

FEBRUARY 2024

# HYCLICX-NL report over year 2023

HYXCLICX is a product developed by HyXchange. This indicator is an instrument to estimate the marginal production cost of hydrogen in the Netherlands.

For questions regarding HyXchange and HYCLICX please contact [j.schellekens@hyxchange.org](mailto:j.schellekens@hyxchange.org) or [b.denouden@hyxchange.org](mailto:b.denouden@hyxchange.org)

# HYCLICX: Key insights

**Introduction: In 2023 HyXchange started publishing the HYCLICX hydrogen spot indicator.**

- HYCLICX estimates marginal cost for renewable hydrogen from electrolysis during cheapest half of electricity hours, mostly coinciding with high share of renewable power.
- It links the marginal cost component of hydrogen to the hourly electricity spot market, reflecting green electricity as source for green hydrogen. Capital costs for electrolysis (substantial but more situational) are not included yet.
- The indicator is calculated for the Netherlands. The method would be also applicable to other countries.
- This report provides insights looking back at prices in 2023, and further analysis and explorations for 2030.

**Average marginal H2 production costs NL 2023 (OPEX), excluding capital and other fixed cost.**

**HYCLICX green best 50%:** 109.4 €/MWh; 4.3 €/kg

**HYCLICX green 2x6h:** 126.1 €/MWh; 4.9 €/kg

**HYCLICX blue:** 71.3 €/MWh; 2.8 €/kg

**HYCLICX grey:** 75.8 €/MWh; 3.0 €/kg

Cost in €/MWh is based on upper heating value of hydrogen (HHV)

**Key insights 2023 (HYCLICX NL green best 50%):**

- Average marginal cost was 4.3 €/kg for green hydrogen at lowest 50% of hours (mostly 2 varying blocks per day).
- Average marginal cost spread between green and grey was 1.3 €/kg in 2023, tending to decrease during the year.
- There is substantial variation in green hydrogen marginal cost due to varying wind and solar input.
- Most production hours correlate with a higher share of Dutch renewable electricity production than average.
- In 20% of production hours the exemption criterion for temporal correlation condition is also met.

*If HYCLICX NL green best 50% is applied to simulated 2030: (with more wind (21 GW) and solar power, increased power demand and green hydrogen industry target of 42%)*

- Almost all production hours correlate with a very high share of hourly Dutch renewable electricity production.
- In 48% of production hours the exemption criterion for temporal correlation condition would also be also met.
- The marginal cost spread between green and grey hydrogen is expected to decrease.

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# HyXchange

## 1. The HyXchange Initiative & HYCLICKX-NL

# The HyXchange Initiative

**Introduction:** Renewable and low-carbon hydrogen are increasingly attracting interest as an important part of the energy transition. No greenhouse gas is released when hydrogen is used. Hydrogen is therefore regarded by many as a climate-neutral energy carrier for the future.

Due to the position that hydrogen will occupy in the future and the many ways in which it can be produced and used, with a variety of producers and users, the development of the trade in hydrogen will become important.

As a result, parties from the sector have started the “HyXchange” Initiative. HyXchange is supported by Gasunie, Port of Rotterdam, Port of Amsterdam, Groningen Seaports, North Sea Ports and a large growing number of interested market parties who participate in meetings, pilots, simulations and/or other HyXchange activities.

**Key objectives:** For the functioning of a hydrogen exchange it is important that the underlying conditions for market forces in hydrogen are met:

- Firstly, an open and accessible transport infrastructure for hydrogen. This will be facilitated with the establishment of the Dutch Hydrogen backbone & storage facility.
- Secondly, a diverse supply of hydrogen: green hydrogen from electrolysis of renewable power, low-carbon hydrogen from industrial processes, imports from various countries. This contributes to the security of supply.
- Thirdly, a dependable and transparent trading platform. This greatly enhances market access, pools liquidity and reduces transaction costs and trading risks.

The HyXchange platform is expected to catalyze an increasing demand for climate-neutral hydrogen produced by an expanding asset base, driving optimal balancing of supply and demand through transparent pricing.

# HYCLICX: introduction

**Introduction:** In 2023 HyXchange published its first issue of the hourly HYCLICX spot market indicator for hydrogen based on lowest-priced electricity hours. HYCLICX acts as an instrument to estimate marginal production cost for renewable hydrogen from electrolysis (for now in the Netherlands, could also be applied in other countries).

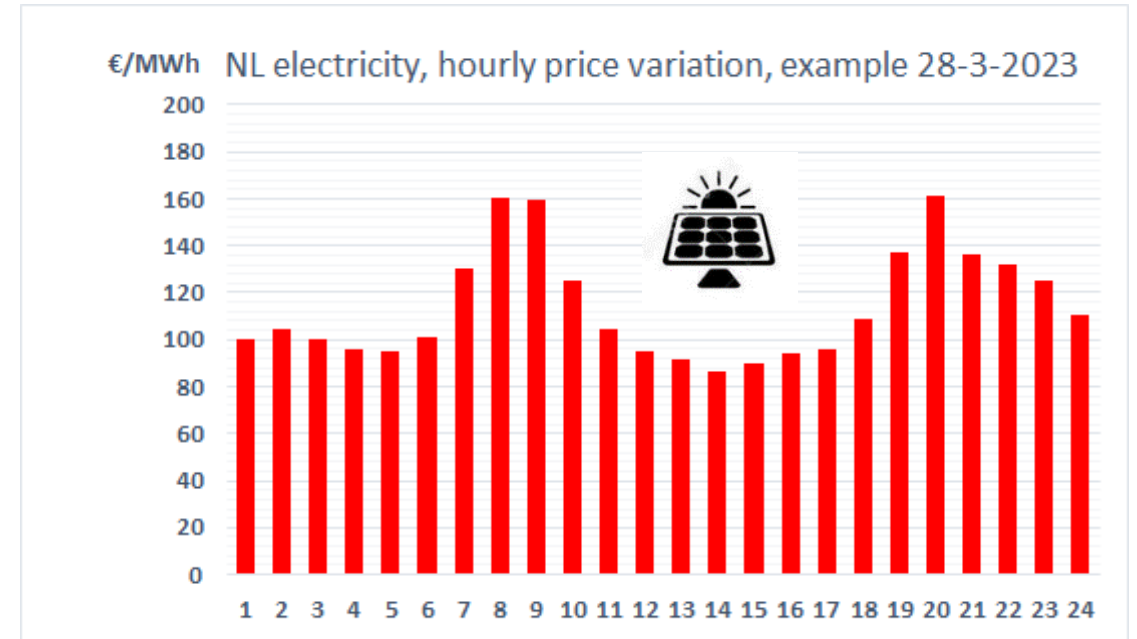
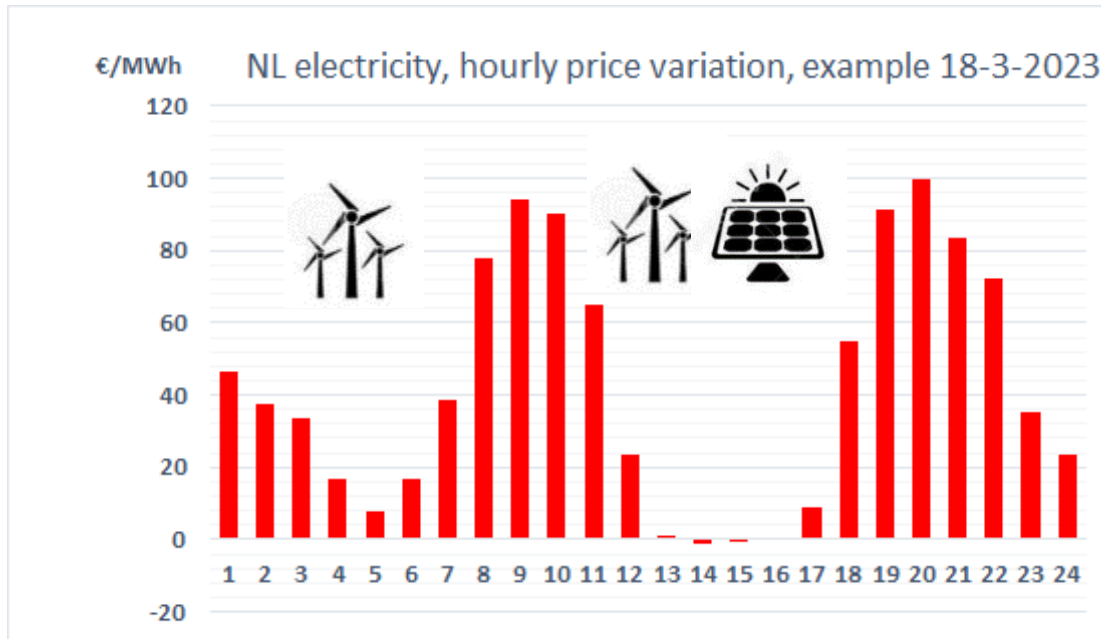
**Approach:** The renewable HYCLICX indicator is linking the marginal cost component of hydrogen to the hourly electricity spot market, reflecting the electrolysis as a source for green hydrogen. By selecting the lowest set of volatile hourly power prices - mostly occurring in two varying blocks per day in the Netherlands - hydrogen can be produced with cheapest cost. The hours are largely coinciding with a high share of renewable electricity production from wind and solar, also providing alignment with certificate rules and the [EU COM Delegated Act on hydrogen](#).

**Selected indicators:** HYCLICX publishes on a monthly interval a selection of relevant indicators for hydrogen:

- **HYCLICX green (daily 2x 6 hour blocks):** The marginal cost price for the cheapest (fixed) 12-h of electricity each day: hours 1-6 and 12-17 (0.00-6.00 and 11.00-17.00)
- **HYCLICX green best 50% (month):** The marginal cost price for the lowest-priced 50%-h of electricity per month.
- **HYXCLICX blue (daily):** The marginal cost price for blue hydrogen, to allow for comparison.
- **HYXCLICX grey (daily):** The marginal cost price for grey hydrogen, to allow for comparison.

The HYCLICX methodology, at the moment calculated for the Netherlands, can also be readily applied to other countries with a transparent hourly electricity price. Interested countries are invited to contact us to discuss options. HYCLICX development is supported by experts from [E-Bridge](#) and [Berenschot](#).

**HYCLIX index takes the time variability of the electricity price during the day into account, especially in the Netherlands: two humps and valleys, see examples below,**



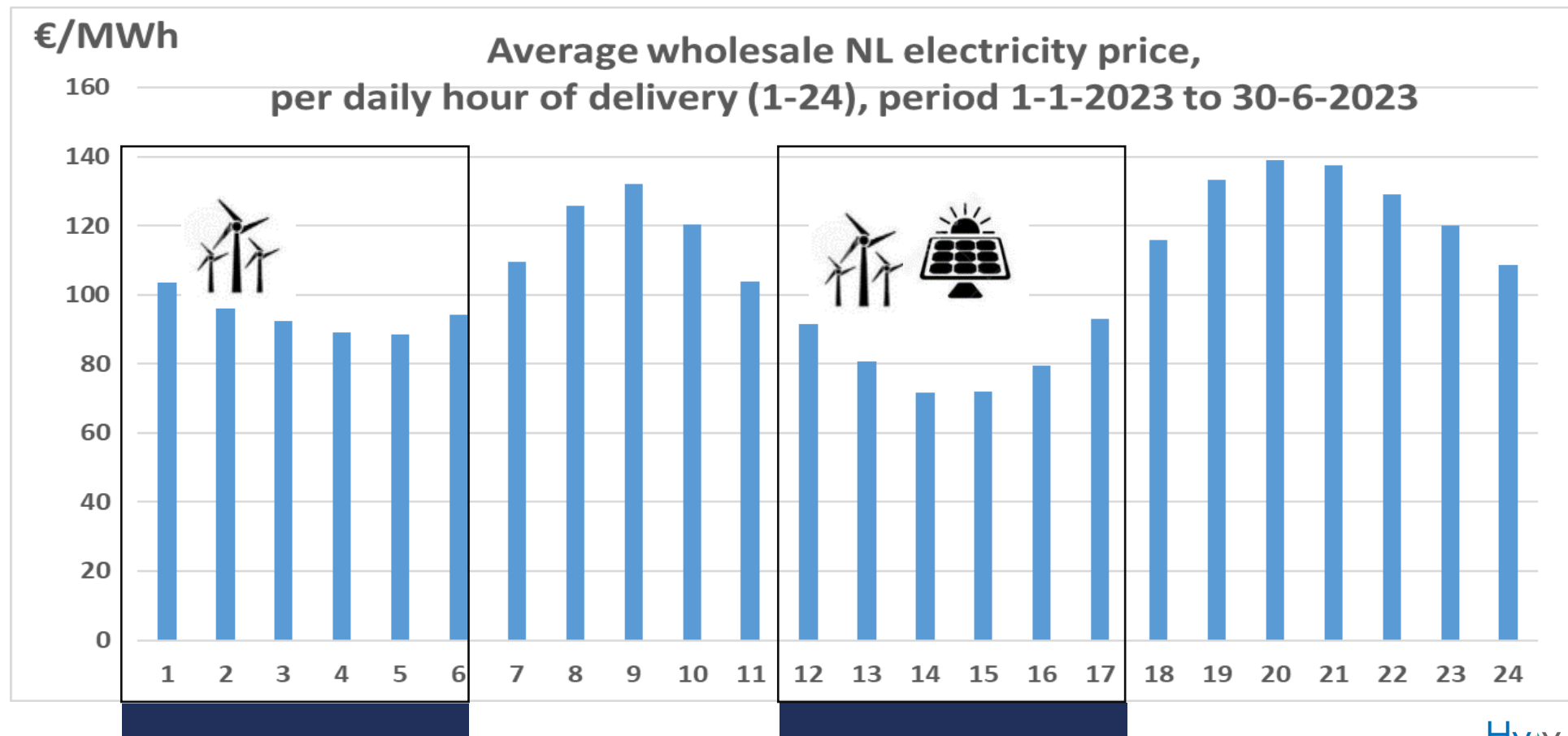
**Hours with low prices increasingly correlated to high renewable input: best hours for hydrogen production.**



# HYCLICX: hours with lowest power prices

Calculate marginal cost for each hour, work together with E-Bridge (HYDEX index Germany)

- **Daily: average lowest-prices 2x6 hour blocks (fixed, see below)**
- **Monthly: lowest priced 50% of hours in that month (varying monthly pattern)**





# HYCLICX: publication frequency

**Frequency:** The HYCLICX is published on a monthly basis, showing in detail the hydrogen marginal cost for the previous months. In addition, a weekly update is available on our website. This annual publication looks additionally to the whole year and also **in 2030**.

**Further analysis:** The pre-defined 2x6 hour operating approach and the monthly 50% best are possible operational patterns. Alternative (equally good) operational options exist. Any market party can apply a different operational pattern in its own individual way by using the hourly HYCLICX data.

Please contact the HyXchange team directly to obtain the hourly dataset for HYCLICX-NL-2023 to allow for further computation.

**Additional information:** Insight in the cost price of hydrogen makes it possible to start hydrogen trading more quickly. Hence, HyXchange with its marginal cost indicator is contributing to the growth of trade in hydrogen produced through renewable energy as a main commodity in the energy transition and at the same time reducing overall natural gas dependence.

The HYCLICX indicator was inspired by the HyXchange spot market simulation of the future hydrogen market, optimizing the spot market outcome on marginal cost. A total of 25 market parties participated in various simulation meetings.

See also: [www.hyxchange.org](http://www.hyxchange.org)

# HYCLICX: marginal cost formula

The marginal costs for hydrogen production are determined according to the following methodology (hourly).

$$\text{HYCLICX} = \sum \text{fixOPEX} + \frac{\text{Elec Price} + \text{Elec tax} + \text{GO}}{\eta} + \frac{\text{Spec Water Cost} \cdot \text{Spec Water Demand}}{\text{HHV}}$$

Selected cost parameters*		HYCLICX Green	HYCLICX Blue	HYCLICX Grey
	Unit	Electrolysis	CH4 + CCS	CH4 (no CCS)
Operation & Maintenance (O&M), <i>fixed part</i>	EUR/MWh	13.72	7.51	6.06
Efficiency (HHV)	%	76.83	82.74	88.65
Electricity and gas levies (incl. Green GOe)	EUR/MWh	7.465	4.01	4.01
Water cost	EUR/m <sup>3</sup>	4	-	-

*\*Basic calculation method and most parameters provided by consultant E-bridge. In line with their HYDEX index for hydrogen in Germany. Approach to assess green hydrogen product cost per hour (and select blocks of operational hours) for HYCLICX provided by HyXchange based on its hydrogen market simulation project and discussions with market parties.*

# HYCLICX: what is included in marginal index

## HYCLICX: what is included?:

- Electricity spot price (hourly variable)
- Green guarantee of origin for renewable electricity (monthly)
- Tax on electricity demand electrolyser not into stack (auxiliary power)
- Water cost
- O&M costs
- Opex component for stack replacement

For blue and grey hydrogen:

- Gas price (daily variable), CO2 price (daily variable) and/or CCS storage cost

→ Costs that are associated with producing additional MWh of hydrogen (marginal-price)

## HYCLICX: what is not included?:

- Capital cost of investment of Electrolyser
- Upfront project preparation cost
- Fixed administration and overhead cost
- One-time electricity grid connection fee or cost
- Yearly fixed electricity grid tariff, capacity related
- Hydrogen grid: all shipper tariffs, connection fees
- Cost for other transportation (by ship or trailer)
- Commercial margin
- Min. load that an electrolyser should operate at

For blue and grey hydrogen:

- Same principles apply as above

→ Costs that are independent of producing additional MWh of Hydrogen





# HyXchange

## 2. Insights HYCLICX-NL, findings 2023

# HYCLICX-NL 2023, intro & summary

**Introduction:** Now that 2023 is over, it is possible to look back and obtain valuable insight in the variable cost of producing hydrogen. This will be done by providing a response (key figures and graph) on the following questions:

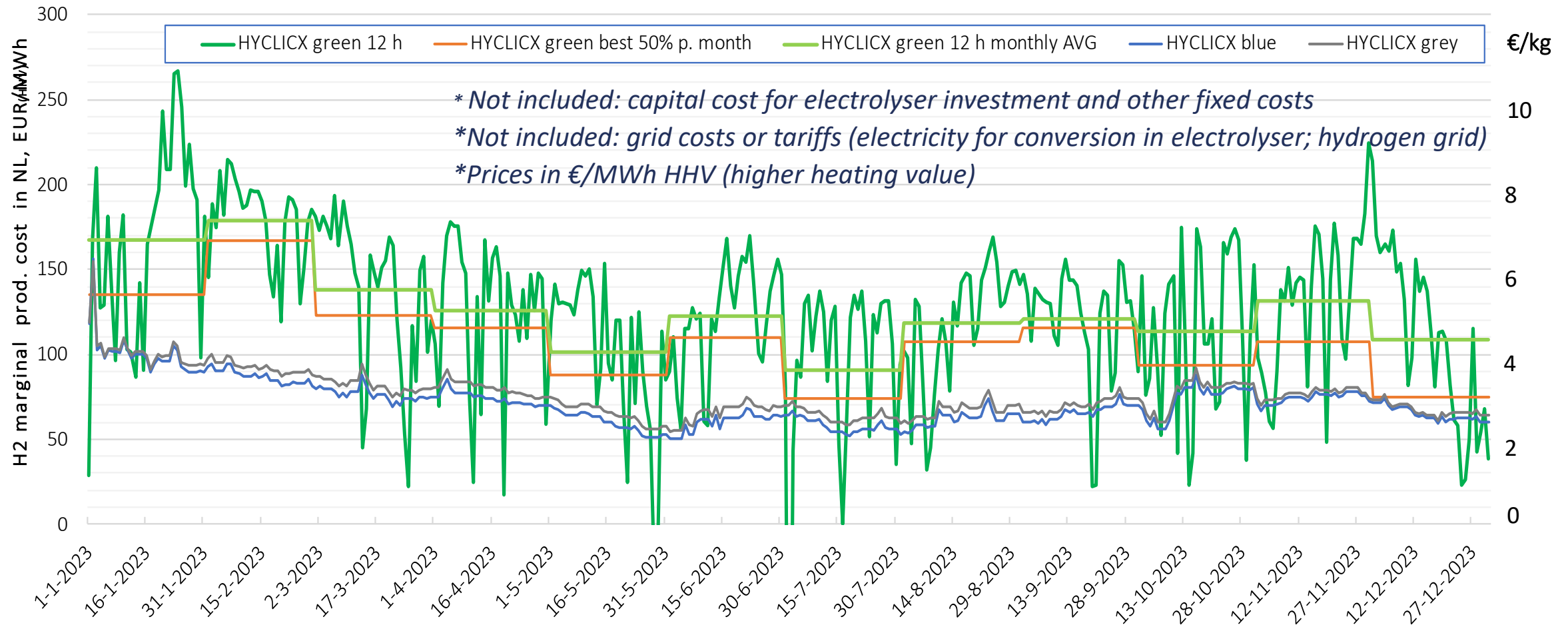
- What is the average cost of production (variable, and for each of the production options)?
- How does the production pattern look like (both across the season and which hours, for 50% best hours)?
- To what extent does production align with requirements for green hydrogen according to the EU Delegated Act?

These questions will also be explored answered for 2030 based on available market simulations. This allows for insight in the role of the HYCLICX its characteristics in next years.

## Key figures HYCLICX-NL-2023:

- **HYCLICX green best 50% (monthly):** 109.4 €/MWh
  - Price in €/kg H<sub>2</sub>: 4.3 €/kg
  - Price in LHV: 129.3 €/MWh
- **HYCLICX green (daily 2x 6h blocks):** 126.1 €/MWh
- **HYXCLICX blue (daily):** 71.3 €/MWh; 2.81 €/kg
- **HYXCLICX grey (daily):** 75.8 €/MWh; 3.00 €/kg
- Spread **green (HYCLICX best 50%) - grey:** 1.3 €/kg

# HYCLICX-NL 2023, marginal cost (OPEX)





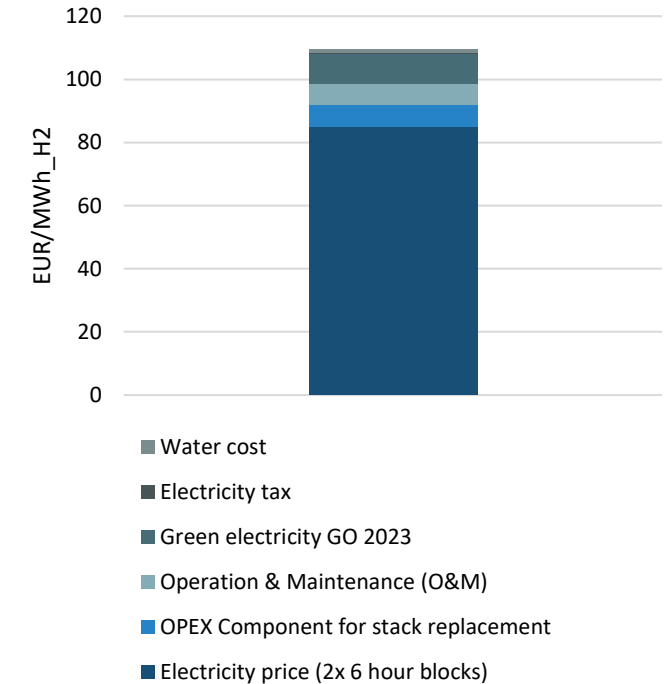
# HYCLICX green best 50%: 2023

Month of 2023	HYCLICX Green best 50% €/MWh HHV marginal cost	HYCLICX Green best 50% €/kg marginal cost	HYCLICX Green best 50% €/MWh LHV marginal cost
January	135.12	5.32	159.71
February	167.08	6.58	197.50
March	122.64	4.83	144.97
April	115.80	4.56	136.88
May	88.22	3.48	104.28
June	110.02	4.33	130.05
July	73.72	2.90	87.14
August	107.43	4.23	126.99
September	115.62	4.55	136.67
October	93.92	3.70	111.02
November	107.69	4.24	127.29
December	75.08	2.96	88.74
<b>Average 2023</b>	<b>109.36</b>	<b>4.31</b>	<b>129.27</b>

- Prices primarily in EUR/MWh HHV higher heating value, full H2 energy content
- Aligned with indexes for natural gas (e.g. TTF), rules of Dutch H2 grid and green G.O
- Conversion factor P/MWhHHV to P/kg: 0.03939 ~ 4 / 100
- Conversion factor MWhHHV to MWhLHV: 1.182

\*Marginal price component (not included: capital cost for electrolyser investment and other fixed costs).

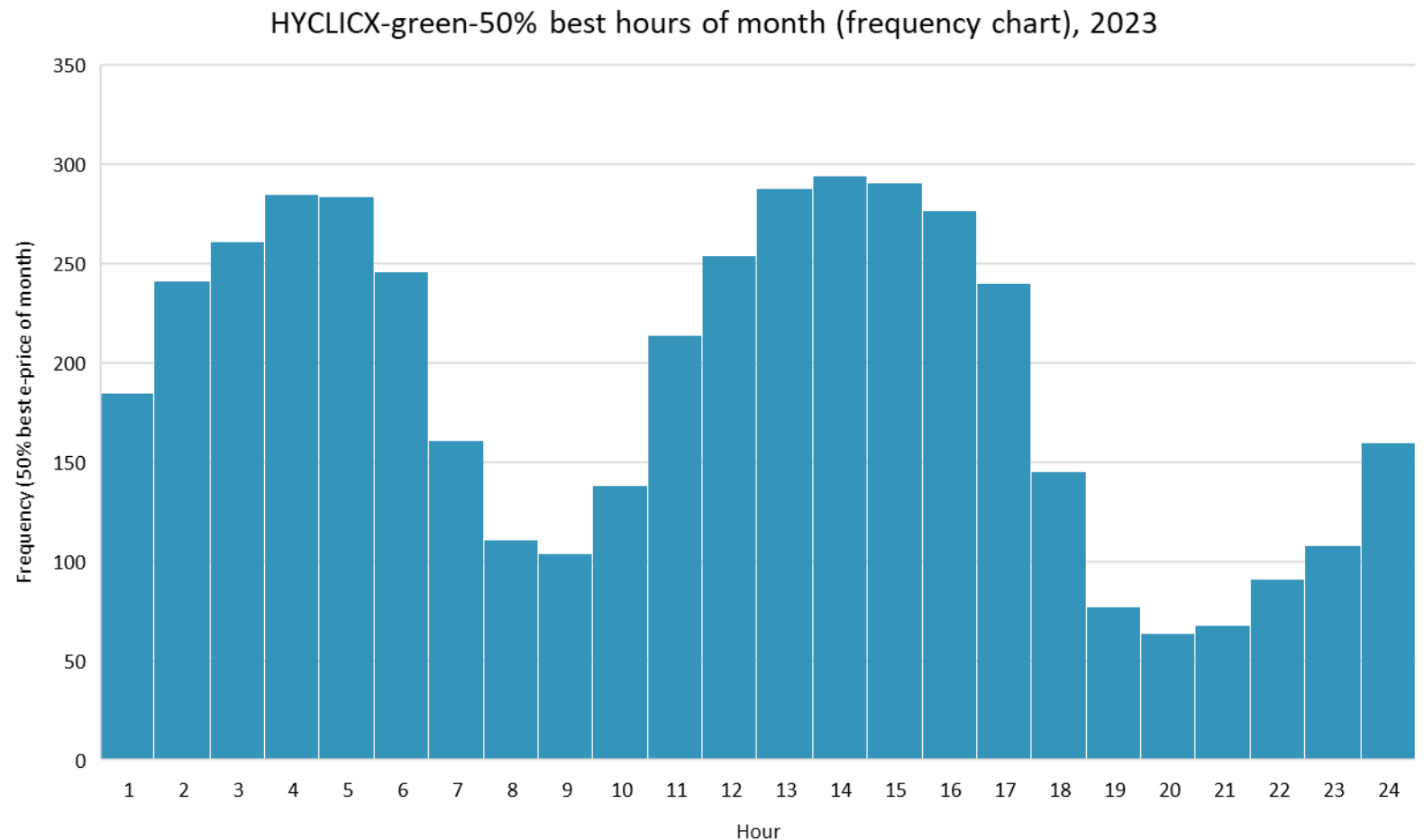
HYCLICX variable hydrogen price  
cost components (average for  
2023)



# HYCLICX-NL 2023, production pattern

**Introduction:** We reviewed two production pattern options as part of the HYCLICX. First a 2x 6h production pattern and second a 50% lowest priced hours per month approach (the latter requiring perfect foresight). The graphs on the right shows results for the 50% best hours production method.

**Insights:** The average marginal cost is 4.3 EUR/kg in 2023 and production takes place mostly during the 2x 6h time blocks, but also outside. This is because some days the marginal cost is very low during the entire day (constant wind and/or holidays).



*\*the number of selected hours in the 50% lowest priced hours provides 4.587 (2023 and 4.551 in 2030) hours; this is because some months multiple hours have an equal 'low' price and hence are both selected. This means slightly more production hours than 4.380 (which would be exactly 50%)*

## 3. Further analysis:

- A. Correlation with renewables, EU Delegated Act and exceptions
- B. Exploration HYCLICX-NL, simulation 2030
- C. Sensitivity analysis of HYCLICX subject to electrolyser ramping and minimum production floor



# 3A .Renewability of HYCLICX in 2023

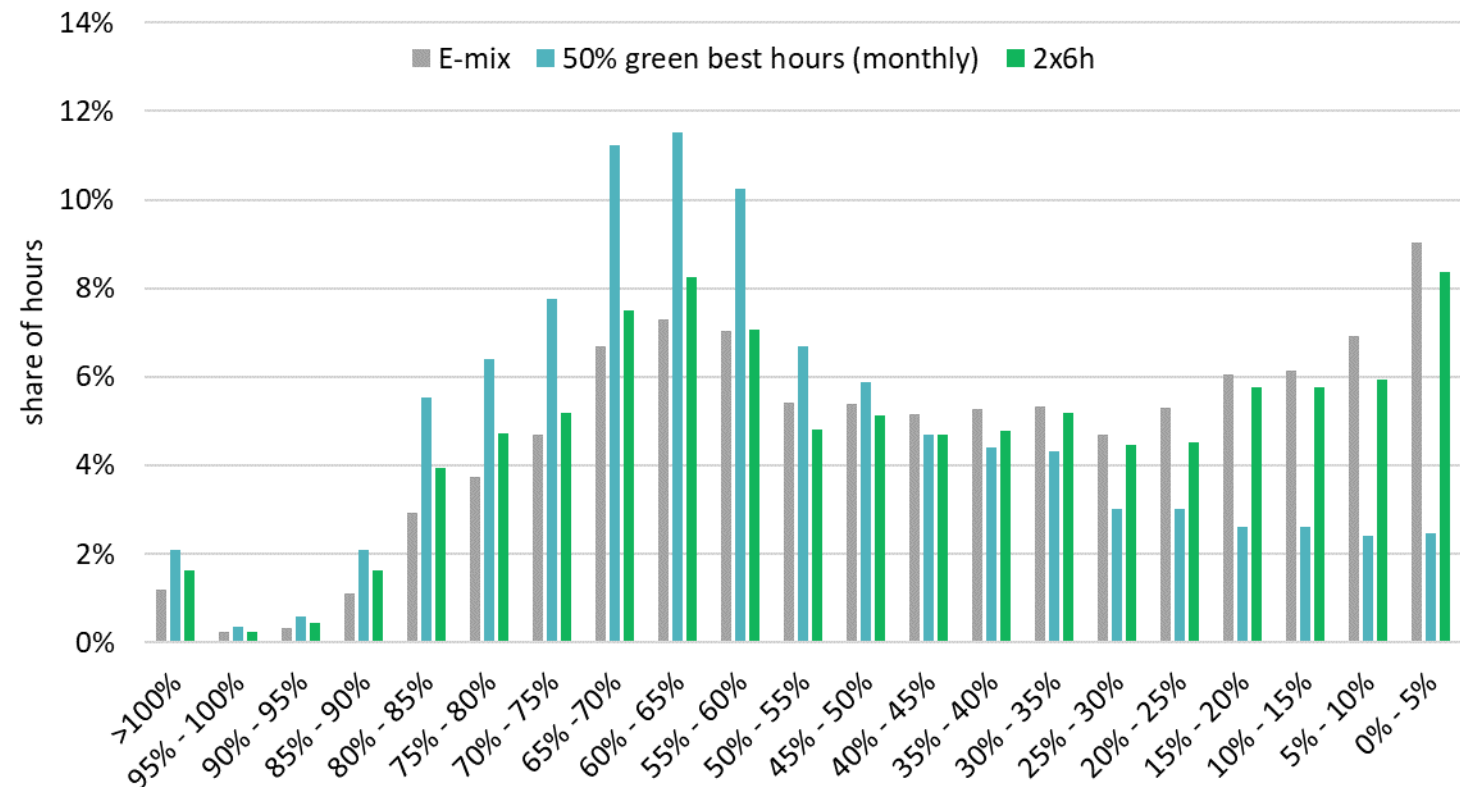
*Based on real market data from 2023 (hourly prices, renewable share data\*)*

**Introduction:** Production of green hydrogen has to meet EU Delegated Act criteria: renewability of power input. For 2023 we compared electrolyser production hour patterns for the HYCLICX 2x6 and best 50% per month, with hourly wind and solar production as share in total national demand.

## Insights:

- HYCLICX best 50% production pattern performs much better than 12h, with production mostly during hours with higher shares of renewable production in E-mix.
- For the monthly correlation required by the Delegated Act up till 2030, this should be suitable for a PPA, to be studied further.
- For hourly correlation required from 2030 onward, renewable share needs to increase.

## Renewables (wind, solar) in electricity mix and HYCLICX



Source for hourly renewable production data 2023: <https://energieopwek.nl/>

# Expected renewability HYCLICX 2030

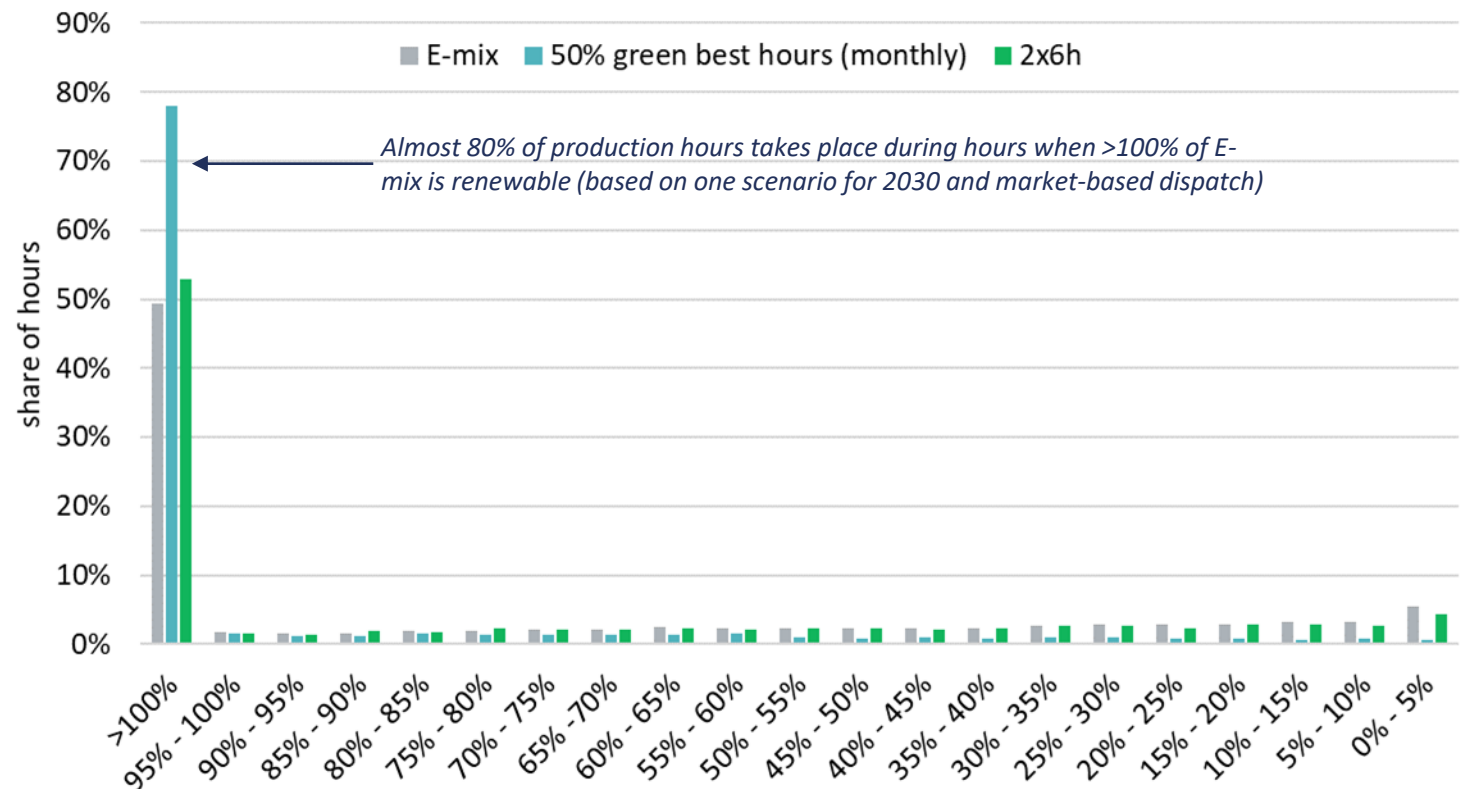
*Based on simulated 2030 electricity market (hourly prices, renewable shares)*

**Introduction:** For 2030 the share of renewability per hour is also calculated using simulated hourly renewability taken from the H2 spot market simulation study (scen. F2).

## Insights:

- With the expected increase in renewable capacity in 2030 (Dutch government target of 21 GW offshore a.o.) the hourly correlation greatly increases.
- The HYCLICX best 50% strongly correlates with high shares of renewable electricity. Only 8.4% production hours have a renewable share lower than 50%.
- This high hourly renewable correlation of the HYCLICX 50% index is a good basis for PPA's, to be studied further.

## Renewables (wind, solar) in electricity mix and HYCLICX

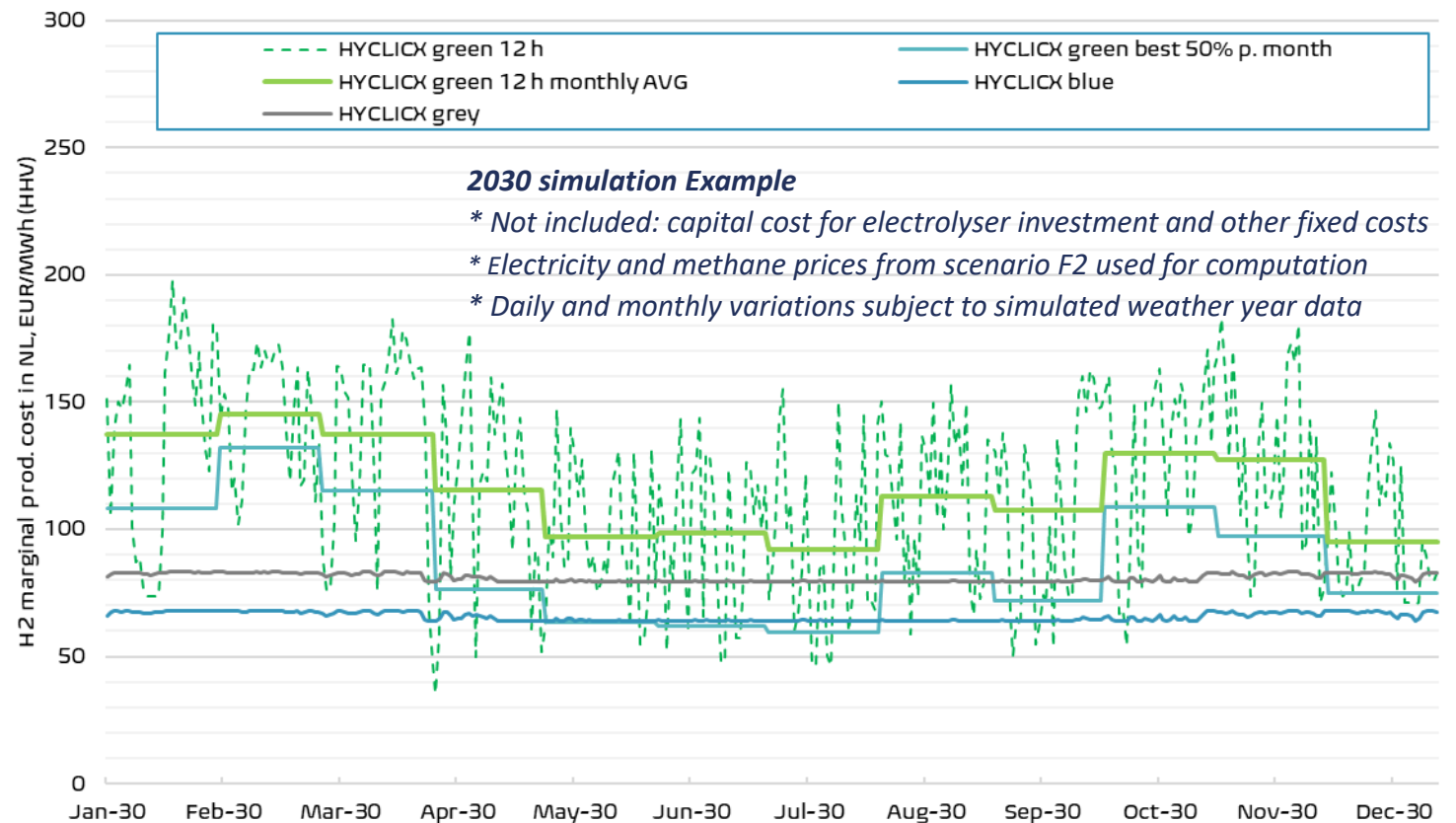


# 3B. Exploration of HYCLICX-NL in 2030

*Based on simulated 2030 electricity market (hourly prices)*

**Introduction:** HyXchange conducted a simulation study on the dynamics of the future hydrogen spot market. The aim of this study was to increase understanding of the dynamics of the future hydrogen system and its balancing needs. This study developed 8 scenarios for the energy system in 2030 and produced a.o. hourly prices for electricity and methane.

In order to explore 2030 market dynamics, the results from one of those scenarios (F2) is used as an example. Results from the simulated HYCLICX-NL in 2030 are plotted on the right. Results are not a prediction but allow for a better insight in the patterns and the (marginal) spreads.



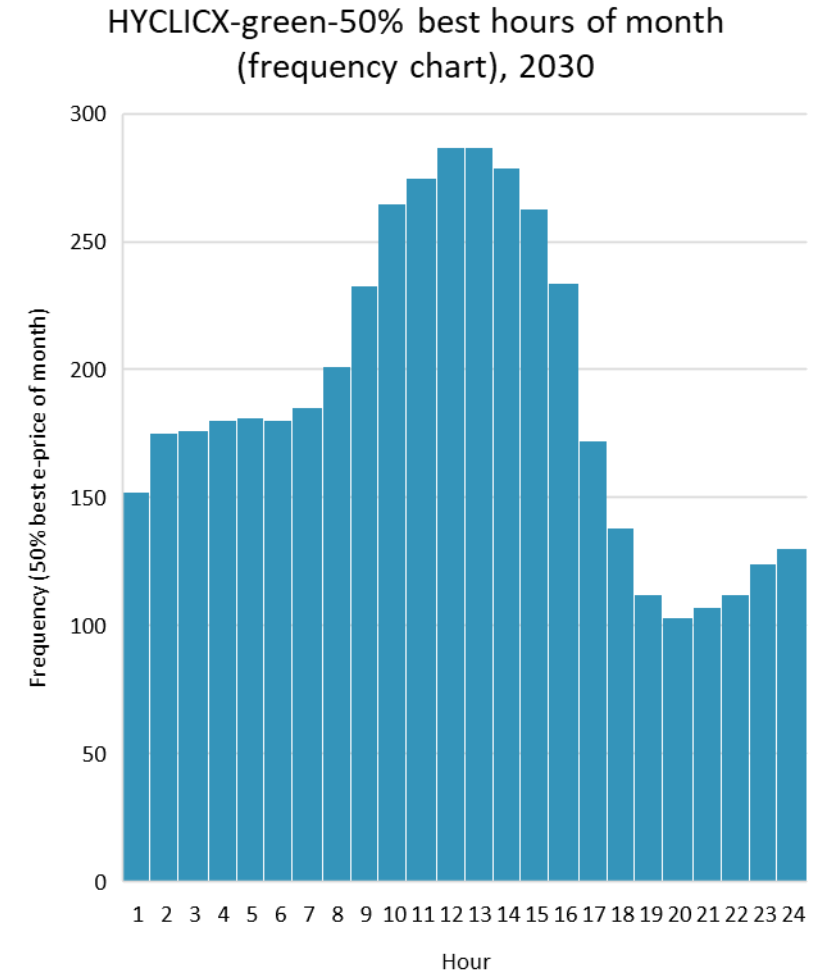
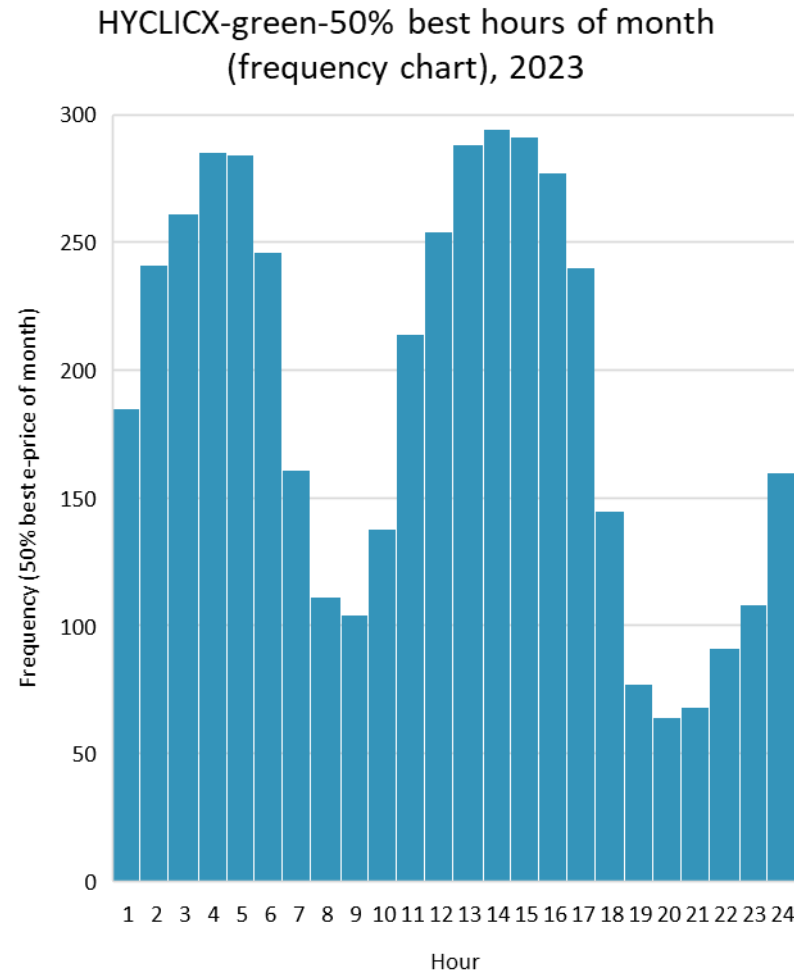
**Disclaimer:** We note that many variables in the hydrogen sector for 2030 are still uncertain and actual prices will be affected by this (e.g., installed capacity offshore wind; in the simulation assumed to meet the 21GW target).

# HYCLICX-NL, production pattern

*Based on HYCLICX-NL-2023 and simulated HYCLICX-NL-2030 electricity market (hourly prices)*

**Introduction:** Similar to 2023 we looked at the result for the 50% lowest-price-hours production pattern.

**Insights:** The production pattern in 2030 becomes more even across the day, with a clear peak during solar production hours and a dip in the evening (likely due to additional demand from charging of EVs and e-cooking/heating, causing higher price). The peak during night hours, visible in 2023, disappears in 2030. In the 2030 simulation we see a reduction in the spread between green and grey marginal production cost (var+fixOPEX).





# HYCLICX-NL, temporal correlation

*Based on HYCLICX-NL-2023 and simulated HYCLICX-NL-2030 electricity market (hourly prices)*

**Introduction:** The EU Delegated Act requires the condition of temporal correlation to be met. This can be achieved using 1) a PPA or 2) an e-price that is below 20 EUR/ MWh OR  $< 0.36 * \text{the CO}_2\text{-price (136 EUR/t)}$ . Figures show which hours HYCLICX meets the latter.

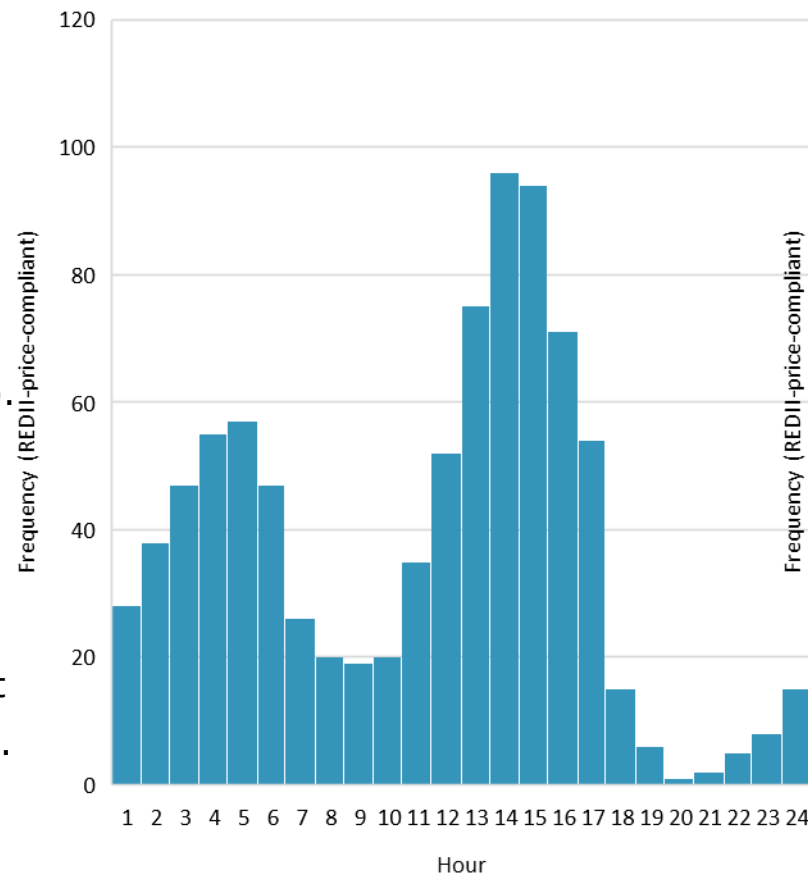
## Results:

- The exemption condition is met in **886 hours** in 2023 (although not yet in effect).
- The exemption condition is met in **2.178 hours** in 2030 (with PPA this can be further increased).

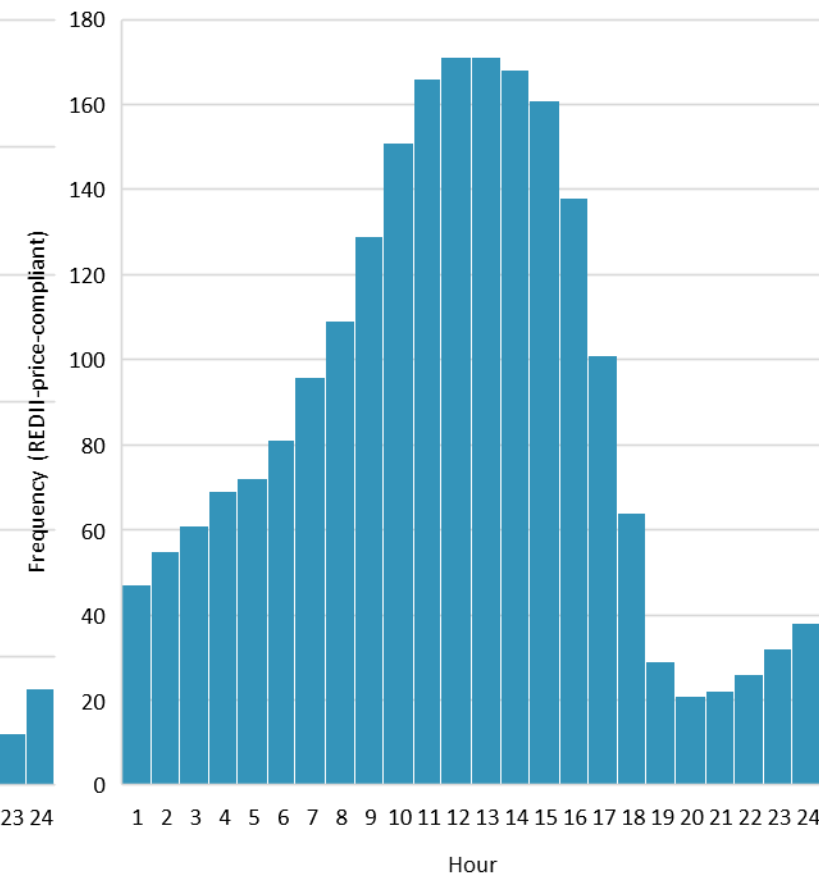
## Insights:

- The number of hours this criteria is met at a national level increases almost threefold.
- Low prices will likely shift from 2x6 hour blocks towards the solar hours

Electricity Price  $\leq 20$  EUR/MWh AND/OR  $\leq 0.36 * \text{CO}_2$  Price, 2023



Electricity Price  $\leq 20$  EUR/MWh AND/OR  $\leq 0.36 * \text{CO}_2$  Price, 2030



# 3C. Effect of minimum 10% elek. load

*Based on HYCLICX-NL-2023 and simulated HYCLICX-NL-2030 electricity market (hourly prices)*

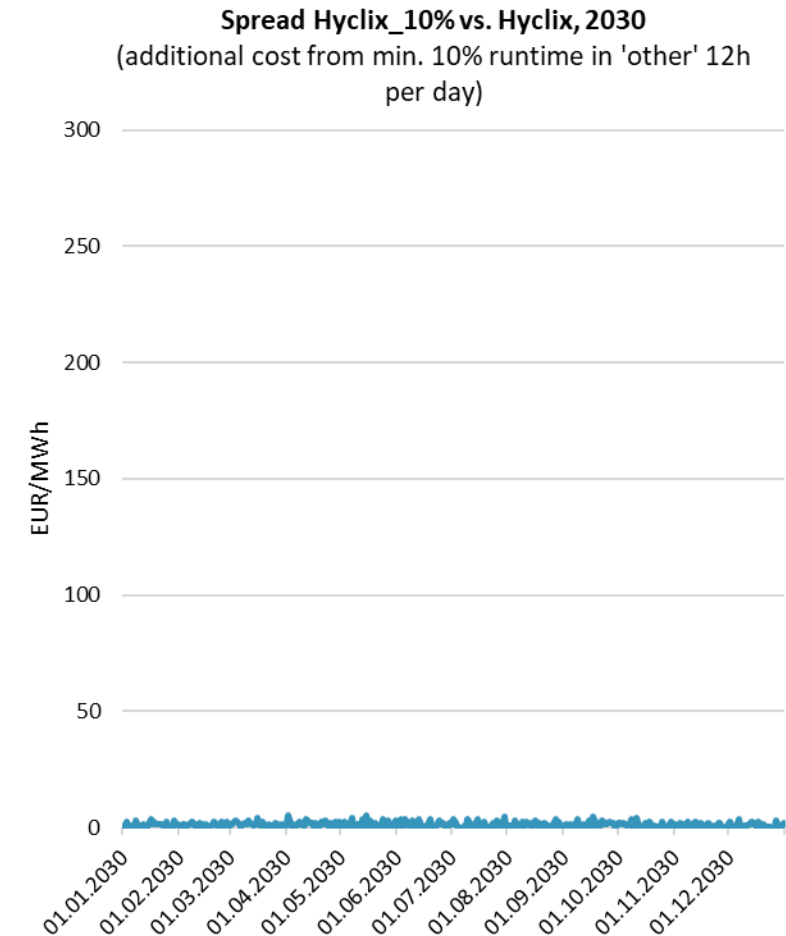
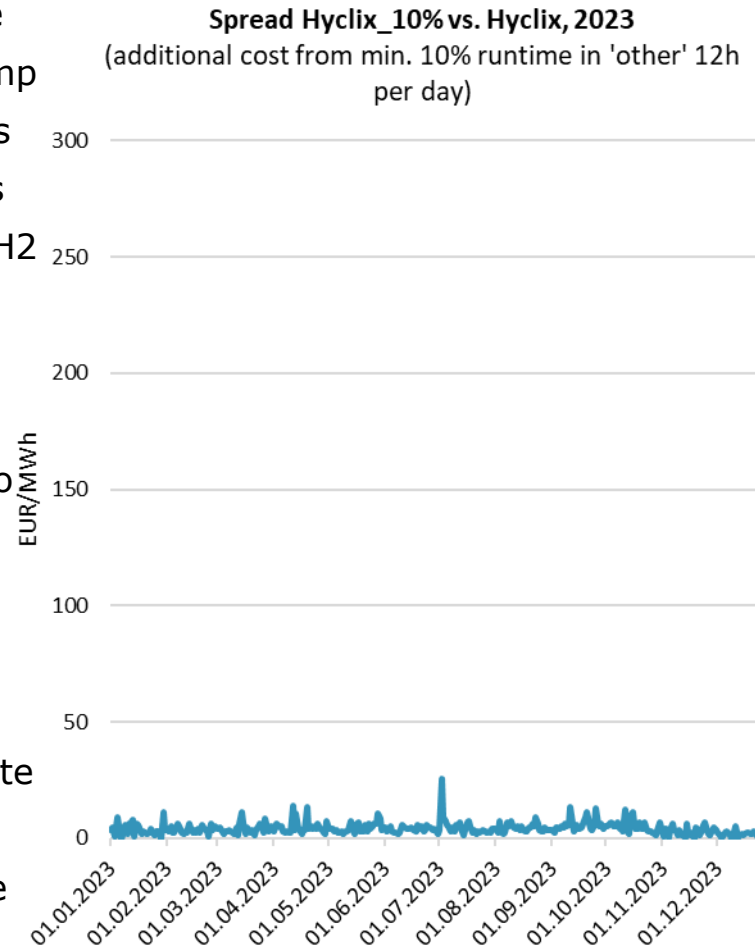
**Introduction:** An electrolyser must operate at a certain minimum load, to be able to ramp up twice a day to full production capacity. As such it also produces hydrogen during hours with high E-prices, this affects the average H2 cost price. We tested this impact assuming minimum production capacity of 10%.

## Results:

- In 2023 (real historic prices) this leads to an **increase of 3.3% in varOPEX** p/a.
- In simulated 2030 this leads to an **increase of 1.0% in varOPEX** p/a.

## Insights:

- The minimum production capacity has little impact on cost price levels in 2023.
- The impact decreases even further in the simulations for 2030 (and may even decrease further due to innovation).





HyXchange

Appendix: parameters and  
sources used by HYCLIX-NL

# Parameters for HYCLICX calculation 2023

Selected cost parameter	Unit	HYCLICX green	HYCLICX blue	HYCLICX grey
		Electrolysis	Reformer + CCS	Reformer w/o CCS
OPEX Component for stack replacement	EUR/MWh_H2	7.18	-	-
Operation & Maintenance (O&M)	EUR/MWh_H2	6.54	7.51	6.06
Lower heating value Hi / LHV	kWh/kg_H2	33.32	33.32	33.32
Higher heating value Hs / HHV	kWh/kg_H2	39.39	39.39	39.39
Efficiency (ref. to lower heating value Hi / LHV)	%	65.00	70.00	75.00
Efficiency (ref. to higher heating value Hs / HHV)	%	76.83	82.74	88.65
Full-load hours (12h. 2 6h blocks per day)	h/a	4380	7000	7000
Water cost	EUR/m <sup>3</sup>	4	-	-
Water demand	m <sup>3</sup> /kg_H2	0.01	-	-
CO2 transport and storage cost (only operational part. no CAPEX)	EUR/t_CO2	-	35	-
CO2 emissions for natural gas	t_CO2/MWh_NG	-	0.201	0.201
Sequestration rate for CCS	%	-	90	0
Additional cost for electricity (Electricity tax and green electricity GO))	EUR/MWh_e	0.115 + 7.35	-	-
Additional cost for natural gas (Gas tax)	EUR/MWh_NG	-	4.01	4.01

*\*For the 2030 analysis key changes are input electricity and methane prices. The hourly values are taken from a study by HyXchange, TNO and Berenschot (Hydrogen Spot Market Simulation, 2024). Additionally, a tax on CO2-emissions of 136 EUR/t\_CO2 is used. According to S&P the price of green GO will drop to 5.5 EUR/MWh\_e. All other parameters and the approach to calculating the varOPEX hydrogen price is similar to the 2023 approach.*



# Literature list

No.	Source
1a	Efficiency Electrolysis: IEA 2020/Platts Methodology and Specifications Guide Global Hydrogen Latest update: October 2020
1b	Reformer with CCS: IEA 2020/ Platts Methodology and Specifications Guide Global Hydrogen Latest update: October 2020
1c	Efficiency Reformer without CCS: IEA 2020/Platts Methodology and Specifications Guide Global Hydrogen Latest update: October 2020
2a	OM Electrolysis 2.2 % of invest: Reuß et al. (2017) Seasonal storage and alternative carriers: A flexible hydrogen supply chain model. Applied Energy
2b	OM Reformer with CCS: IEA 2020/ Platts Methodology and Specifications Guide Global Hydrogen Latest update: October 2019
2c	OM Reformer without CCS: IEA 2020/ Platts Methodology and Specifications Guide Global Hydrogen Latest update: October 2020
3a	Invest Electrolysis: Fraunhofer ISE (2022) Cost Forecast for low temperature electrolysis. S. 56
3b	Invest Reformer with CCS: IEA 2020 Platts Methodology and Specifications Guide Global Hydrogen Latest update: October 2020 (EUR/\$ = 1.15)
3c	Invest Reformer without CCS: Platts Methodology and Specifications Guide Global Hydrogen Latest update: October 2020 (EUR/\$ = 1.15)
4	Benutzungsstunden für Elektrolyse und SMR nach Prognos-Studie (Kosten und Transformationspfade für Strombasierte Energieträger S. 88; <a href="https://www.bmwk.de/Redaktion/DE/Downloads/Studien/transformationpfade-fuer-strombasierte-energetraeger.pdf?__blob=publicationFile">https://www.bmwk.de/Redaktion/DE/Downloads/Studien/transformationpfade-fuer-strombasierte-energetraeger.pdf?__blob=publicationFile</a> )
5	Sequestration rate of CCS: IEA 2020/ Platts Methodology and Specifications Guide Global Hydrogen Latest update: October 2022
6	Electricity tax - Tabellen tarieven milieubelastingen. <a href="https://www.belastingdienst.nl/wps/wcm/connect/bldcontentnl/belastingdienst/zakelijk/overige_belastingen/belastingen_op_milieugrondslag/tarieven_milieubelastingen/tabellen_tarieven_milieubelastingen?projectid=6750bae7%2D383b%2D4c97%2Dbc7a%2D802790bd1110">https://www.belastingdienst.nl/wps/wcm/connect/bldcontentnl/belastingdienst/zakelijk/overige_belastingen/belastingen_op_milieugrondslag/tarieven_milieubelastingen/tabellen_tarieven_milieubelastingen?projectid=6750bae7%2D383b%2D4c97%2Dbc7a%2D802790bd1110</a>
7	Gas tax - Tabellen tarieven milieubelastingen. <a href="https://www.belastingdienst.nl/wps/wcm/connect/bldcontentnl/belastingdienst/zakelijk/overige_belastingen/belastingen_op_milieugrondslag/tarieven_milieubelastingen/tabellen_tarieven_milieubelastingen?projectid=6750bae7%2D383b%2D4c97%2Dbc7a%2D802790bd1110">https://www.belastingdienst.nl/wps/wcm/connect/bldcontentnl/belastingdienst/zakelijk/overige_belastingen/belastingen_op_milieugrondslag/tarieven_milieubelastingen/tabellen_tarieven_milieubelastingen?projectid=6750bae7%2D383b%2D4c97%2Dbc7a%2D802790bd1110</a>
8	CO2 emission acc. BAFA (2021) Informationsblatt CO2-Faktoren. S.6
9	Porthos CCS - Cost for transport and storage. <a href="https://zoek.officielebekendmakingen.nl/blg-947442.pdf">https://zoek.officielebekendmakingen.nl/blg-947442.pdf</a>
10	Hourly electricity prices are taken from Nordpool. <a href="https://www.nordpoolgroup.com/en/Market-data1/data-downloads/historical-market-data2/">https://www.nordpoolgroup.com/en/Market-data1/data-downloads/historical-market-data2/</a>



# HyXchange

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