AUCTION DESIGN REPORT

Keep it simple: Aligning auction objectives for success

December 2024

H2Global Stiftung

Authors

Jan Klenke, Program Lead, H2Global Foundation

Contributions

Emanuel Henrich, Matteo Massera and Hanna Graul (H2Global Foundation).

Publisher

Department—Analysis and Research
Trostbrücke 1
20457 Hamburg

H2Global Knowledge Hub reports

ISSN: 2944-7801

Table of contents

List of figures and tables

Acknowledgements

This report was developed by the research team of the H2Global Foundation. It is part of the H2Global Knowledge Hub, a research program sponsored by the 7th Energy Research Program funded by the German Federal Ministry of Education and Research. The author was Jan Klenke, with support from Emanuel Henrich, Matteo Massera and Hanna Graul. Victor Ponsford provided editing and communications support and Anne Sorkamo design expertise.

Sincere thanks are extended to Alex Barnes (Oxford Institute for Energy Studies, Alex Barnes Associates), Emanuele Bianco (IRENA) and Diala Hawila (IRENA), whose invaluable contributions have significantly enriched this work. Their expertise, insight, and diligent efforts have greatly improved the quality of our output.

Gratitude is also extended to esteemed peer reviewers, Jan George (Fraunhofer ISI), Theresa Steinfort (Frontier Economics), and Miguel Vazquez (Bocconi University), for their important feedback on the report that greatly helped to enhance its quaility.

The donors to the H2Global Foundation that so graciously provided feedback to the “Keep it simple: Aligning auction objectives for success” working group are appreciatively acknowledged. Their comments have enabled the report to speak to practitioners of auction design. Lastly, the team greatly appreciates the input and guidance of Susana Moreira and Timo Bollerhey.

H2Global Stiftung

Federal Ministry of Education and Research

Glossary

Term	Definition
CAPEX	Capital expenditure
CCUS	Carbon capture, utilization and storage
CEEAG	European guidelines on state aid for climate, environmental protection and energy
CfD	Contract-for-difference
CINEA	European Climate, Infrastructure and Environment Executive Agency
DEA	Danish Energy Agency
DESNZ	Department of Energy, Security and Net Zero, United Kingdom
EEA	European Economic Area
EFTA	European Free Trade Association
EHB	European Hydrogen Bank
e-SAF	Electricity-based sustainable aviation fuel
ESG	Environmental, social and governance
EU	European Union
GHG	Greenhouse gas
HAR1	Hydrogen Allocation Round 1
Hintco	Hydrogen Intermediary Company
HPA	Hydrogen purchase agreement
HSA	Hydrogen sales agreement
IRENA	International Renewable Energy Agency
LCOH	Levelized cost of hydrogen
LOHC	Liquid organic hydrogen carrier
OPEX	Operational expenditure
PtX	Power-to-X
REDII	Second Renewable Energy Directive
SME	Small and medium-sized enterprise
SNG	Synthetic natural gas
TRL	Technology-readiness level
WtP	Willingness-to-pay

Foreword

H2Global is committed to addressing the challenge of climate change with its unique double-auction mechanism, international stakeholder engagement, and research on the clean hydrogen economy. In 2024, the H2Global Pilot Auction delivered first results in the form of a renewable ammonia offtake agreement worth EUR 300 million for a project delivering renewable ammonia from Egypt to Europe due to start in 2027. Four new H2Global tenders, totaling EUR 4.43 billion, committed and/or earmarked by Germany, the Netherlands, Canada and Australia, are to be launched in the coming months.

H2Global's mission extends beyond auctions to identifying and alleviating market development barriers. As part of this endeavor, H2Global is building the H2Global Knowledge Hub, which is financially supported by a research grant issued by the German Federal Ministry of Education and Research. With the Knowledge Hub's support, H2Global has engaged its current 72 private sector supporters in producing valuable insights into market creation for clean hydrogen and its derivatives. The result is a series of reports in 2024 addressing three key challenges: the clean hydrogen infrastructure investment gap, the lack of clean hydrogen demand commitments, and the need to optimize auction designs.

This report focuses on auctions and how their designs can be streamlined for maximum effectiveness. Auction designers often pursue (and legal contexts may require) diverse objectives to be implemented through auctions, resulting in different auction designs. Auctions have specific strengths and excel, for example, at price discovery. Objectives that go beyond these strengths may reinforce them or create trade-offs. Auctions must be evaluated with their stated objectives in mind and be carefully designed to ensure their goals are reached. It turns out, however, that the pool of objectives auction designers can draw from is enormous. This report offers a way to streamline goals, while taking into consideration their multiple interactions, with the aim of producing more effective auction designs.

Optimizing support allocation through auction mechanisms is an important contribution to unlocking both supply and demand for clean hydrogen. But it is not enough. Demand build-up requires additional targeted measures, which can take the form of hydrogen demand hubs, detailed in the H2Global Foundation's "Unlocking potential: Scaling demand through hydrogen hubs" report.

Another key bottleneck for clean hydrogen market creation is insufficient infrastructure. The H2Global Foundation's report—"Bridging the gap: Mobilizing investments in hydrogen infrastructure"—focuses on how to attract investment into infrastructure.

With these 2024 reports, H2Global is working towards becoming a center of excellence in clean fuels' market creation, reinforcing its role as a green market maker and its commitment to protecting the climate and the environment.

"As the 2024 Breakthrough Agenda report made clear, the risk of a mismatch between supply and demand is becoming the major obstacle to clean hydrogen scale up globally. As this report shows auctions are a valuable and underutilized tool that can help address that challenge and many related objectives. The insights from this analysis will help many more countries accelerate their hydrogen transitions."

Dr. Paul Durrant
Joint head of the Breakthrough Agenda secretariat, UK co-lead
Hydrogen Breakthrough

Executive Summary

Auctions in the nascent hydrogen market

Auctions are key to jumpstarting hydrogen markets, revealing prices and drawing in investment

As the world accelerates its decarbonization efforts, clean hydrogen has become a cornerstone in reducing emissions across energy-intensive sectors. However, due to the nascent stage of hydrogen markets, efficient allocation mechanisms like auctions are pivotal. Auctions enable competitive price discovery, helping stakeholders make informed decisions and connect hydrogen supply with demand. Beyond price optimization, auctions are instrumental in advancing objectives like scalability, sustainability, and resilience, which are essential for fostering a robust hydrogen market.

Objectives of clean hydrogen auctions

Network analysis of auction objectives

The report identifies 22 distinct auction objectives derived from the literature and stakeholder workshops. Using network analysis, these 22 objectives were grouped into four thematic clusters critical to clean hydrogen market development:

1. **Scaling**—The objectives in this cluster emphasize the need to expand hydrogen production capacity and infrastructure by leveraging economies of scale to reduce costs and support widespread adoption. Scaling is essential for achieving global decarbonization targets and for establishing hydrogen as a viable energy carrier.

2. **Domestic development and speed**—Focused on establishing robust local hydrogen supply chains, this cluster prioritizes rapid deployment to meet immediate market needs. It aims to foster regional production, create jobs, and build a resilient supply network. Accelerated development timelines are critical to keeping pace with global energy demands and the urgency of climate goals.

3. **Sustainability and resilience**—These objectives ensure hydrogen production and distribution practices are environmentally responsible, emphasizing reduced carbon footprints, circular economy principles, and long-term resilience against market fluctuations. Sustainability is vital for aligning hydrogen auctions with broader environmental and social goals, while resilience ensures that projects remain viable amid changing conditions.

4. **Efficiency**—Efficiency-oriented objectives prioritize cost-effectiveness by optimizing resource use while minimizing expenses. Achieving efficiency not only reduces operational costs but also attracts investment by making projects financially viable. This cluster underscores the importance of lean, effective auction processes that support competitive bidding.

Uncovering synergies and potential trade-offs

In the report H2Global explores the interrelationships among the auction objectives, revealing where synergies can be maximized and trade-offs minimized. For example, objectives within the *sustainability and resilience* cluster often reinforce each other, creating complementary effects that support sustainable market development. Conversely, objectives from within different clusters, such as the *scaling* and the *sustainability and resilience* clusters, can sometimes create challenges; rapid scaling might compromise sustainability and resilience goals, if not managed carefully.

Comparative case studies: insights from leading European hydrogen auctions

Evaluating practical implementations

The report examines four significant European hydrogen auctions—the Danish Power-to-X (PtX) Tender, the British First Hydrogen Allocation Round (HAR1), the European Hydrogen Bank (EHB) Pilot Auction, and the H2Global Pilot Auction. These case studies offer a comprehensive view of how distinct auction models can achieve, or struggle to achieve, their stated objectives. Each case study provides valuable insights into the complexities and practical trade-offs in designing hydrogen auctions.

- **Danish PtX Tender:** The PtX Tender was structured to promote power-to-X (PtX) technologies, which include the use of hydrogen for renewable energy storage and sector coupling. This auction prioritized objectives within the *scaling* and the *domestic development and speed* clusters, aiming to rapidly expand Denmark's hydrogen infrastructure and reduce reliance on fossil fuels.

- Challenges and outcomes: The auction faced significant implementation delays, largely due to high compliance costs and strict qualification requirements. While the PtX Tender succeeded in supporting domestic hydrogen production, feedback from stakeholders highlighted the need for simpler processes to encourage broader participation.

- Key learnings: This case study illustrates the importance of balancing *domestic development* and *speed* objectives with *efficiency*. By reducing compliance requirements, future tenders can encourage more widespread participation while still achieving *scaling* goals.

— **First Hydrogen Allocation Round (HAR1):** HAR1 was designed with a strong emphasis on *speed* and *scaling*, with less focus on *sustainability.*

- Challenges and outcomes: While HAR1 achieved its deployment targets, its complexity led to extended timelines for regulatory approvals, delaying the actual implementation. Moreover, limited compliance flexibility meant that some projects faced difficulties meeting contractual obligations, impacting overall project completion.

- Key learnings: HAR1 highlights the need to allow flexibility in early-stage hydrogen auctions, particularly when multiple high-priority objectives are involved. Simplifying regulatory processes and ensuring realistic timelines can help future auctions achieve both speed and scalability.

— **European Hydrogen Bank (EHB) Pilot Auction:** This auction was one of the region's first attempts to integrate *sustainability* and *resilience* as primary objectives, reflecting the European Union's (EU's) commitment to renewable hydrogen production. The auction combined financial incentives with environmental criteria, favoring projects that demonstrated a reduced carbon footprint and long-term resilience.

- Challenges and outcomes: While the auction successfully attracted projects with high environmental standards, this also led to increased project costs and financial hurdles for participants, as meeting strict sustainability requirements often required significant upfront investment. Some participants found it difficult to compete on price alone, indicating a need for cost-balancing measures.

- Key learnings: This case study emphasizes that auctions prioritizing sustainability should consider financial support mechanisms to offset the higher costs associated with low-carbon technology compliance. Future iterations could balance *sustainability* with *cost-efficiency* to support more widespread adoption.

IMAGE CREDIT: H2GLOBAL FOUNDATION

— **H2Global Pilot Auction:** H2Global used a double-sided auction approach to balance market creation with supply diversity, using contracts for both hydrogen suppliers and end-users. It prioritized a mix of *domestic development*, *efficiency* and *sustainability* objectives, aiming to create a diverse, stable supply chain that aligns with environmental goals.

- Challenges and outcomes: This auction faced challenges related to limited project readiness of many bidders that resulted in multiple extensions in the auction duration. However, the Pilot Hydrogen Sales Agreement (HSA) Auction has uncovered supplier costs, which provide critical data for future market creation efforts.

- Key learnings: H2Global demonstrated the utility of double-sided auctions for emerging markets, where both supply and demand remain uncertain. It also highlighted the potential to manage volatility through structured contract terms, an approach that could benefit future hydrogen market auctions.

Best practices for designing effective hydrogen auctions

Strategies for balancing objectives and streamlining processes

Drawing from these case studies and the broader analysis, the report recommends several best practices to guide auction design:

1. **Prioritize clear, coherent goals**—Auctions that focus on fewer, cohesive objectives achieve better results by minimizing complexity. Clear goals help streamline the bidding process, reduce administrative burden, and ensure that outcomes align with market needs.

2. **Use legislative frameworks for broader goals**—Comprehensive policy tools can address sustainability and regional development goals that may be difficult to incorporate into auction design. This approach allows auctions to concentrate on market-specific objectives while aligning with external regulatory frameworks.

3. **Maintain flexibility to support early-stage market development**—The hydrogen sector is evolving, requiring experimental and adaptable auction designs. Flexibility allows stakeholders to test and refine auction structures, adjusting them in response to changing market dynamics and feedback.

Mitigating risks in auction processes

Addressing underbidding, compliance, and value-chain risks

Effective auction design should include safeguards to mitigate common risks like underbidding, non-compliance, and supply chain disruptions. Recommendations for risk mitigation include:

— **Enforce penalties for non-compliance**—Strict penalties create accountability, discouraging delays and ensuring that projects are delivered on time and within specifications.

— **Establish financial pre-qualifications**—Requiring financial stability among bidders mitigates the risk of project abandonment or suboptimal performance.

— **Implement value-chain safeguards**—Protecting the entire hydrogen supply chain from disruptions enhances the reliability and stability of project outcomes.

Legal and regulatory considerations in auction design

Navigating compliance while ensuring effectiveness

Hydrogen auctions operate within a complex regulatory landscape, balancing national and international legal requirements. It is therefore imperative that the clean hydrogen industry collaborates closely with legal experts to ensure compliance, safeguard transparency, and address cross-border regulatory nuances.

Building a robust foundation for hydrogen auctions

Looking forward to sustainable and scalable hydrogen auctions

As hydrogen markets continue to grow, adaptive auction designs that balance scalability, speed, efficiency, sustainability, and resilience will play an increasingly critical role in supporting decarbonization efforts. Policymakers, industry leaders, and regulatory bodies are encouraged to collaborate in refining auction frameworks that are facilitating a global transition to clean hydrogen. This ongoing cooperation will be essential for establishing hydrogen as a cornerstone of the low-carbon economy.

Recommendations

Good practices	Risk mitigation	Regulatory compliance
✓ Focus on fewer, cohesive objectives to streamline bidding and align outcomes with market needs.	✓ Apply strict penalties to promote accountability and minimize project delays.	✓ Work closely with legal teams to ensure regulatory compliance and transparency.
✓ Leverage broader policy tools to address sustainability and regional goals outside auction scope.	✓ Require financial stability of bidders to minimize the risk of project abandonment.	✓ Account for international regulatory requirements in auction frameworks.
✓ Support early-stage development with adaptable designs that respond to market dynamics.	✓ Protect the hydrogen supply chain from disruptions to enhance project reliability and stability.	
✓ Streamline approval timelines and reduce compliance complexity to enhance delivery efficiency.	✓ Provide financial mechanisms to support projects with high sustainability costs.	✓ Waive or streamline regulatory checks for smaller or early-stage auctions to prevent delays.
✓ Balance supply and demand by managing price volatility through double-sided auctions.	✓ Use structured contract terms to handle pricing fluctuations, especially in volatile markets.	
✓ Increase scalability by supporting fewer, larger projects.	✓ Implement penalties and financial checks to discourage bids that are not cost-covering.	
✓ Choose objectives from a single cluster to streamline design and minimize trade-offs.	✓ Use independent verification to confirm the environmental and financial viability of winning projects.	

IMAGE CREDIT: HXDBZXY / SHUTTERSTOCK

1

Creating a clean hydrogen market: the role of auctions

In 2015, 192 parties adopted the Paris Agreement, thereby setting the goal to limit global temperature rise to 1.5°C. Critical to achieving this goal will be the transition from fossil fuels to clean fuels.

Hydrogen is expected to play a significant role in the energy transition. It has several advantages over other fuels, including its high energy density and its ability to be produced from a variety of sources. However, there are challenges that need to be overcome for hydrogen to deliver on its promise. To start with, there is not yet a fully developed clean hydrogen market in which supply is linked with demand through an effective market price. Up to now, hydrogen is only used at scale in the chemical and refinery sector, which typically produces hydrogen for internal consumption using unabated fossil fuels. As a result, public trading of hydrogen is limited, which reduces competition and the incentive to drive down hydrogen supply costs.

In the absence of a liquid clean hydrogen market, governments and companies have adopted different approaches to accelerate the match between the supply and demand of clean hydrogen. A few—mostly large—companies, alone or with the support of governments, have entered bilateral trade contracts with either fixed prices or clear pricing mechanisms, effectively linking producers and buyers, and providing the investment security needed to develop a few capital-intensive hydrogen projects. Companies and governments have also been using buyers' clubs and trade platforms (e.g., the EU Energy Platform) that aggregate demand in order to negotiate contracts with suppliers. Additionally, primarily to spur demand for hydrogen, regulators have developed mandates and/or quotas for the use of hydrogen and its derivatives in the industry, transport, and heating sectors.[1]

These instruments perform differently when it comes to the creation of a functioning clean hydrogen market. While quotas for clean hydrogen stimulate demand for these products by restricting a market, government support to lighthouse projects encourages private sector investment. Buyers' clubs and trade platforms tackle coordination problems through the aggregation mechanism and long-term contracting that they establish for companies participating in these processes. However, these tools do not address a pervasive problem of nascent markets: identifying and overcoming the difference between cost of production and willingness-to-pay (WtP). To this end, governments around the world have historically applied a host of instruments, including capital expenditure (CAPEX) subsidies, operational expenditure (OPEX) subsidies, price ceilings, and guaranteed offtake by the state, to socialize the cost difference. These instruments do not uncover true market prices, which can only be revealed through competitive processes such as auctions.

Auctions are a fundamental allocation mechanism in economic theory. Their basic concept consists of a competitive scheme in which prices are optimized by admitting multiple bidders. Depending on whether the auctioneer intends to buy or sell a product, either purchasing prices are minimized or selling prices maximized, as the winner is awarded, respectively, according to the lowest or highest price bid in the process. Consequently, the core intention of auctions is to uncover private price information in order to make an informed decision about the purchase. Revealing this private information is a prerequisite for the purchase decision of the auctioneer, who has little or no information about the prices that can be achieved, for a number of possible reasons: the composition of prices is untransparent; the product in question is new and has not yet received a price; or it is a unique product so no comparable products can serve as a reference.[2] The latter is famously the case in art auctions but does not apply to a commodity like clean hydrogen and its derivatives. Regardless of the price discovery issue, the collection of competitive prices in comparable conditions set by the auctioneer allows auctioneers to pick the economically most viable price and optimize the economic value of the transaction.[3]

Using auctions therefore makes sense in a market situation with non-existent or untransparent price information, such as the still nascent clean hydrogen market. Some governments have already employed a variety of auction designs to accelerate a match between clean hydrogen supply and demand curves, including single- and double-sided auctions.[4] They are seen as particularly effective tools to allocate incentives at a time when public resources are limited.[5] They not only uncover the offtakers' WtP and the cost of production, but they also help reduce the gap between the two, by encouraging competition. In so doing, they lessen the amount that governments are required to allocate to cover this gap and accelerate the match between supply and demand.

Using auctions makes sense in a market situation with non-existent or untransparent price information, such as the still nascent clean hydrogen market.

Germany, the Netherlands, Canada and Australia have earmarked or committed over EUR 5.8 billion to auctions using the H2Global mechanism. The first pilot H2Global Auction was launched in late 2022. H2Global's double-sided auction mechanism is designed to uncover the WtP on the demand side and the lowest supply cost and makes this information available to the public. Uncovering price points at the time of award provides a snapshot of the cost of clean hydrogen and WtP, which in turn supports decision-makers in reaching financial investment decisions.[6] The combination of long-term hydrogen purchase agreements with short-term hydrogen sales agreements provides offtake security for suppliers and an opportunity to offtakers to pursue flexible procurement strategies to react to price developments. H2Global tenders also bundle and assign different market risks within the supply chain.[7] The H2Global mechanism is thus implicitly designed to provide volumes to offtakers as part of a portfolio strategy rather than to cover full long-term volume needs. Short-term

IMAGE CREDIT: H2GLOBAL FOUNDATION

demand tenders also allow a differentiated analysis of firm WtP information for different sectors.

The European Hydrogen Bank (EHB) is a European Commission initiative that puts together financial instruments, transparency tools, and coordination schemes to support the development of domestic renewable hydrogen production and imports. In 2023 it launched a pilot auction on a fixed premium for renewable hydrogen production within the European Economic Area (EEA), as part of the "domestic pillar" of the EHB approach.[8] The European Union (EU) announced its interest in using H2Global as the "external pillar" of the EHB for renewable hydrogen imports from outside the EU.[9]

The use of auctions and tenders is not limited to Europe nor to governments. Countries like Chile, India and the United Kingdom, as well as companies like JERA and TotalEnergies, have launched auctions, too.

In the public debate, these different auctions are often compared in order to identify which of them most cost-efficiently delivers the fastest and largest volumes of clean hydrogen and its derivatives.[10] Such comparisons are key to extracting lessons from each auction process; however, not all auctions have the same objectives. For example, the H2Global auctions produce hydrogen purchase and sales contracts, while other auctions determine only the size of the subsidy to be awarded, leaving participating companies to engage in contract negotiations after the awarding process.

This report aims to inform the decisions of policymakers in their role as auction designers against the backdrop of regulatory requirements that often limit their range of choices. It starts with an analysis of auctions' diverse objectives and how they interact. Based on the synergies and trade-offs uncovered, the report conducts a structured comparison of the designs and real-world implementation of a number of hydrogen auctions. The report concludes that there are benefits to keeping it simple: Instead of using a single auction to address simultaneously all the issues affecting the creation of a hydrogen economy, auction designers should focus on a narrow set of mutually reinforcing objectives.

The next sections discusses the objectives that can be pursued through auctions, the synergies and trade-offs that emerge in the process of combining objectives, and the design options that follow from the objectives. The fourth section discusses how hydrogen auctions can be compared and applies a comparison to assess how recent auctions have balanced diverse objectives and what design elements were chosen to attain this balance. The fifth section identifies the unintended consequences of design choices and how they can be prevented.

IMAGE CREDIT: THANAPORN / ADOBE STOCK

2

Auction objectives: uncovering trade-offs and synergies

Decision makers opting for an auction to procure clean hydrogen or allocate support to clean hydrogen projects primarily pursue the basic objectives associated with auctions: allocating resources efficiently, discovering prices effectively, and stimulating competition.

Auctions are flexible tools, however, and they can be adjusted to incorporate other objectives as well as satisfy regulatory requirements. Additional objectives may be derived from the state and development of clean hydrogen (derivatives) markets, the role clean hydrogen and its derivatives are strategically supposed to play in a country's energy transition, or broader political goals.

Sponsors of auctions may, for example, additionally try to maximize greenhouse gas (GHG) emission reductions, support local value creation, spur technological innovation, or transform existing—or kickstart new—industries. They may also adopt a domestic or international focus; or give preference to a specific technology and/or sector or be flexible/open to all technologies/sectors; or just give priority to quality, quantity or speed. A full list of the objectives identified in this analysis can be found in the Annex.

There are often trade-offs and synergies between different objectives. Auction designers seeking to leverage synergies and minimize the number of trade-offs in their auction should carefully consider the relations between their objectives before picking auction design elements. Notably, some objectives share trade-offs which can be exploited by auction designers to increase the effect of the design elements used to pursue them, as the "opposing" objective is more strongly restrained this way. For example, aiming for "maximum auction process speed" and "minimum supply project cost" are objectives that are not necessarily positively or negatively related. Both objectives, however, benefit from a concentration on fewer projects, as this implies leaner processes and larger potential effects on scale. In other words, they share a trade-off against a diversification of supply geographies, which may consequently be ruled out by design.

The report identifies 22 distinct objectives, without claiming completeness, derived from real-life hydrogen auctions, relevant literature, and stakeholder workshops. These are referred to, where appropriate, with a number in square brackets that can be found in Table 1 (a detailed description of each is in the Annex).

To gauge the relations between the objectives collected here, the H2Global team assigned a value to each dyadic relationship, e.g., the relationship of *reducing domestic GHG emissions* [10] to *minimizing the duration of the award procedure* [21], or the relationship of *supporting social sustainability criteria* [11] to *maximizing cost reductions* [2]. The relationship between objectives was assigned a positive value if it was synergistic, a negative value if it represented a trade-off, and a value of zero if there was no relationship or an ambiguous one. Industry experts in the H2Global working groups and H2Global Knowledge Partners were then asked to weigh the strength of the relationships by giving a value from 1 (weak relationship) to 3 (strong relationship) in a survey that received 18 responses. Respondents could also indicate that they saw an ambiguous relationship instead of the indicated positive or negative one. The results are displayed in Table 1.

Auction designers seeking to leverage synergies and minimize the number of trade-offs in their auction should carefully consider the relations between their objectives before picking auction design elements.

IMAGE CREDIT: NTHASONE / ADOBE STOCK

Table 1. Dyadic relations of 22 auction objectives

Legend
The table reads that the objectives in the rows impact those listed in the columns.

0 = no or ambiguous effect
>0 = synergistic/positive effect
<0 = negative effect

|1| = weak relation
|2| = intermediate relation
|3| = strong relation

	supporting H2 (derivatives) market creation	reducing cost of H2 (derivatives) for offtakers	maximizing economies of scale	supporting value chain establishment	increasing H2 (derivatives) market liquidity	diversifying energy supply geographies	diversifying energy supply companies	ensuring project completion	reducing global GHG emissions	reducing domestic GHG emissions	supporting social sustainability and local value creation	supporting environmental sustainability beyond GHG emissions	supporting development policy targets	supporting domestic supply market development	enhancing national industrial competitiveness	supporting SMEs	fostering H2 (derivatives) innovation	developing specific technologies	developing specific (offtake) sectors	minimizing time to delivery	minimizing duration of award procedure	maximizing fiscal efficiency
supporting H2 (derivatives) market creation	0	2	2	2	3	-1	-2	-2	2	2	0	0	0	0	0	0	1	-1	-2	0	-2	2
reducing cost of H2 (derivatives) for offtakers	2	0	2	2	2	-1	-2	0	2	2	-1	-1	-1	0	2	0	2	-1	2	0	0	0
maximizing economies of scale	2	2	0	0	0	-1	-1	-2	2	2	1	-1	-1	0	0	0	0	0	0	-2	-1	2
supporting value chain establishment	0	0	0	0	-2	0	0	2	0	0	1	0	0	0	0	0	0	2	2	1	-2	-1
increasing H2 (derivatives) market liquidity	3	0	0	-2	0	2	2	0	0	0	0	0	0	0	0	2	0	0	0	0	-1	-2
diversifying energy supply geographies	-1	-1	-1	0	2	0	2	0	2	0	0	2	1	-2	-1	0	0	0	0	0	-2	-1
diversifying energy supply companies	2	-2	-1	0	2	2	0	1	0	0	0	1	0	0	0	2	0	0	0	0	0	-2
ensuring project completion	2	-2	0	2	0	0	1	0	2	2	1	1	1	2	2	1	0	1	1	-2	-2	0
reducing global GHG emissions	2	2	2	0	0	0	0	2	0	-2	0	2	2	0	0	0	0	0	0	0	0	-1
reducing domestic GHG emissions	0	-2	0	0	0	0	0	2	-2	0	0	1	-1	2	1	0	0	0	0	0	0	-1
supporting social sustainability and local value creation	0	-1	0	0	0	0	0	0	0	0	0	1	2	0	0	2	0	0	1	-1	-1	-1
supporting environmental sustainability beyond GHG emissions	0	-1	-1	0	0	0	1	1	2	1	1	0	0	0	0	2	2	0	1	-1	-1	-1
supporting development policy targets	0	-1	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	-1	-2	-2
supporting domestic supply market development	0	0	0	0	0	-2	0	0	0	2	0	0	0	0	0	0	0	1	2	0	2	-1
enhancing national industrial competitiveness	0	2	0	0	0	0	0	-2	0	1	0	0	0	0	0	0	2	0	0	0	2	-2
supporting SMEs	0	0	0	0	2	0	2	1	0	0	2	0	0	0	0	0	0	0	0	1	0	0
fostering H2 (derivatives) innovation	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	-2	-1	0	-1	1
developing specific technologies	0	-1	0	2	0	0	0	1	0	0	0	0	0	1	0	0	0	0	2	1	1	-1
developing specific (offtake) sectors	0	0	0	2	0	0	0	1	0	0	1	1	0	2	0	0	0	1	0	0	1	-2
minimizing time to delivery	0	0	-2	1	0	0	0	-2	0	0	-1	-1	-1	0	0	0	0	0	1	0	1	-2
minimizing duration of award procedure	-2	0	0	0	0	-2	0	-2	0	0	-1	-1	-2	2	0	0	0	0	0	1	0	0
maximizing fiscal efficiency	2	0	2	0	0	-1	0	0	-1	-1	-1	-1	-2	-1	2	0	0	-1	-1	0	0	0

Notably, only the relationship between the objectives *supporting H2 (derivatives) market creation* [1] and *increasing H2 (derivatives) market liquidity* [5] was assigned the highest possible positive value of 3 and identified as a symmetric relationship. Some relationships, on the other hand, may not be symmetric: Focusing on market creation may aid efforts to establish supply chains, but a focus on supply chains may also work in favor of discreet trade like over-the-counter interactions. These interactions do not undermine market establishment, but also do not directly contribute to transparent markets. At the other end of the score, no relationship was assigned a score of -3. Besides that, *supporting SMEs* (small and medium-sized enterprises) [16] is in principle compatible with all other objectives. This aspect has been debated, as smaller companies may not be best positioned to achieve maximum scaling effects. However, economies of scale can be realized with SMEs in consortia and, for some parts of the value chain, numbers instead of size may be the more efficient way to scale. This points to the importance of selecting design elements after identifying the principal objectives. *Maximizing fiscal efficiency* [22] appears as the objective with the most trade-offs. This is particularly important for auction designers that give a high priority to this objective, as they must therefore be particularly cautious when picking additional objectives. When preparing an auction, designers will usually not only consider dyadic relationships such as those detailed above, but a more complex set of conditions. This complexity may be introduced by political preferences, legal frameworks (see Box 1) that the auction needs to comply with, and/or technoeconomic conditions. This complex set of relations can be represented as a web of relationships, in which the objectives are the nodes of the web. Dyadic relationships can be transposed into a network to uncover patterns in the relations and to identify potential clusters of objectives that work well together. Figure 1 displays the result of the network analysis implemented in Python. Generally, no objectives or cluster of objectives is fully isolated from the other objectives. This implies that each decision to add objectives bears consequences for the ability to pursue other objectives effectively.

Box 1: Auctions and regulation

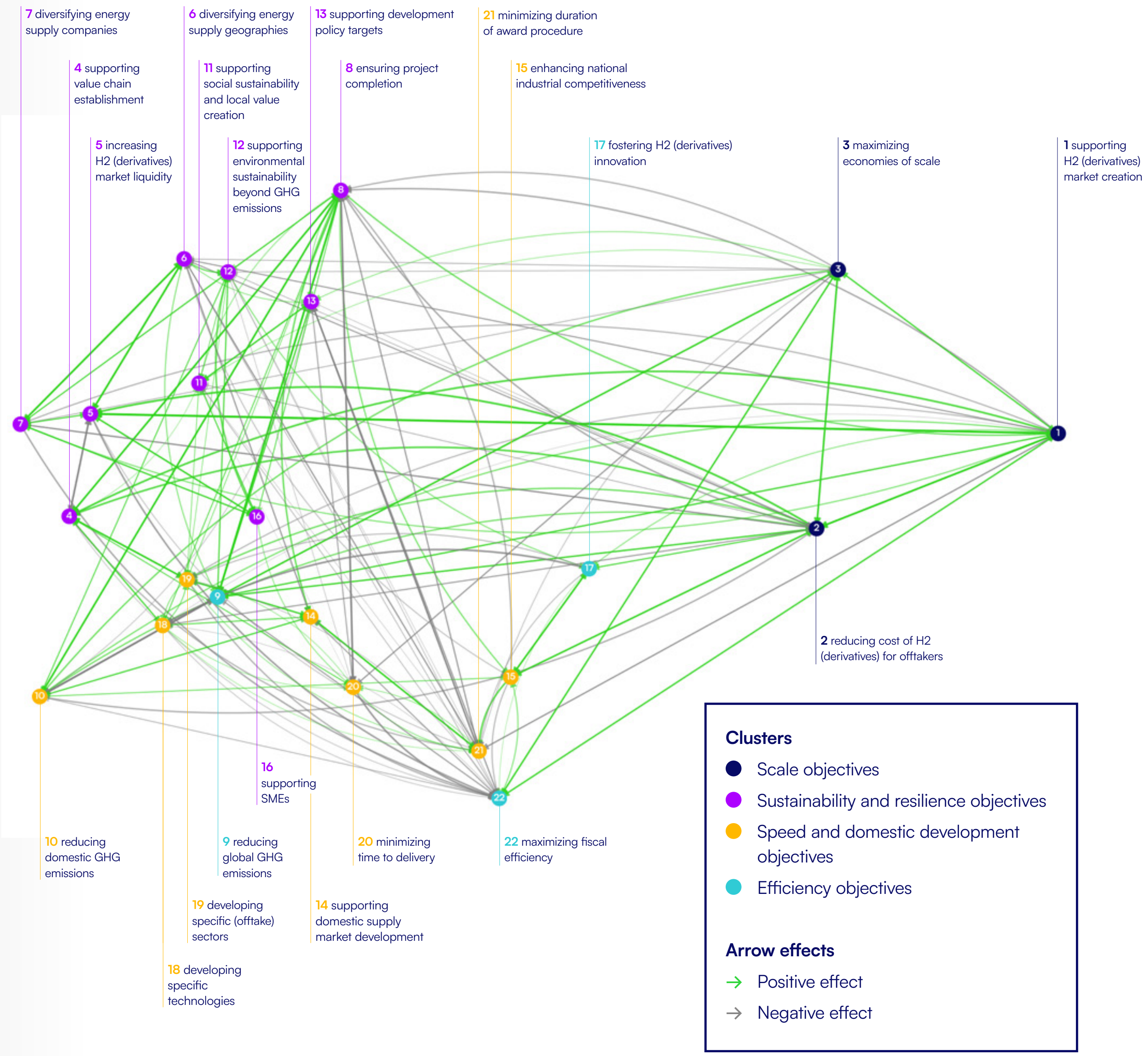
Despite market liberalization efforts in many parts of the world over the last few decades, the energy sector remains relatively strongly regulated.[11] This means that some objectives for auctions for clean hydrogen (derivatives) are mandatory and not subject to the discretion of auction designers, resulting in the need to navigate some trade-offs from the start.

Moreover, regulation in the energy sector has largely been designed to fit existing, mature fossil fuel-based markets, with some adjustments made to aid the introduction of renewable energy sources. Hydrogen (derivatives) are often not addressed explicitly, and instead subsumed under the regulation for gas and/or chemicals (depending on the derivative). This implies that rules designed for mature markets are applied to the still nascent hydrogen economy. Established actors need to learn how this new market can work and to understand that, as many new actors enter this nascent market, they may not yet have the capabilities to deal with complex regulation and fulfill a host of additional conditions for market or auction participation.

In the case of auctions for clean hydrogen (derivatives), procurement laws and state-aid regulation are particularly relevant. For example, the European guidelines on state aid for climate, environmental protection and energy (CEEAG) require competitive bidding processes to have a sufficient number of bidders (Recital 49) and require aid per unit to constitute at least 70% of the selection criteria if the process is not designed as a price-only auction (Recital 50). Depending on the derivative, however, identifying a sufficient number of bidders in nascent markets can be challenging and objectives beyond prices may be more relevant in immature markets that may require, for example, a high level of volume security, flexibility, or competition for high sustainability standards.

IMAGE CREDIT: JEREMY POLAND / ISTOCKPHOTO

Figure 1: Clustered representation of synergies and trade-offs identified in the expert workshops



From the network, four topical clusters of objectives have been identified:

- Scale objectives
- Sustainability and resilience objectives
- Speed and domestic development objectives
- Efficiency objectives

The ***scale objectives*** cluster contains three individual objectives, namely: its namesake, *maximizing economies of scale* [3], *supporting H2 (derivatives) market creation* [1], and *reducing cost of H2 (derivatives) for offtakers* [2]. The three targets have a strong synergistic relationship, as effects of scale imply a reduction of cost per unit of product, which benefits the price offtakers must pay.

Similarly, market creation fosters competition among the most efficient locations and projects, driving prices toward Pareto-optimal levels—an outcome that can be further supported by economies of scale.

These objectives also share a negative relation to the objectives aiming for deliberate diversification of energy supply (implying inclusion of less efficient projects), and some trade-offs with the different environmental, social and governance (ESG) objectives (because of additional costs) and implementation speed (due to development time of larger projects).

The second cluster bundles together a broad set of nine objectives that share a focus on ***sustainability and***

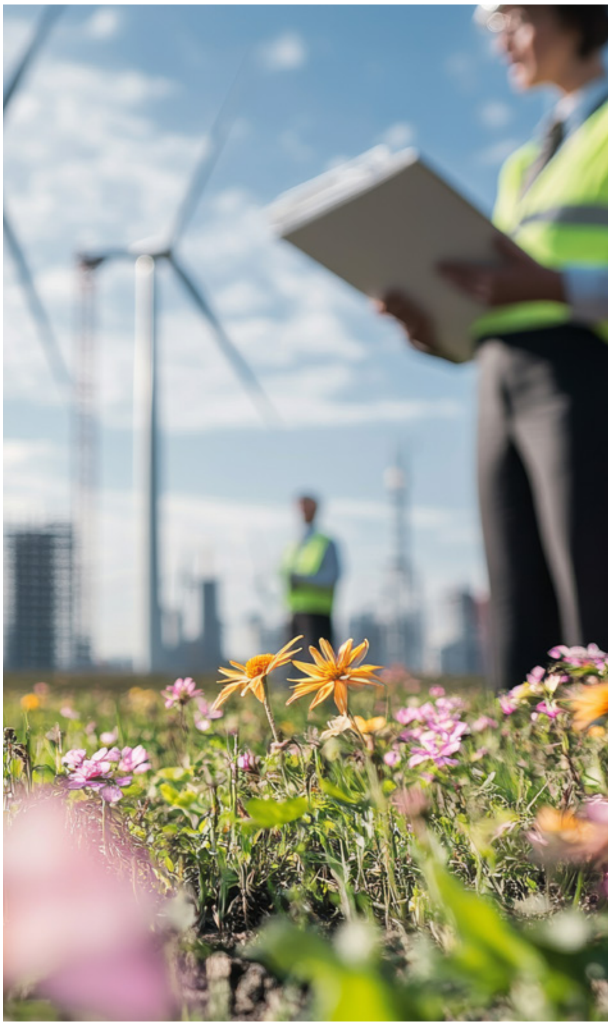


IMAGE CREDIT: ZAHRA / ADOBE STOCK

resilience. They are: *supporting value chain establishment* [4], *diversifying energy supply geographies* [6], *diversifying energy supply companies* [7], *ensuring project completion* [8], *supporting social sustainability and local value creation* [11], *supporting environmental sustainability beyond GHG emissions* [12], *supporting development policy targets* [13], *supporting SMEs* [16], and *increasing H2 (derivatives) market liquidity* [5]. These objectives share a tension with objectives that aim at lowering costs for companies or the treasury, except for the SME objective which is ambiguous in this regard. The objectives that are more on the resilience side (diversification, liquidity, project and value chain build-up) also have in common with the SME objective that they promote a truncation of budgets. In principle, projects that have increased social and environmental sustainability can also be expected to enjoy an elevated social license to operate and are more resilient from this perspective.

Seven objectives comprise the ***speed and domestic development*** cluster. These are: *reducing domestic GHG emissions* [10], *supporting domestic supply market development* [14], *enhancing national industrial competitiveness* [15], *developing specific (offtake) sectors* [19], *developing specific technologies* [18], *minimizing time to delivery* [20], and *minimizing duration of award procedure* [21]. Several of these objectives indicate a narrowed geographic scope, which implies trade-offs with more internationally minded objectives regarding development policies or geographical diversification of supply. This narrowed geographic scope also implies a deliberate decision to renounce comparative benefits from international trade, which conceptually implies reduced cost efficiency. However, concentration on the domestic setting means that projects are situated in the same regulatory setting, which reduces the auction's complexity and allows for quicker awarding and permitting processes. Shorter distances to the destination market also imply reduced infrastructure needs, potentially facilitating a speedy delivery.

Projects that have increased social and environmental sustainability can also be expected to enjoy an elevated societal license to operate and are more resilient from this perspective.

The final cluster—***efficiency***—only contains three objectives, namely: *reducing global GHG emissions* [9], *fostering H2 (derivatives) innovation* [17], and *maximizing fiscal efficiency* [22]. This cluster has the loosest internal connections among all clusters, but all three objectives share some tension with objectives concentrating on domestic scope, which suggests a connection to missed opportunities from comparative advantages. On the positive side, they relate well with the use of markets and scale and cost-reduction objectives.

Given the trade-offs that these four clusters present, it would make sense for auction designers to pick objectives from a single cluster to streamline the effect of the auction. Objectives from outside these clusters should be pursued through other policies and measures to minimize complications. Additional objectives may, however, be imposed as a result of the regulatory context in which auctions for clean hydrogen and its derivatives are conducted. After objectives are selected, auction designers need to sort out which design elements are suitable to pursue these priorities.


IMAGE CREDIT: FANGXIANUO / ISTOCKPHOTO

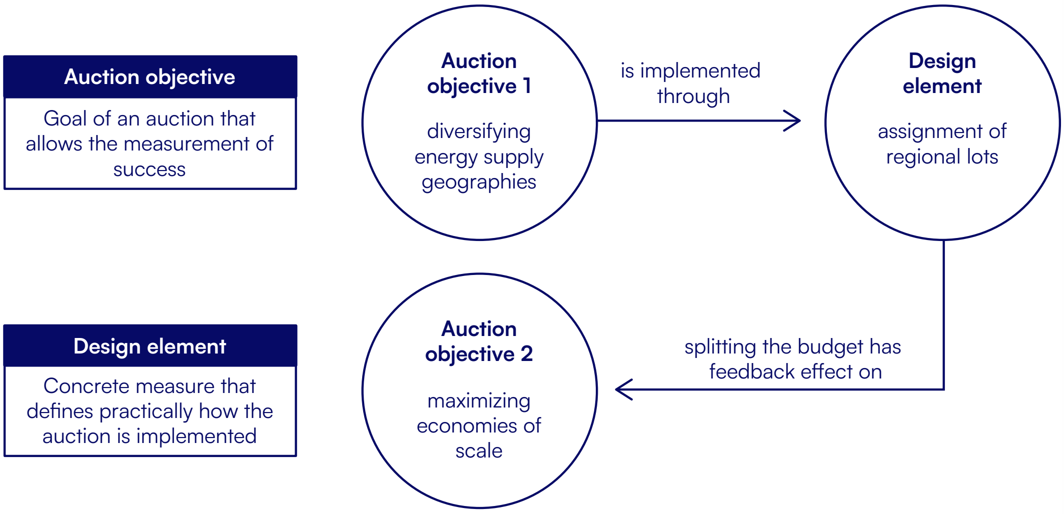
IMAGE CREDIT: KOOKKII / ADOBE STOCK

3

Auction design elements: translating objectives into practice

The number of design elements from which auction designers may choose is extensive. Consequently, to make informed decisions about design, it becomes even more important to consider the auction's objectives. Design elements structure how the auction works practically. The practical choices made subsequently have synergistic or antagonistic feedback effects on the objectives identified in the previous section (see Figure 2).

Figure 2: Schematic relation of auction objectives and design elements



For auctions concerned with clean hydrogen and its derivatives, auction designers need to make decisions, inter alia, about:

— **Product** to be procured (including vector or product-openness vs. specification, as presented in Box 2) and specifications of product qualities

— Type of **auction result** to be awarded (including purchase agreement vs. grant agreement) and, if support is awarded, which **type of support** (including capital expenditure (CAPEX), fixed premium, or contract-for-difference (CfD)

— Eligible **markets** from which to procure (domestic production vs. import orientation)

— **Pre-qualification criteria** (including criteria like minimum annual turnover, creditworthiness, existing expertise and staff size, sector affiliation, minimum or maximum project size)

— **Award criteria** (price-only awarding vs. additional criteria)

Examples of these decisions in practice are provided in the following section, showcasing auction results for clean hydrogen and its derivatives.

IMAGE CREDIT: FIZKES / ADOBE STOCK

A decision about the product to be procured and the quality of the product are the most fundamental decisions for auction designers to make. Once they have made a decision about the product, potential bidders that would have participated if other products were eligible, are automatically ruled out. Product decisions also inform which type of infrastructure is needed for organizing deliveries and they enable estimates to be made of the budget needed for the auction. Conversely, if the budget is predetermined, it may inform the choice of product, depending on other framework conditions.

Box 2: Product specifications for clean hydrogen and its derivatives

Clean hydrogen and its derivatives can be procured in a variety of ways. Besides necessary technical specifications, like the purity of the product that is delivered, auctions may specify the product—or vector—used to transport the product.

The definition of the product that suppliers deliver can be specified to be pure hydrogen, ammonia, methanol, synthetic natural gas (SNG) or another derivative. If such a specification is not implemented, an auction is considered product-open and needs to include a formula by which to make the products comparable for the awarding process. This may happen through a reference to the price per unit of energy content (e.g., EUR/ MWh) or GHG emissions saved.

If auction designers decide to procure hydrogen instead of derivatives, suppliers are currently presented with a transport challenge: Hydrogen as an element is difficult to transport economically in large volumes due to low volumetric energy density. This challenge forces suppliers to decide—when transport via pipeline is not possible—whether to cool and pressurize hydrogen, to dissolve it in liquid organic hydrogen carriers (LOHC), or to use a derivative as a carrier and reconvert it at the destination. These transport options are called vectors. A technology-agnostic auction designer may leave this decision to market participants, but if there is an interest in testing particular technologies, a corresponding requirement may be included in the auction. A decision about a particular point of delivery (for example, the mid-point of the delivery-chain or end-user site) may provide an implicit advantage for certain vectors, as the distribution of costs along the value chain may differ depending on the ability to reuse infrastructure or the need for reconversion.

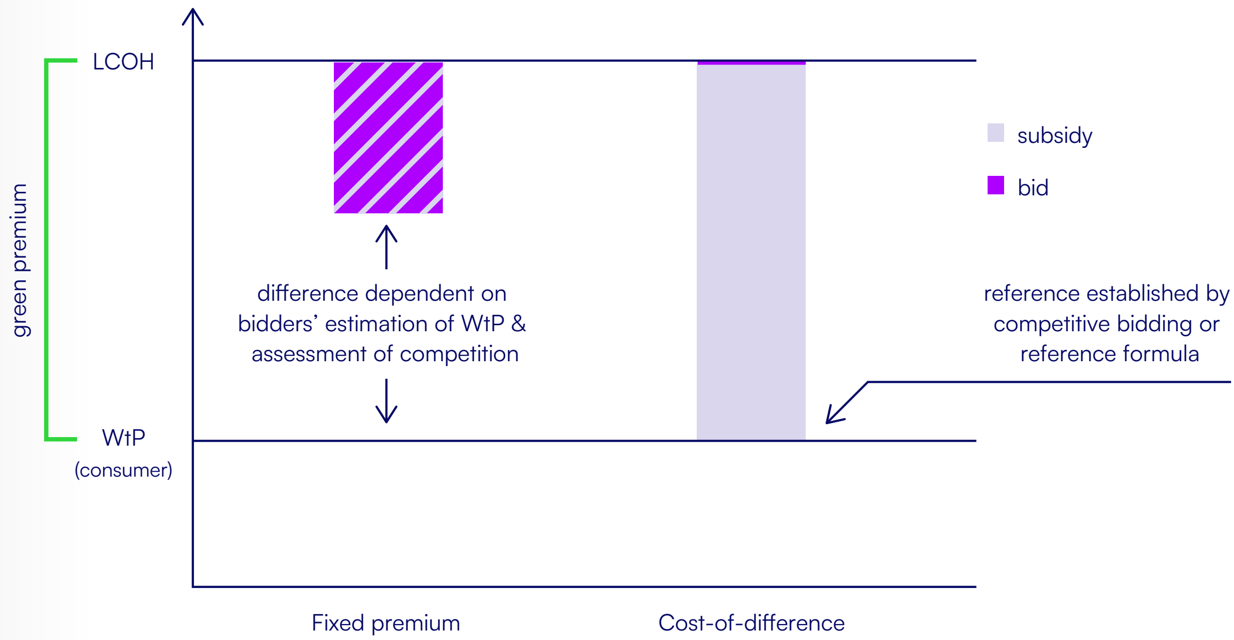
IMAGE CREDIT: HOPSALKA / ISTOCKPHOTO

Box 3: Relevance of greenhouse gas emissions certification

The added value of promoting clean hydrogen and its derivatives lies in the low emission profile of these commodities that can help decarbonize industrial processes, long-haul transport, and other applications that cannot be efficiently decarbonized with direct electrification or direct use of renewable energy. As hydrogen can also be produced using unmitigated fossil fuels as a resource, prescribing emission standards is key to achieving the desired effect to bring down emissions. The traditional steam reformation and gasification technologies using unabated natural gas or coal today provide 95 Mt of hydrogen as a feedstock to refinery, fertilizer, and synthetics production processes, emitting 612 Mt of CO2 equivalents in the process.[12] To reduce these emissions, technologies with lower specific emissions per unit of hydrogen are needed, making specific emissions the decisive criterion for the design of certification schemes. Such certification schemes further need to account for leakages of natural gas in the value chain of fossil fuel-based hydrogen production, even after the introduction of carbon capture technologies.[13] Additionally, hydrogen leakages may also produce short-term climate effects, even if the production is clean.[14] Thus, definitions of greenhouse gas emission levels are a core quality criterion for the purchase of clean hydrogen and its derivatives.

IMAGE CREDIT: ARIFIN STUDIO / ADOBE STOCK

Figure 3: Bidding and allocated subsidies for different subsidy types in reference to levelized cost of hydrogen (LCOH) and willingness-to-pay (WtP)



The type of result produced by the auction affects the award procedure. Awarding a grant agreement shortens the time of the award procedure, as extensive negotiations about delivery details are postponed to the phase after the award in exchange for an increased risk that awarded projects are not realized. Awarding a purchase agreement internalizes this risk to the award process and simultaneously mitigates offtake risks, which is beneficial to the bankability of the winning project. Different types of support may affect the volume of support per project, as fixed premium support allows bidders to weigh their chances of winning the auction against the level of support they need to make the project viable (see Figure 3). Auctions that conceptually tie the subsidy available to the cost-of-difference and determine the cost-of-difference through an auction or formula may prevent this effect. However, this approach may increase the size of support provided to projects participating in the auction, as bidders cannot deliberately and strategically underbid.

The eligibility of markets from which supply is sourced has a strong effect on the set of objectives discussed in the previous section: A decision to limit supply geographies firmly cuts off international, regional, or domestic bidders from participation. Handling differences in regulation between the production site in one jurisdiction and the offtake site in another jurisdiction also requires additional efforts from the involved parties, which may require additional time. Conversely, restraining supply to certain regions may lead to missed opportunities from efficiencies that could be leveraged in other parts of the world.

Pre-qualification criteria filter the set of potential bidders in order to reduce the effort associated with assessing the quality of a large number of bids. They are also a means of setting minimum standards for criteria that need to be fulfilled without gradual variation. For example, an auction designer pursuing a high level of confidence in project completion may set strict requirements for bidders regarding their financial health or existing project-related expertise (see Box 4). Typically, pre-qualification criteria are presented in a binary logic—the criterion is fulfilled or not—but it is sometimes possible to convert them into scales that can be used as award criteria instead of pre-qualification criteria.

An auction designer pursuing a high level of confidence in project completion may set strict requirements for bidders regarding their financial health or existing project-related expertise.

Box 4: Financial stability requirements

Security of supply requires the financial stability of the supplier. A supplier that runs a higher risk of bankruptcy poses a risk to the supply chain in the early phases of the market ramp-up. Consequently, an auctioneer may require auction participants to have reached a certain level of project maturity or to enjoy very good credit ratings in order to secure supply chain stability and avoid default risk. This may prevent smaller or newly founded companies from entering the auction, potentially at the loss of some innovation and cost-saving potential, as competitive bidders are excluded from the tender. A solution to this challenge is to allow bidding by consortia that mitigate some of the default risk.[15] As the development of the clean hydrogen market is progressing, more companies are starting up production, which allows offtakers to run portfolio approaches with diverse suppliers. On the other hand, as the market grows, suppliers may fulfill their delivery commitment using different production sites. Delivery risks may then be distributed through temporal or quantitative redistribution of deliveries or using smaller lots in auctions to enhance smaller companies' competitive chances.[16]

IMAGE CREDIT: JOYFOTOLIAKID / ADOBE STOCK

Award criteria are of course the decisive aspect that transparently defines who will win the auction. Besides the crucial bid price, auctioneers may apply additional awarding criteria that account for the varying qualities of offers. Such varying qualities may, for example, pertain to the timing of deliveries, fluctuating volumes of products being delivered, carbon intensity, or an inflation-adjusted price scheme if the contract foresees multiple deliveries over time.[17] It is also possible to use product qualities for this purpose. To this end, bidders who submit bids with higher standards for clean hydrogen production will receive more points and this could, for example, partially compensate for a higher bid price. Depending on the selected product(s) for the auction, it may also make sense to include infrastructure cost or life-cycle cost. Such additional objectives may, however, impinge on the ability to discover the optimal price of the basic product. Therefore, auctioneers need to carefully balance the extent to which they apply additional criteria.

To make these concepts more comprehensible, the authors applied them to a set of recently implemented clean hydrogen auctions. Their designs were screened for the decisions that were made about objectives and about which design elements were used to promote these objectives. The expected effects of the decisions were also discussed, and compared to the results seen in practice.

IMAGE CREDIT: ARTHIT / ADOBE STOCK

IMAGE CREDIT: JACK / ADOBE STOCK

4

Comparing auctions for clean hydrogen and its derivatives

The impact of the trade-offs and synergies between auction objectives identified in this report can be studied through a comparison of different hydrogen auctions.

To maximize the success of each auction, auction designers need to pick the design elements best placed to meet the objectives set by policymakers within regulatory constraints. If one were tasked to identify the most successful auction, a limitation to auctions with comparable objectives would be required. The analysis at hand, however, is focused on assessing the impact on the results of selecting different objectives, which requires a diversification of cases within a comparable context.

Recently, various auctions for purchasing clean hydrogen and its derivatives have taken place. Initiatives include auctions sponsored by Japan, South Korea, the United Kingdom, the EU, and the following EU member states: France, Germany, Italy, the Netherlands, Portugal, and Romania.[18] To ensure sound comparison, the comparison was restricted to auctions aiming to supply clean hydrogen and its derivatives to markets in the EU or the United Kingdom, as the latter still shares many regulatory prerequisites with EU countries due to its former membership of the EU. At the time of writing, the following clean hydrogen auctions were completed and thus eligible for this comparison:

— The **PtX Tender** implemented by the Danish Energy Agency (DEA) in 2023

— The **First Hydrogen Allocation Round** (HAR1) implemented by the Department for Energy Security and Net Zero in the United Kingdom in 2022-2023

— The **European Hydrogen Bank (EHB) Pilot Auction** implemented by the European Climate, Infrastructure and Environment Executive Agency (CINEA) in 2023-2024

— The **H2Global Pilot Auction for Hydrogen Purchase Agreements for Renewable Ammonia** conducted by Hintco with funding for cost-of-difference provided by the German Federal Government in 2022-2024

As the detailed analysis below shows, the Danish and EU auctions took the most similar approaches among the four, with very similar objectives regarding the build-up of domestic clean hydrogen production combined with fast deployment and low subsidies. The British approach, too, prioritized domestic production combined with a strong interest in securing project realization. The approach pursued in the H2Global Pilot Auction deviated most strongly from the other auctions, as it aimed for market creation via large-scale import projects from outside the EU. This implies that the latter added a layer of complexity associated with the need to navigate the challenges posed by international trade, the different regulatory contexts of the countries of origin and the target markets, and higher transport costs.

The H2Global Pilot Auction deviated most strongly from the other auctions, as it aimed for market creation via large-scale import projects from outside the EU.

The following sections describe the objectives of the individual auctions, the corresponding design choices, and the effects these had on the results. After this, the auctions are linked back together again through a comparison of the effects of their respective design choices.

4.1 The Danish PtX Tender

The Danish PtX Tender was conducted between February 2023 and September 2023. Through the tender, the Danish government sought to allocate DKK 1.25 billion (roughly EUR 165 million) worth of support to clean hydrogen projects.

The stated key objective of the Danish PtX Tender was to support the development of Denmark's domestic hydrogen production [14]. Additionally, the government wanted to retain an openness regarding the vectors to be used to carry hydrogen to end-users [17]. To address the difference between the cost of supply and the willingness-to-pay (WtP) for clean hydrogen (or its derivatives), the government attempted to drive down supply costs [2] while retaining a frugal fiscal approach [22].[19]

Considering its key objective, the DEA chose to limit the eligibility of projects to those situated in Denmark. This restriction directly impeded the objective to reduce supply costs of clean hydrogen (or its derivatives), as global competition would in theory allow for the most cost-effective outcomes. Thus, a minimization of supply costs would only take place within the boundaries of Danish territory. As a means to achieve this in line with EU state-aid regulations, the DEA decided to use an auction-based approach rather than other support instruments.

The DEA tendered clean hydrogen equivalents but, in line with its objective of technological openness, it refrained from specifying the vector or derivative to be used. In compliance with EU regulation, projects were required to comply with the standard set out by the Delegated Act to the Second European Renewable Energy Directive (RED II DA, see Box 5), which effectively reduced producers' options to electrolysis-based production routes. As this was implemented as a mandatory condition, it doubled as a pre-qualification criterion.

Box 5: The EU's Delegated Acts on the second Renewable Energy Directive (RED II DA)

The Delegated Acts to the second Renewable Energy Directive (RED II DA) on Articles 27 and 28, which came into force on July 10, 2023, were introduced to provide safeguards that renewable hydrogen production would not cannibalize existing renewable energy capacities and to ensure significant GHG emission savings.

Article 27 sets detailed requirements for sourcing renewable energy, defining three options for producers to choose from:[20]

1. Direct connection: the RE facility must start operations not more than 36 months before the electrolyser (Art. 3).

2. Grid connection sourcing electricity from the electricity bidding zone in which the project is located with a share of renewable energy above 90% (Art. 4).

3. Grid connection sourcing electricity via power-purchasing agreements (PPAs) and adhering to three conditions:

    - Additionality: The renewable energy facility must begin operations no more than 36 months before the electrolyser (Art. 5).

    - Temporal correlation: Until the end of 2029, hydrogen must be produced within the same calendar month as the production of the renewable energy that was purchased; from 2030 onward, production must occur within the same one-hour period (Art. 6).

    - Geographic correlation: Hydrogen production and renewable energy sources must be in the same or an adjacent bidding zone, or within an interconnected offshore bidding zone (Art. 7).

Transitional phase: Additionality requirements do not apply to hydrogen production facilities commissioned before January 1, 2028 (Art. 11).

Article 28 sets a minimum threshold for greenhouse gas (GHG) emission savings of 70% (Art. 1 & 2).[21] It also establishes a fossil fuel comparator of 94g CO2eq/MJ (Annex) and specifies the methodology for calculating GHG savings from hydrogen production (Art. 3 & Annex).

To be fiscally frugal, the DEA tendered a grant agreement that simplified the process for the auctioneer. It also provided support in the form of a fixed premium provided to the supplier for ten years. The fixed premium provided a high degree of predictability to the treasury and bidder, and conceptually allowed bidders to pick bids that did not fully cover their expected cost-of-difference. Bids ended up being sorted in ascending order, starting from the lowest bidding price per unit (DKK/GJ). The bids were then awarded based on bid price only.[22] The DEA only applied minimal formal pre-qualification criteria, aside from the power-related criteria mentioned above.

Overall, the Danish PtX Tender pursued three clusters of objectives: efficiency [17, 22], speed and domestic development [14], and scale [2]. Despite pursuing objectives from different clusters, only the domestic focus and fiscal efficiency had a conceptual trade-off, as potential cost savings from international trade and specialization ended up not being pursued. The design choices, however, imply some conceptual trade-offs with other objectives assessed here. Firstly, the discriminatory allocation of support to multiple bidders split the available—yet relatively small—budget for support, limiting potential effects of scale. Secondly, the budgetary constraint prohibited the implementation of a dynamic pricing model covering full cost-of-difference by design, although individual projects may still be able to achieve such full coverage. Apart from the strict RED II Delegated Acts criteria applied in the auction, the emphasis on frugality and the domestic market also meant that the auction had limited ability to pursue objectives in the sustainability and resilience cluster.

On 27 October 2023, the DEA announced that six projects had been awarded support while there had been bids worth three times the available budget in total. The awarded projects had offered a total electrolysis capacity of 280 MW.[23] On average, this resulted in a fixed premium of 0.73 EUR/kg per project. The marginal sixth awardee would receive a reduced subsidy if they agreed. Eighty percent of the budget ended up being allocated to three projects by a single developer, European Energy (see Table 2). The projects must come online by 2027 to receive the support.[24] The Plug Power project decided not to move forward with the procedure shortly after the tender results were announced.

IMAGE CREDIT: EUROPEAN ENERGY

Table 2. Winning Projects in the Danish PTX-tender

Project	Allocated budget [EUR]*	Installed electrolysis capacity [MW]	Subsidy [EUR/kg H2]*
Plug Power	14,451,066	100	0.15
European Energy / Vindtestcenter Måde	5,904,652	9	0.64
European Energy / Padborg PtX	122,240,266	90	0.74
Electrochaea / Biocat Roslev	9,566,598	10	0.97
European Energy / Kassø PtX Expansion	10,989,216	10	1.08
HyproDenmark (Everfuel & Hy24 JV)*	18,591,347**	Undisclosed (≈142, at 4,000 full load hours)	1.09**

* Converted from DKK to € using the average exchange rate for the year 2023
** The marginal bidder was offered a reduced subsidy.
Source: Hydrogen Insight

In terms of its stated objectives, the Danish auction mostly attained its goals. Not only is the achieved production capacity of 280 MW quite sizeable but the bids contained different hydrogen derivatives (or carriers). So far, the levelized cost of production of the awarded projects has not been disclosed, thus it is not yet possible to assess the relative effectiveness of the subsidy in significantly driving down supply costs. Indeed, the small premia may risk the realization of the projects and may have been a contributing factor to the retreat of the best bidder shortly after the announcement of the results, as they could not provide a bank guarantee.[25] The results also revealed that larger projects do not necessarily reap smaller subsidies per unit of produced hydrogen in a competitive procedure that is designed to be product open: both the European Energy/ Padborg PtX project and the HyproDenmark project by Everfuel & Hy24 JV needed much higher subsidies per unit of hydrogen than the comparatively small European Energy/ *Vindtestcenter Måde* project. The difference between these projects is that the former produce e-fuels and thus need additional synthesis steps than the latter, which focuses on pure hydrogen. These two larger projects among the awardees also show that the hypothesized negative effect on the scale of projects has been limited. Both the 100 MW and 90 MW projects are large compared to the current average size of 26 MW per project under construction in Europe.[26]

4.2 The First Hydrogen Allocation Round (HAR1)

The HAR1 took place between July 2022 and December 2023. With the tender, the British government (through the Department of Energy Security & Net Zero, DESNZ) sought to allocate GBP 2 billion (roughly EUR 2.3 billion) worth of support to clean hydrogen projects.

The key objective of the HAR1 was to support the development of the United Kingdom's domestic hydrogen production [14]. Additionally, the government wanted to foster innovation through technological neutrality [17]. In response to the problem of difference between the cost of supply and the WtP for clean hydrogen (or its derivatives), the government also intended to drive down supply costs [2]. Finally, the British government was eager to enhance security of supply, including the diversity of suppliers [7], and ensure the deliverability of the projects [8].[27]

IMAGE CREDIT: DAVID MADDOCK / ADOBE STOCK

Corresponding to its key objective, the DESNZ chose to limit the eligibility of projects to those situated in the United Kingdom and made sure that selected projects were distributed across the country. This approach, however, directly impeded the objective of reducing supply costs of clean hydrogen (or its derivatives) as global competition would, in theory, have allowed for the most cost-effective outcomes. Thus, a reduction of supply costs could only take place within the boundaries of the British territory.

To implement the objective of technological openness, no specifications for the vector or derivative were made, but projects had to comply with the British Low Carbon Hydrogen Standard, which includes hydrogen production that emits less than 20g of CO2 equivalents per MJ (at lower heating value).[28] The HAR1 was open to projects using electrolysis technologies.

To provide long-term security of supply and increase project feasibility, DESNZ decided to cover the full cost-of-difference. To determine the cost-of-difference, bidders had to provide a memorandum of understanding with potential offtakers. The annual support would be based on the prices that the project would be able to achieve in practice. The support would be granted in the form of a subsidy for the cost-of-difference for 15 years. The conditions of the support were developed in lockstep with the industrial consortia participating in the auctions, to ensure that projects were able to deliver,[29] which meant that the process looked more like extensive negotiations than an auction in the end.[30]

The HAR1 was intended to drive down prices and adhere to principles of competition. Projects were sorted in ascending order starting from the lowest bidding price per unit (GBP/MWh) and then awarded until the budget was depleted.[31] Additional pre-qualification criteria included a technology readiness level (TRL) of seven and a minimum size of 5MW for participating projects. While no public statement on the reasoning for these design choices was made, the TRL criterion can enhance economic viability and the 5MW-criterion can ensure at least some scaling effects, ruling out research projects.

Overall, the HAR1 pursued five stated objectives (scale [2], sustainability & resilience [7, 8], speed and domestic development [14], and efficiency [17]). These five objectives are associated with all four objective clusters. Among the objectives from different clusters, the aim to reduce costs [2], on the one hand, and company diversification [7] and project completion assurance [8], have a conceptually strong trade-off as they entail a deliberate compromise on efficiencies. Additionally, the design choices developed trade-offs with another objective assessed here: The

Table 3. Winning projects of the British First Hydrogen Allocation Round

Project	Allocated budget [EUR]*	Installed electrolysis capacity [MW]	Subsidy [EUR/kgH2]*
Barrow Green Hydrogen	2,299,405,604*	21.0	9.24**
Bradford Low Carbon Hydrogen		24.5	
Cromarty Hydrogen		10.6	
Green Hydrogen 3		10.6	
HyBont		5.2	
HyMarnham		9.3	
Langage Green Hydrogen		7.0	
Tees Green Hydrogen		5.2	
Trafford Green Hydrogen		10.5	
West Wales Hydrogen		14.2	
Whitelee Green Hydrogen		7.1	

* Converted from GBP to EUR using the average exchange rate for the year 2023
** The DESNZ only disclosed the total budget for all projects and the weighted average subsidy
Source: United Kingdom Department for Energy Security & Net Zero

extensive requirements and lengthy negotiation processes to ensure project feasibility impinged on the ability of the HAR1 to deliver results quickly [20, 21].

On 14 December, 2023, the DESNZ announced that 11 projects had been awarded support while there had been 15 bidders in total. The awarded projects had offered a total electrolysis capacity of 125 MW. On average, the eleven projects were awarded a subsidy of 9.24 EUR/kg.[32] Projects remained on the smaller scale of up to 21 MW of installed electrolysis capacity (see Table 3). The projects still had to negotiate a support agreement with the DESNZ after the conclusion of bidding procedures.

In terms of its stated objectives, the British auction managed to meet most of them. The 125 MW production capacity was relatively small for the funds that were allocated. The levelized cost of production of the awarded projects has yet to be disclosed; therefore, the effectiveness of the subsidy to significantly drive down supply costs is unclear. The results suggest that the trade-off between "ensuring project viability" and "scale" ends up prioritizing smaller projects close to the current average size of projects in Europe (26 MW).[33] This can be interpreted either as an argument for the competitiveness of this type of project, an indication of a different need for support, or diverging readiness levels and associated project risks.

4.3 The European Hydrogen Bank Pilot Auction

The EHB Pilot Auction took place between October 2023 and April 2024. Through the tender, the EU Commission sought to allocate EUR 1.15 billion worth of support to renewable hydrogen projects (including a EUR 800 million contribution from the EU's own Innovation Fund and a top-up by Germany of EUR 350 million as part of the Auctions-as-a-Service scheme, which is yet to be awarded).

The key objective of the EHB Pilot Auction was to support the development of the EU's domestic hydrogen production [14] to reach 10 million tons by 2030. Additionally, the Commission wanted to support the discovery of real market prices and market formation [1] for renewable hydrogen and its derivatives, connect supply and demand [4], bridge the difference between the cost of supply and the WtP for renewable hydrogen (or its derivatives) [2], and de-risk projects to contribute to their completion [8]. The EU approach specifically made electrolysis-based technologies a fixed requirement [18]. The auction designers also intended to ensure a fast award process [21].[34]

To meet its main objective, the European Commission chose to limit the eligibility of projects to those situated in the European Economic Area (EEA). Given the market size of the EEA, this allowed for substantial competition, which is a necessary precondition for the creation of markets and discovery of market prices. However, an element of geographic restriction remains preventing the full utilization of global markets.

In terms of the definition of the product that was tendered, hydrogen had to be produced via electrolysis using renewable energy compliant with the regulations of the RED II Delegated Acts. Awardees would be granted a fixed premium for ten years. Bidders also needed to undergo general financial status checks and provide an MoU with a potential offtaker. After a limited pre-qualification, bids were sorted in ascending order starting from the lowest bidding price per unit (EUR/kg) and then awarded until the budget was depleted. If awarded support, bidders had to convert the MoU with the offtaker into a hydrogen purchase agreement (HPA) within two years or replace it with an equivalent HPA by another offtaker. Captive business models were also allowed to submit an MoU, i.e., companies could ask for a subsidy for hydrogen production and be their own offtakers of, for example, renewable ammonia.

As price discovery and minimization of prices were important objectives of the EHB auction, organizing the procurement in the form of an auction (as opposed to other support instruments) represents a well-tailored approach

IMAGE CREDIT: HANS HARALD HELLANDSJØ

in line with the EU's own public procurement laws. The EU decided to auction a grant agreement instead of an offtake contract, leaving the establishment of the supply chain to the bidding companies, which were requested to identify an offtaker by way of an MoU. In return, bidders would receive fixed premium support for ten years. Fixed premium support on its own is not conceptually geared to cover the full cost-of-difference as auction participants may choose to bid lower. Combining this design element with the need for an MoU with an offtaker, however, facilitates the identification of the gap and encourages cost-covering bids. Practically, this comes with the advantage that the auctioneer does not need to engage in finding the market price or assume offtaker responsibilities, although these aspects are not overtly stated objectives of the EHB's auction.

The EU's seven objectives for the auction belong to three of the identified clusters: scale [1, 2], sustainability & resilience [4, 8], and speed & domestic development [14, 18, 21]. By design, the chosen objectives entail five potential trade-offs on the objectives level. Three of these are connected to the objective to de-risk projects and support project completion [8]. Pursuing this objective conceptually implies taking time and costly measures to hedge risks, which can extend the duration of the award procedure [21] and increase the cost of clean hydrogen [2]. Although there is no market without projects, an emphasis on project completion [8] also works against the inherent possibility of failure in a functioning market [1]. Creating a market [1] and supporting supply chain build-up [4] also takes time that may extend the bidding process [21]. Simultaneously, the technological focus [18] prevented a more open competition of technologies [17] that could have reaped additional cost savings [2].

The EU had to make design choices that solved these trade-offs. In particular, its choice to reduce pre-qualification criteria to a minimum, to award a grant agreement instead of offtake contracts, and to provide fixed premium support instead of full cost-of-difference imply a priority for speed of the awarding process and low cost, with less emphasis on project completion. The overtly stated objectives of the tender also entailed trade-offs with a pursuit of objectives from the sustainability and resilience cluster, including a deliberate diversification of supply geographies, and increased environmental and social standards.

On 30 April 2024, the European Climate, Infrastructure and Environment Executive Agency (CINEA) announced that seven projects had been awarded a total support of EUR 719 million before the cut-off point for the marginal bidder, and there had been a total of 132 participants in the procedure. The awarded projects had offered a total electrolysis capacity of 1,502 MW. On average, this resulted in a subsidy of 0.44 EUR/kg. In terms of project size, the awarded ones range from 35 MW to 500 MW, including three at industrial scale starting at 200 MW (see Table 4).[35] The grant agreements were negotiated until September 2024 and one project (El Alamillo H2) decided not to sign the grant agreement.

Table 4. Winning Projects of the Hydrogen Bank Pilot Auction

Project	Allocated budget [EUR]	Installed electrolysis capacity [MW]	Subsidy [EUR/kg]
eNRG Lahti	45,228,375	90	0.37
El Alamillo H2	24,605,819	60	0.38
Grey2Green-II	84,227,910	200	0.39
HYSENCIA	8,104,918	35	0.48
SKIGA	81,317,443	117	0.48
Catalina	230,178,772	500	0.48
MP2X	245,178,772	500	0.48

In terms of its stated objectives, the EHB auction achieved most of them. The production capacity of 1,502 MW corresponds to 1.5 per cent of the EU goal for domestic hydrogen production. The large production capacity also corresponds to very low bidding prices. So far, the winning and median bid prices, as well as median expected offtake prices, have been disclosed as a contribution to market information and creation. The proxy median cost of production corridor is estimated between 5.3 EUR/kg and 13.5 EUR/kg, depending on the expected offtake price and the assumption that the bidders did not bid low. It is important to note that the winning bid prices represent the subsidy that companies hope to secure and not the product cost. The mean estimations of suppliers for achievable offtake prices (including a green premium), on the other hand, do not represent market-determined real offtake prices and are subject to subsequent contract negotiations. For the orientation of market participants, information about currently achievable prices is more important to prepare financial investment decisions.

Moreover, it is still uncertain as to whether the very low subsidies per unit will indeed allow projects to materialize or whether the incentive to bid low has jeopardized cost-covering results. However, at least three of the winning projects use captive procurement strategies, i.e., consume the produced renewable hydrogen themselves. This potentially allows for some degree of cross-subsidization of the project within the corporate structure and thus an opportunity to strategically bid below cost-covering subsidy levels. An assessment of this aspect will only be possible after the respective deadlines have passed for contracting the support with the EU authorities and converting the offtake MoUs to proper contracts.

4.4 The H2Global Pilot Auction for Hydrogen Purchase Agreements for Renewable Ammonia

The first H2Global Auction for Hydrogen Purchase Agreements (HPAs) for Renewable Ammonia was conducted between December 2022 and July 2024. This tender represents one of three lots auctioned by Hintco, a fully-owned subsidiary of the H2Global Foundation, as part of its EUR 900 million pilot tender. At the time of writing, the lot for renewable ammonia had successfully been concluded and will be the focus for this analysis.[36]

The key objective of the H2Global mechanism is to create markets for clean hydrogen (derivatives) [1]. H2Global intends to support the increase in the liquidity of hydrogen markets [5] by publishing as much price information as possible from a legal and functional perspective. The approach also aims to temporarily bridge and close the cost gap between clean hydrogen supply and offtakers' WtP [2]. To achieve this, it intends to promote maximum economies of scale [3]. Additionally, H2Global's approach aims to provide a high level of security to suppliers [8] and make efficient use of public funding [22]. Hintco secured financial support from the German Federal Government to cover the cost-of-difference in the pilot auction.

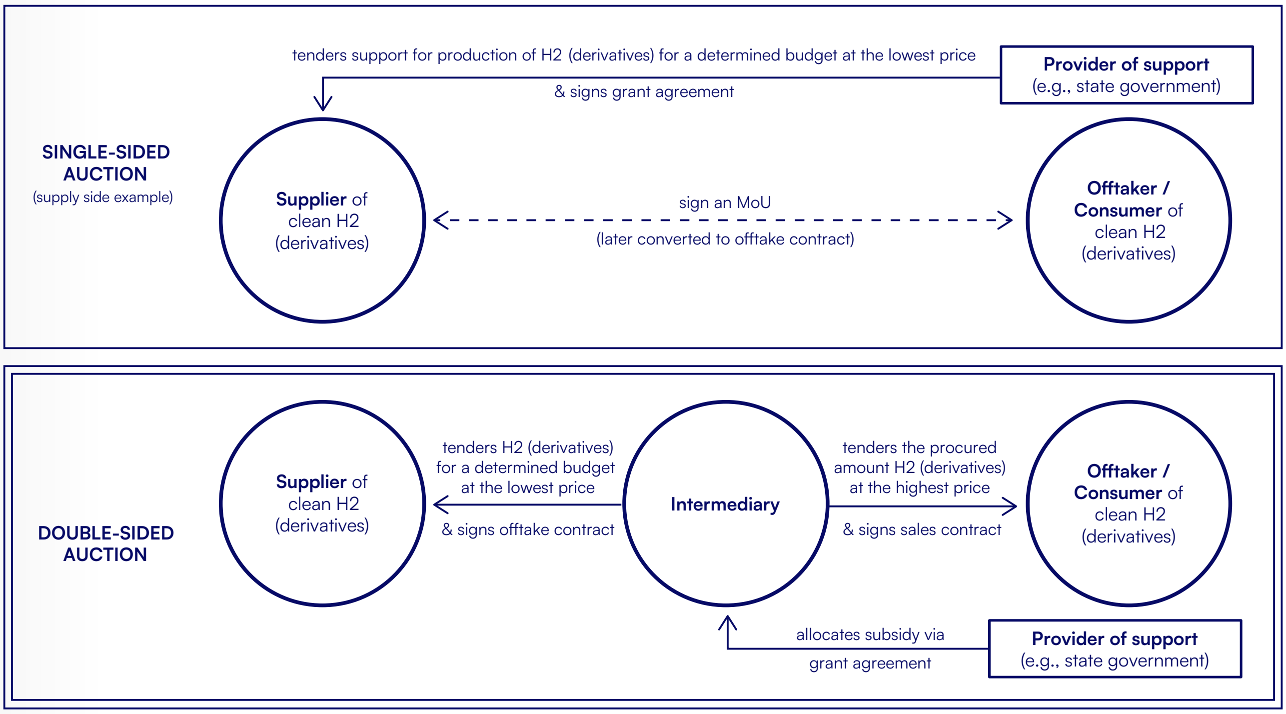
In conversation with the German government, the objectives of the pilot tender were tailored to diversify renewable hydrogen production beyond domestic production [6] and contribute to development policies [13], while achieving a high level of social [11] and environmental [12] standards, including a focus on electrolysis-based production technologies. The import objective also informed the focus on specific hydrogen derivatives as a "production and transport technology" [18], since it helped address the transport challenges arising from the low volumetric energy density of hydrogen and the absence at this time of fully developed hydrogen infrastructures.

H2Global tenders are designed as a double-auction scheme. This means that an intermediary first conducts an auction on the supply side and then tenders the procured amounts on the demand side.

H2Global tenders are designed as a double-auction scheme. This means that an intermediary first conducts an auction on the supply side and then tenders the procured amounts on the demand side. Differences of cost between the two auctions remain with the intermediary, who is consequently installed as the recipient of support in the form of a grant agreement (see Figure 4). Suppliers, in turn, negotiate 10-year offtake contracts with the intermediary, while offtakers negotiate short-term contracts with the intermediary. This set up implies that price signals from this mechanism are not subsidies, but product prices, and the total cost-of-difference is ascertained only after the demand side auctions are closed.

The objectives of supporting diversification and development policies were operationalized as an eligibility criterion limiting participation to production sites outside the EU and countries of the European Free Trade Association (EFTA). The H2Global Pilot Auction therefore needed to address the specific challenges of cost-efficient long-

Figure 4: Schematic comparison of single-sided and double-sided auctions



distance transport of clean hydrogen (derivatives). In accordance with the objective to focus on derivatives and electrolysis-based technologies, the budget was truncated into three lots of equal size and respectively dedicated to purchasing renewable ammonia, renewable methanol, and electricity-based sustainable aviation fuel (e-SAF). Pursuing high sustainability criteria was implemented through auction requirements: For one, hydrogen had to be produced via electrolysis using renewable energy compliant with the regulations of the RED II Delegated Act. For the intermediary, this meant translating European legislation to international contexts. Additional sustainability measures regarding local benefits and water supplies were imposed as the likelihood of having projects in less developed and arid regions was deemed high.

Implementing the H2Global Pilot Auction as an import scheme involved additional risks for the supply chain, including currency and regulatory risks. To mitigate such risks and help build the supply chain, high confidence in the awardees' capability to deliver on the project was imperative. Bidders thus needed to undergo pre-qualification in the form of financial status checks and to pre-certify the sustainability of their projects with an external auditor. Bids for the HPA were sorted according to a points system including three criteria: the lowest price per unit (EUR/t), the minimum supply volume, and additional delivery options that could be drawn if revenue is generated in the following hydrogen sales agreement (HSA) auctions. The three criteria were weighted 30:60:10 for the decision. In the HPA auction, one winner was to be selected for each lot, so as to allow for maximum economies of scale by affording larger allocations per winning project.

Overall, the H2Global Pilot Auction for renewable ammonia encompasses eleven objectives from all four clusters identified in this analysis (scale [1,2, 3], sustainability & resilience [5, 8, 11, 12, 13], speed & domestic development [6, 18], and efficiency [22]). The chosen design elements attempt to balance the trade-offs between these objectives and comply with regulatory requirements. In general, the objectives from the sustainability and resilience cluster present challenges when balanced with the objective to maintain fiscal efficiency [22] and drive down the cost of clean hydrogen projects [2]. The focus on safeguarding project viability [8] through financial status checks may narrow the field of eligible competitors, potentially influencing the extent to which a comprehensive picture of the market [1] can be gained. Simultaneously, the focus on projects outside of Europe allows the pilot to achieve the first cross continental shipment, though it may not fully leverage the competitive potential of the H2Global mechanism given the EU's market size. It should be noted that supporting SMEs (small and medium-sized enterprises) [16] was not a deliberate objective of the first HPA auctions. The stated objectives of the H2Global auction may have lengthened the award process [21].

On 11 July 2024, Hintco announced that a winning consortium had been identified for Lot 1 for renewable ammonia, with five bidders involved in the second stage of the bidding process. The winning project offered an

electrolysis capacity of 100 MW at an estimated product price of 3.7 EUR/kg for hydrogen based on electrolysis using renewable energy and excluding synthesis to ammonia and transport to Europe (see Table 5).[37] Other bidding projects proposed similar at-scale production capacities.[38] Ammonia deliveries from the production site in Egypt to the Port of Rotterdam are scheduled to start in 2027, from where the product will be sold by Hintco to final consumers through the demand-side auction process.

In terms of its stated objectives, the H2Global Pilot Auction for Renewable Ammonia achieved balanced results. In terms of market creation, the H2Global Pilot Auction resulted in a successful award, after attracting a competitive field of bidders and having to translate European regulation to international markets. The auction also provided transparent information on product and transport costs and delivery timelines, improving intelligence for project developers on both the supply and demand side of the market. Although it was not the focus of this analysis, the unsuccesful e-SAF lot that was part of the H2Global Pilot Auction similarly provided information on the existing barriers in this market segment and the requirement of larger funding volumes for this type of project.

On the matter of product cost, the successful bid in the H2Global Pilot Auction placed 37% below the maximum bid price, indicating functioning competition. The awarded

Table 5: Winning project of the first H2Global HPA Auction for Renewable Ammonia

Project	Allocated budget [EUR]	Installed electrolysis capacity [MW]	Subsidy [EUR/kgH2]
Egypt Green Hydrogen	397,000,000	100	3.70*

* Calculation of a price for hydrogen by the authors, based on the ex-factory contract price for ammonia (811 EUR/tNH3 excluding the transport cost to the port of Rotterdam); the price represents the maximum possible amount.

offtake contract increases the bankability of the project and, along with financial robustness checks, indicate that project completion is likely. High environmental and social standards of the project should also be achieved, as these criteria were set as *sine qua non* conditions.

On the other hand, the high standards applied to the auction led to an extended award process in which the intermediary—Hintco—had to push deadlines to allow projects to comply with the various requirements.[39] This affected the speed of the award process but ultimately resulted in the identification of a bidder that met all requirements. Lessons learnt in this process will inform the next planned H2Global auctions, with faster award times expected.

The H2Global Pilot Auction's results in terms of fiscal efficiency and market liquidity can only be fully determined once demand side auctions begin and are completed. Only then can the cost-of-difference be identified and with it the amount of funds that Hintco must draw from the government funding the auction. The assessment of liquidity effects in turn hinges on the number of successful bidders participating in the demand side auctions.

4.5 Comparison of the auctions

An analysis of the individual auctions was important to appreciate each of the approaches in its own right. However, additional insights and lessons can be gained from explicitly comparing them.

First, one must recognize that the four auctions compared in this report address a different number of objectives: the Danish auction selected four objectives, the British auction five, the European auction seven, and the H2Global Pilot Auction eleven. None of the auctions concentrated on one of the clusters identified in the network analysis; thus auction designers had to balance the trade-offs inherent in the objectives they picked.

In practice, the Danish auction selected and implemented objectives from different clusters in a way that minimized the number of trade-offs and allowed the maintenance of a focus on speedy delivery of support for domestic supply. The British design, too, had few trade-offs and prioritized its two objectives from the sustainability and resilience cluster (security of supply and project completion) within the framework of an auction restricted to the British territory. Auction designers at the European Hydrogen Bank (EHB) in turn prioritized the speed of the awarding process over other objectives, as highlighted by their choice of low pre-qualification requirements and award of fixed premium grant agreements. Finally, H2Global's Pilot Auction balanced eleven objectives, which meant that trade-offs were unavoidable. In the pursuit of a successful award and results consistent with the material objectives, H2Global's intermediary, Hintco, had to accept compromises regarding the duration of the award procedure while bidders were preparing their projects for participation in the tender.

The different objectives resulted in differences in design. While the Danish, British and European auctions entailed a process of allocating public support, the H2Global mechanism went one step further and produced negotiated contracts (HPAs) between suppliers and the intermediary, Hintco, for hydrogen deliveries to target ports. In the H2Global model, government support consists of a grant letter that is provided to Hintco that ensures it will have access to the funds required to enter contracts with suppliers, and eventually cover the expected difference in the purchase and sales price. In the other three clean hydrogen auctions analyzed, suppliers needed to establish a grant agreement with the authorities and sign contracts with offtakers after being awarded support, even after securing an MoU or a letter of intent to enter the auction. These distinct design choices reflect the priority given to mobilizing support for domestic suppliers versus the objective of creating markets.

In the pursuit of a successful award and results consistent with the material objectives, H2Global's intermediary, Hintco, had to accept compromises regarding the duration of the award procedure while bidders were preparing their projects for participation in the tender.

Another important difference is that the British First Hydrogen Allocation Round (HAR1) and the H2Global Pilot Auction have more strongly emphasized the aspect of project completion. HAR1 implemented this objective by opting to secure the coverage of the full cost-of-difference and to allow for a flexible allocation process that allowed for adjustments and made the subsidy scheme work for the projects. In the case of the H2Global Pilot Auction, this objective was pursued through a combination of full coverage of cost-of-difference, award of offtake contracts instead of grant agreements, and willingness to extend deadlines.

The Danish and EHB auctions were primarily interested in allocating support efficiently and quickly. Thus, they chose the legal vehicle of grant agreements and fixed premia that conceptually allow bidders to decide the extent to which they want to cover the cost-of-difference in exchange for their chances to win the auction.

These design choices had an impact in the form of the results accomplished: While the Danish and EHB auctions can publish the determined subsidy at closure of the auction process, the HAR1 and H2Global pilot tenders are only able to provide estimates at the time of the award. The H2Global Pilot Auction will only determine final numbers for the subsidy at the end of the support period once the actual cost-of-difference for each year has been determined. Both auctions are, however, able to determine more precisely the actual cost of production and WtP, and share that information publicly, contributing to market creation.

Among the four auctions assessed, the H2Global Pilot Auction is the only one focused on promoting imports into Europe to contribute to a diversification of supply geographies. As a consequence, this auction faced some additional practical challenges as the auctioneer had to navigate differences in regulation between non-European countries and the EU's internal market. At a time when some of the regulations were in preparation, handling these differences meant finding solutions to cope with the uncertainty. Auction results for the H2Global Pilot Auction also entailed transport costs and import fees, which were not included in the other auctions' published product price. Moreover, the focus on a product—renewable ammonia—that requires additional synthesis steps also means that the budget must cover the cost of the synthesis process in addition to the cost of the production of hydrogen using electrolysis. Thus, it is to be expected that the total installed electrolysis capacity resulting from the tender at comparable product prices is significantly smaller than the capacity achieved when focusing only on pure hydrogen auctions. Additionally, the data from the winning projects need to be converted to comparable units of the same currency per unit of pure hydrogen to make sense. This price can be calculated either at ex-factory levels or including transport to the agreed delivery target. As the projects awarded in the Danish, European and British auctions still need to define offtakers and are not disclosing transport costs, a comparison of calculated ex-factory costs is currently the only viable option (see Table 6).

IMAGE CREDIT: ORG / ADOBE STOCK

Table 6: Auctions in comparison

Project	Danish PtX tender	European Hydrogen Bank Pilot Auction	British Hydrogen Allocation Round (HAR1)	H2Global HPA Pilot Auction Lot 1
Key objectives	Domestic clean hydrogen supply chain development [14]	Domestic clean hydrogen supply chain development [14] & fast implementation [21]	Domestic hydrogen supply development [14] & project completion [8]	Market creation [1], scale [3], efficient use of concessionary capital [22], environmental safeguards [12]
Design implementation	Geographic restriction (domestic market)	Geographic restriction (domestic market)	Geographic restriction (domestic market)	Geographic restriction (external markets)
	Fixed support for supplier	Fixed support for supplier	Dynamic support for supplier	Dynamic support for intermediary
	Single-sided auction	Single-sided auction	Single-sided auction	Double-sided auction
	Pay-as-bid auction	Pay-as-bid auction	Pay-as-bid auction	1st price sealed bid auction (winner takes all)
Budget (million EUR)	165	800	2,400	300
Award process duration (years)	0.75	0.75	1	1.5
Type of result	Grant Agreement	Grant Agreement	Grant Agreement	Offtake Contract
Electrolysis capacity (MW)	280	1,502	125	100
Product cost (EUR/kg of H2)	Not published	5.8-13.6*	11.9**	3.7***
Subsidy (EUR/kg of H2)	0.73	0.44	6.18	TBD after HSA auction

* EHB only published a range for all bidders
** Average of all bidders
*** The winning consortium only provided an ammonia price. The values represents a recalculation by the H2Global Foundation for an ex-factory H2 price based on a levelized cost of energy of EUR 112.77 and 82% energy efficiency of the Haber-Bosch-process.


IMAGE CREDIT: OKSANA / ADOBE STOCK

5

Unintended consequences of auction designs

Picking multiple objectives for an auction may lead to tension between both the stated objectives and some implicit or generally valued objectives. Two important examples are the duration of the award procedure and the successful completion of projects.

Generally, governments seeking to allocate support through auctions have an interest in a timely delivery of results contributing to the overall success of the endeavor. The HAR1 and H2Global Pilot Auction have shown that accommodating bidders to allow for a successful conclusion of the auction may cause delays. These may be caused in particular by design elements that require auction participants to provide independent verification or certification before the conclusion of the auction process. This may include financial statements, or environmental sustainability reports, which must be externally reviewed to ensure compliance with the minimum requirements.

Regarding unintended consequences, underbidding and underbuilding are salient. Underbidding means offering a bid price that does not allow for cost-recovery due to high competition, which therefore increases the risk that the project will not be implemented. This phenomenon is often referred to as the "winner's curse". Underbuilding is a potential consequence of underbidding in that the project developer is not able to deliver on the project due to the failure to achieve a price that covers costs.[40] Observers have discussed whether there has been underbidding in the Danish PtX Tender and EHB Pilot Auction, considering the unexpectedly low bids and the immediate withdrawal of a winning project in Denmark.[41]

One reason for underbidding is the lack of immediate legal consequences.[42] Indeed, the award in both the Danish and European auctions required the grant agreements to be negotiated with the authorities after the award. Thus, there was no direct legal consequence from a low bid and one of the projects eventually decided not to sign a grant agreement. Additionally, even the successful conclusion of a grant agreement provides few safeguards. In the Danish auction, a retention penalty of 40 DKK/GJ was agreed, and a termination of the grant agreement was not foreseen. Aside from the default clause that bidding companies could not be in financial difficulty, bidders merely needed a non-binding opinion from the environmental authority stating general alignment with environmental regulation and a screening agreement from a transmission system operator. The authorities also did not require any form of agreement with potential offtakers.[43] In the case of the EHB Pilot Auction, companies faced a completion guarantee of 4% of the maximum grant amount that would be payable in case of non-completion and a completion deadline of five years after the conclusion of the grant agreement. Other checks were deliberately kept to a minimum, including a price hedging strategy for volatile electricity prices. Environmental permitting and grid access would only have to be initiated at the time of the auction and both electricity procurement and offtake had to be indicated within an MoU.[44]

Such conditions, in combination with a set of pre-award incentives, provide a setting that is conducive to underbidding. The set of incentives includes the definition of the support recipient, the support type, and optimistic market assessment by the bidder. Auction designs that directly allocate support to suppliers instead of an intermediary allow for the supplier to choose whether they prefer higher support or higher chances to win the auction. Similarly, fixed support types without dynamic elements—like inflation adjustment, reference prices, or price determination by the market—allow bidders to more freely position themselves strategically and put them in a position to judge market developments. If bidders misjudge the need for subsidies following their expectations regarding achievable prices, underbidding is the consequence.

An inaccurate assessment of the risks embedded in the value chains, for example regarding the readiness of infrastructure or offtakers to absorb the tendered products, may also contribute to underbuilding.

As a solution to underbidding, auction designers may link the bidding behavior to consequences by awarding support at the same time as a contract. Such a contract may preferably be an offtake contract instead of a grant agreement. Making use of an intermediary as the beneficiary of support reduces the appeal of strategic behavior by the bidder, as does the use of external references like indexes or market-based approaches for offtake prices to determine support levels. External references need to work with fossil fuel prices, general inflation and similar indicators, as reliable prices for clean hydrogen (derivatives) are not available yet. Underbuilding, in turn, may be prevented through sufficiently strict penalties for delays or reduced capacities, additional financial pre-qualifications, and strict compliance rules. It is, however, important to consider that overly strict compliance rules may reduce the number of eligible participants in the process and thus impinge on successful competition.

External references need to work with fossil fuel prices, general inflation and similar indicators, as reliable prices for clean hydrogen (derivatives) are not available yet.


IMAGE CREDIT: GIBSTER / ADOBE STOCK


IMAGE CREDIT: BAJIMBA / ADOBE STOCK

6

Recommendations

The recommendations presented in this section are intended to help auction designers, regulators, and policymakers to make the best possible use of auctions to support the ramp-up of the clean hydrogen economy. Some aspects may pertain to wider regulatory contexts in line with the analysis presented above.

Auction objectives should be drawn from coherent sets of objectives in a mutually reinforcing way to maximize the desired impact. If possible, auction designs should avoid the combination of objectives from different sets. Where additional objectives from other clusters are introduced, implications for the key objectives of the auction should be checked thoroughly.

This recommendation applies only to the extent that objectives are not already mandated by legal provisions outside the auction designer's control. The analysis presented here has identified four major sets of auction objectives:

- Scaling
- Domestic development of hydrogen supply and speed
- Sustainability and resilience
- Efficiency

Individual objectives within each set work well together in the sense that they are mutually reinforcing or at least produce only a few trade-offs. Trade-offs increase in between sets, suggesting that auction designers should be careful when adding further objectives. By aligning objectives, the overall aim to achieve progress regarding the scale of projects and cost, the fast build-up of domestic hydrogen supply, or particularly sustainable hydrogen supply, can be enhanced significantly. Other objectives are better pursued through alternative, not project-specific support schemes, such as improved taxation, permitting, or regulation.

Auction designs should reduce incentives for underbidding and underbuilding to improve project delivery and the credibility of price signals.

Auction designs may link the bidding behavior to consequences by awarding support at the same time as a contract. Such a contract may preferably be an offtake contract instead of only a grant agreement. Making use of an intermediary as the beneficiary of support reduces bidders' interest in strategic behavior, as does the use of external references such as indexes or market-based approaches for offtake prices to determine support levels. Underbuilding, in turn, may be prevented through sufficiently strict penalties for delays or reduced capacities, additional financial pre-qualifications and strict compliance rules, and the reduction of value-chain risks. It is, however, important to consider that overly strict compliance rules may reduce the number of eligible participants in the process and thus impinge on functioning competition.

General political goals should be implemented through general regulation rather than project specific auctions.

Auctions have specific strengths and weaknesses. They excel in price discovery and achieving efficient results, yet are flexible enough to incorporate additional elements depending on the desired outcomes and objectives. As an instrument to allocate support, they are project specific by nature. The combination of project-specific support allocation and flexibility present an opportunity for experimentation with regulation.

Auctions should, however, not be used by regulators as a silver bullet, since pursuing a larger number of objectives coincides with more potential trade-offs that may disguise the effects of experimentation rather than reveal important takeaways. The limited number and volume of auctions, moreover, results in insufficient reach to implement general policy goals. Imposing too many such criteria may also cause unintended consequences that are better solved through general legislation.

General procurement law and regulations should allow for exceptions in immature market settings, such as the clean hydrogen economy, to allow for more flexible auctions.

Auction designers face varying regulatory requirements in different jurisdictions. Depending on the context, auctions may need to fulfill extensive criteria to attain permission to proceed. These criteria are often defined by general public procurement law, which has been designed for mature markets, with their diversity of market participants and functioning competition. The addition of a series of new conditions targeting more sustainable procurement practices has been necessary, especially in developing and emerging countries.

In early market development stages, many projects still struggle to build functional business cases and can easily be overburdened by additional criteria they are required to implement. To the extent that auctions may

Auction designers need flexibility to implement auctions that successfully procure clean hydrogen at prices and conditions that allow for a ramp-up of the hydrogen economy.

be used to allocate support within budgetary constraints, auction designers need flexibility to implement auctions that successfully procure clean hydrogen at prices and conditions that allow for a ramp-up of the hydrogen economy. Auctioneers may experiment with auction designs afterwards to work out the most effective designs for different objectives. The necessary flexibility must be permitted in the relevant legislation.

Literature and sources

Beard, Thomas, ‘EU Approves First Subsidies for Hydrogen Projects’, *Economist Intelligence Unit*, 2024, <https://www.eiu.com/n/eu-approves-first-subsidies-for-hydrogen-projects/> [accessed 16 August 2024]

Bollerhey, Timo, Markus Exenberger, Florian Geyer, and Kirsten Westphal, *H2Global- Idea, Instruments and Intentions* (H2Global Stiftung, February 2023) <https://files.h2-global.de/H2Global-Stiftung-Policy-Brief-01_2022-EN.pdf>

Burgess, James, ‘First UK Green Hydrogen Funding Round Awards Just Half of 250 MW Capacity’, *S&P Global*, 2023 <https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/121423-first-uk-green-hydrogen-funding-round-awards-just-half-of-250-mw-capacity> [accessed 26 April 2024]

Clean Hydrogen Partnership, ‘The European Hydrogen Market Landscape’, *Clean Hydrogen Observatory*, 2023 <https://observatory.clean-hydrogen.europa.eu/reports/report-1-european-hydrogen-market-landscape> [accessed 9 August 2024]

Collins, Peter, ‘European Hydrogen Bank and H2Global Join Forces to Boost Global Hydrogen Ramp-Up’, *Hydrogen Europe*, 2023 <https://hydrogeneurope.eu/european-hydrogen-bank-and-h2global-join-forces-to-boost-global-hydrogen-ramp-up/> [accessed 28 October 2024]

Côté, Elizabeth, Mak Đukan, Cristian Pons-Seres De Brauwer, and Rolf Wüstenhagen, ‘The Price of Actor Diversity: Measuring Project Developers’ Willingness to Accept Risks in Renewable Energy Auctions’, *Energy Policy*, 163 (2022), p. 112835, doi:10.1016/j.enpol.2022.112835

Danish Energy Agency, *Danish PtX-Tender Documents* (Danish Energy Agency, 2023) <https://www.ethics.dk/ethics/eo#/2b3ea81c-1ca9-4d3d-b563-b87f629fb79c/publicMaterial> [accessed 16 July 2024]

———, ‘The First PtX Tender in Denmark Has Been Determined: Six Projects Will Establish Electrolysis Capacity on More than 280 MW’, *Energistyrelsen*, 2023 <https://ens.dk/en/press/first-ptx-tender-denmark-has-been-determined-six-projects-will-establish-electrolysis-capacity> [accessed 28 November 2023]

———, ‘The Government’s Strategy for Power-to-X’, 2022 <https://www.bing.com/ck/a?!&&p=02558757d23787b5JmltdHM9MTcxNDYwODAwMCZpZ3VpZD0wZDQxNWFhZi1lMGMwLTY0MTgtMzY0OC00OTBmZTE2YjY1MGYmaW5zaWQ9NTI4MA&ptn=3&ver=2&hsh=3&fclid=0d415aaf-e0c0-6418-3648-490fe16b650f&psq=objectives+danish+ptx+tender&u=a1aHR0cHM6Ly90aGV0cmFkZWNvdW5jaWwuZGsvZW4vLS9tZWRpYS93ZWJzaXRlcy9pbnZlc3QtaW4tZGVubWFyay9maWxlcy9zdGlnLXJhc211c3Nlbi1wdHgtY29uZmVyZW5jZS1wcmVzZW50YXRpb24uYXNoeA&ntb=1> [accessed 2 May 2024]

Department of Energy Security & Net Zero, ‘Hydrogen Allocation Rounds’, *Government of the United Kingdom*, 2024 <https://www.gov.uk/government/collections/hydrogen-allocation-rounds> [accessed 26 April 2024]

———, ‘UK Low Carbon Hydrogen Standard’, *Government of the United Kingdom*, 2024 <https://www.gov.uk/government/publications/uk-low-carbon-hydrogen-standard-emissions-reporting-and-sustainability-criteria> [accessed 26 April 2024]

Emma Woodward, Kirsten Stone, Aashwij Prabhu, and Dilara Caglayan, *Auctions to Action: Catalysing Renewable Hydrogen Uptake across Europe* (Aurora Energy Research, January 2024)

EU Commission, ‘Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the European Hydrogen Bank’, 2023 <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0156> [accessed 26 April 2024]

European Commission, ‘Delegated Regulation - 2023/1184 - EN - EUR-Lex’, 2023 <https://eur-lex.europa.eu/eli/reg_del/2023/1184/oj> [accessed 1 February 2024]

———, ‘Delegated Regulation - 2023/1185 - EN - EUR-Lex’, 2023 <https://eur-lex.europa.eu/eli/reg_del/2023/1185/oj> [accessed 1 February 2024]

———, ‘European Hydrogen Bank’, 2024 <https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen/european-hydrogen-bank_en> [accessed 28 October 2024]

———, 'REPowerEU Plan', 2022 <https://eur-lex.europa.eu/resource.html?uri=cellar:fc930f14-d7ae-11ec-a95f-01aa75ed71a1.0001.02/DOC_1&format=PDF> [accessed 2 November 2023]

———, 'Upcoming EU Hydrogen Bank Pilot Auction: European Commission Publishes Terms & Conditions', 2023 <https://climate.ec.europa.eu/news-your-voice/news/upcoming-eu-hydrogen-bank-pilot-auction-european-commission-publishes-terms-conditions-2023-08-30_en> [accessed 28 November 2023]

European Hydrogen Bank, *Results of the European Hydrogen Bank Pilot Auction for Renewable Hydrogen* (European Commission, 30 April 2024)

Habibic, Ajsa, 'UK Reveals Winners of First Hydrogen Allocation Round', *Offshore Energy*, 2023 <https://www.offshore-energy.biz/uk-reveals-winners-of-first-hydrogen-allocation-round/> [accessed 26 April 2024]

Hintco, *H2Global Pilot Auction Results: Lot1 and Lot 3* (Hint.co GmbH, 11 July 2024) <https://cdn.sanity.io/files/u4w9plcz/production/8df5b11af3214c47b1d8ffd8fccc63ad81985b6b.pdf> [accessed 14 August 2024]

———, *Lot 1: Renewable Ammonia* (Hint.co GmbH, 11 July 2024) <https://www.hintco.eu> [accessed 13 August 2024]

Howarth, Robert W., and Mark Z. Jacobson, 'How Green Is Blue Hydrogen?', *Energy Science & Engineering*, 9.10 (2021), pp. 1676—87, doi:10.1002/ese3.956

IEA, *Global Hydrogen Review 2023 — Analysis* (IEA, September 2023) <https://www.iea.org/reports/global-hydrogen-review-2023> [accessed 12 February 2024]

IPHE, 'Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen', 2021 <https://www.iphe.net/_files/ugd/45185a_ef588ba32fc54e0eb57b0b7444cfa5f9.pdf>

IRENA, *Renewable Energy Auctions: A Guide to Design* (IRENA; CAM, 2015) <https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/Jun/IRENA_Renewable_Energy_Auctions_A_Guide_to_Design_2015.pdf?rev=dd6699497a974bcb88dc8b2dc39b6611> [accessed 11 January 2024]

Jenny Winkler; Bridget Woodman; Anna Billerbeck; Vasilios Anatolitis; Pia Kerres, *Auctions beyond Electricity - How Auctions Can Help Reform the Energy System of the Future* (Fraunhofer ISI; UNEXE, March 2022) <http://aures2project.eu/wp-content/uploads/2022/10/AURES_II_D7_4_auctions_beyond_electricity.pdf> [accessed 12 January 2024]

Kerres, Pia, Fabian Wigand, Felix von Blücher, Corinna Klessmann, Vasilios Anatolitis, Lin Zheng, and others, *Auctions for the Support of Green Hydrogen: Applying RES Auction Expertise to Green Hydrogen* (Guidehouse; Fraunhofer ISI, March 2022) <http://aures2project.eu/wp-content/uploads/2022/04/AURES_II_Policy_Brief_hydrogen_auctions.pdf> [accessed 11 January 2024]

Martin, Polly, 'A Single Developer Sweeps 80% of Budget from Denmark's First Green Hydrogen and Derivatives Tender', *Hydrogen Insight*, 2023 <https://www.hydrogeninsight.com/production/a-single-developer-sweeps-80-of-budget-from-denmark-s-first-green-hydrogen-and-derivatives-tender/2-1-1543084> [accessed 26 April 2024]

———, 'Analysis: Why the Risks and Potential Rewards Are Both High for Green Hydrogen Producers at the Upcoming EU Subsidy Auction', *Hydrogeninsight.Com*, 2023 <https://www.hydrogeninsight.com/policy/analysis-why-the-risks-and-potential-rewards-are-both-high-for-green-hydrogen-producers-at-the-upcoming-eu-subsidy-auction/2-1-1514639> [accessed 16 August 2024]

———, 'Embattled Plug Power Ousted from Denmark's Green Hydrogen Tender Winners' List', *Rechargenews.Com*, 2023 <https://www.hydrogeninsight.com/production/embattled-plug-power-ousted-from-denmarks-green-hydrogen-tender-winners-list/2-1-1557659> [accessed 7 May 2024]

Necoechea-Porras, Pablo David, Asunción López, and Juan Carlos Salazar-Elena, 'Deregulation in the Energy Sector and Its Economic Effects on the Power Sector: A Literature Review', *Sustainability*, 13.6 (2021), p. 3429, doi:10.3390/su13063429

Oeko-Institut, *PTX Business Opportunity Analyser (BOA): Data Documentation of Data Sources and Data Processing for Version 2.0* (Commissioned by Agora Energiewende and Agora Industry, 25 June 2024) <https://www.agora-industry.org/fileadmin/Projects/2022/2022-01_INT_PtX-Dialog/Oeko-Institut_2024_PTXBOA_Data_Documentation_v_2.1.pdf> [accessed 13 August 2024]

Parkes, Rachel, 'Analysis: Winners of the First European Hydrogen Bank Subsidies Have Been Revealed — but Will It Be Enough to Kickstart the Sector?', *Hydrogeninsight.Com*, 2024 <https://www.hydrogeninsight.com/policy/analysis-winners-of-the-first-european-hydrogen-bank-subsidies-have-been-revealed-but-will-it-be-enough-to-kickstart-the-sector-/2-1-1635957> [accessed 16 August 2024]

Reijonen, Helen, Jani Saastamoinen, and Timo Tammi, 'The Importance of SMEs' Network Partners in Consortium Bidding for Public Sector Tenders', *International Journal of Public Sector Management*, 35.1 (2021), pp. 1—15, doi:10.1108/IJPSM-04-2021-0082

Roth, Agustin, Andrea Dertinger, Bastian Lotz, and Matthias Schimmel, 'Making Sense of Green Hydrogen Costs and Recent Market Developments in Europe', *www.Euractiv.com*, 2023 <https://www.euractiv.com/section/energy-environment/opinion/making-sense-of-green-hydrogen-costs-and-recent-market-developments-in-europe/> [accessed 2 May 2024]

Vazquez, Miguel, and Michelle Hallack, 'Auctions to Reveal Consumers' Willingness to Pay for Low-Carbon Hydrogen Projects: Combining Lessons from Renewables and Natural-Gas Industries', *Clean Energy*, 8.4 (2024), pp. 103—10, doi:10.1093/ce/zkae040

Wang, Shengquan, and Jiawen Luo, 'Understanding the Energy Sector Deregulations: International Evidence', *Empirical Economics*, 66.4 (2024), pp. 1511—51, doi:10.1007/s00181-023-02508-5

Westphal, Kirsten, Madjid Kübler, Ludwig Möhring, and Jens Völler, *Hydrogen and Market 'Ramp-Up'- Phases and Target Models* (H2Global Stiftung, March 2023) <https://files.h2-global.de/H2Global-Stiftung-Policy-Brief-04_2023-EN.pdf>

Annex

Workshop methodology

In the working group 'Aligning Auction Designs', the H2Global Foundation gathered 38 industry experts to provide structured, practice-related feedback to the desk research results. These experts represent companies from the whole hydrogen value chain, including industrial plant manufacturers, hydrogen producers, logistics, infrastructure, and demand sectors, as well as companies from the finance and insurance sector. Additionally, academic knowledge partners from the International Renewable Energy Agency (IRENA) and the Oxford Institute for Energy Studies took part in the regular meetings to help guide the discussions.

A workshop in the early preparation phase was used to open the debate using a virtual world café set-up. In a world café, participants are sorted into randomly selected groups that spend time on a set of guiding questions for some time before rotating to the next set. At each new virtual set, the participants see the results produced by the previous group, which allows the new group to add and expand on the information they find. For the workshop on 'Aligning Auction Designs', the participants were given the same question prompts on three overarching aspects. These were choice of markets and technologies, qualification for participation in an auction, and risk allocation. On each of the aspects, participants were asked to brainstorm the objectives that can be pursued before the discussion moved to the design elements that could be implemented to achieve the objectives. Finally, participants were requested to discuss which design elements and objectives were complementary and which rather presented trade-offs that auction designers need to address.

Table 7: Objectives and trade-offs in clean hydrogen auctions

ID	Objective	Objective Group	Definition
[1]	supporting H2 (derivative) market creation	Scale objectives	The auction focuses on identifying H2 (derivatives) producers and offtakers and facilitating the contracting regarding the exchange of H2 (derivatives) between these market participants
[2]	reducing cost of H2 (derivatives) for offtakers	Scale objectives	The auction focuses on lowering the price that the demand side must pay for H2 (derivatives), including curtailing production cost or compensating cost differences
[3]	maximizing economies of scale	Scale objectives	The auction focuses on optimizing the economic viability of projects by increasing the size of projects (volume or number)
[4]	supporting value chain establishment	Sustainability & resilience objectives	The auction focuses on connecting production, transport, infrastructure and/or offtake companies with contractual arrangements
[5]	increasing H2 (derivatives) market liquidity	Sustainability & resilience objectives	The auction focuses on increasing the number and speed of interactions in H2 (derivatives) trade
[6]	diversifying energy supply geographies	Sustainability & resilience objectives	The auction focuses on identifying auction winners from different regions/countries/jurisdictions, typically to improve supply security and derisk dependencies on single suppliers
[7]	diversifying energy supply companies	Sustainability & resilience objectives	The auction focuses on identifying multiple auction winners, typically to improve supply security and derisk dependencies on single suppliers
[8]	ensuring project completion	Sustainability & resilience objectives	The auction focuses on derisking projects, typically to improve supply and/or offtake security

ID	Objective	Objective Group	Definition
[9]	reducing global GHG emissions	Efficiency objectives	The auction focuses on the mitigation of greenhouse gas (GHG) emissions independently of the location where these reductions occur
[10]	reducing domestic GHG emissions	Speed & domestic development objectives	The auction focuses on the mitigation of GHG emissions on the territory of the sponsor of the auction
[11]	supporting social sustainability and local value creation	Sustainability & resilience objectives	The auction focuses on project designs that introduce community benefits at the project locations, ensuring socioeconomic participation of local populations
[12]	supporting environmental sustainability beyond GHG emissions	Sustainability & resilience objectives	The auction focuses on project designs that avoid negative externalities on local ecosystems at the project locations, including inter alia the sustainable management of water, brine and gas transport, and the protection of local biodiversity
[13]	supporting development policy targets	Sustainability & resilience objectives	The auction focuses on the identification of projects that are aligned with the objectives of (domestic) industrial policies or (international) development aid, depending on the sponsor
[14]	supporting domestic supply market development	Speed & domestic development objectives	The auction focuses on the establishment of clean hydrogen production on the territory of the auction's sponsor
[15]	enhancing national industrial competitiveness	Speed & domestic development objectives	The auction focuses on the improvement of the relative economic position of the companies active on the territory of the auction's sponsor
[16]	supporting SMEs	Sustainability & resilience objectives	The auction focuses on enhancing market access for small and medium-sized enterprises (SMEs)
[17]	fostering H2 (derivative) innovation	Efficiency objectives	The auction focuses on encouraging original solutions and technological progress, typically with a technologically neutral approach
[18]	developing specific technologies	Speed & domestic development objectives	The auction focuses on a narrow set of technologies to provide certainty regarding preferable technologies, and to push market participants to make decisions on technologies and/or infrastructure compatibility
[19]	developing specific (offtake) sectors	Speed & domestic development objectives	The auction focuses on products and/or solutions that are tailored to support the decarbonization of specific sectors, for example sustainable aviation or shipping fuels
[20]	minimizing time to delivery	Speed & domestic development objectives	The auction focuses on reducing the time between the auction award and the start of supply to offtakers
[21]	minimizing duration of award procedure	Speed & domestic development objectives	The auction focuses on keeping the auction process itself short to come to quick decisions
[22]	maximizing fiscal efficiency	Efficiency objectives	The auction focuses on reducing the budgetary expenditure to support clean H2 (derivatives) projects, in particular on a per unit base

Endnotes

1 European Commission, 'REPowerEU Plan', 2022 <https://eur-lex.europa.eu/resource.html?uri=cellar:fc930f14-d7ae-11ec-a95f-01aa75ed71a1.0001.02/DOC_1&format=PDF> [accessed 2 November 2023].

2 For an extensive list of properties and further literature, see Miguel Vazquez and Michelle Hallack, 'Auctions to Reveal Consumers' Willingness to Pay for Low-Carbon Hydrogen Projects: Combining Lessons from Renewables and Natural-Gas Industries', *Clean Energy*, 8.4 (2024), pp. 103—10, doi:10.1093/ce/zkae040.

3 Pia Kerres and others, *Auctions for the Support of Green Hydrogen: Applying RES Auction Expertise to Green Hydrogen* (Guidehouse; Fraunhofer ISI, March 2022) <http://aures2project.eu/wp-content/uploads/2022/04/AURES_II_Policy_Brief_hydrogen_auctions.pdf> [accessed 11 January 2024].

4 European Commission, 'Upcoming EU Hydrogen Bank Pilot Auction: European Commission Publishes Terms & Conditions', 2023 <https://climate.ec.europa.eu/news-your-voice/news/upcoming-eu-hydrogen-bank-pilot-auction-european-commission-publishes-terms-conditions-2023-08-30_en> [accessed 28 November 2023].

5 Kerres and others, *Auctions for the Support of Green Hydrogen: Applying RES Auction Expertise to Green Hydrogen*.

6 Kirsten Westphal and others, *Hydrogen and Market 'Ramp-Up'- Phases and Target Models* (H2Global Stiftung, March 2023) <https://files.h2-global.de/H2Global-Stiftung-Policy-Brief-04_2023-EN.pdf>.

7 Timo Bollerhey and others, *H2Global- Idea, Instruments and Intentions* (H2Global Stiftung, February 2023) <https://files.h2-global.de/H2Global-Stiftung-Policy-Brief-01_2022-EN.pdf>.

8 European Commission, 'European Hydrogen Bank', 2024 <https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen/european-hydrogen-bank_en> [accessed 28 October 2024].

9 Peter Collins, 'European Hydrogen Bank and H2Global Join Forces to Boost Global Hydrogen Ramp-Up', *Hydrogen Europe*, 2023 <https://hydrogeneurope.eu/european-hydrogen-bank-and-h2global-join-forces-to-boost-global-hydrogen-ramp-up/> [accessed 28 October 2024].

10 Compare Agustin Roth and others, 'Making Sense of Green Hydrogen Costs and Recent Market Developments in Europe', *www.Euractiv.com*, 2023 <https://www.euractiv.com/section/energy-environment/opinion/making-sense-of-green-hydrogen-costs-and-recent-market-developments-in-europe/> [accessed 2 May 2024].

11 Pablo David Necoechea-Porras, Asunción López, and Juan Carlos Salazar-Elena, 'Deregulation in the Energy Sector and Its Economic Effects on the Power Sector: A Literature Review', *Sustainability*, 13.6 (2021), p. 3429, doi:10.3390/su13063429; Shengquan Wang and Jiawen Luo, 'Understanding the Energy Sector Deregulations: International Evidence', *Empirical Economics*, 66.4 (2024), pp. 1511—51, doi:10.1007/s00181-023-02508-5.

12 IEA, *Global Hydrogen Review 2023 — Analysis* (IEA, September 2023) <https://www.iea.org/reports/global-hydrogen-review-2023> [accessed 12 February 2024].

13 Robert W. Howarth and Mark Z. Jacobson, 'How Green Is Blue Hydrogen?', *Energy Science & Engineering*, 9.10 (2021), pp. 1676—87, doi:10.1002/ese3.956.

14 IPHE, 'Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen', 2021 <https://www.iphe.net/_files/ugd/45185a_ef588ba32fc54e0eb57b0b7444cfa5f9.pdf>.

15 Helen Reijonen, Jani Saastamoinen, and Timo Tammi, 'The Importance of SMEs' Network Partners in Consortium Bidding for Public Sector Tenders', *International Journal of Public Sector Management*, 35.1 (2021), pp. 1—15, doi:10.1108/IJPSM-04-2021-0082; Elizabeth Côté and others, 'The Price of Actor Diversity: Measuring Project Developers' Willingness to Accept Risks in Renewable Energy Auctions', *Energy Policy*, 163 (2022), p. 112835, doi:10.1016/j.enpol.2022.112835.

16 Reijonen, Saastamoinen, and Tammi, 'The Importance of SMEs' Network Partners in Consortium Bidding for Public Sector Tenders'.

17 Jenny Winkler; Bridget Woodman; Anna Billerbeck; Vasilios Anatolitis; Pia Kerres, *Auctions beyond Electricity - How Auctions Can Help Reform the Energy System of the Future* (Fraunhofer ISI; UNEXE,

March 2022) <http://aures2project.eu/wp-content/uploads/2022/10/AURES_II_D7_4_auctions_beyond_electricity.pdf> [accessed 12 January 2024].

18 Emma Woodward and others, *Auctions to Action: Catalysing Renewable Hydrogen Uptake across Europe* (Aurora Energy Research, January 2024).

19 Danish Energy Agency, 'The Government's Strategy for Power-to-X', 2022 <https://www.bing.com/ck/a?!&&p=02558757d23787b5JmltdHM9MTcxNDYwODAwMCZpZ3VpZD0wZDQxNWFhZi1lMGMwLTY0MTgtMzY0OC00OTBmZTE2YjY1MGYmaW5zaWQ9NTI4MA&ptn=3&ver=2&hsh=3&fclid=0d415aaf-e0c0-6418-3648-490fe16b650f&psq=objectives+danish+ptx+tender&u=a1aHR0cHM6Ly90aGV0cmFkZWNvdW5jaWwuZGsvZW4vLS9tZWRpYS93ZWJzaXRlcy9pbnZlc3QtaW4tZGVubWFyay9maWxlcy9zdGlnLXJhc211c3Nlbi1wdHgtY29uZmVyZW5jZS1wcmVzZW50YXRpb24uYXNoeA&ntb=1> [accessed 2 May 2024].

20 European Commission, 'Delegated Regulation - 2023/1184 - EN - EUR-Lex', 2023 <https://eur-lex.europa.eu/eli/reg_del/2023/1184/oj> [accessed 1 February 2024].

21 European Commission, 'Delegated Regulation - 2023/1185 - EN - EUR-Lex', 2023 <https://eur-lex.europa.eu/eli/reg_del/2023/1185/oj> [accessed 1 February 2024].

22 Danish Energy Agency, 'The First PtX Tender in Denmark Has Been Determined: Six Projects Will Establish Electrolysis Capacity on More than 280 MW', *Energistyrelsen*, 2023 <https://ens.dk/en/press/first-ptx-tender-denmark-has-been-determined-six-projects-will-establish-electrolysis-capacity> [accessed 28 November 2023].

23 Danish Energy Agency, 'The First PtX Tender in Denmark Has Been Determined'.

24 Polly Martin, 'A Single Developer Sweeps 80% of Budget from Denmark's First Green Hydrogen and Derivatives Tender', *Hydrogen Insight*, 2023 <https://www.hydrogeninsight.com/production/a-single-developer-sweeps-80-of-budget-from-denmark-s-first-green-hydrogen-and-derivatives-tender/2-1-1543084> [accessed 26 April 2024].

25 Polly Martin, 'Embattled Plug Power Ousted from Denmark's Green Hydrogen Tender Winners' List', *Rechargenews.Com*, 2023 <https://www.hydrogeninsight.com/production/embattled-plug-power-ousted-from-denmarks-green-hydrogen-tender-winners-list/2-1-1557659> [accessed 7 May 2024].

26 Clean Hydrogen Partnership, 'The European Hydrogen Market Landscape', *Clean Hydrogen Observatory*, 2023 <https://observatory.clean-hydrogen.europa.eu/reports/report-1-european-hydrogen-market-landscape> [accessed 9 August 2024].

27 Ajsa Habibic, 'UK Reveals Winners of First Hydrogen Allocation Round', *Offshore Energy*, 2023 <https://www.offshore-energy.biz/uk-reveals-winners-of-first-hydrogen-allocation-round/> [accessed 26 April 2024].

28 Department of Energy Security & Net Zero, 'UK Low Carbon Hydrogen Standard', *Government of the United Kingdom*, 2024 <https://www.gov.uk/government/publications/uk-low-carbon-hydrogen-standard-emissions-reporting-and-sustainability-criteria> [accessed 26 April 2024].

29 Habibic, 'UK Reveals Winners of First Hydrogen Allocation Round'.

30 James Burgess, 'First UK Green Hydrogen Funding Round Awards Just Half of 250 MW Capacity', *S&P Global*, 2023 <https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/121423-first-uk-green-hydrogen-funding-round-awards-just-half-of-250-mw-capacity> [accessed 26 April 2024].

31 Department of Energy Security & Net Zero, 'Hydrogen Allocation Rounds', *Government of the United Kingdom*, 2024 <https://www.gov.uk/government/collections/hydrogen-allocation-rounds> [accessed 26 April 2024].

32 Burgess, 'First UK Green Hydrogen Funding Round Awards Just Half of 250 MW Capacity'.

33 Clean Hydrogen Partnership, 'Report 1'.

34 EU Commission, 'Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the European Hydrogen Bank', 2023 <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0156> [accessed 26 April 2024].

35 European Hydrogen Bank, *Results of the European Hydrogen Bank Pilot Auction for Renewable Hydrogen* (European Commission, 30 April 2024).

36 The lot for e-SAF has also been concluded albeit there has been no winning bid, and the budget was reallocated to the renewable methanol lot.

37 The bidder was only required to provide a price for clean ammonia. The authors of this report calculated the cost of ex-factory clean hydrogen for this report to enhance comparability with the ex-factory prices of the other auctions discussed in this work. For the calculation, the Haber-Bosch-process was assumed to work with levelized cost of energy at EUR 112 and an energy efficiency of 82% Source: Oeko-Institut, *PTX Business Opportunity Analyser (BOA): Data Documentation of Data Sources and Data Processing for Version 2.0* (Commissioned by Agora Energiewende and Agora Industry, 25 June 2024) <https://www.agora-industry.org/fileadmin/Projects/2022/2022-01_INT_PtX-Dialog/Oeko-Institut_2024_PTXBOA_Data_Documentation_v_2.1.pdf> [accessed 13 August 2024].

38 Hintco, *Lot 1: Renewable Ammonia* (Hint.co GmbH, 11 July 2024) <https://www.hintco.eu> [accessed 13 August 2024].

39 Hintco, *H2Global Pilot Auction Results: Lot1 and Lot 3* (Hint.co GmbH, 11 July 2024) <https://cdn.sanity.io/files/u4w9plcz/production/8df5b11af3214c47b1d8ffd8fccc63ad81985b6b.pdf> [accessed 14 August 2024].

40 IRENA, *Renewable Energy Auctions: A Guide to Design* (IRENA; CAM, 2015) <https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/Jun/IRENA_Renewable_Energy_Auctions_A_Guide_to_Design_2015.pdf?rev=dd6699497a974bcb88dc8b2dc39b6611> [accessed 11 January 2024].

41 Polly Martin, 'Analysis: Why the Risks and Potential Rewards Are Both High for Green Hydrogen Producers at the Upcoming EU Subsidy Auction', *hydrogeninsight.com*, 2023 <https://www.hydrogeninsight.com/policy/analysis-why-the-risks-and-potential-rewards-are-both-high-for-green-hydrogen-producers-at-the-upcoming-eu-subsidy-auction/2-1-1514639> [accessed 16 August 2024]; Rachel Parkes, 'Analysis: Winners of the First European Hydrogen Bank Subsidies Have Been Revealed — but Will It Be Enough to Kickstart the Sector?', *hydrogeninsight.com*, 2024 <https://www.hydrogeninsight.com/policy/analysis-winners-of-the-first-european-hydrogen-bank-subsidies-have-been-revealed-but-will-it-be-enough-to-kickstart-the-sector-/2-1-1635957> [accessed 16 August 2024]; Thomas Beard, 'EU Approves First Subsidies for Hydrogen Projects', *Economist Intelligence Unit*, 2024 <https://www.eiu.com/n/eu-approves-first-subsidies-for-hydrogen-projects/> [accessed 16 August 2024].

42 Kerres and others, *Auctions for the Support of Green Hydrogen: Applying RES Auction Expertise to Green Hydrogen*.

43 Danish Energy Agency, *Danish PtX-Tender Documents* (Danish Energy Agency, 2023) <https://www.ethics.dk/ethics/eo#/2b3ea81c-1ca9-4d3d-b563-b87f629fb79c/publicMaterial> [accessed 16 July 2024].

44 Department of Energy Security & Net Zero, 'Hydrogen Allocation Rounds'.

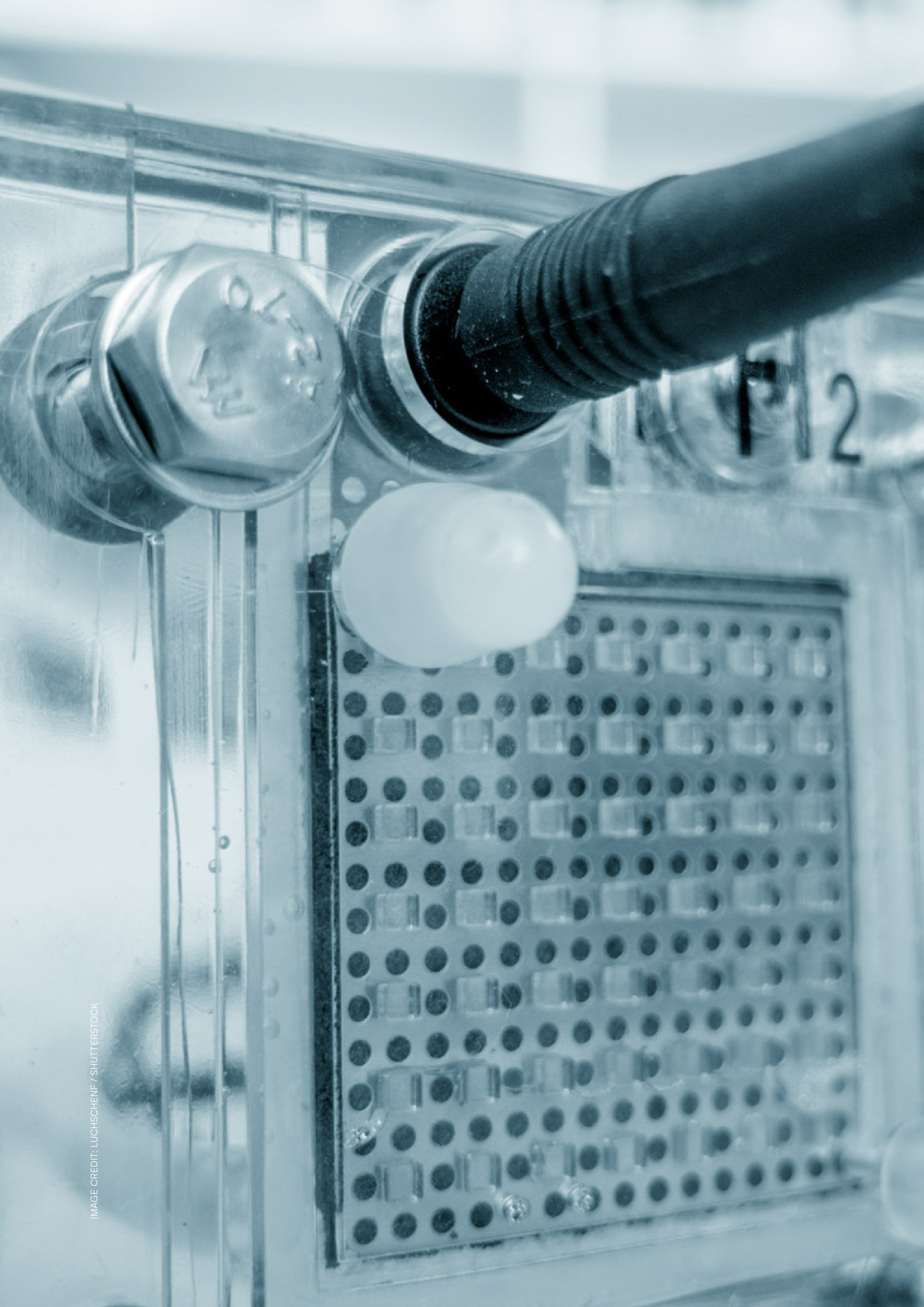


IMAGE CREDIT: LUCHSCHENF / SHUTTERSTOCK

H2Global-Stiftung
Trostbrücke 1
20457 Hamburg

T: +49 40 36197500
E: info@h2-global.org

www.h2-global.org

H2Global Stiftung