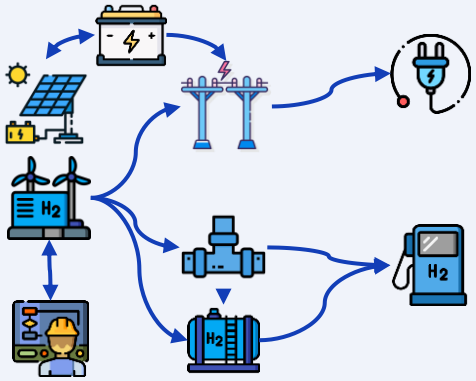
Hydrogen Projects in the Netherlands and Opportunities

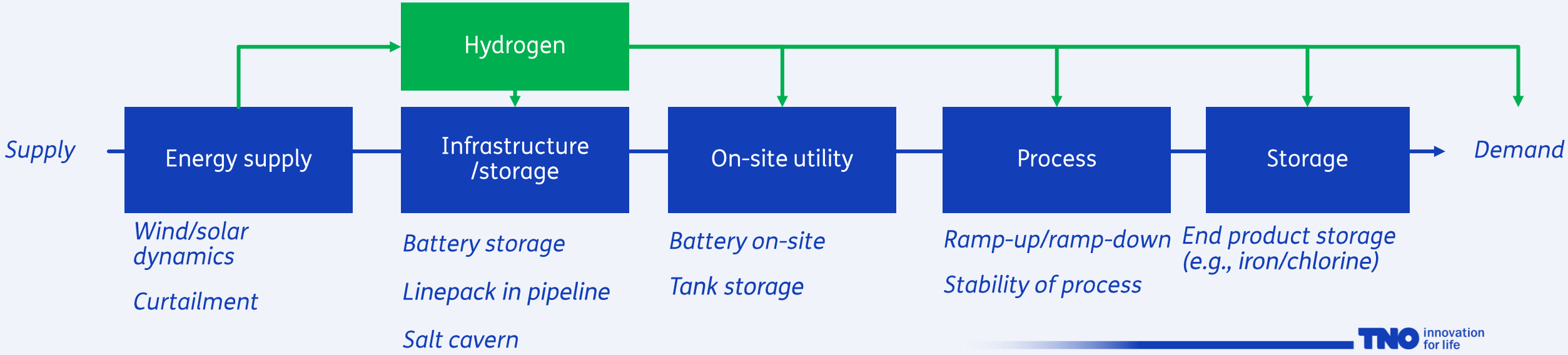
Javier Fatou Gómez, Rene Peters, Lennert Buijs
Senior Scientist Energy Infrastructure and System Flexibility
TNO (Netherlands Organization for Applied Scientific Research)



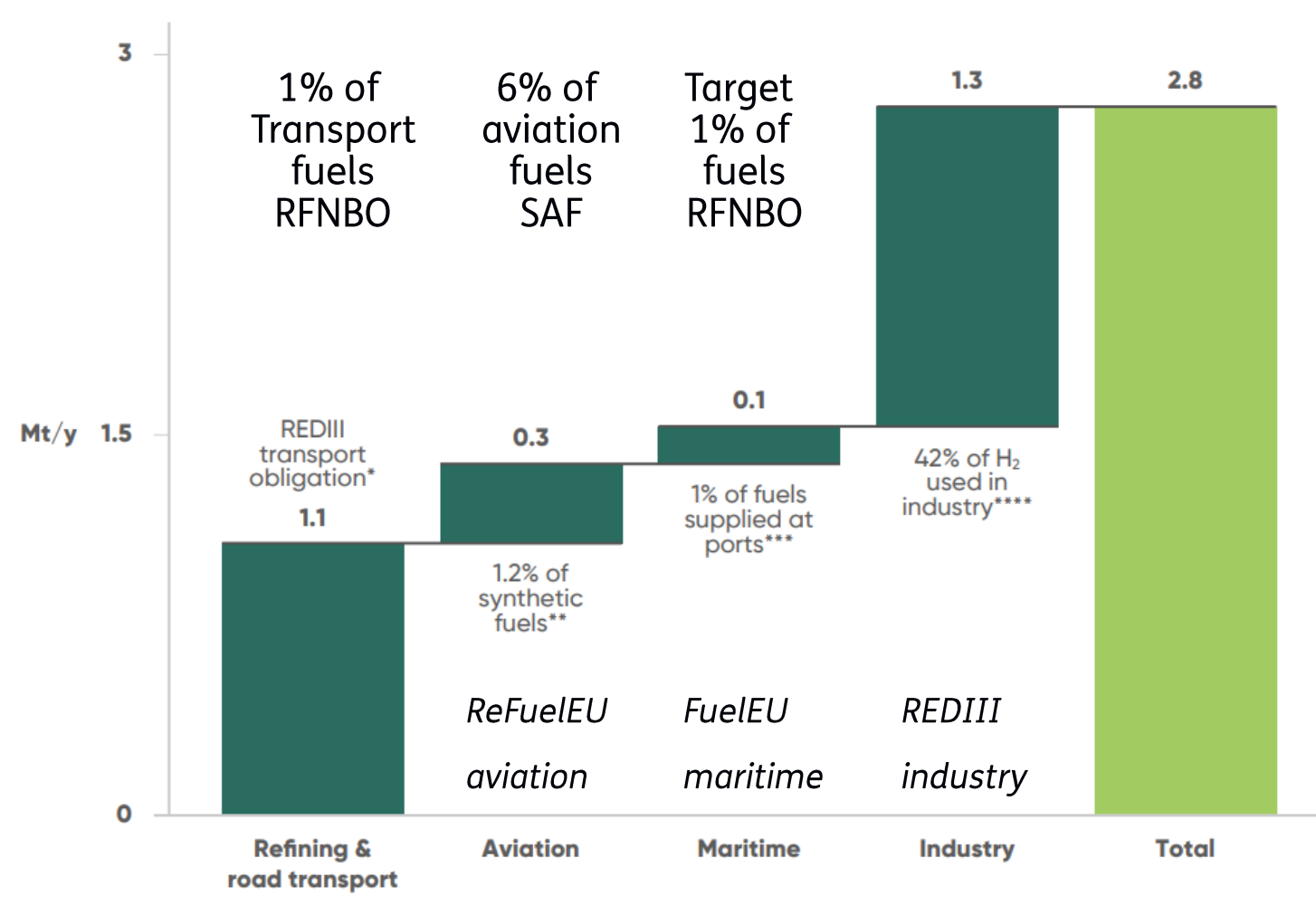
Dealing with intermittency

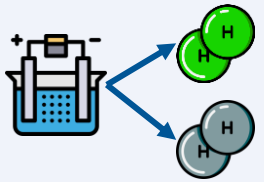


- **With an increase in the energy mix of intermittent sources, dealing with this flexibility becomes of paramount importance.**
- Large-scale energy users (e.g., industrial processes) are often not very flexible.
- Connections with technologies such as green hydrogen production can help to both decarbonize the industry and to deal with this intermittency.
- This can improve the flexibility and resilience of the whole system.



H_2 regulated demand in EU by mandates in 2030





Renewable Fuel of Non-Biological Origin (RFNBO)

Non-RFNBO

2.8 Mton of regulated demand

requires about 30 GW

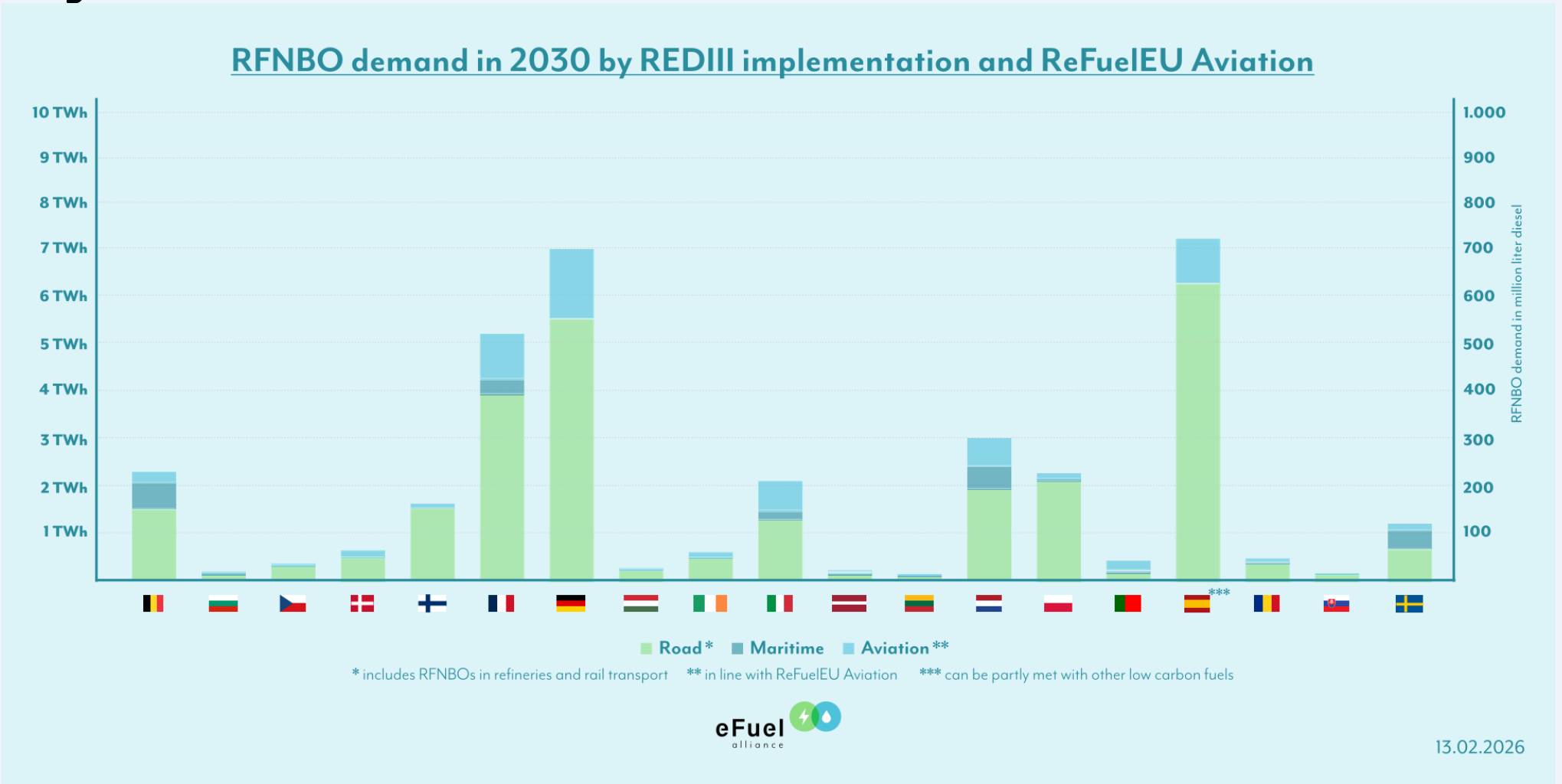
electrolysis capacity

In Europe by 2030

or large import of H_2 (carriers)

Clean Hydrogen Monitor 2025

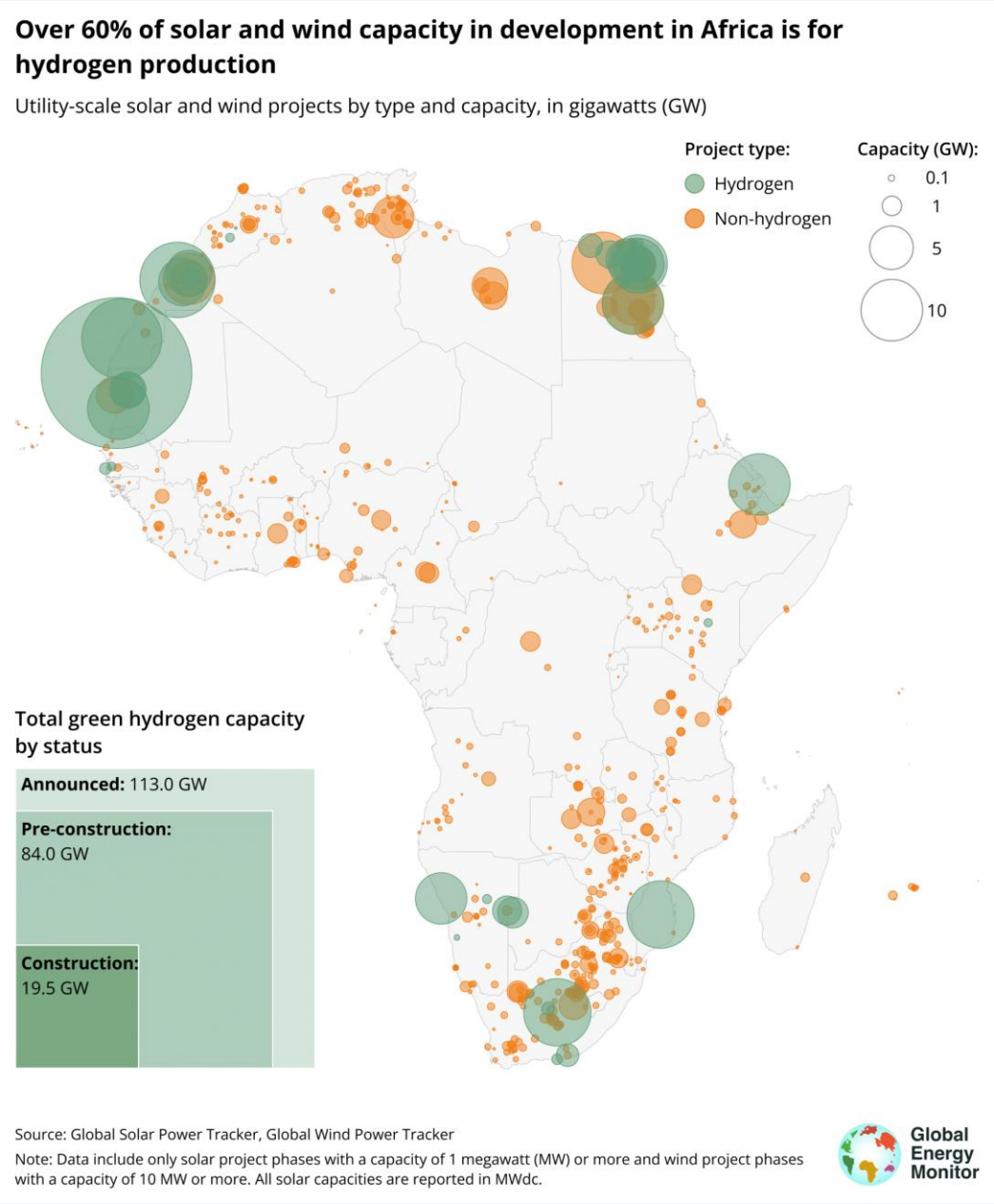
Future demand of green hydrogen from EU mandates per country



Source: eFuel Alliance Post | LinkedIn

Beyond Europe: H_2 import

- Large-scale hydrogen production using wind/solar sources is expected to be deployed in other continents, with some of the largest development projects being planned for hydrogen production.
- These imports can help to complement local production to reach the EU targets.
- While hydrogen only needs to comply with Carbon-Border Adjusted Mechanism for *direct* emissions (not for e.g., power consumed), overseas production also needs to comply with strict RFNBO rules to be within the RED III/Delegated Acts targets.



Source: Europe's push for hydrogen diverts solar and wind potential from Africa | Global Energy Monitor

SUCCESS FACTORS IN HYDROGEN PROJECT DEVELOPMENT

TNO innovation for life

Success factor 1: secured off-take agreement

- **Hydrogen for the refinery sector**

Decarbonizing Refining: TotalEnergies Launches a Call for Tenders for the Supply of 500,000 tons per year of Green Hydrogen

09/14/2023 News Hydrogen

Download the Press Release (PDF)

Paris, September 14, 2023 – As part of the drive to decarbonize its European refineries, TotalEnergies is launching a call for tenders for the supply of 500,000 tons per year of green hydrogen. The use of green hydrogen should avoid the emission of around five million tons of CO_2 each year from the Company's European refineries by 2030.

TotalEnergies has six refineries in Europe – Antwerp (Belgium), Leuna (Germany), Zeeland (Netherlands), Normandy, Donges and Feyzin (France) – as well as two biorefineries in La Mède and Grandpuits (France), all of which use hydrogen. The Company wants to replace 500,000 tons per year of this hydrogen consumed in its refineries with green hydrogen produced with renewable energies by 2030. This is a major step towards achieving TotalEnergies' objective of reducing the net greenhouse gas emissions directly linked to its oil and gas operations (Scopes 1+2) by 40% by 2030 compared to 2015 levels.

TotalEnergies

Projects under construction with FID:

Normand'hy project 200 MW for Normandy

ELYgator Rotterdam 200 MW for Antwerp

RWE Lingen 200 MW for Leuna

EnergHys 250 MW for Vlissingen

Strong partnership with Air Liquide also in mobility (TEAL)

Success factor 2: production on-site

- **Hydrogen for the refinery sector**

Projects under construction / FID:

Normand'hy project 200 MW for Total (Fr)

Refhyne Koln 100 MW for Shell (DE)

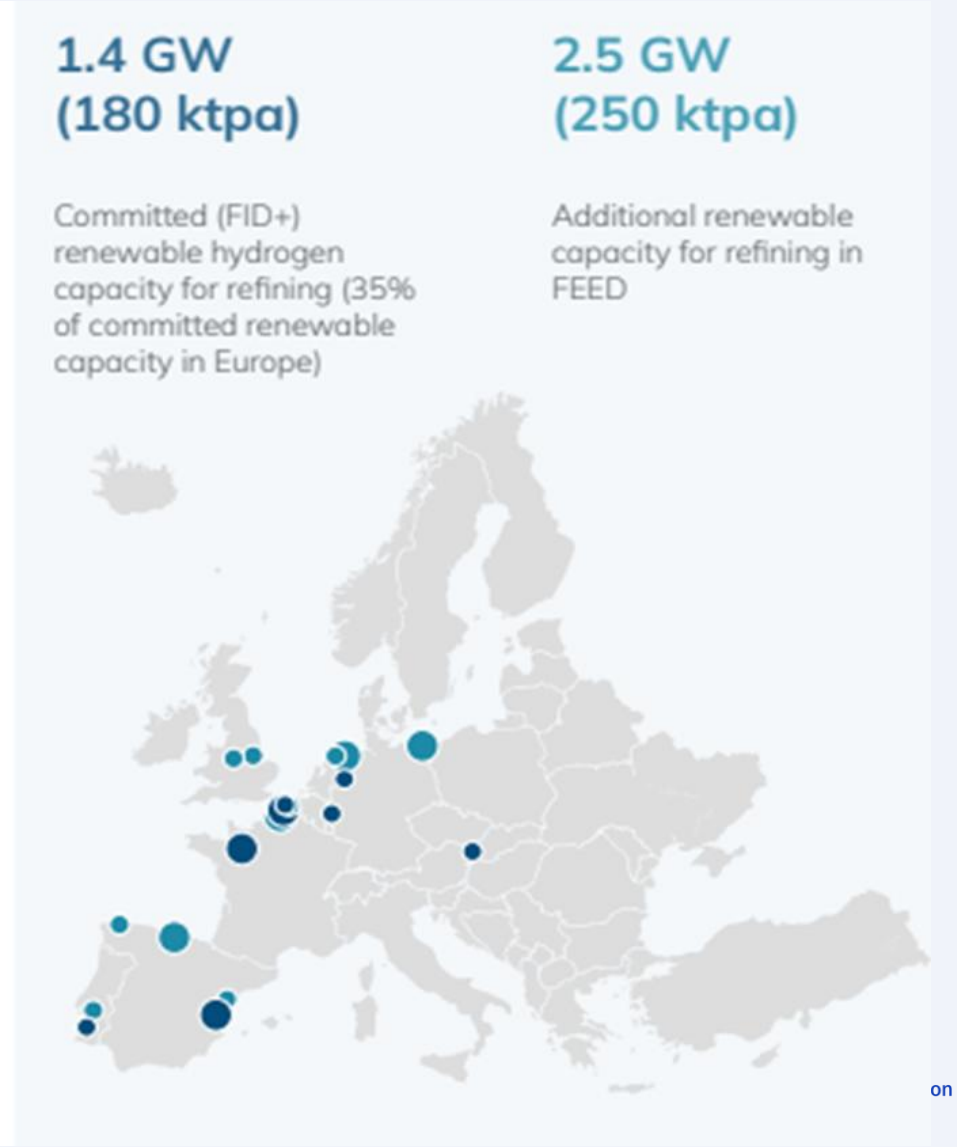
HyVAL Valencia 200 MW for BP (ES)

UpHY 140 MW for OMV (AT)

GreenHydrogenValley 100 MW for Repsol (ES)

Grey2Green Sines 100 MW for GALP (PT)

H2 production on refinery site, no transport infrastructure or storage



Success factor 3: owner of full value chain

Project ELYgator (FID 2025)

- Windpark OranjeWind 760 MW RWE/TotalEnergies
- Electrolyser 200 MW Air Liquide at Maasvlakte (23 kt/yr H2 production)
- Use of existing pipeline network Air Liquide
- Hydrogen offtake TotalEnergies Refinery Antwerp (15 kt/yr)
- 30% of H2 production available for mobility market

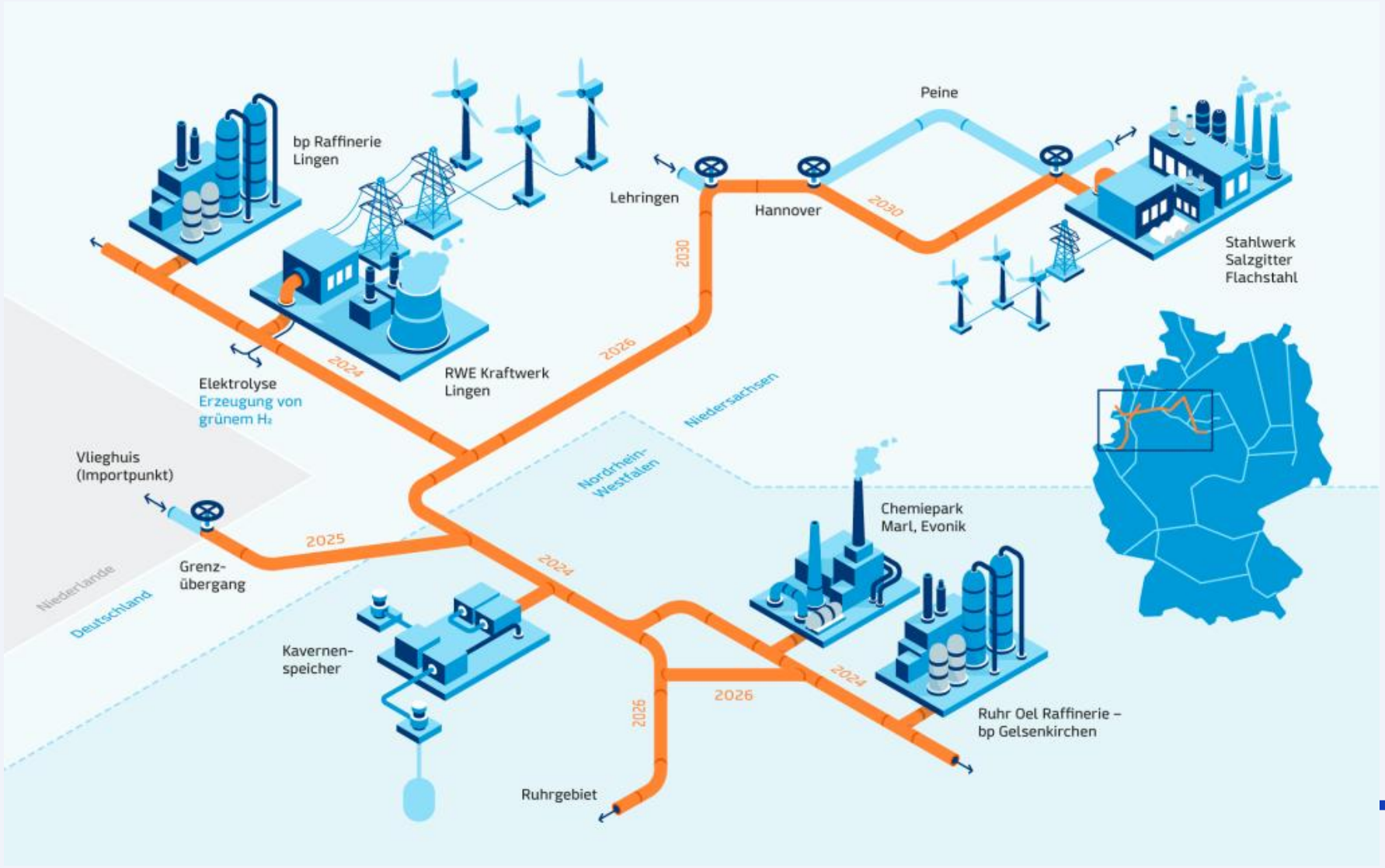
Second phase:

- Project EnergHYs (FID 2026 (tbc))
- 250 MW electrolyser near Zeeland Refinery
- Production: Air Liquide
- Offtake: Total Energies – Zeeland Refinery



Success factor 4: cluster development

Large-scale hydrogen development in the Lingen area



GETH2 Nukleus

RWE Lingen 100 MW

BP Lingen 100 MW

Reuse OGE pipeline

H2 for BP refinery

H2 to Evonik

H2 storage RWE Epe

Interconnection NL via Thyssengas

Satzgitter steel plant

RWE increase 300 MW

TNO innovation for life

Synergies between grid operator and an onshore solar + H_2 asset: grid tariffs for grid congestion

Javier Fatou Gómez, Aitazaz Raja, Femke Janssen



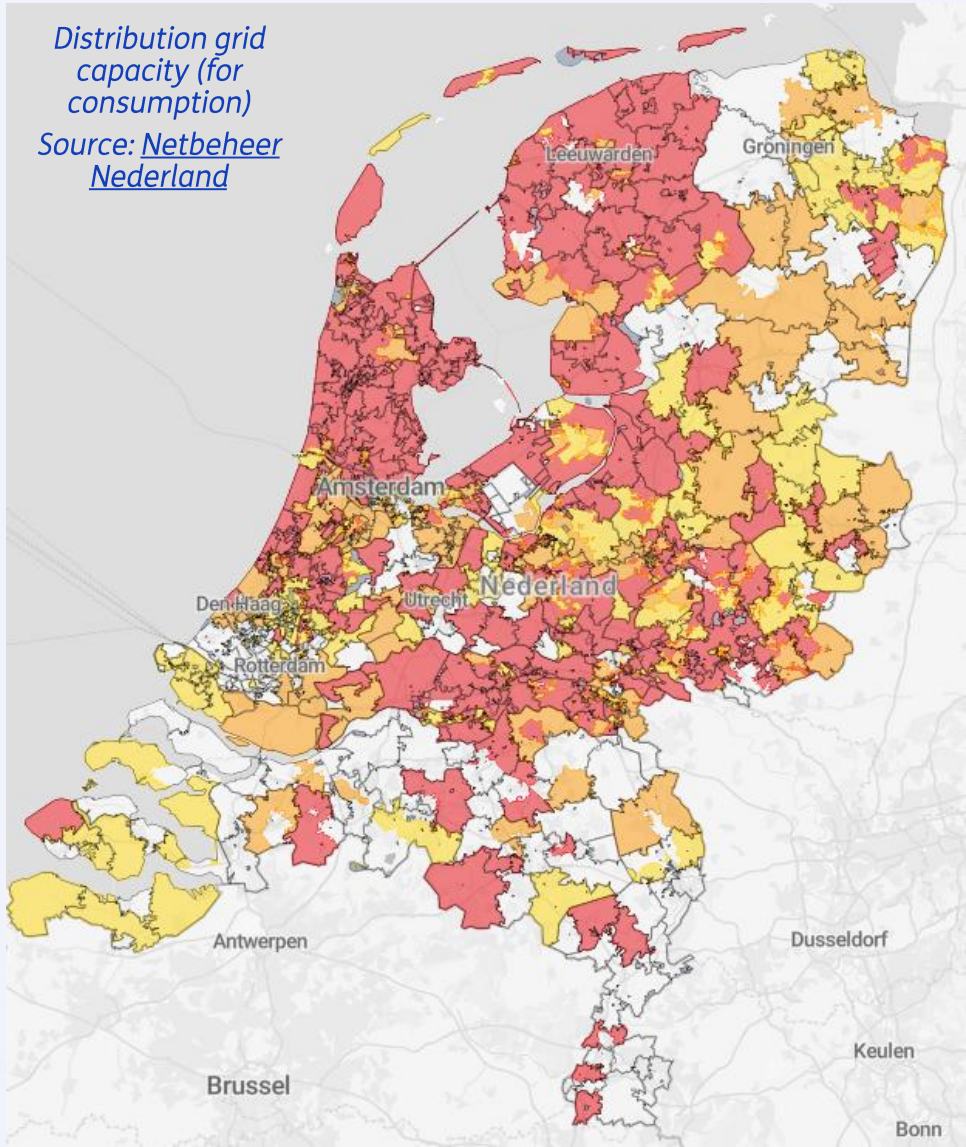
Effects of grid tariffs for an onshore solar + H_2 asset

- **Problem definition:**
  - Several areas of the Netherlands are reaching their limits in the transmission/distribution grids.
  - Long-term grid reinforcement can become very expensive (~BEUR of investment by DSOs *per year).*
  - Grid reinforcement can take a long time to be fulfilled (shortage of technical workers, raw materials, land provision, authorization).

- We aim to explore if there are **contract-based mechanisms that can achieve synergies between the Distribution System Operator (DSO) and an asset owner** in order to contribute to grid congestion relief while improving its business case.

Distribution grid capacity (for consumption)

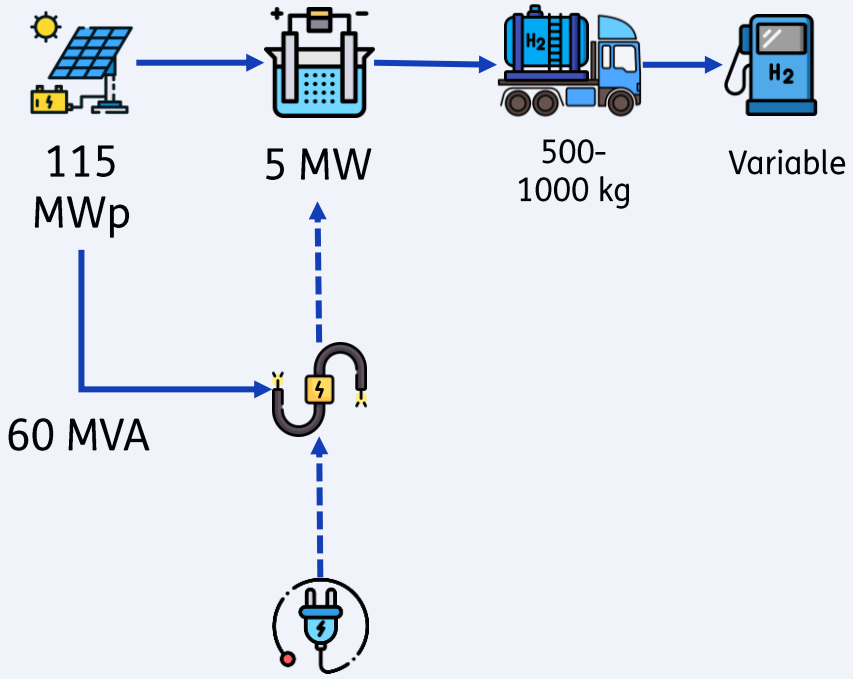
Source: Netbeheer Nederland



Full report (HyDelta3): D2a.3 – Electrolyzer business case in a standalone hydrogen area and the effect of adding firm/non-firm grid tariffs

Effects of grid tariffs for an onshore solar + H_2 asset

- **Methodology:**
- The system is composed of a solar farm with an electrolyzer behind the solar farm.
- This asset is inspired by H2 Hollandia, a project located in the North-East part of the Netherlands.
- Physics-based solver (TNO's PyDOLPHYN tool).
- Synthetic market data simulating a II3050 scenario for 2030 (TNO's EYE tool).
- Main KPI: Levelized Cost of Hydrogen (LCoH).

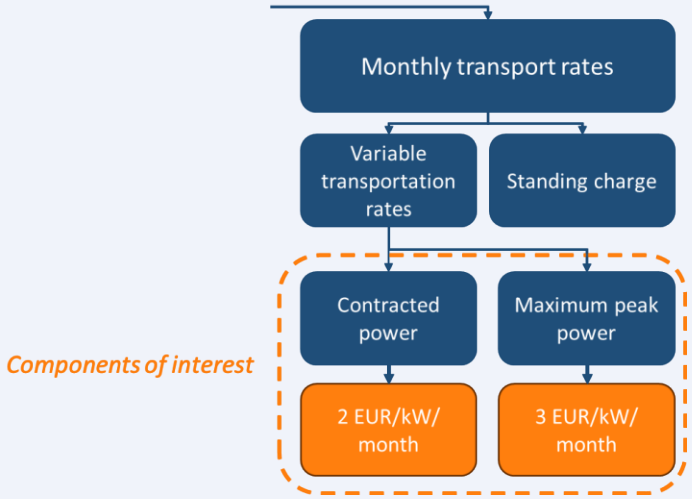


- Power is purchased from the grid *if the market price fulfills the EU conditions to consider the hydrogen produced as Renewable Fuel of Non-Biological Origin (RFNBO) following the EU Delegated Acts.*
  - This price has a threshold of 0.36 times the Emissions Trading System price, which requires polluters to pay for their greenhouse emissions.

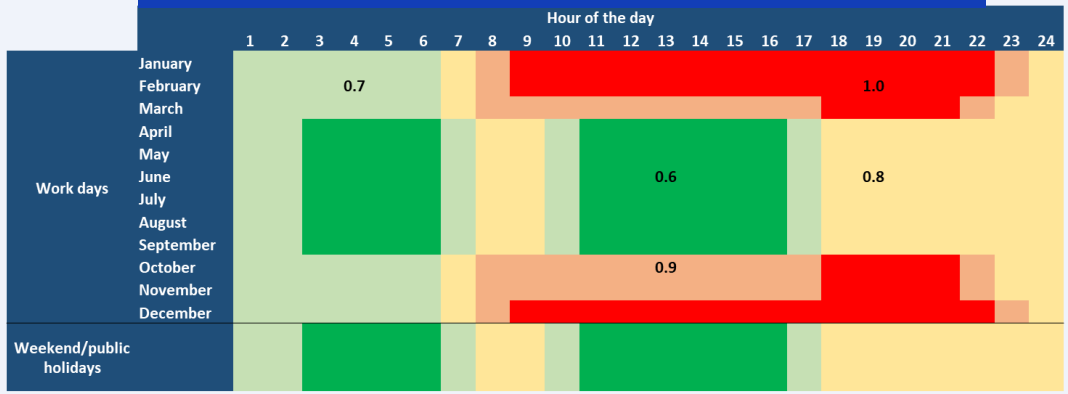
Effects of grid tariffs for an onshore solar + H_2 asset

- **Methodology (grid tariffs):**
- DSO grid tariffs have several components. Two of them depend on contracted power and consumption.
- The non-firm tariff schemes aim to find a *reduction* in these components in exchange for restricting grid consumption in certain periods (up to 15% of the time in the red areas, when congestion is expected to happen).
- Two non-firm tariffs tested:
  - Non-firm 1: average monthly consumption for $kW_{contract}$, time-based factors for kW_{peak}.

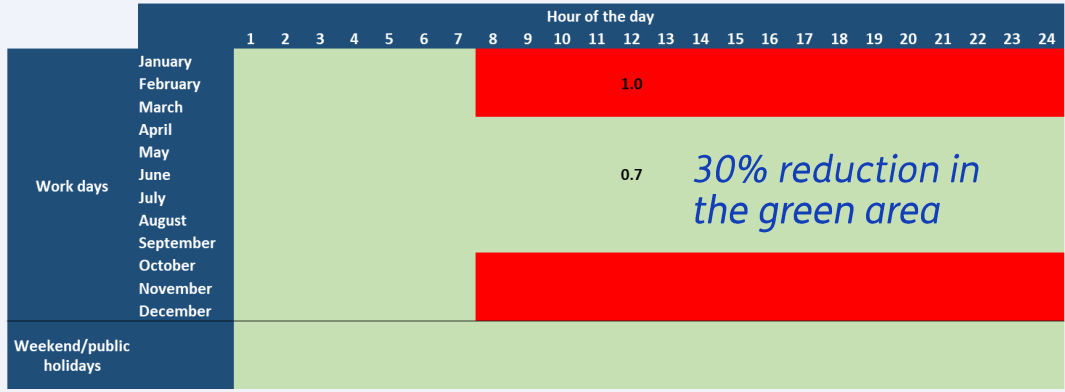
s for kW_{peak}.



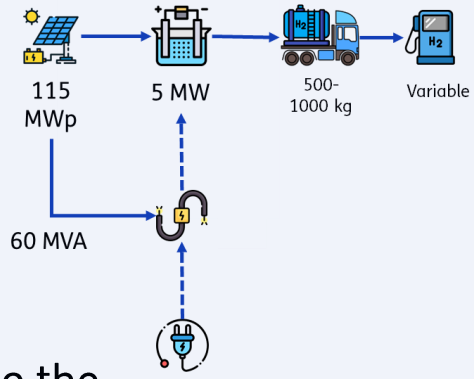
Grid tariff reduction table.
Source: Netbeheer Nederland



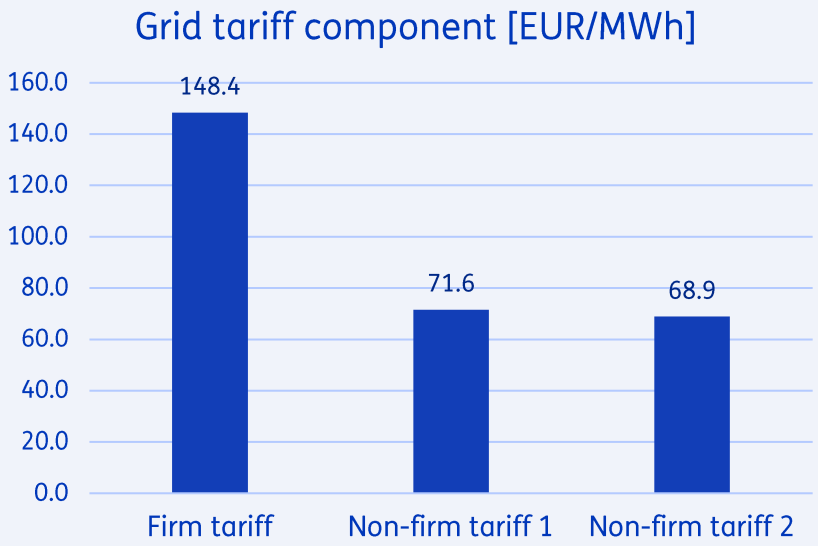
Simplifying

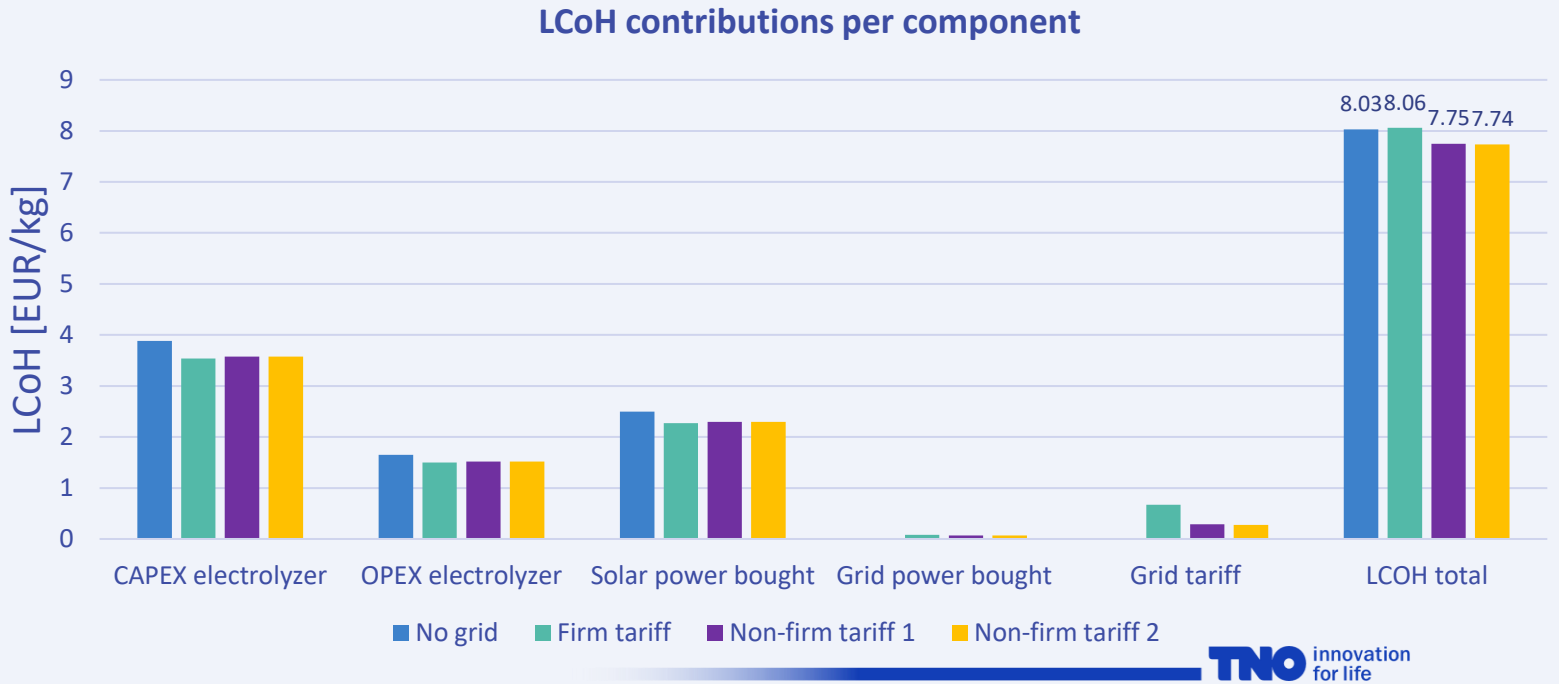


Effects of grid tariffs for an onshore solar + H_2 asset



- **Results:**
- The LCOH for the given conditions is very similar when having no grid or a firm tariff. This is due to the grid tariff component, which offsets the other cost reductions.
- Non-firm tariffs can reduce the tariff component by around 50%.
  - Under the given conditions, this results in an **improvement of the business case (up to 0.3 EUR/kg), with expected benefits in grid congestion relief.**





Conclusions on success factors and opportunities

- **Clear demand and partnership:** example Total Energies and Air Liquide
- **Mandates from EU and national regulations:** RefuelEU, REDIII….
- **Captive production near refineries**: example BP, Shell, TotalEnergies, Repsol, Galp
- **Captive production near steel manufacturing:** example Stegra Sweden, Salzgitter in Germany
- **Energy hub development** with production, transport, storage and use – example Get H2 Lingen Germany
- **Use of (existing or new) H2 infrastructure:** example Rotterdam
- **Full value chain in one hand:** example Holland Hydrogen 1 of Shell
- **Cheap renewable electricity** (solar, wind and hydro): Spain, Sweden
- **Synergies with other actors:** e.g., grid operators



Backup slides



Countries are using a diverse set of instruments with strongest support for renewable hydrogen

Production pathways: Renewable, Gasification, All

Policy instrument: Fixed premium, Grant, Tax incentive, Double auction, Contract for difference

Region	Program name	Funding[1] (EUR M)	Pathways	Status	Capacity	Incentive
Austria	Auction-as-a-service	400 (10 years)	Renewable	Awarded	290 MW	EUR 0.7/kgH_2
Australia	Headstart	474 (10 years)	Renewable	Awarded	1500 MW	EUR 0.32/kgH_2
Australia	Production tax credit	3900 ('24-'34)	Renewable	Open to applications	-	EUR 1.16/kgH_2
Denmark	Power-to-X tender	167 (10 years)	Renewable	Awarded	130 MW	EUR 0.11-0.81/kgH_2
EU	EHB 1st auction	695 (10 years)	Renewable	Awarded	1142 MW	EUR 0.37-0.48/kgH_2
EU	EHB 2nd auction	271 (10 years)	Renewable	Awarded	381 MW	EUR 0.33-1.88/kgH_2
Germany	H2Global	397 (6-7 years)	Renewable	Awarded	100 MW	EUR 4.6/kgH_2 [2]
India	SIGHT	110 (3 years)	Renewable	Awarded	724 ktpa ammonia	EUR 3.3-4.3/kgH_2 [2]
Netherlands	OWE Large scale	700 (5-10 years)	Renewable	Awarded	602 MW	EUR 1780/kW
Netherlands	SDE++ 2024	650 (15 years)	Renewable	Awarded	8 ktpa	EUR 5.5/kgH_2 [3]
Netherlands	SDE++ 2025	1160 (15 years)	Gasification	Bid	276 MW	EUR 65/tCO_2
Portugal	CfD	140 (10 years)	Renewable	Awarded	3.6 ktpa hydrogen	EUR 3.8/kgH_2
Spain	Auction-as-a-service	241 (10 years)	Renewable	Awarded	210 MW	EUR 0.61-2.53/kgH_2
United Kingdom	HAR	241 (10 years)	Renewable	Awarded	125 MW	EUR 7.9-9.9/kgH_2 [3]
United States	45V	400 ('25-'29)	All	Open to applications	-	EUR < 2.6/kgH_2

[1] Using exchange rates from 2 Feb 2026; [2] Prices correspond only to supply bids rather than the cost gap or incentive because offtake bids have not been carried out; [3] Number represents the strike price (incentive will depend on the reference price)

Success factors for H_2 projects

- **Clear demand and partnership** – example Total Energies and Air Liquide
- **Mandates** from EU and national regulations (RefuelEU, REDIII….)
  - Captive production near *refineries* example BP, Shell, TotalEnergies, Repsol, Galp
  - Captive production near *steel manufacturing* – example Stegra Sweden, Salzgitter in Germany
- **Energy hub development** with production, transport, storage and use – example Get H2 Lingen Germany
- Use of (existing or new) **H2 infrastructure** – example Rotterdam
- **Full value chain** in one hand – example Holland Hydrogen 1 of Shell
- **Cheap renewable electricity** (solar, wind and hydro) – Spain, Sweden



Diversifying revenue streams with multiple markets/ancillary services

Bart Klootwijk, Dimitris Ntagkras, Max Houwing, Javier Fatou Gómez



Diversifying revenue streams with multiple markets/ancillary services

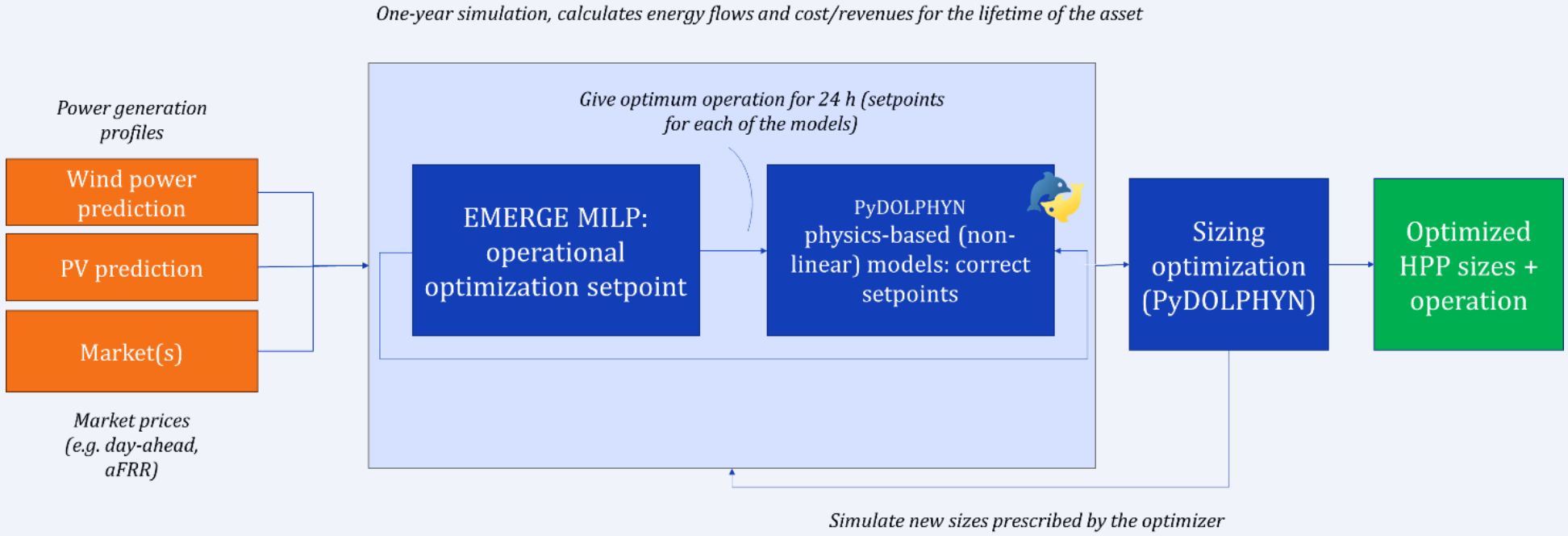
- **Problem definition:**
  - Challenging business case of certain offshore assets, due to costs and future market expectations.
  - Hybrid Power Plants (HPPs) with sufficient degrees of flexibility may be able to diversify their revenue streams (*revenue stacking*).
  - Due to aspects such as supply/demand mismatch and forecasting errors, balancing markets and ancillary services may be suitable for HPPs participation.
  - Revenue stacking may be able to increase the overall profitability of a project, but introduces operational complexity.

- Goal: determine the **optimal size and configuration** of a HPP while fully leveraging its flexibility across **multiple markets.**
  - Ensuring that operational strategies remain feasible under **real-world physical constraints.**



Diversifying revenue streams with multiple markets/ancillary services

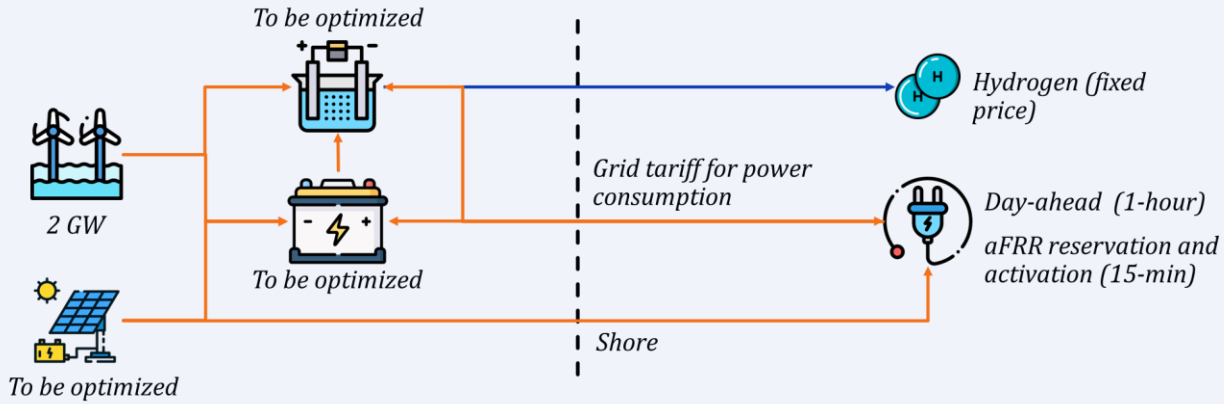
- **Methodology (modelling approach):**
  - Combination of physics-based, (non-)linear models (PyDOLPHYN) with MILP-based operational optimization (EMERGE).

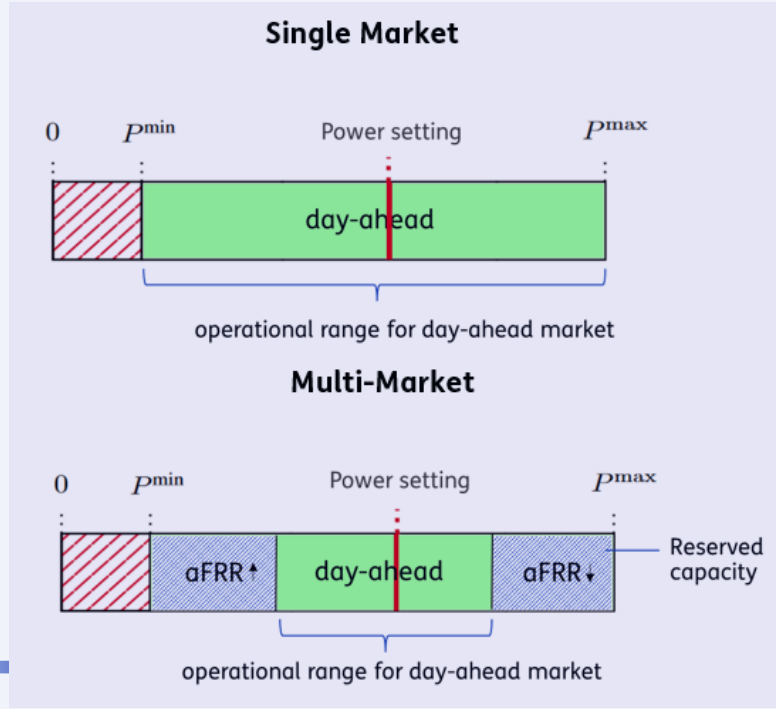


Sources:
J. Fatou Gómez, A. Martín-Gil and S. Dussi, "PyDOLPHYN: Dynamic simulations and optimization of multi-energy assets," Energy, 2025.
M. Houwing, Cassamo, N., Wiggelinkhuizen, E., "Energy management system for combined renewable generation, storage and conversion (EMERGE model): Renewable Hybrid Power Plant Optimization," TNO, 2022.
B. Klootwijk, D. Ntagkras, M. Houwing, J. Fatou Gómez, "The Impact of Multi-Market Operational and Sizing Optimisation for upcoming Offshore Energy Areas", submitted to IOP Journal of Physics Conference Series , 2025

Diversifying revenue streams with multiple markets/ancillary services

- **Methodology (asset and assumptions):**
  - Fixed wind farm (Dutch North Sea, Ijmuiden Ver Gamma).
  - 2024 historic market data for the Netherlands.
  - Two time scales: 1 hour (day-ahead) and 15 minutes (automatic Frequency Restoration Reserve).
  - H_2 revenues of 8 EUR/kg (without distinctions between subsidies, premiums, etc.).
  - Operational optimization objective function: 24-hours profit.
  - Sizing optimization objective function: non-discounted profit of the system over its lifetime.
  - **Physics-based corrections:** when discrepancies arise between linearized/non-linear models, aFRR takes precedence, correct with day-ahead setpoints.





Example of electrolyser setpoint for different market strategies

Diversifying revenue streams with multiple markets/ancillary services

- **Results:**
  - **Optimum size of electrolyzer increases for multi-market** (ca. 300 MW) compared to single-market (ca. 250 MW) case.
  - **Multi-market case can yield a higher profit** than the single-market case (ca. 5%).
  - The electrolyzer can be used as a flexibility-absorbing asset for aFRR services.
  - However, grid tariffs play a significant role in limiting further profit.
  - **Negligible impact on curtailment compared to wind-only** setup (+0.2%), due to storage/H_2 conversion prioritizing electricity imports during negative electricity prices.

