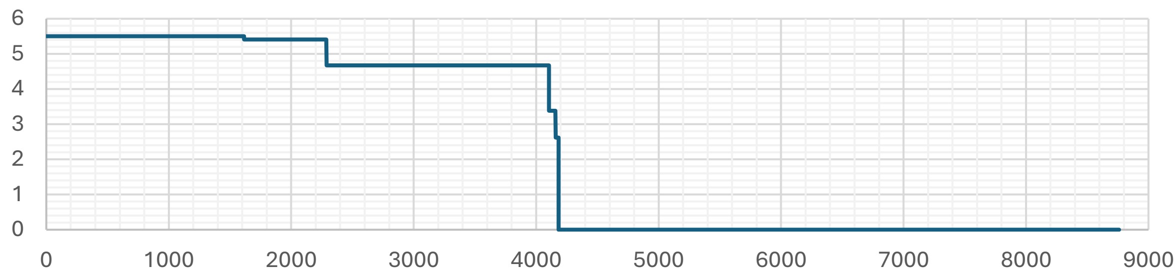


Figure 4: Hydrogen price ($ per kg) duration curve.

Throughout the year, electricity prices range from 0 to 11,496 $ per MWh with a weighted average of 79.2 $ per MWh. Similarly, hydrogen prices fluctuate between 0 and 5.5 $ per kg, with a weighted average of 2.43 $ per kg.

Figure 5 show the impact of stricter emission limits on electricity and hydrogen prices. Lower emissions correlate with higher electricity prices and vice versa. However, interestingly, moving towards net-zero appears to benefit the price of green hydrogen.

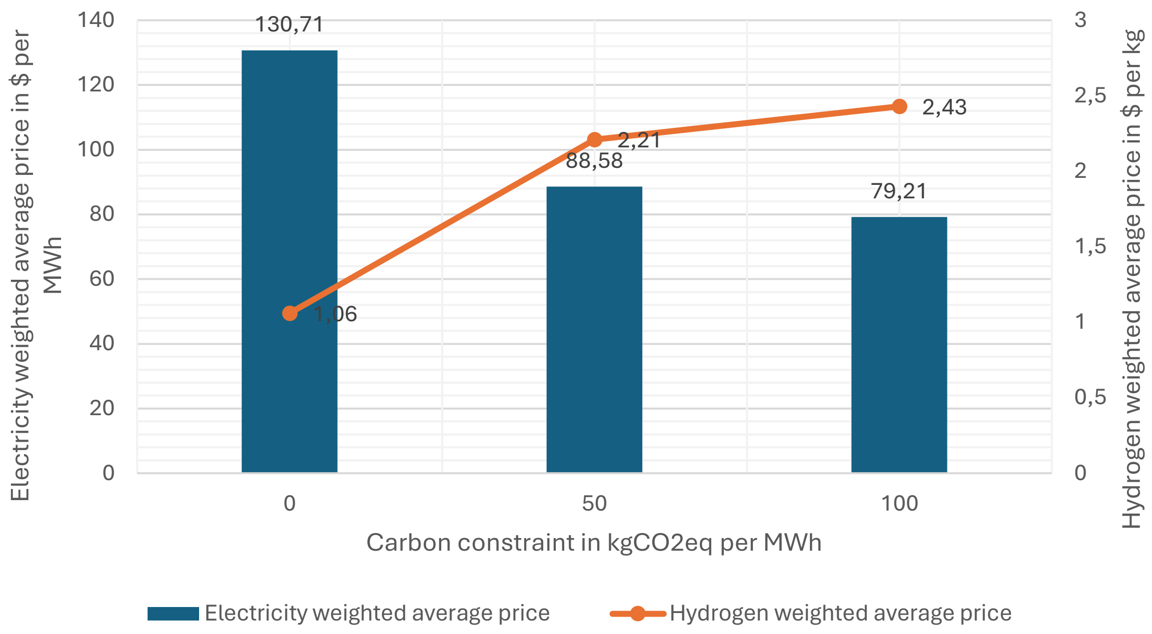


Figure 5: Impact of stricter emission limits on electricity and hydrogen prices.

In systems with high shares of intermittent renewable energy sources, Power-to-Hydrogen processes seem to take full advantage of excess energy to produce hydrogen and store it for later use, driving down prices, reducing curtailment and stabilising the grid.

# Appendix: Set of Assumptions

| | |
|---|---|
| Annual demand for electricity | 50 TWh |
| Non-service penalty | 20,000 $ per MWh |

Table 2: Demand for electricity.

| Technology | Fixed costs | Variable costs | Emissions |
|---|---|---|---|
| Solar | 70,046 | — | — |
| Wind | 133,553 | — | — |
| Battery storage [4] | 27,248 | — | — |
| OCGT [5] | 75,182 | 96.11 | 523 |
| Fixed costs in $ per MW (or MWh (battery storage)) per year<br>Variable costs in $ per MWh<br>Emissions in kg$CO_2$eq per MWh | | | |

Table 3: Technologies' attributes.

| | |
|---|---|
| Annual demand for electricity | 35 million kg |
| Non-service penalty | 1,000 $ per kg |

Table 4: Demand for hydrogen.

| | |
|---|---|
| Capacity factor | Up to 85% |
| Specific electricity consumption | 50 kWh per kg |
| Fixed production costs | 2486 $ per kg per hour per year |
| Fixed storage costs | 49.2 per kg per year |
| Variable production costs (excluding energy) | — |

Table 5: Electrolyser's attributes.

[4] Hours of storage at maximum discharge: 4; Round-trip efficiency: 85%.

[5] Capacity factor: up to 85%.

# References

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# Disclosure: Use of AI-assisted Writing Technologies

In the spirit of transparency, we acknowledge the use of AI-assisted writing technologies — Google's Gemini and Open AI's ChatGPT — in the creation of this note. These technologies were employed solely to improve the clarity and flow of the language, and did not contribute to the core research, analysis, or arguments presented.