

H2eart for Europe's position on ENNOH's draft Cost-Benefit Analysis (CBA) Single-Sector Methodology

A response to open consultation

15 December 2025

Executive Summary

H2eart for Europe welcomes ENNOH's draft **Cost-Benefit-Analysis (CBA) Single-Sector methodology** and strongly supports the ambition to develop a harmonised, transparent and system-wide evaluation framework for hydrogen infrastructure projects.

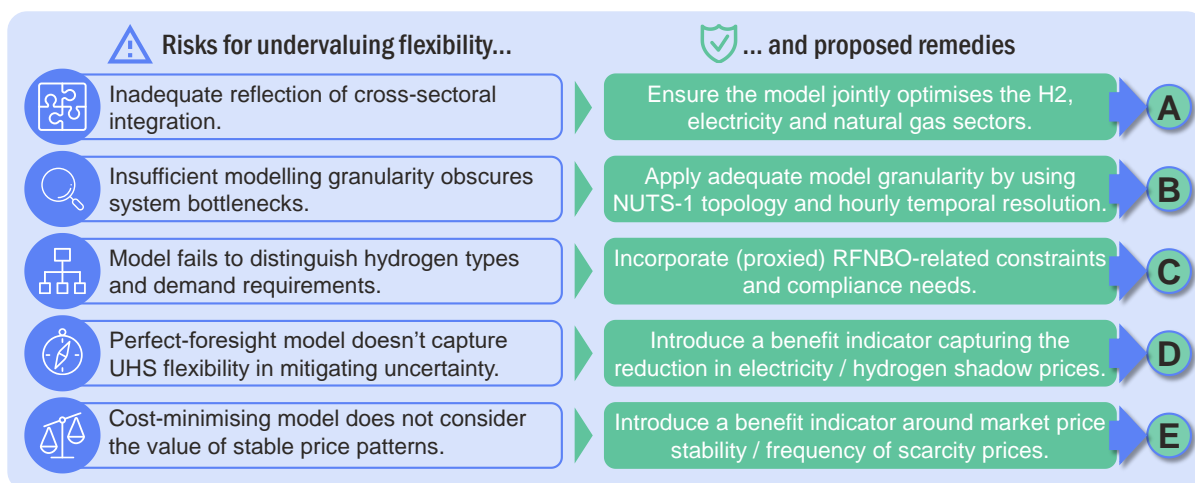
As a consortium of leading operators of **underground hydrogen storage (UHS)** in Europe, we consider this methodology foundational for ensuring that the upcoming TYNDP processes appropriately reflect the hydrogen infrastructure needed for a resilient, decarbonised European energy system. As a critical enabler of a decarbonised hydrogen economy – supporting renewable integration, providing security of supply, enabling industrial transformation, and stabilising energy markets – it is crucial for UHS that these qualities are appropriately reflected in the CBA methodology.

The CBA methodology is highly consequential for the identification of Projects of Common Interests (PCIs) and Projects of Mutual Interest (PMIs), and for the investment environment for storage infrastructure more generally. H2eart therefore submits this response with the intention to strengthen methodological robustness and avoid systematic undervaluation of UHS within the TYNDP process.

The current draft represents important progress towards a holistic assessment framework, but H2eart for Europe finds that several multi-energy system (MES) modelling choices risk understating the flexibility value of UHS. If these limitations remain unaddressed, the resulting benefit indicators may fail to reflect the full contribution of UHS to system functioning, resilience and cost efficiency.

Figure 1 summarises the areas where we see a risk that the current approach may not fully capture the contribution of UHS, alongside suggestions that, in our view, could support a more balanced and robust assessment.

Figure 1 Identified risks of undervaluing flexibility and proposed remedies



Source: Frontier Economics on behalf of H2eart for Europe.

H2eart for Europe values that flexibility is intended to be reflected in the current draft's benefit indicator B8, but considers the current formulation to not be sufficient to capture the full system value of cross-sector flexibility. As it stands, B8 provides limited additional insight beyond what is already embedded in the MES model outcome. A more detailed differentiation between hydrogen types as well as the consideration of further indicators that go beyond the standard model output, combined with appropriate model architecture and resolution, can help address the limitations of the MES optimisation model and improve the accuracy with which the value of hydrogen infrastructure is represented.

We remain committed to close cooperation with ENNOH as the methodology and future TYNDP cycles evolve.

The current draft methodology is at risk of undervaluing the contribution of UHS to the energy system

We appreciate that the draft methodology aims to create a holistic evaluation of hydrogen infrastructure projects and as such also addresses some limitations identified in previous versions.¹ This includes the introduction of the draft benefit indicator B8, which we understand is intended to capture system flexibility, an aspect particularly relevant to the evaluation of UHS. Nonetheless, the current draft may fail to capture the value added by UHS across various dimensions, as the assessed benefit indicators do not reflect the actual contribution these assets make to system functioning and cost efficiency:

- A. First, it is pivotal that the model architecture appropriately captures **sector integration** – in particular the interactions between the hydrogen, electricity, and natural gas sectors, which drive much of the UHS flexibility value. While the draft methodology identifies this as an objective, the final modelling approach has not yet been confirmed.
- B. **Spatial and temporal aggregation** can conceal important local and time-specific constraints, which in turn leads the model to underestimate system bottlenecks and the resulting need for flexibility. While the draft methodology proposes NUTS-0 as the minimum spatial resolution, we consider this to be too coarse to serve as the central level of analysis.
- C. The methodology does not distinguish between **different hydrogen product demand** (e.g. RFNBO-compliant hydrogen), which reduces the model's ability to capture structuring needs in hydrogen supply.
- D. Assuming **perfect planning foresight in the model** limits the modelled role of storage to intertemporal arbitrage only, and therefore does not capture its value in mitigating supply and demand uncertainty – a key contribution to system resilience.
- E. **Market stability** – specifically the reduction of the frequency and severity of price spikes – is not valued, even though it provides benefits in terms of investment certainty and overall system robustness.

In the following, we will elaborate on each of these points, and, where relevant, suggest potential ways to address a potential undervaluation in a final methodology.

A) Appropriately reflect cross-sectoral integration

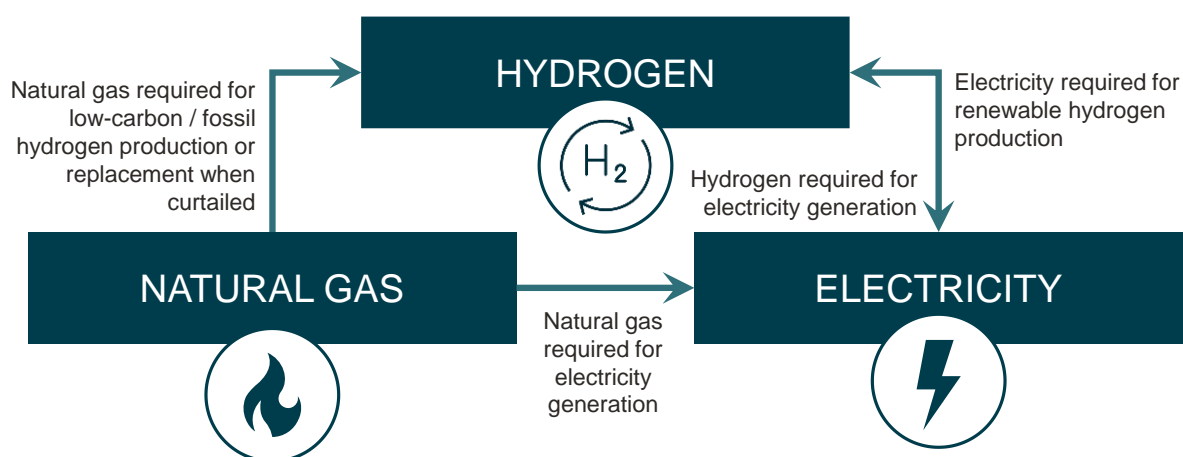
UHS acts as a bridging technology **across the hydrogen, electricity and natural gas sectors**. Most importantly, it can absorb surplus electricity through electrolysis and supply energy back to the power system via turbines or fuel cells, which will become an increasingly critical aspect in a decarbonised energy system. These sector-interlinkages play a key role in

¹ Such as the societal cost savings from reduced emission of otherwise curtailed hydrogen volumes.

determining when UHS is charged or discharged, how it competes with other flexibility options, and what system-wide benefits it can unlock. Without modelling these cross-sector dynamics, the assessed value of UHS risks being understated. Key sources of flexibility, substitution effects and price formation mechanisms would be overlooked.

The draft methodology notes that, ideally, the model used would be sector-integrated and capture not only the hydrogen market, but also electricity and natural gas in a joint optimisation.² H2eart for Europe would like to emphasise that appropriate cross-sectoral reflection is absolutely pivotal for deriving meaningful benefit assessments of hydrogen infrastructure elements, in particular for UHS.

Figure 2 Linkages between hydrogen, electricity and natural gas sector in a MES model



Source: Frontier Economics on behalf of H2eart for Europe.

Note: Other systematic linkages between sectors may exist in practice (for example, natural-gas appliances switching to hydrogen), but they are not expected to appear dynamically in a MES model run.

Appropriately capturing the value of UHS is highly dependent on the appropriate representation of the future energy system. This should not only be reflected in the overarching model setup, but also in the key assumptions entered during the modelling process.

To support transparency and retraceability, we recommend publishing a modelling annex alongside the CBA implementation guidelines. This would also help ensure that all relevant costs along the value chains are appropriately accounted for in a consistent manner. We

² "In the context of sector coupling, the calculation of total supply costs must extend beyond the hydrogen supplied to meet final demand. It should also account for the interlinkages between hydrogen and other energy carriers, whose supply costs may be affected by the implementation of the project. (...) The sector included in the calculation of the benefit will be detailed in the CBA implementation guidelines and will depend on the modelling tools available for the TYNDP.", ENNOH's First Draft Cost-Benefit Analysis (CBA) Single-Sector Methodology (2025): p. 38.

recommend carefully reviewing and aligning all cross-sector assumptions, with particular attention to other flexibility options. This includes, but is not limited to

- Flexibility sources in the electricity sector, like demand-side response.³
- Hydrogen import profiles, in particular from ship-imports via terminals.

Addressing these points will help not overestimating these alternative flexibility options .

Key suggestions

- Ensure that the modelling framework jointly optimises the hydrogen, electricity and natural gas sectors in an integrated and interlinked manner.
- Review standing cross-sector assumptions carefully, in particular with regard to sources of flexibility and import profiles of hydrogen.
- Publish a modelling annex alongside the CBA implementation guidelines that ensures that the model architecture and associated assumptions are transparent and retraceable.

B) Reveal system bottlenecks through adequate granularity

Adequate **spatial and temporal granularity** in the MES model is essential to reveal system bottlenecks and accurately assess the value of UHS. Without this spatial and temporal richness, key congestion points, price differentials and flexibility needs remain hidden, leading to a distorted valuation of hydrogen infrastructure projects.

Spatially, ENNOH's draft methodology suggests a resolution "*at least (...) at country level (NUTS-0)*"⁴. However, in many cases this level of aggregation is already too coarse – particularly for larger countries with significant internal network constraints. As a result, assets such as UHS, which can relieve local congestion, reduce curtailment, or support regional balancing, risk being undervalued.

Modelling at NUTS-1 is important to approximate the actual value UHS bring to the system.⁵ The NUTS-1 level of detail comes closer to appropriately capturing regional variations in renewable generation, grid constraints, demand patterns and infrastructure availability, all of which strongly influence where and when UHS can provide value.

³ We note that ideally, a joint optimisation of the electricity, hydrogen and natural gas sectors leads to the most efficient deployment of each source of flexibility.

⁴ ENNOH's First Draft Cost-Benefit Analysis (CBA) Single-Sector Methodology (2025): p. 13.

⁵ We understand that a higher regional resolution may impose technical constraints and therefore suggest that the analysis could be supplementary at least for the immediate country in which the (group of) project(s) is located.

Temporally, a sufficiently granular time resolution is equally critical to capture variations in renewable output, periods of system stress, and the operational flexibility that storage can provide. The ENNOH draft methodology refers to plans for using an hourly temporal resolution⁶, which we support as the minimum temporal detail required for the MES model. Implementing hourly granularity is also essential to create consistency with the wider regulatory framework, such as the RFNBO-criteria, which presume temporal correlation at the hourly level.

Key suggestions

- Resolve the MES model topology at NUTS-1, where feasible, to capture regional variation appropriately.
- Ensure that the MES model applies an hourly temporal resolution to capture variability of supply and demand appropriately.

C) Differentiate hydrogen product requirements

In particular during the market ramp up, **not all hydrogen is created equal**. Available volumes will not only vary by source (or colour), but also regarding certification, carbon footprint and possibly quality.

A significant share of initial demand will be driven by regulatory obligations – such as RFNBO quotas in the transport and industry sectors, which carry heavy penalties for non-compliance. Demand from these sectors cannot easily be replaced alternative hydrogen sources or even other energy carriers, even if there are no strict technical constraints. Instead, offtakers rely on UHS as the primary mean of structuring the supply of RFNBO-compliant hydrogen by balancing continuous demand with highly variable compliant supply.

In the draft methodology, it is not detailed (i) to what extent the MES model will distinguish between different hydrogen sources, and (ii) whether final demand will include requirements on which types of hydrogen can be used to meet it. Therefore, the model risks underestimating the actual role of UHS – not only in structuring hydrogen supply as a whole, but also the different supply streams of different hydrogen types.

We therefore recommend introducing an explicit distinction of RFNBO-compliant hydrogen volumes in the model. If this is not feasible, a second-best approach would be to approximate this distinction as follows:

⁶ ENNOH's First Draft Cost-Benefit Analysis (CBA) Single-Sector Methodology (2025): p. 8.

- Treat renewable hydrogen as a proxy for **RFNBO-compliant hydrogen**. This includes that non-EU hydrogen imports should also be differentiable according to whether they are renewable by regulatory standards or not.
- Apply **mandatory quotas** – ideally at an hourly level – to sector-specific final hydrogen demand that must be met with RFNBO-compliant hydrogen (proxied by renewable hydrogen in the model).
- If implemented as a soft constraint⁷, introduce the expected **substantial penalties** for using non-RFNBO-compliant hydrogen as a cost factor within the curtailed hydrogen demand concept described in the methodology.

In addition, various sensitivities around the mandatory share of renewable hydrogen should be explored – including a case in which all final hydrogen demand is met exclusively with renewable hydrogen, already in years leading up to 2050.

Key suggestions

- Introduce a distinction for RFNBO-compliant hydrogen within the model.
- If this is not feasible, use renewable hydrogen as a proxy and apply mandatory quotas to the relevant final-demand segments (e.g. industry, transport).
- Introduce RFNBO-related penalties to be reflected in the context of curtailed hydrogen demand.
- Introduce sensitivities with renewable-hydrogen quotas of up to 100% for different reference years.

D) Reflect flexibility's role in mitigating uncertainty

Both the energy transition but also the future decarbonised energy system will inevitably be coined by the uncertainty inherent to renewable energy sources. A core benefit of storage assets is their ability to **mitigate these uncertainties and provide buffers** for unanticipated situations of demand and supply. This is something that cannot be demonstrated in a MES model with perfect planning foresight: Supply and demand patterns are known for the entire year, and system calibration and operation is optimised accordingly.⁸ In such a setting, storage is used only for intertemporal arbitrage, while its value in managing uncertainty and providing ad-hoc back-up is not captured.

⁷ Similar to hydrogen demand more generally, with the option to curtail / disrupt hydrogen demand.

⁸ Model runs that incorporate extreme weather events or infrastructure disruptions would still assume perfect foresight – and thus full anticipation of these conditions – allowing the system to plan optimally despite their severity.

We recognise that perfect foresight is a core feature of the MES model and not easily modified. Hence, we suggest addressing this limitation constructively without altering the model architecture: We propose developing an indicator that reflects the system’s supply response to an unanticipated change in demand, approximated by the (sum of) shadow prices of supply.

Shadow prices are generated as a by-product of the system cost optimisation with fixed final demand levels. They present the marginal cost of providing one additional MWh of electricity or hydrogen outside of the optimisation. As such, they provide an estimate of the cost of supplying unforeseen demand volumes, assuming all other factors remain constant. These prices reflect operational scarcity and indicate the overall “stress level” of the system; and are a standard output in many MES models.

There are several ways to refine this approach further. One option is to consider shadow prices not only for the first additional MWh of electricity/hydrogen, but for a larger increment of additional demand – for example, the marginal shadow price of the 100th additional MWh. In addition, differentiating shadow prices by hydrogen type would provide further insight into how the system responds across different supply streams.

Key suggestions

- Introduce a benefit indicator valuing the incremental reduction in shadow prices of supply of electricity/hydrogen through a (group of) project(s).
- Explore whether shadow prices can be derived for a larger increment of unforeseen additional demand, and whether they can be differentiated by the type of hydrogen being supplied.

E) Incorporate the value of market stability

A pure system cost-minimising MES model does not capture the **broader value of market stability**. Although it identifies the cheapest system configuration, it treats any price pattern as acceptable as long as total costs are minimised. In reality, smoother and more predictable price profiles have their own value: They lower uncertainty, reduce risk premiums, and support efficient investment and operational decisions.

In particular during the ramp up of the decarbonised energy system, high supply prices act as a scarcity signal.⁹ They indicate that supply is struggling to keep pace with demand. Such signals play an important role in directing investment, including into technologies like UHS that can relieve tight market conditions. MES models may undervalue flexibility options – such as

⁹ In the model architecture, the Cost of Disrupted Hydrogen (CODH) will effectively cap the hydrogen price.

UHS – that help dampen price volatility, if the stability aspect of price patterns and the frequency of scarcity prices is not taken into account.

This gap could be addressed by incorporating simple indicators that proxy market stability. Metrics such as the price spread (max-min), measures of price fluctuation (standard deviation or mean absolute deviation), or the frequency of extreme prices provide a clearer picture of how flexibility improves market conditions. These indicators require no change to the model architecture but allow the value of flexibility to be assessed more fully than through total system cost alone.

Key suggestions

- Introduce a benefit indicator evaluating market price stability to better account for the benefits associated with a more predictable market environment.

Additional methodological considerations

Benefit indicator B8 may not capture additional value of flexibility

As set out before, we believe that **flexibility risks being undervalued** in the current modelling, and we welcome the inclusion of a **dedicated indicator B8** (“Hydrogen system flexibility”) intended to address this gap. However, in its current form, we do not consider B8 to be well suited to capturing the full value and role of cross-sector flexibility.

First, it is unclear whether approximating flexibility through changes in a correlation coefficient between uncurtailed renewable power generation and renewable hydrogen production is appropriate. The inclusion of UHS projects is expected to affect dispatch patterns in a more fundamental way than simply absorbing excess generation during peak hours.

Second, the indicator only provides a partial view of cross-sector interactions: It reflects UHS acting as a sink for surplus renewable generation, but not hydrogen’s potential to supply back-up generation when renewable output is low – a limitation also acknowledged in the methodology.¹⁰

Consequently, the interaction between the electricity and hydrogen sectors is unlikely to be well represented by (a change in) a linear relationship.

Finally, there is conceptual overlap with system costs (indicator B5), since the efficiency gains from reducing curtailment are reflected in the system cost function. As the indicator is not monetised, there is no double counting. However, this suggests that B8, as currently defined, may not offer additional insight into flexibility beyond what is already embedded – albeit potentially undervalued – in the MES model.

Key suggestions

- Critically review methodological setup of benefit indicator B8.

Security-of-supply indicators B6 and B7 provide a critical complementary aspect

We strongly welcome the inclusion of impacts of **extreme weather conditions and infrastructure disruptions in benefit indicators B6 and B7** (“Hydrogen system adequacy” and “Hydrogen system resilience” respectively). Capturing system performance under

¹⁰ ENNOH’s First Draft Cost-Benefit Analysis (CBA) Single-Sector Methodology (2025): p. 40.

stressed conditions is integral to assessing the value of hydrogen infrastructure, as some assets, like UHS, play a disproportionate role in maintaining system resilience when conditions deviate from the norm. Reflecting these impacts explicitly is therefore an essential part of the methodology.

However, we propose to expand the assessment beyond the evaluation in terms of the associated disrupted hydrogen demand alone, as currently foreseen in the methodology.¹¹ Extreme system conditions can also lead to curtailed hydrogen demand¹², where either an alternative hydrogen type or an entirely different energy carrier cover demand – that come at costs of efficiency and incremental emissions. Failing to capture curtailed hydrogen demand may understate the value of storage and flexibility assets that mitigate such situations. We therefore recommend broadening the scope of benefit indicators B6 and B7 impacts to encompass both disrupted and curtailed hydrogen demand.

Key suggestions

- Broaden indicators B6 and B7 to also capture curtailed hydrogen demand.

Design of indicator B3 may penalise projects enhancing hydrogen imports

We understand that **indicator B3** (“Share of renewable EU hydrogen production”) is designed to capture the **benefits of greater energy independence**, measured through the incremental change in the share of renewable EU hydrogen production relative to total hydrogen supply. The indicator is not monetised, thereby avoiding double-counting.

However, it is important to highlight that in its current form, indicator B3 may inadvertently **penalise projects that facilitate hydrogen imports from non-EU countries**, as it rewards increases in the relative share of EU renewable hydrogen production without recognising the benefits of other supply options.

UHS, as a source of operational flexibility, has the potential to materially enhance import flows. By smoothing peak capacity utilisation, UHS allows other infrastructure elements – such as terminals and pipelines – to operate more efficiently and achieve higher overall throughput. In this way, UHS supports more efficient infrastructure planning, strengthens security of supply, and contributes to diversification. These benefits may, however, be counteracted by the current design of indicator B3.

¹¹ ENNOH's First Draft Cost-Benefit Analysis (CBA) Single-Sector Methodology (2025): p. 37-39

¹² This refers to the distinction between the concepts of “curtailed hydrogen demand” and “disrupted hydrogen demand”, as introduced in ENNOH's draft CBA methodology.

In addition, the current design of the indicator does not account for curtailed or disrupted hydrogen demand in the denominator. All else equal, any unit of curtailed or disrupted demand would raise the share of renewable EU hydrogen (unchanged numerator) relative to total hydrogen supply (reduced denominator), thereby artificially inflating measured energy independence. To avoid this distortion, we recommend that the denominator – if indicator B3 is retained in the methodology – explicitly includes curtailed and disrupted hydrogen demand.

Key suggestions

- Critically review methodological setup and formalisation of benefit indicator B3.

Inclusion of hydrogen substitute emissions in indicators B1 and B2 enhances consistency

We welcome the fact that the draft methodology accounts for the societal costs associated with hydrogen substitutes when hydrogen demand is curtailed. In the previous ENTSOG CBA methodology for hydrogen infrastructure, the emissions impact of these substitutes was not captured within the core assessment.¹³

ENNOH's proposal to include an additional term within **indicator B1** (“GHG emissions”) and **B2** (“Non-GHG emissions”) therefore represents a meaningful improvement, as it broadens the scope to reflect the **full societal costs associated with emissions from alternative energy carriers** used when hydrogen demand is curtailed. This introduces consistency in how emissions are treated in the assessment.

This is particularly relevant from a storage perspective, since UHS is expected to reduce hydrogen curtailment and disruption, and thereby avoid these additional emissions and the associated societal cost savings.

Key suggestions

- Retain the treatment of hydrogen-substitute emissions in benefit indicators B1 and B2 to ensure consistency.

¹³ ENTSOG's Methodology for Cost-Benefit Analyses of Hydrogen Infrastructure Projects (2024), p. 34.