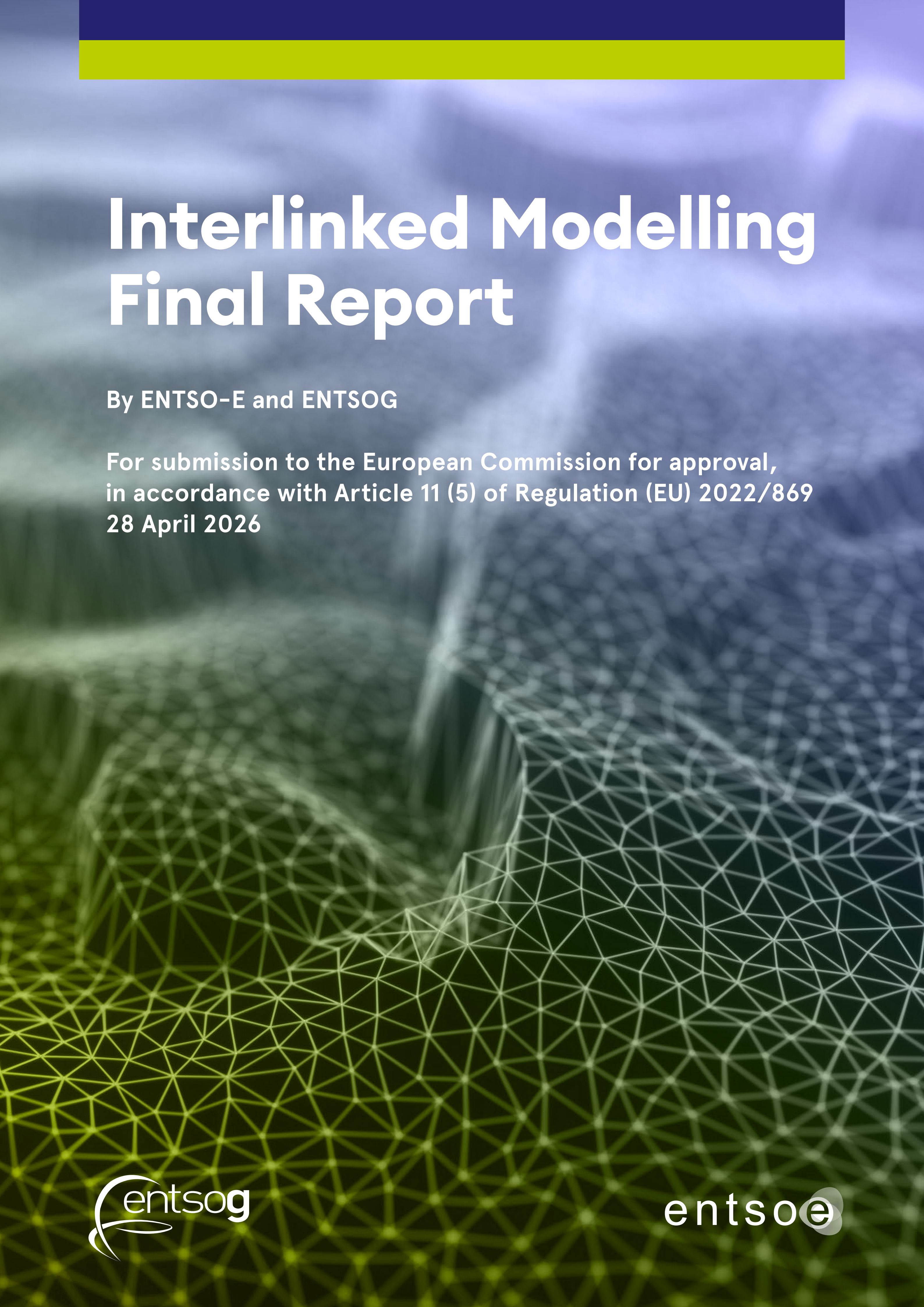

Interlinked Modelling Final Report

By ENTSO-E and ENTSOG

For submission to the European Commission for approval,
in accordance with Article 11 (5) of Regulation (EU) 2022/869
28 April 2026

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Contents

1 Executive summary

The Interlinked Modelling (ILM) Framework is a strategic enabler for the core planning products of ENTSO-E, ENTSOG (and soon ENNOH). These products include Scenario Building, Identification of System Needs/Infrastructure Gaps Identification, and Cost Benefit Analysis. It helps unlock unprecedented insights into cross sector system integration.

The Frameworks strength lies in its ability to harmonise and progressively integrate electricity, hydrogen, and gas datasets, assumptions, methodologies, and computational workflows to:

- **Reveal Sector Interactions:** By coupling the electricity, hydrogen and natural gas systems, the ILM framework aims at revealing the systems complementary needs and benefits along with their synergies that single sector models cannot capture.

- **Enhance Joint Scenarios:** As part of the ILM Framework, the TYNDP Scenario Building exercise ensures that TYNDP storylines reflect coherent trajectories from many angles: supply-demand projections, market topologies, sectorial interfaces, etc, creating a robust foundation for downstream Cost-Benefit Analysis (CBA) and systems needs assessments.

- **Guide Infrastructure Planning:** Within the System Needs Assessment and the TYNDP projects assessment, the ILM Framework aims at harmonising the models key assumptions and methodologies for explicit modelling of infrastructures across energy carriers (so far mainly electricity and hydrogen). As sector specific characteristics and analysis are critical for the quality of the infrastructure planning, the ILM Framework also aims at informing impact of interactions between electricity, methane and hydrogen, to support the scoping of sector integration in the context of system needs assessment and infrastructure projects assessment.

Key Features:

- **Multi-Model Framework:** Ensures an appropriate level of granularity (sectoral and geographical) required to assess impact of the integrated energy system for each planning phase – always with the aim to ensure sufficient balance between the level of detail required, the reliability of the results and the viability of the model (e.g. a CBA model should be capable of running hundreds of projects across multiple scenarios in a limited timeframe as required for the TYNDP).

- **Data Harmonisation:** Aligns fuel/CO_2 prices, technology capacities – technical characteristics – costs, demand profiles, and interconnection forecasts – ensuring consistency across planning products.

- **Methodologies Harmonisation:** Ensures harmonisation of methodological approaches followed to produce the different TYNDP work results. The Scenarios being jointly developed by ENTSO-E, ENTSOG, (and soon ENNOH), the methodological approach followed is used as a common baseline. The methodologies developed for downstream processes (CBA and the system needs assessment) are prepared separately by each association. However, the ILM Framework ensures a profound alignment process between the associations to ensure consistent assessments across infrastructures linked to each energy carrier.

Strategic Outcomes:

- Empowers policy makers and stakeholders with transparent, comparable benefit metrics across sectors, spanning social economic welfare, CO_2 reduction and renewable integration.

- Supports Europe's decarbonisation ambitions with holistic scenarios and congruent TYNDP planning tools, helping the quantification of supply, demand, cross-border and sector coupling synergies, infrastructure needs, etc.

- Preserves the boundary between high-level system assessment and detailed grid design, ensuring the ILM Framework role remains a strategic process supporting methodologies development and harmonisation rather than network specification.

By embracing the ILM Framework as a strategic process rather than a grid planning solution, ENTSO-E, ENTSOG (and soon ENNOH) can deliver cohesive, multisector insights that shape Europe's energy transition. It also empowers network operators to translate those insights into concrete grid planning actions.

2 Introduction

The transformation of Europe's energy system is marked by increasing complexity, intensified decarbonization objectives, and a growing interdependencies between energy carriers. In this context, the need for coordinated cross-sectoral planning has become paramount. To support these challenges and enable coherent infrastructure development across energy vectors, the Interlinked Modelling (ILM) Framework has emerged as a strategic instrument that supports harmonisation of methodological approaches and progressive sector integration across the TYNDP products and associations (ENTSO-E, ENTSOG and soon ENNOH).

This report consolidates the status-quo of sector integration in energy planning and methodological evolution as a result of the ILM Framework and how it has supported the pan-European Ten-Year Network Development Plans (TYNDPs) developments in the recent years, closing with a developments roadmap for the years to come.

The ILM Framework follows a system-wide approach that ultimately aims at enabling comprehensive assessments of the future European energy systems, by capturing interactions between the energy carriers electricity, gas, and hydrogen. Rather than serving as a grid design tool, the ILM provides a framework that can support cross-sector consistency in the scenario development, system needs assessment, and cost-benefit analysis products. Its development is governed by EU regulatory mandates, most notably Regulation (EU) 2022/869 and Regulation (EU) 2024/1789, which establish legal obligations for progressive integrated network planning, and by the ACER Framework Guidelines for joint TYNDP Scenarios. The framework also acknowledges observations and recommendations received through the ACER Opinion process.

The report is structured to reflect the strategic role of the ILM Framework. It begins with an overview of the regulatory background and prior work that set the foundation for cross-sectoral modelling. It then describes the process flow that guides the development of the TYNDP planning products. This report explains how the ILM Framework contributes to scenario building, infrastructure gap identification, and project specific cost benefit analysis.

Key elements covered include:

- The design and implementation of joint scenarios with harmonised assumptions for demand, technology, and policy.
- Cross-sector consistency beyond the scenario building process for the downstream TYNDP processes (CBA and system needs assessment).
- Sector-coupling mechanisms, particularly electrolysis, and the role of shared renewable energy sources.
- The evolution of modelling topologies for hydrogen and electricity systems and the rationale for different model structures, leading to a multi-model framework.

An emphasis is placed on the 2024 Interlinked Modelling Progress Report (see section 5), which served as a critical milestone in testing and validating sector coupling modelling capabilities. The methodological innovations introduced include the global Socio-Economic Welfare (SEW) computation in a multi-sector CBA model (with insights on its decomposition) and a two-zone hydrogen system topology. These innovations have influenced ongoing TYNDP processes and are shaping future methodological approaches.

The objectives of this report are threefold:

1. To document the state-of-play of the ILM Framework and highlight the technical progress achieved at this stage.

2. To present the modelling approaches and/or insights that have informed the latest TYNDP scenario, cost-benefit, and infrastructure gap assessments.

3. To outline the remaining challenges and future focus areas for the Framework, to keep supporting European energy system planning.

The report describes the processes of the products underpinning the TYNDP i.e. scenario development, system needs identification, and cost-benefit analysis; highlighting how the ILM Framework contributes methodologically and structurally to each of these pillars. The report has been prepared with an even representation from ENTSO-E, ENTSOG, and ENNOH.

From this point on, when not explicitly written, the Interlinked Modelling Framework will be referred to as the "ILM Framework" or the "Framework".

3 Regulatory backgrounds and previous work

The Interlinked Modelling Framework represents a key instrument to enable integrated energy system planning in Europe with higher accuracy. Its development reflects both a growing recognition of the need for cross-sectoral coordination and the formalisation of this necessity through EU legislations. While early cooperation between ENTSO-E and ENTSOG laid the technical groundwork, recent regulatory developments, most notably Regulation (EU) 2022/869 and Regulation (EU) 2024/1789, have established a binding framework for its implementation. This chapter outlines the legal evolution and institutional efforts that have shaped the ILM Framework into a cornerstone of future infrastructure planning.

3.1 Previous Work

Long before formal legal mandates required it, ENTSO-E and ENTSOG had already initiated close cooperation to align electricity and gas system planning through the CoGasEl joint project. This collaboration was further formalised with the report delivered in December 2016 in compliance with the Article 11(8) of Regulation (EU) 347/2013 and with the TYNDP Scenario Report 2018, which marked the first joint efforts to develop consistent cross-sectoral energy scenarios. It continued with the TYNDP Scenario Reports of 2020[1], 2022[2] and 2024[3], which progressively refined the methodology and assumptions used to model the future European energy system across multiple energy carriers.

At the end of 2019, the two associations published, in cooperation with Artelys, a report on the interlinkages between gas and electricity energy system, their impact on the scenarios and how to navigate these interlinkages during the project assessment phase, laying the analytical foundation for integrated energy system evaluation. This was followed in 2022 by the Interlinked Model Investigation Report, which explored the technical and methodological requirements for a fully integrated model capable of assessing cross-sectoral impacts. Building on this foundation, ENTSO-E and ENTSOG released the ILM Progress Report in 2024, which focused on the CBA assessment methodology, shared renewable resources and the impacts a variety of asset types have on CO_2 emissions.

Through these joint endeavour, ENTSO-E and ENTSOG jointly made methodological developments, improvements, and alignments throughout the years and across the

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[1] https://2020.entsos-tyndp-scenarios.eu/

[2] https://2022.entsos-tyndp-scenarios.eu/

[3] https://2024.entsos-tyndp-scenarios.eu/

products of their respective TYNDPs. This Framework brings improved consistency, value and insights to system analyses across the associations. These initiatives demonstrate a long-standing commitment to system integration and coordinated planning.

3.2 Regulatory Background

The evolution of the Interlinked Modelling Framework is motivated by the European Union's broader efforts to foster a more integrated and decarbonised energy system. In recent years, the increasing complexity of the energy transition has underscored the need for coordinated planning across the electricity, gas and hydrogen networks. Today, these sectors operate under distinct regulatory frameworks, with separate Ten-Year Network Development Plans (TYNDPs) prepared by ENTSO-E and ENTSOG. The growing interdependencies between energy carriers, driven by the expansion of renewable energy and the emergence of hydrogen as a key carrier, necessitates a harmonisation in the approaches followed to assess infrastructures in these key sectors. By taking such an approach, synergies between the sectors can be captured.

The first step in this direction was the adoption of Regulation (EU) No 347/2013, which laid down guidelines for trans-European energy infrastructure. It emphasised, among others, the importance of integrated planning, particularly through the development of consistent cost-benefit analysis methodologies.

This development was reinforced with the adoption of Regulation (EU) 2022/869, which introduced the requirement for the development of a progressively integrated model, enhancing cooperation between the electricity and gas sectors, particularly through the development of joint scenarios and the alignment of cost-benefit analysis methodologies. The regulation also calls for the creation of a framework capable of assessing the interdependencies between energy systems, which can be accommodated within the Interlinked Modelling Framework.

The legal obligation for the ILM Framework was further shaped with the adoption of Regulation (EU) 2024/1789 on 13 June 2024. This Regulation recasts and consolidates the rules governing the internal markets for renewable gases, natural gas, and hydrogen. It establishes a binding obligation for ENTSO-E and ENTSOG[4] to jointly submit the progressively integrated model by 31 October 2025, amending Regulation (EU) 2022/869. Furthermore, it recognises the ILM Framework as a joint effort of ENTSO-E and ENTSOG to support the products of the TYNDPs, ensuring that infrastructure development aligns with the Union's climate neutrality objectives.

This evolving legal framework reflects the EU's commitment to a system-of-systems approach, where infrastructure planning and operation are no longer confined to individual energy carriers but are instead guided by a holistic, integrated vision of the future energy landscape across sectors and carriers.

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[4] As ENNOH is not yet legally established, this document is formally submitted by ENTSO-E and ENTSOG only. Nevertheless, since its informal establishment, ENNOH has been continuously involved in the developments of this report and the related ILM Framework Developments Roadmap presented at the end of this document.

3.3 Governance and Structure

The work presented in this document is the result of a collaborative development process involving representatives from ENTSOG, ENTSO-E, and ENNOH. The process was coordinated and the report compiled by the ILM Task Force (ILM TF) and the ILM Steering Group (ILM SG).

The ILM Task Force and its Steering Group is composed of the associations and their TSO members. This structure fosters close alignment with other working groups contributing to the TYNDP planning deliverables and methodologies, such as Scenario Building and CBA methodologies.

Figure 1 shows the governance over the TYNDP process and how pool of experts from the ENTSO-E and ENTSOG interact.

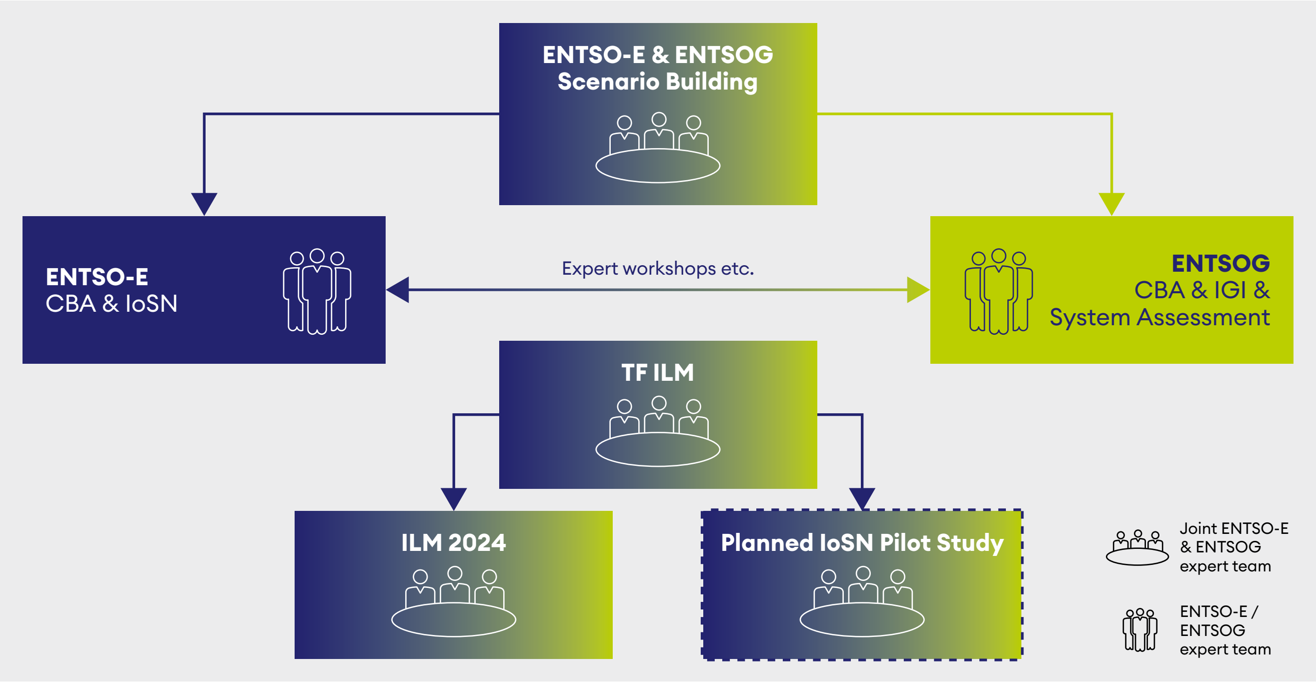

Figure 1: Work Structure

The governance structure illustrated above establishes a clear framework for coordination between the associations. It ensures that responsibilities are well defined and that information flows efficiently at technical, and operational levels. The arrangement allows decisions to be taken on a well-informed basis, with members feeding into Secretariat work. This setup supports consistency in methodological development and facilitates coherent collaboration among ENTSOG, ENTSO-E and, after its final establishment, ENNOH within the ILM process.

4 TYNDP Process flow

4.1 The TYNDP Products: Scenarios, System Needs and Cost Benefit Analysis

The TYNDP follows a structured and coordinated process that ensures consistency across sectors' infrastructures while allowing for flexibility suited to each associations' domain.

The cycle begins with the joint development of scenarios, which encompasses common macroeconomic, policy, and technological assumptions spanning to 2050. These scenarios form the analytical foundation, providing harmonised profiles for demand (hourly to monthly granularity), generation, and cross-sector energy flows. It is at this step that all inputs and assumptions relevant for the relevant energy carriers being modelled are aligned, in particular capacities and locations of electrolysers and gas/H_2-fired power plants, size of H_2 storages, expected build-out trajectories of electricity, and hydrogen infrastructures.

So far, the joint nature of the scenario development product has ensured that electricity and hydrogen system projections are aligned in terms of climate objectives and system context. From this staging point, the associations follow separate, but properly informed and coordinated (where necessary) analytical tracks that reflect their distinct infrastructure mandates. All key data points, inputs and assumptions relevant for each sector are aligned during the scenarios development stage, including capacities and locations of electrolysers and gas/H_2-fired power plants, H_2 storages, Shared Renewable Energy Sources (SRES), and expected build-out of electricity, gas and hydrogen infrastructure.

Building on these shared scenarios, each association conducts a System Needs Assessment, identifying where cross-border capacity bottlenecks lie, through expansion modelling (ENTSO-E) or infrastructure level comparison (ENTSOG), where flexibility assets deployment bring more value, or where resilience gaps should be solved, in order to maximise social-economic welfare, using a range of network and market models calibrated to the scenario data. Consequently, the infrastructure needs and gaps identified through the System Needs Assessment support infrastructure project plan submission by TSOs and third-party project promoters to the TYNDP.

The Cost–Benefit Analysis, is a process where infrastructure projects submitted to the TYNDP by TSOs and third-party project promoters are evaluated to determine their contribution to pan-European energy system in terms of sustainability, system welfare, and energy security. While the specific methodologies, such as CBA guidelines or geographical granularity and scope, may differ between sectors, all associations apply a consistent analytical structure based on the same family of models and principles. This ensures that project evaluation and prioritisation are grounded in a coherent and comparable framework, enabling transparent selection of Projects of Common or Mutual Interest by the European Commission.

Figure 2 summarises the different steps referred to above and is generalised for the two associations, ENTSO-E and ENTSOG. Scenario Building, infrastructure projects collection, System Needs Assessment, and CBA Assessment of these projects are highlighted as key steps of the TYNDP cycle. It also highlights the role of the System Needs Assessment in informing a broad range of stakeholders, including energy infrastructure projects developers, that can develop projects to fulfil part of the needs identified, the gaps.

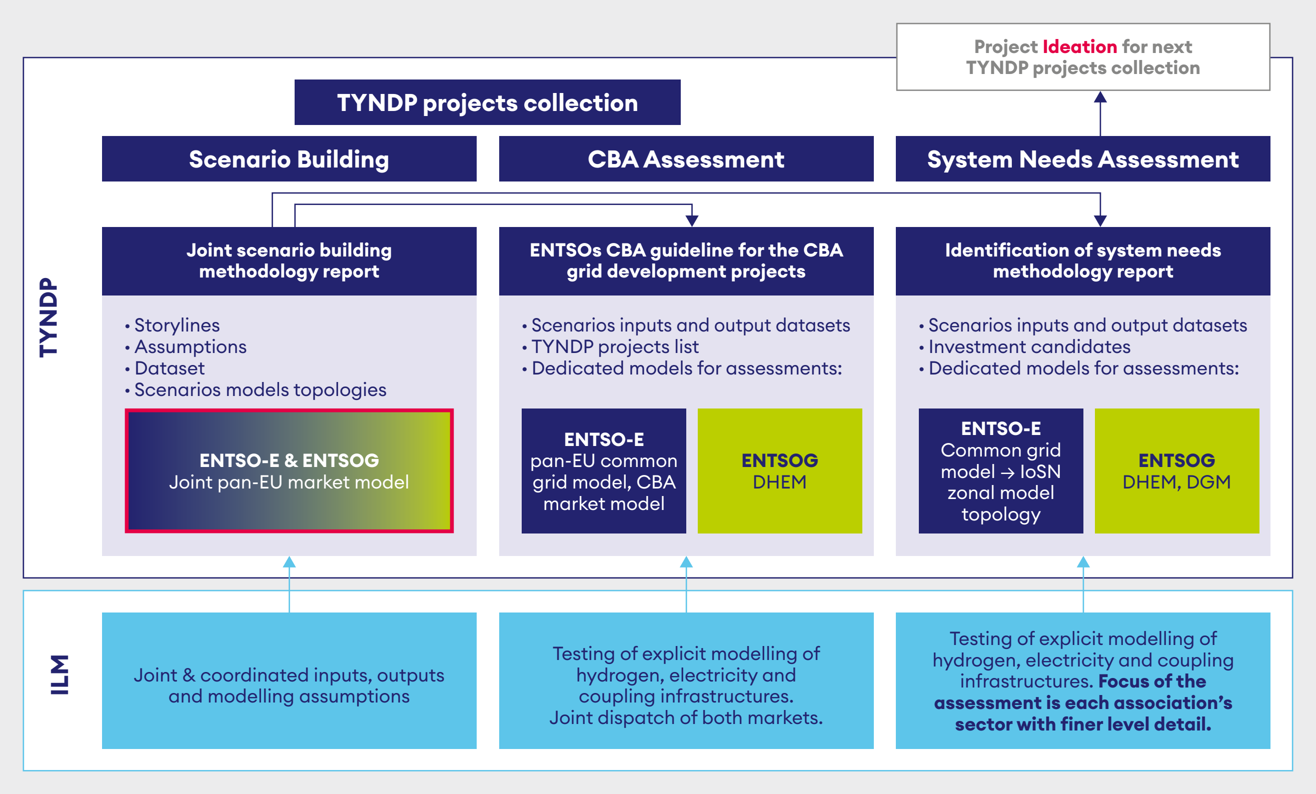

Figure 2: TYNDP process flow and ILM contribution

The solid blue arrows show the relationship between the different steps of the TYNDP, mainly in terms of data and assumptions. Scenario building is the initial key step and common nucleus to all processes within the organisations, informing CBA and System Needs steps with its input, output and key assumptions.

The red band representing the Interlinked Modelling Framework, highlights its transversal role across the TYNDP products. The ILM Framework supports an integrated modelling approach that aims at fostering proper integration of the electricity, hydrogen and natural gas systems (as well as other relevant energy carriers). The Framework supports this integration by tailoring it to the needs of each of the planning products of the European TYNDPs, while supporting consistency in methodological approaches and modelling granularity across the products.

The Framework has supported the joint scenario development, but also enabled dual assessments of energy infrastructure projects on both the electricity and the hydrogen sectors, with harmonised CBA methodologies and assumptions. The Framework is therefore meant to ensure methodological coherence and to allow the different TYNDPs' steps to properly reflect interdependencies across sectors.

ENNOH has not committed to a specific modelling methodology for its own system assessment, yet. Such methodology will be aligned to the regulatory requirements guiding the TYNDP 2028 process and shall enable the full application of the approved ENNOH Single Sector CBA Methodology.

4.2 General Description – The Influence of the 2024 Interlinked Modelling Progress Report

This chapter describes the joint modelling effort performed between 2023 and 2024 presented in the Interlinked Modelling 2024 Progress report, which focused mainly on CBA analyses in a multi-sectorial context, with an additional attention shared RES operation modelling and revision of the hydrogen multi-zones hypotheses per node and many more. Among other key developments within the TYNDP context supporting sector integration and consistency across the TYNDPs products and across the associations, the ILM 2024 played an important role in the progress of the Interlinked Modelling Framework.

The joint TYNDP 2022 scenario process produced three quantified scenarios: Global Ambition (GA), Distributed Energy (DE) and National Trends (NT). The DE and GA scenarios followed a top-down modelling approach with main target being to meet the European climate and energy efficiency goals. The NT+ scenario on its end followed a bottom-up approach, based on TSO data collection, reflecting national energy and climate plans. For the ILM 2024 analysis, the Distributed Energy scenario was considered.

Findings and learnings from the ILM 2024 analysis enabled improvements in some of the TYNDP 2024 methodological approaches for integrated planning (e.g. scenario building modelling, cost benefit analysis methodologies). ENTSOG developed the Dual Hydrogen Electricity Model (DHEM) for National Trends, basing the underlying model topology on the one defined in the ILM 2024. This DHEM rebuild provided the foundation for the Infrastructure Gaps Identification process and the projects specific cost benefit assessment (PS-CBA) of hydrogen infrastructures. In both cases, this consideration of the ILM 2024 developments improved assessment of the European hydrogen system, with a focus on the of interactions between the electricity and hydrogen systems.

In parallel, the TYNDP 2024 process in both ENTSOG and ENTSO-E adopted a new global socio-economic welfare (SEW) computation methodology, transitioning away from a total system cost approach and from the single sector SEW definition. This SEW calculation method in the cross sectoral assessments was validated through the ILM 2024, providing the foundation and confidence for its formal adoption in the TYNDP 2024 CBAs of both ENTSOG and ENTSO-E.

The ILM 2024 model was a market model derived from the TYNDP 2022 DE scenario model, which explicitly modelled the electricity and the hydrogen systems, leaving out the natural gas sector in a first step. The explicit modelling of natural gas, performed using the Dual Gas Model (DGM) during ENTSOG's System Assessment process, is further discussed in section 6.3.2.

The TYNDP 2022 DE Scenario Model was modified, reducing the electricity system nodes from 3 to 1 node per market zone (integrating residential/prosumer nodes and electric vehicle nodes to the main electricity markets nodes). The hydrogen system was reduced from 5 nodes to 2. This had the advantage of simplifying the data preparation and model building process with minimal impacts on modelling results. Infrastructure internal to the market zones and their physical constraints are not represented in detail. Natural gas is considered as a fuel for electricity and hydrogen systems, with unlimited availability and fix price across the geography of the systems, used to supply gas CCGTs and steam methane reformers.

This simplification allowed the team to model gas plants (for power production), and SMR (for hydrogen production), under the assumptions that

1. the natural gas grid is flexible enough to supply the electricity and hydrogen demand when it was needed, and
2. the natural gas production infrastructures were available.

The adjustments made to the topologies of the hydrogen and electricity systems with respect to the scenario topology, justified the need of at least 2 modelling tools to compare the outputs when it comes to the CBA assessments, obtaining a greater level of quality control. The testing process put further pressure on the need to reduce the size and complexity of the model as high-volume testing is required, thus simulation time must be within an acceptable range. The tools used to create the model were PLEXOS and ANTARES.

In the ILM 2024, among others, comprehensive tests were conducted on the operation modes of shared Renewable Energy Sources (RESs), enabling RESs in shared RES nodes to be either used for electrolysis in priority before serving the electricity system, or freely optimised in the model to serve either of the two sectors in priority whenever it minimises system costs.

5 ILM 2024 modelling topology

5.1 Electricity Topology

The electricity system modelling in the ILM 2024 was in line with the scenario building model in terms of generation capacities, storage capacity, electricity demand, transmission infrastructures and electrolysers capacities. As mentioned above, the ILM 2024 considered one node per market zone in the electricity system by integrating residential/prosumer nodes and electric vehicle nodes to the main electricity markets nodes.

Each node represents one market zone. While most countries use one market zone per country, there is a limited number of countries, which use additional nodes:

Italy: 7 market zones	**Greece:** 2 Market zones	**Sweden:** 4 Market zones	**Denmark:** 3 Market zones
Norway: 3 market zones	**Luxemburg:** 4 Market zones	**United Kingdom:** 2 Market zones	

The electricity reference grid was established based on the currently existing grid, on top of which some of the projects submitted to the ENTSO-E TYNDP with cross border impact are added based on the criteria laid out in ENTSO-E's 4th CBA Guideline for the cost benefit analysis of grid development projects. The Guideline helps in categorising cross-border infrastructure projects based on their status and their commission years, which allows transmission infrastructure projects to be part of a reference grid.

5.2 Hydrogen Topology

In the 2022 scenario model, the Working Group Scenario Building introduced a five-Zones hydrogen topology to represent different hydrogen supply and demand characteristics clearly:

- **Zone 1:** Dedicated to synthetic fuels production, primarily via electrolysers connected directly to renewable energy sources, thereby creating off-grid hydrogen used as feedstock for synthetic fuels.
- **Zone 2:** Captured industrial hydrogen demands, primarily off-grid, supported by steel tank storage solutions.
- **Zone 3:** Represented existing hydrogen demand predominantly satisfied through Steam Methane Reforming (SMR), covered primarily by grey hydrogen.
- **Zone 4:** Constituted the hydrogen market area, including hydrogen that could be traded, transported via transmission pipelines, and is mainly associated with green hydrogen exchanges.
- **Zone 5:** Defined as a zone external to the main hydrogen and electricity markets, likely covering dedicated pipeline flows and isolated or specialised hydrogen distribution channels.

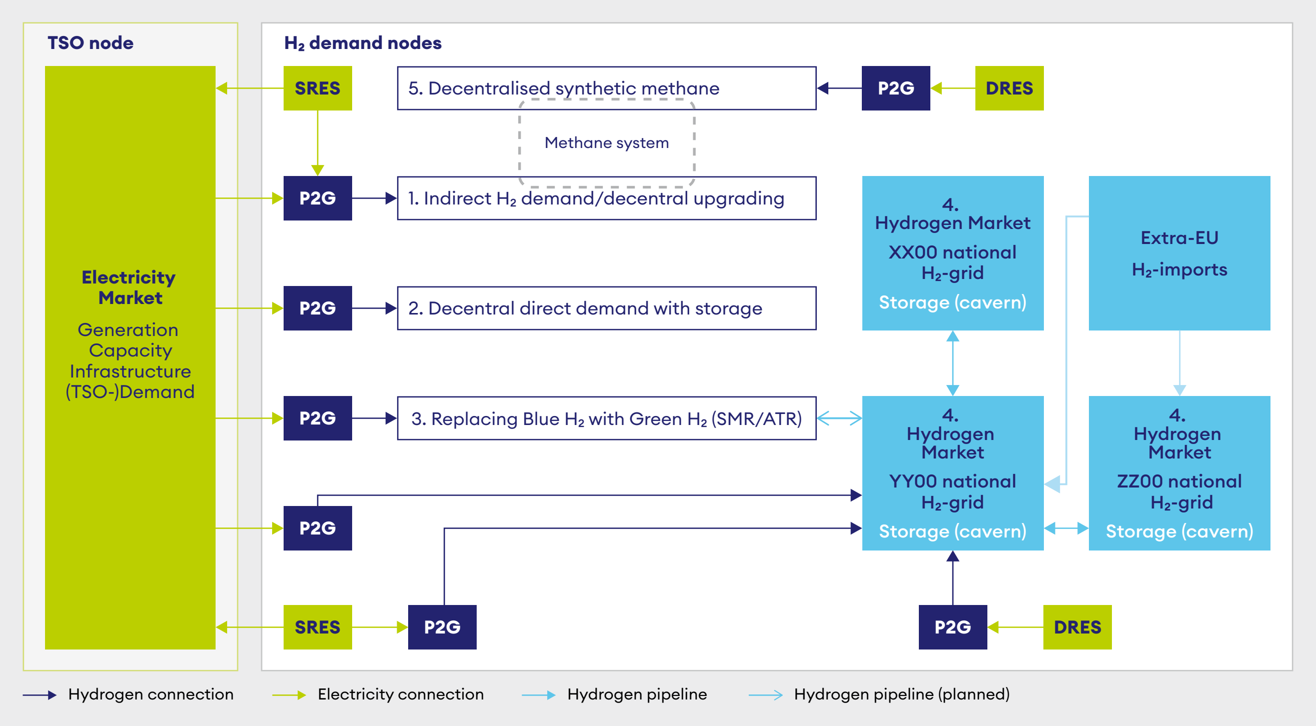

Figure 3: Five Zones topology of the hydrogen system in TYNDP 2022 Scenarios

The ILM 2024 streamlined the five-Zones structure into two primary Zones:

- **Zone 1 (ILM 2024):** Consolidated former Zones 1, 2 and 3, thus encompassing all off-grid hydrogen demand and production, industrial usage (with steel tank storages), power plants and SMR hydrogen that does not directly interact with market mechanisms.
- **Zone 2 (ILM 2024):** Derived from the original Zone 4, this zone became the central hydrogen market, focusing on network-based hydrogen trade, storage, and cross-border interactions.

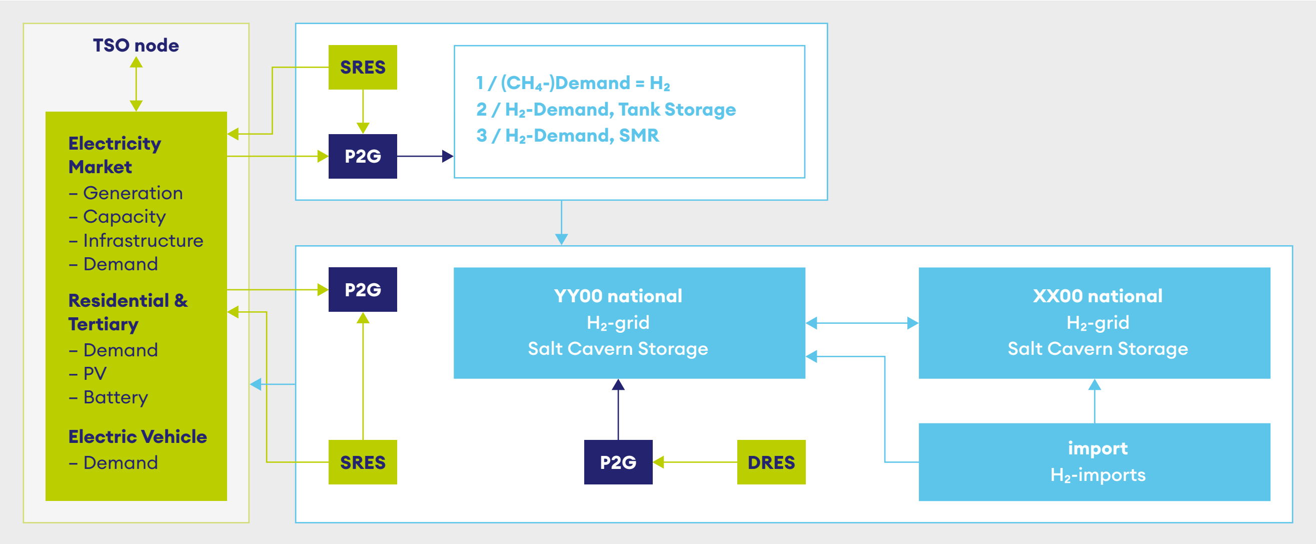

Figure 4: Two Zones topology of the hydrogen system in the ILM 2024

The hydrogen reference grid and the reference storage levels were based on Infrastructure Level 1 from ENTSOGs TYNDP 2022[5]. Additional pipelines provide a connection between ILM 2024 Zone 1 and ILM 2024 Zone 2 and this represents the possibility that hydrogen production outside of the market may be eventually connected into the market.

5.3 Interlinkages

The electricity and the hydrogen sectors are linked via electrolysers, which are constrained to allow only low carbon electricity to be used for hydrogen production. The ILM2024 contains three types of electrolysers that can be distinguished by the hydrogen zones. Electrolyser capacities connected to the hydrogen Zone 1 and Zone 2 nodes are either connected to the electricity market or shared RES. Additionally for the hydrogen Zone 2 certain electrolysers capacities are supplied off-market, through the clean electricity generated by dedicated RES on-site that connect directly to these electrolysers. The different types of electrolysers can be observed in Figure 4.

Shared RES can operate in two modes which were tested during the ILM 2024 analysis. In mode 1, electricity demand takes priority due to the high cost of demand shortage. Mode 2 hydrogen demand takes priority, in alignment with the spirit of shared RES. Mode 2 can be seen as a simplified representation of Power Purchased Agreements (PPAs), a form of long-term supply contract between RES generation and hydrogen producers, which is seen as key enabler for the ramp-up of renewable hydrogen production in the EU. Further details on the impact of these two modes to the dispatch outcomes are detailed in section 5.1 of the ILM 2024 Progress Report.

5.4 Informing TYNDP 2024

Among other in the ILM Framework, key insights from the analysis made during the preparation of the ILM 2024 progress report supported further developments in the scenario building modelling as well as in the cost benefit analysis of both ENTSOG and ENTSO-E. A few of these elements have been mentioned above and further details is provided in section 6, from the perspective of the ENTSO-E TYNDP process first and then from the perspective of ENTSOG's TYNDP process.

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[5] The Infrastructure level 1 was composed of all TYNDP 2022 hydrogen projects (including also TYNDP 2022 hydrogen-ready infrastructure), as well as hydrogen projects submitted to the first PCI selection process that were not previously submitted to TYNDP 2022.

6 Impact of the ILM Framework on the TYNDPs products

This section provides a comprehensive overview of how ENTSO-E and ENTSOG transferred learnings from the Interlinked Modelling Framework into their core planning products: Scenario Building, System Needs Assessment, and CBA. Section 6.1 gives detailed information on the joint scenario building process, while section 6.2 and 6.3 focus on the individual System Needs Assessment and CBA for ENTSO-E and ENTSOG, respectively.

6.1 Joint TYNDP Scenarios

Scenario Building forms the basis for the downstream models of the TYNDP. It guides the following processes which include the system needs assessments and cost-benefit analyses of infrastructure projects submitted to the TYNDP. The European Union Agency for the Cooperation of Energy Regulators (ACER) published binding Framework Guidelines for Joint TYNDP Scenarios on 25 January 2023, setting the methodological requirements for future TYNDP scenarios.

The process defines long-term storylines, over a 20-year timeframe (2030–2050), modelled in 5-year steps. It quantifies sector-specific generation and demand, and preliminary topology design. The 2024 edition used an expansion model to determine the Distributed Energy and Global Ambition scenario whilst the National Trends scenario was developed through an extensive data collection process[6].

The scenario development process is lead jointly by ENTSO-E and ENTSOG under the oversight of the European Commission and ACER in alignment with the TEN-E Regulation (EU) 2022/869 recently amended by Regulation (EU) 2024/1789. ACER's guidelines mandate specific scenario formulations and establish a Stakeholder Reference Group (SRG) to validate methodologies and inputs. Starting with the TYNDP 2028 cycle, the process will for the first time be led jointly by ENTSO-E, ENTSOG and ENNOH. For the TYNDP 2026 cycle, ENNOH is taking on a supporting role.

ACER guidelines necessitate timely delivery of draft scenarios for the TYNDP 2026, ensuring they robustly align with EU climate objectives for 2030 and 2050. The scenarios must include one central "Best-Estimate" scenario, aligned closely with National Energy and Climate Plans (NECPs), supplemented by two stress-test economic variants, reflecting divergent macroeconomic pathways.

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[6] https://2024.entsos-tyndp-scenarios.eu/

Detailed methodological approaches guide the scenario-building phase. TSO data collection explicitly aligns with NECP figures, with established methodologies for addressing data gaps in long-term forecasts (2050 horizon). Infrastructure modelling incorporates electricity, hydrogen, and synthetic fuels.

The scenario quantification phase uses energy market models to determine the cost optimal dispatch across the modelled energy vectors. The models cover the interactions across energy carriers, including dynamic electrolyser and H_2 CCGT dispatch forming the key interlinkage between the electricity and hydrogen systems. Offshore renewable energy developments are also modelled considering cross sectoral links, enabling the production of electricity and hydrogen using these offshore assets. Electric vehicle topology addresses previous limitations by introducing fleet segmentation to realistically simulate charging flexibility. Offshore network topology is now set by predefined topologies provided by TSOs.

Synthetic fuel modelling uses stoichiometric breakdowns to accurately forecast CO_2 and hydrogen demand for synthetic methanol, kerosene, and diesel production. Dedicated renewable energy sourcing (both virtual and physical PPAs) is one option for electrolyser modelling, influencing hydrogen price formation and market interactions.

The hydrogen import methodology includes supply potentials for import routes (green pipeline hydrogen, blue pipeline hydrogen, shipped hydrogen and shipped hydrogen derivatives), accounting for the variability of RES based supply corridors and competitive pricing structures. Hydrogen storage modelling distinctly represents geological and operational flexibility, crucial for balancing supply-demand dynamics.

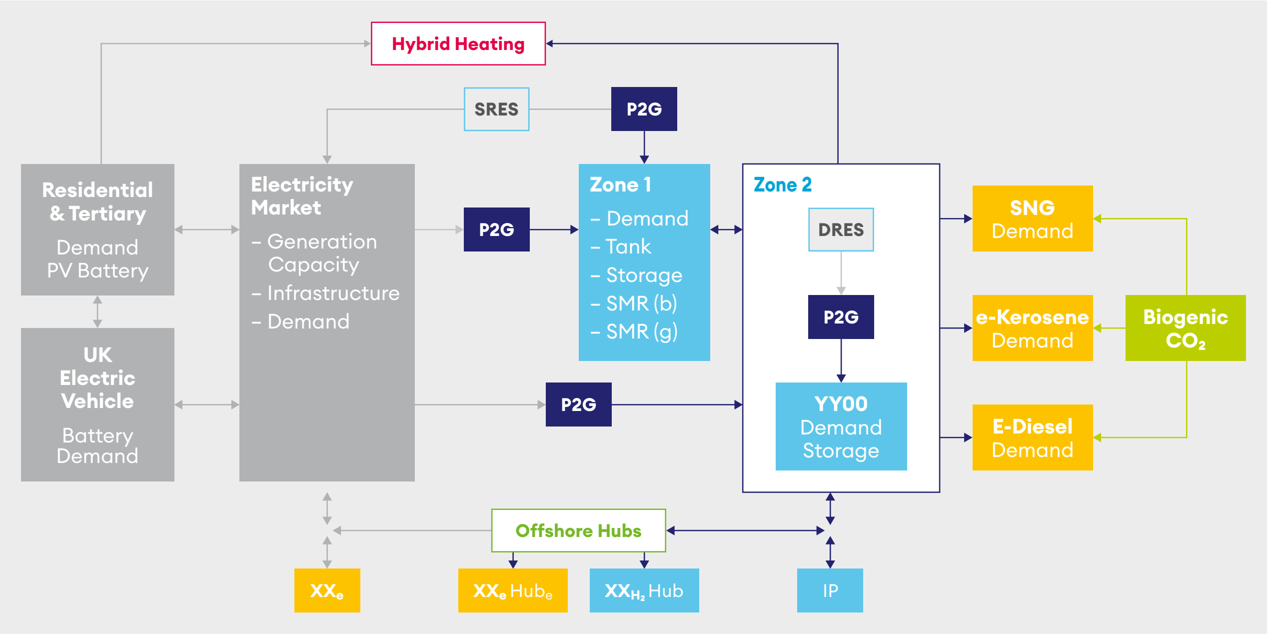

Figure 5: TYNDP 2024 Scenario Topology

6.2 ENTSO-E

This section provides a comprehensive overview of how ENTSOE integrates the ILM 2024into the Identification of System Needs (IoSN), and CBA, focusing on electricity system impacts and explicit coupling with hydrogen system components.focusing on electricity system impacts and explicit coupling with hydrogen system components.

6.2.1 Overview of ILM Application in ENTSO-E Planning Products

Interlinked modelling for ENTSOE has evolved in close cooperation with the hydrogen and natural gas TSOs, fostering further of data, assumptions, and computational workflows between the electricity and hydrogen sectors. Integrated modelling was inspired by Scenario Building and the ILM work picked up the task to test and validate the feasibility of an integrated approach for Cost Benefits analysis purposes, serving as the basis for the feasibility of integrated modelling in the CBA mainly.

In addition to the jointly performed Scenario Building, the framework contributes to the following key planning products of ENTSO-E:

1. **System Needs Identification/Infrastructure Gap Analysis:** Identification of economically viable electricity cross-border interconnection reinforcement opportunities and energy storage capacities deployment, which maximise social welfare at a pan-European level. Explicit modelling of the hydrogen system in accordance with the Scenario Building outcomes (ensuring consistency) but without expansion of the hydrogen system.

2. **Cost Benefit Analysis:** Economic dispatch, co-optimising the electricity and hydrogen systems to evaluate electricity infrastructure projects (transmission and storage assets). The co-optimisation allows capturing sectoral complementarity and synergies.

Key elements and learnings from the ILM framework:

- **Scenario Drivers:**
  - Harmonised fuel and CO_2 price trajectories
  - Coordinated electricity, gas and hydrogen supply projections (capacities, technologies, locations)
  - Harmonised electricity, hydrogen, heat and synthetic fuel demand projections
  - Harmonised interconnection and storage development forecasts.

- **Scenario market model topology:** Pan-European electricity market model linked with an explicit hydrogen network layer, including electrolyser capacities, storage capacities (in both sectors), SRES capacities, and hydrogen-fired CCGTs. The market model also includes an explicit modelling of the electricity system residential and tertiary sector (Prosumers) and of the electric vehicle sector.

- **CBA market model topology:** is based on the Scenario market model topology where the level of granularity is reduced in both the electricity (mainly in terms of sectors explicitly modelled) and the hydrogen systems (mainly in terms of hydrogen demand zones as defined in the TYNDP scenarios). The topology of the electricity and hydrogen systems (incl. the hydrogen network and hydrogen storages), as well as the interlinkages between the two are close to that of the ILM 2024.

6.2.2 Identification of System Needs

Evolution of IoSN Model Topology

The Identification of System Needs study performed within ENTSO-E aims at identifying cross-border needs and opportunities for electricity infrastructure development at least cost for the system. In the last three cycles, the Identification of System Needs study, that maximises Social Economic Welfare, RES integration and Security of Supply, has evolved from a pragmatic NTC-based approach to a more complex expansion problem with a zonal modelling approach. The zonal network modelling approach considered by ENTSO-E in its identification of system needs study relies on an extensive combination of expertise on the electricity market functioning and of the national networks configurations. As described in ENTSO-E's TYNDP identification of system needs methodologies, this zonal model is derived from market simulation outputs, which are based on the market models prepared for the TYNDP Scenarios process and adjusted to the CBA market topology, in combination with the Pan European common grid model covering the electricity system. Given the complexity that running an expansion optimisation problem on the full pan European grid model would entail, the main purpose of the zonal model is to develop a network with a level of granularity (number of nodes per country) that is the best trade-off between acceptable runtime and adequate representation of the full grid model. The zonal modelling allows to reflect internal corridors bottlenecks that would otherwise not be visible in an NTC model approach.

The zonal modelling approach that is considered for the electricity system in the IoSN model is the main change with respect to the NTC-based CBA model. In the ENTSO-E process, the zonal modelling implies moving from country-level aggregated data to lower geographical level aggregation for the electricity supply. The data split between the zones of a country includes the supply potential, the storage potential, the electricity demand and the Demand Side Response of that country. Additionally, the cross-border capacities (which in the CBA model connect the markets nodes) have to connect the relevant zones in the zonal model, enabling higher precision of the electricity corridors compared to the NTC based approach.

Sector Integration in the IoSN

Most recently in the TYNDP 2024, an explicit modelling of the hydrogen system infrastructures was part of the model, without any further expansion on the hydrogen system or coupling assets (electrolysers) on top of the scenario building data. ENTSOG has the responsibility on hydrogen infrastructure assumption for the TYNDP 2024 and TYNDP 2026, whereas ENNOH will be responsible from 01/01/2027 onwards.

The modelling of the hydrogen system in this Needs Assessment is in line with the topology followed for the CBA market model described earlier. No expansion nor locational optimisation is performed on the hydrogen system assets and the sector coupling assets. Even though the impact of this modelling approach remains at macro level, it gives a first approximation of the level of complexity of a system needs identification in coupled systems. This experience also highlighted the complexity that integrated system needs identification would entail, with high technical challenges that could potentially compromise the quality and timely delivery of the TYNDPs.

Data Management and Harmonisation

- **Market Data package:** Full alignment with Scenario Building process inputs and outputs. Demand profiles, PEMMDB, PECD, thermal ratings, hydro inflows and constraints, cross-border transfer capacities, sector coupling assets capacities, dispatch results, fuel and CO_2 prices.
- **Network Data package:** Pan-European common grid model developed based on the scenario building dataset (PEMMDB), the electricity reference grid and the list of projects submitted and accepted to the TYNDP.
- **Investments Candidates and economic assumptions:**

  - **Transmission assets:** Real investment candidates package defined based on the projects received during the TYNDP project collection. Conceptual investment candidates stemming from the scenario building process. ONDP 2024 identified infrastructure corridors set as investment candidates for the offshore grid for the relevant target horizons.
  - **Storage flexibility assets:** Taken from the scenario building process
  - **Economic assumptions:** usual 25 years of asset economic lifetime as considered in the TYNDP CBA process; general cost and cost of capital assumptions taken directly from the scenario building process.

6.2.3 Cost Benefit Methodologies and Assessment

Evolution of CBA Model Topology

- **Legacy approach (until 2020):** Electricity-only dispatch used in the ENTSO-E TYNDP CBA assessment; one node per country in general except for those countries having multiple market zones[7] and a few other exceptions.
- **TYNDP 2022 approach:** hydrogen, heat and other carrier loads are considered exogenous in the modelling, one node per country in general considered in the electricity system, except for those countries having multiple market zones.
- **ILM-Enhanced CBA (2024):** Joint electricity-hydrogen dispatch in the ENTSO-E TYNDP CBA assessment. Key components:

  - **Explicit modelling of electricity transmission system infrastructures:** Economic dispatch with thermal, renewables, hydro, storage, demand side response supplying electricity demand and part of the hydrogen demand through electrolysis.
  - **Explicit modelling of hydrogen transmission system infrastructures:** Economic dispatch with Steam Methane Reformers, imported hydrogen, hydrogen storage assets and hydrogen produced through electrolysis to supply the hydrogen demand.
  - **Coupling assets:** electrolyser assets couple the electricity and the hydrogen systems, enabling a joint price forming capabilities that always minimises the overall system operational costs.

The most recent TYNDP CBA model therefore follows a topology that is highly in line with that of the ILM.

CBA modelling and link with the ILM

- **Market Clearing Logic:** Hourly dispatch with joint merit order incorporating production bids in both in the electricity and the hydrogen sectors to supply the demand on respective sectors at least cost for the entire system.
- **Treatment of the hydrogen sector Value of Lost Load (VoLL):** to reflect the VoLL of the hydrogen sector defined in the ILM model as being equal to the price of the cheapest CO_2 emitting thermal power plant, virtual SMR units are added with a VO&M cost that equals the short run marginal cost of that cheapest CO_2 emitting plant.
- **Hydrogen system zones:** instead of a two zones representation in the hydrogen system per market node, one single zone per hydrogen market node is considered in the ENTSO-E CBA model. It is equivalent to considering unlimited capacity between the zones 1 and 2 defined by ENTSOG in the scenario. This alleviates some burden to the optimisation problem and should not distort the results of the CBA assessment, when assessing projects that are built only in the electricity transmission system.

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[7] Denmark, Italy, Norway, Sweden

- **Offshore system:** existing and planned offshore hybrid infrastructures are modelled, reflecting offshore RES non-binding targets in National Trends + scenarios[8]. This represents a further enhancement of the model in comparison to the ILM.

Data Management and Harmonisation

- **Data package:** Full alignment with Scenario Building process inputs and outputs. Demand profiles, PEMMDB, PECD, thermal ratings, hydro inflows and constraints, cross-border transfer capacities, sector coupling assets capacities, dispatch results, investment outcomes, fuel and CO_2 prices.
- **Gas alignment:** This process is set to ensure alignment between the electricity and their gas counterparts regarding the projections of installed generation capacities of gas-fuelled thermal units.

- **Data aggregation from scenario to CBA:**
  - **Electricity sector:** Based on the dispatch runs outcomes of the scenario building process, the consumption and feed in from the prosumer nodes can be aggregated to the demand of the market nodes to which the prosumer node is connected. A consumption would be an additional load demand while a feed in would contribute to reducing the load demand. For the electric vehicles fleet, the flexibility of these assets is considered through implicit Demand side response in the CBA market model. The electricity demand for hybrid heat pumps from the scenario is also directly reflected in the electricity demand. This leaves us with a model that has on average one market node per country and would produce comparable market dispatch outcomes.
  - **Hydrogen sector:** Given the explicit modelling of the hydrogen system, most of the data is kept identical to that of the scenario building process. The main exception consists in aggregating the demand, the import potential, the storage and the supply capacity in the two hydrogen Zones into one single zone. This level of granularity of one hydrogen Zone per country should be sufficient when it comes to assessing electricity transmission infrastructure. A two-Zones per node approach might be more relevant for the hydrogen infrastructures assessments, including multiple geographical zones per country, as it could also help in identifying bottlenecks in the hydrogen market structure[9]. The hydrogen demand from hybrid heat pumps and the hydrogen demand to produce synthetic fuels are also directly reflected in the hydrogen demand.

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[8] For TYNDP 2024 deviation scenarios, the RES capacities slightly differ with respect to the Member States offshore non-binding targets, as they are the results of the deviation scenarios expansion loop.

[9] Similar comments could be made for the electricity system where a bidding zone level visibility might be enough for hydrogen infrastructure assessments but more granular geographical information is needed for a process like the system needs assessment.

- **Additional data:**
  - **MedTSO:** So far in the development of the TYNDP Scenarios, the focus has been kept on the European countries. However, non-European MedTSO[10] countries play a great role to the European energy mix, given the good level of interconnection of those markets to the European electricity market. Therefore, these countries are explicitly modelled also in the CBA market model, allowing among others to assess electricity transmission projects that connects Europe to those regions.

It must be noted that the role of the MedTSO is limited to the electricity system infrastructure (at this stage), since they do not represent natural gas nor hydrogen system operators.

Benefit Metric Enhancements

- **Traditional metrics:** Greenhouse Gas (GHG) and non GHG emissions reductions, RES integration, system security of supply, network losses, social-economic welfare.

- **Implication of sector integration:**
  - **Flexibility Value:** extra flexibility brought by the hydrogen system and with the hydrogen storage assets.
  - **Curtailment Reduction:** additional value of avoided renewable curtailment thanks to the production of green hydrogen through electrolysers.
  - **Emission Cost Savings:** further CO_2 reduction benefits in both sectors via combined electricity-hydrogen economic dispatch.

The implementation of the global SEW (accounting for both the SEW in the hydrogen sector and the electricity sector SEW) captures these effects. The intrinsic effect on the RES integration benefit and the CO_2 savings benefit is part of the global SEW value. Above all, the global SEW concept opens new doors for further consideration of other sector coupling means.

The global SEW approach has been a key change from previous TYNDPs to the TYNDP 2024 CBA of electricity infrastructure projects and the final SEW value reported from ENTSO-E was this global SEW. This value reflects the overall social welfare brought to the more integrated system by energy infrastructure projects and can facilitates infrastructure comparability across sectors

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[10] The MedTSOs countries consist of 20 members. Those countries are either in southern Europe, North Africa and Middle East. The non-ENTSO-E members considered in our models are Morocco, Algeria, Tunisia, Libya, Egypt, Palestine, Israel, Turkey.

6.3 ENTSOG

This section provides a comprehensive overview of how ENTSOG integrates the Interlinked Model (ILM) into its core planning products. Whilst Scenario Building was already presented in detail in section 6.1, this section focusses on the ILM application in the remaining planning products of ENTSOG: Cost-Benefit Analysis, IGI and System Assessment, focusing on methane and hydrogen system impacts and explicit coupling with the electricity system components.

6.3.1 Overview of ILM Application in ENTSOG Planning Products

In close cooperation with ENTSO-E and the electricity TSOs, ENTSOG's Modelling of sector integration has evolved significantly. Besides the jointly performed scenario building, the current framework consists of the following key steps:

1. **CH_4 System Assessment:** Introduced in 2024 and carried out with the DGM, this step evaluates the resilience of the integrated methane and hydrogen networks under stress scenarios (e.g. cold spells). Unlike DHEM, the DGM simulates infrastructure adequacy, using monthly and peak-day resolutions. It validates methane supply security, tests repurposing impacts, and quantifies avoided hydrogen curtailment under infrastructure stress.

2. **H_2 Infrastructure Gaps Identification:** Conducted with the DHEM model, which performs full-year hourly dispatch of the electricity and hydrogen systems. It identifies bottlenecks based on hydrogen price spreads, curtailment, and cross-border limitations across two infrastructure levels for the hydrogen system (PCI/PMI vs. Advanced), using real project submissions and a two-Zones hydrogen topology per country.

3. **Cost-Benefit Analysis:** The DHEM is used for the PS-CBA. The analysis combines economic, environmental, and security indicators to assess the added value of infrastructure projects across consistent infrastructure scenarios.

Key elements and learnings from the ILM Framework:

- **DHEM Grid Representation:**
  - **Explicit modelling of electricity transmission system infrastructures:** Economic dispatch with thermal, renewables, hydro, storage, demand side response supplying electricity demand and part of the hydrogen demand through electrolysis.
  - **Explicit modelling of hydrogen transmission system infrastructures:** Economic dispatch with Steam Methane Reformers, imported hydrogen, hydrogen storage assets and hydrogen produced through electrolysis to supply the hydrogen demand.
  - **Coupling assets:** electrolyser assets couple the electricity and the hydrogen systems, enabling a joint price forming capabilities that always minimises the overall system operational costs.

- **Hydrogen System Topology:**
  - Zone 1: Local hydrogen production (green, grey and blue variants), on-site storage, and demand not requiring access to the national transmission system. Electrolysers in zone 1 connect to the electricity market.
  - Zone 2: High-pressure hydrogen transmission pipelines, import terminals, ammonia cracking terminals, and large-scale storage (e.g. salt caverns), representing the national backbone. The topology, update in the ILM 2024, simplifies the cross sectoral interlinkages between H_2 and electricity. Electrolysers in zone 2 connect the hydrogen market to the electricity market and hydrogen gas turbines are supplied using energy from the hydrogen market.

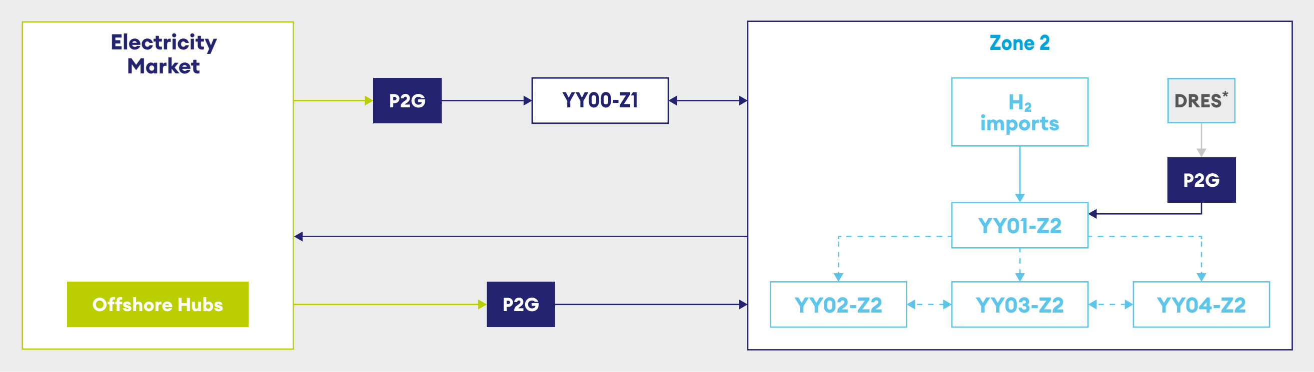


Figure 6: DHEM Topology

6.3.2 System Assessment

The System Assessment is a process additional to the IGI which evaluates the overall adequacy and resilience of the integrated natural gas and hydrogen system under various conditions. The main objective of the SA is the assessment of the Natural gas infrastructure. This step is underpinned by the DGM, which represents both the hydrogen network and the natural gas network across Europe. The DGM is essentially a network flow and supply model run at a coarser resolution (monthly time steps, using representative peak days) to test scenarios like extreme weather, demand spikes, or supply disruptions. It explicitly models pipelines, underground storages, and LNG terminals for natural gas alongside hydrogen pipelines, hydrogen storages (e.g. salt caverns), and import terminals (e.g. ammonia cracking facilities) for hydrogen. The two systems (hydrogen and natural gas) are interlinked by conversion facilities: for example, a hydrogen production unit like SMR or ATR appears in DGM as a node that consumes natural gas and produces hydrogen. This allows DGM to account for fuel-switching and sector coupling, if hydrogen demand surges, more natural gas might be needed for SMR hydrogen, impacting the gas network, and vice versa (hydrogen pipelines repurposed from gas can reduce gas transport capacity).

Evolution of System Assessment

TYNDP 2020 and previous: Methane Only Assessment

- Carrier scope: Only natural gas (methane).
- Time resolution: Monthly granularity using one representative day per month.
- Infrastructure levels assessed:
  - Existing: assets operational before end-2019.
  - Low: Existing + Final Investment Decision (FID) projects.
  - PCI: Adds PCI-tagged non-FID projects.
  - Advanced: Includes all submitted advanced-status projects.

- Gap identification logic:
  - Compared supply-demand balance, system congestion, and resilience across infrastructure levels.
  - Identify regions with unserved gas demand or security shortfalls under constrained levels.

TYNDP 2022 – First Integrated Methane + Hydrogen

- Carrier scope: Full dual gas model, methane and hydrogen modelled.
- Time resolution: Monthly granularity using one representative day per month.
- Gap identification logic:
  - Ran two infrastructure cases: minimal vs advanced project inclusion.
  - Identified gaps via:
    - Persistent hydrogen price spreads between zones or countries.
    - Curtailed hydrogen demands due to transmission bottlenecks.
    - Limited cross-border hydrogen transport capacity.

TYNDP 2024 – Integrated Methane + Hydrogen

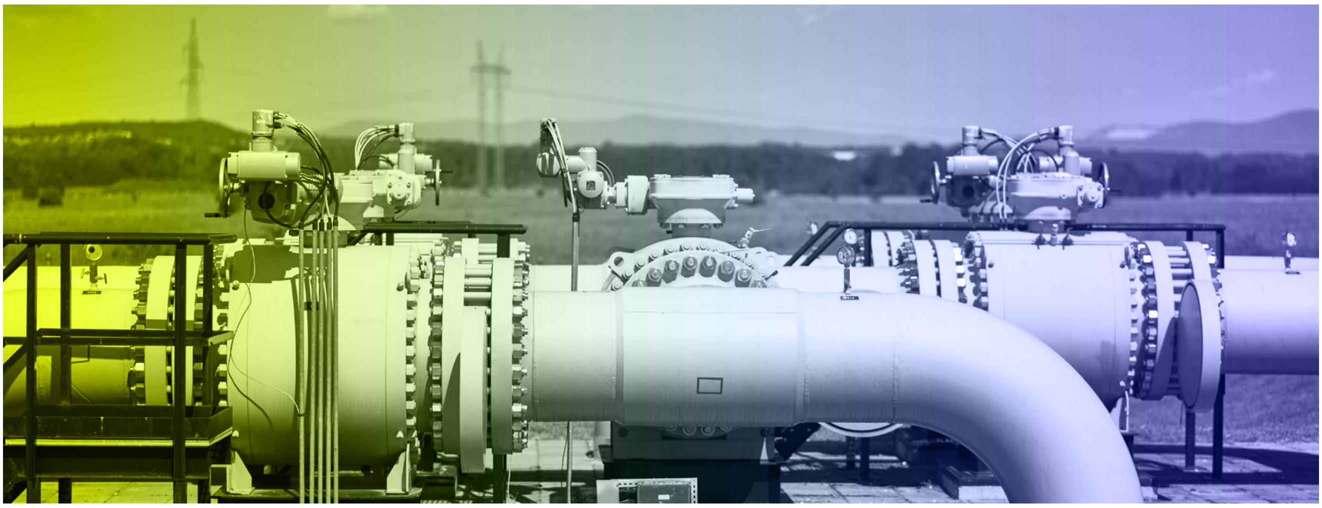
- Carrier scope: Full dual gas model, methane and hydrogen modelled.
- Time resolution: Monthly granularity using one representative day per month.
- Gap identification logic:
  - Ran two infrastructure cases: minimal vs advanced project inclusion.
  - Identified gaps via:
    - Persistent hydrogen price spreads between zones or countries.
    - Curtailed hydrogen demands due to transmission bottlenecks.
    - Limited cross-border hydrogen transport capacity.

System Assessment Overview

- Purpose: Assesses the resilience and adequacy of the integrated methane and hydrogen networks under normal and extreme conditions.
- Model used: DGM; complements DHEM by focusing on infrastructure stress testing rather than market optimisation.
- Carrier scope: Methane and hydrogen networks, with fixed electricity boundary conditions derived from DHEM outputs.
- Time resolution:
  - Monthly flow simulations over the full year.

- Gap identification logic:
  - Multiple Infrastructure cases assessed, including:
    - Minimal: PCI/PMI projects only.
    - Advanced: All submitted infrastructure.
  - Identified system needs via:
    - Hydrogen and methane demand curtailment under stress conditions.
    - Supply disruptions leading to unserved demand in key regions.
    - Security of supply issues caused by pipeline repurposing from methane to hydrogen.
    - Storage and import terminal shortfalls under high-demand periods.

- Sector Coupling
  - The DGM uses results from DHEM simulations to define boundary conditions, particularly during peak demand.
  - Electrolyser output (hydrogen from electricity) and gas-fired power generation demand are incorporated from DHEM outputs.
  - The model includes hydrogen and methane networks, with conversion from methane to hydrogen through Steam methane reformers.
  - Repurposed pipelines reducing gas transport capacity while enhancing hydrogen flows.



System Assessment Architecture

The DGM is a simulation tool employed by ENTSOG within the TYNDP 2022 and 2024 process, complementing the analyses conducted by the DHEM but also providing information relevant form the perspective of the natural gas. While the DHEM assesses detailed hydrogen-electricity market dynamics on an hourly basis, the DGM evaluates system resilience and security of supply of methane and hydrogen networks at a broader temporal resolution, typically monthly and during peak-demand scenarios.

The DGM incorporates two interrelated subsystems, the natural gas network and the hydrogen network, explicitly modelling their interactions and dependencies. It encompasses key infrastructure components such as pipelines (interconnections and import), underground gas storages, LNG terminals, hydrogen import terminals (e.g., ammonia cracking facilities), and hydrogen storage solutions (such as salt caverns).

The model captures the interplay between gas and hydrogen systems by including conversion assets like SMRs (or ATRs), which consume natural gas to produce hydrogen. To favour the green H_2, the H_2 network representation of each country is split in two zones, one zone is linked with the CH_4 network with the SMR (or ATR) and covers mainly a local demand, the second zone (linked with the first one with a limited capacity) represents the H_2 international network linked with the other countries.

The two networks are also linked through the repurposing process (when a CH_4 pipeline is used to reinforce the H_2 network, the interconnection capacity of CH_4 is reduced while it is increased for H_2).

System Assessment Goals

A fundamental strength of the DGM lies in its ability to simulate extreme scenarios and stress conditions, such as unusually cold winters, supply disruptions, or periods of low renewable generation (through the analysis of a more stressful climatic year but also a two-week Dunkelflaute period). Under these circumstances, the model tests whether the integrated gas-hydrogen infrastructure can reliably satisfy demand across Europe. By modelling scenarios such as the failure of major infrastructure asset of each country (the "N-1" security criterion) or a complete disruption of the Russian supply, the DGM calculates potential curtailments, identifying locations and magnitudes of unmet gas and hydrogen demand allowing to investigate the impact of repurposing of the gas infrastructure to transmission of hydrogen. In the yearly, winter & summer outlooks (besides the TYNDP), it is also more specifically used to assess the level of the storages in the context of seasonal needs.

Practically, the DGM has been used to assess the natural gas infrastructure. It was first foreseen to complement the results of the DHEM for the indicator B5 (Uncovered H_2 demand) as the H_2 curtailed demand could be caused by a lack of methane supply (that produces H_2 through SMR [or ATR]) but a deeper analysis has shown that the monthly results of DGM were in any case less constraining than the results of the DHEM.

Interlinkage with other sectors

In the DGM, CH_4 and H_2 are intrinsically linked though the production of H_2 from CH_4 (SMR & ATR) that is optimised in the model. Moreover, through the repurposing process, the two sectors shared complementary grids which some parts can be switched from CH_4 to H_2.

Another strong link between the sectors (CH_4, H_2 and electricity) is the fact that main inputs of the DGM come from the Scenario report (more specifically the National Trends+ scenario) conjointly established by ENTSOG and ENTSO-E.

- the CH_4 & H_2 demands (except for power generation)
- the production capacity of CH_4 (conventional and biomethane)
- the SMR & electrolysis capacity
- the CH_4 & H_2 import supply potentials from each supplier (and their prices that permit to determine a specific merit order).
- the capacity of CH_4 and H_2-fired power plants

Furthermore, the results of the DHEM and the DGM are also linked as the CH_4 and H_2 demands for power in the DGM as well as the electrolyser usage are based on the DHEM simulation results.

Some results of the DGM are indirectly used to verify that the CH_4 network limitations (potential bottleneck or shortage) do not prevent sufficient production of H_2 or electricity.

- This mutual `exchange' of results permits to ensure that, even if the computations are split into two models, their limitations and specificities are shared and integrated and that their conclusions are consistent and coherent.

6.3.3 Infrastructure Gaps Identification

The IGI aims to pinpoint where hydrogen network capacity may be insufficient under future scenarios. This analysis uses the DHEM to simulate an integrated hydrogen and electricity market and identify bottlenecks in the hydrogen system. The DHEM performs an hourly dispatch simulation linking electricity and hydrogen at each country, capturing how power availability affects hydrogen supply. Each country's hydrogen system is modelled with a simplified topology: "Zone 1" for local hydrogen supply, demand, and storage that do not require the national transmission grid, and "Zone 2" for the main transmission network (pipelines, large storage, import terminals and Ammonia gasification terminals). Zone 1 might include on-site electrolysers, steam methane reformers and steel tank storage, serving a share of demand locally, while Zone 2 represents the high-pressure pipeline system (including underground storages and import terminals for ammonia or liquid hydrogen) that connects regions and countries. To ensure the modelling reflects the latest infrastructure proposals, ENTSOG updates the hydrogen network data with projects submitted by TSOs and project promoters.

Evolution of Infrastructure gaps Identification

TYNDP 2024 – Full Electricity – Hydrogen interlinkage

- Carrier scope: Integrated hydrogen – electricity system.
- Time resolution:
  - Hourly resolution over a full year using the DHEM
- Climate years
  - Two climatic years: one reference climatic year, and one stressful climatic year (in terms of demand, RES profile of production, hydro).
- Gap identification logic:
  - Two H_2 infrastructure cases: PCI/PMI vs Advanced.
  - One reference grid for electricity, based on NT+ scenario 2024.
  - Identified gaps via:
    - Hydrogen price spreads between zones or countries indicating transmission bottlenecks.
    - Hydrogen demand curtailment in minimal infrastructure case (PCI/PMI level).
    - Cross-border transport limitations, especially where repurposed gas pipelines are insufficient.
    - Applied policy constraints to exclude cross-border flows of unabated hydrogen (e.g. SMR without CCS).
    - Cross-sectorial limitations, when Electrolysis capacity and/or SMR are used at their maximum capacity

Modelling Approach

- The electricity system is taken from the ENTSO-E CBA models from the TYNDP 2024. Adaptions are made to ensure hydrogen demand is not curtailed to supply hydrogen to CCGTs.
- IGI uses the DHEM to simulate the hydrogen market over a full target year at hourly resolution.
- The model includes actual hydrogen infrastructure projects submitted by TSOs and project promoters, such as pipelines, storage sites, electrolysers, and import terminals.
- Two scenarios are run: one with a minimum infrastructure set (e.g. PCI/PMI-only projects) and one with all submitted projects included.
- No hypothetical or assumed pipelines are added; all elements reflect real submissions, with appropriate maturity filters applied (Annex D).

IGI Indicators and Outputs

- Price Differentials: Persistent price gaps between hydrogen zones (Zone 1 ↔ Zone 2 or cross-border) indicate bottlenecks in transmission capacity or limited supply capacities (SMR, NH3 terminals, or P2X saturated capacity).
- Curtailment: Unserved hydrogen demand in the base infrastructure case, which is mitigated in the advanced infrastructure case, reveals infrastructure gaps.
- Decarbonisation Constraints: Hydrogen produced via unabated SMR or ATR is restricted from export via Zone 2 pipelines. Only low-carbon hydrogen is eligible for cross-border transport in the model.
- Result: A clear map of hydrogen infrastructure gaps – missing links, insufficient import capacity, or inadequate storage – to guide project prioritisation.

6.3.4 Cost-Benefit Analysis

The DHEM serves as ENTSOG's primary model for analysing hydrogen-related aspects within the TYNDP 2024 process. The DHEM undertakes hourly dispatch simulations over the target year, minimising total system costs, including fuel usage, curtailment costs, carbon emissions, and variable operating expenses. Some key KPIs include:

- Emissions reductions
- Hydrogen price spreads
- Electricity price spreads
- Curtailment minimisation
- Sector integration benefits

Project-Specific CBA Framework

- ENTSOG applies both PINT (Put one IN at a Time) and TOOT (Take One Out at a Time) methodologies.
- Total System Cost and Socio-Economic Welfare (SEW) metrics are computed, combining consumer surplus, producer surplus, and congestion rents.
- Outputs are monetised where possible, complemented by non-monetised indicators (e.g. security of supply, GHG reduction potential).
- The full system benefits, including electricity and hydrogen, are considered in the CBA analysis as the objective function is a system wide cost minimisation problem.

Integration with Scenarios

- Scenario assumptions from the NT+ framework, including hydrogen demand, Electricity demand, electricity generation capacity and storages, electricity grid, SMR capacity, and import potentials, are used throughout.
- Project maturity, location, and technology type determine inclusion in the reference case.
- Sensitivity analyses ensure robustness of PS-CBA under different climate, policy, and infrastructure assumptions.

The DHEM explicitly incorporates detailed hydrogen infrastructure, updated with actual projects submitted by Transmission System Operators (TSOs) and project promoters. This includes capacities and flow constraints for pipelines, storage facilities, and electrolysers, ensuring compliance with policy constraints such as prohibiting cross-border transportation of unabated hydrogen produced via steam methane reforming (SMR) or autothermal reforming (ATR). Outputs from the DHEM include hourly hydrogen and electricity market prices, curtailed volumes, and emissions, which directly inform infrastructure gap assessments, system resilience evaluations, and PS-CBA. Since the hydrogen infrastructure is largely still in the planning phase and not yet operational, it is necessary to decide which projects to include in the reference grid of the DHEM used for assessments in the TYNDP. These decisions, outlined in Annex D of the TYNDP, are primarily based on project maturity and PCI/PMI status.

In contrast, the TYNDP 2024 Scenario Model, operates as an upstream planning tool, establishing macro-level trajectories and capacities aligned with EU decarbonisation targets and national energy and climate plans (NECPs). This model uses an open-source Energy Transition Model (ETM) alongside a capacity model. The purpose of the scenario development cycle is to provide hourly profiles of supply, demand, transport and storage infrastructure and commodity prices, which form the foundational assumptions and context for subsequent analyses.

A key difference between the DHEM and the scenario model lies in their scope and granularity. While the scenario model outlines a plausible energy future, using a simplified hydrogen grid templates without detailed infrastructure specifics, the DHEM rigorously tests the performance and feasibility of actual proposed infrastructure within a scenario context. The scenario outputs, such as demand profiles and electrolyser distributions, feed directly into the DHEM, where further refinement based on data collections for infrastructure take place.

The outputs of the DHEM are instrumental in calculating many of the benefits outlined in the CBA methodology. The model's hourly granularity and its ability to capture the interconnections between hydrogen and electricity are particularly valuable for identifying flexibility needs within the energy infrastructure system, including instances of hourly demand curtailment. This level of detail is especially to capture a project's contribution to the security of supply of the system.

6.4 Modelling Architecture Overview

All input parameters are established during scenario development through collaboration among all European Electricity and Gas TSOs, forming the exclusive data source for supply and demand inputs in both System Needs and CBA products across ENTSO-E and ENTSOG. While variations in reference grids may arise due to project collection timelines, these scenarios underpin all model inputs. Most models operate with hourly granularity, except for the DGM model, which functions monthly. In the electricity sector, all models are executed at the bidding zone level, except for the IoSN, which is modelled at a higher geographical resolution. The hydrogen system remains under development, and as further alignment between electricity and hydrogen topologies is requested, continued evolution in this area is anticipated.

The TYNDP 2026 scenarios, now developed in accordance with the ACER Framework Guideline, will transition from the previous bottom-up and top-down approaches to NECP-based scenarios, complemented by two economic variants: High Economy and Low Economy. Ongoing innovations include efforts to incorporate additional constraints in the modelling of hydrogen storage, ensuring alignment with various geological types, the reimplementation of shared RES, more detailed EV modelling and green hydrogen imports following renewable profiles.

Table 1 illustrates how interlinkages have be integrated into the TYNDP products.

ID	Name	Associa-tions	Scenario	Carriers & Sectors	Target Years	Model	Tool	Changes	Dependen-cies (ID – Data)
1	TYNDP Scenarios 2022	ENTSO-E, ENTSOG	NT, DE, GA	Electricity, H_2	2030, 2040, 2050	Scenario 2022	PLEXOS		
2	Interlinked Modelling 2024	ENTSO-E, ENTSOG	DE	Electricity, H_2	2030, 2040	ILM 2024	PLEXOS, ANTARES	H_2 Zones	1 – All Data
3	TYNDP Scenarios 2024	ENTSO-E, ENTSOG	NT, DE, GA	Electricity, H_2, Hybrid Heat, EV	2030, 2040, 2050	Scenario 2024	PLEXOS		2 – H_2 Zones
4	TYNDP CBA 2024	ENTSO-E	NT, DE	Electricity, H_2	2030, 2040	2024 CBA Models	PLEXOS, ANTARES, MARCO, GridSuite, PSSE, INTEGRAL, PowerFactory	Electricity Zones	3 – All Data
5	Infrastructure Gaps Identification 2024	ENTSOG	NT	Electricity, H_2	2030, 2040	DHEM	PLEXOS	H_2 Grid	3 – All Data 4 – NT
6	System Assessment 2024	ENTSOG	NT	H_2, CH_4	2030, 2040	DGM	PLEXOS	H_2 Grid	3 – All Data
7	Identification of System Needs 2024	ENTSO-E	NT, DE	Electricity, H_2	2030, 2040, 2050	2024 IoSN Models	PLEXOS, ANTARES, PowSybl	Electricity Grid	3 – All Data
8	TYNDP CBA 2024	ENTSOG	NT	Electricity, H_2	2030, 2040	DHEM	PLEXOS	H_2 Grid	3 – All Data
9	TYNDP Scenarios 2026	ENTSO-E, ENTSOG	NT, 2 variants	Electricity, H_2, Hybrid Heat, EV	2030, 2035, 2040, 2050	Scenario 2026	PLEXOS		2 – SRES 5 – H_2 Grid

🟩 Scenario workstream 🟦 Interlinked Modelling 2024 workstream 🟥 ENTSO-E TYNDP CBA and IoSN

■ ENTSOG TYNDP IGI, System assessment and CBA

Table 1: Modelling Architecture Overview

7 Future developments roadmap

7.1 Executive Summary

This Interlinked Modelling (ILM) Framework Future developments roadmap complements this Report by setting out a forward-looking pathway for deepening sector integration. It responds directly to internal stakeholders within the associations of ENTSO-E, ENTSOG and ENNOH but also to expectations from stakeholders such as the European Commission (EC), ACER – including observations from ACER Opinion No 01/2026 – and the TYNDP Scenario Reference Group, outlining how electricity, natural gas, and hydrogen planning will evolve. The Roadmap establishes progressive ambition levels, from short-term feasible steps to longer-term goals, with clear milestones and trade-offs. Needs assessment is prioritised as the immediate focus, with CBA enhancements following thereafter.

The document is meant to be a living one, which means that it could be updated along the cycles to better reflect the progresses and better specify the ambitions and milestones.

7.2 Introduction & Context

The ILM framework has been supporting the task of addressing the expected increase in interdependencies between electricity, natural gas, and hydrogen systems. It builds on a shared commitment by Transmission System Operators (TSOs) across energy carriers, but also on EU regulations (TEN-E and the Hydrogen and Gas Market Package) that mandate cross-sector consistency in scenario building, needs assessment, and cost-benefit analysis (CBA) of the European energy systems planning. Stakeholders have underlined that the ILM should not be a static framework but a continuously evolving process composed of building blocks. The Roadmap therefore provides a structured approach to ensure methodological advances are embedded into future TYNDP cycles.

The ILM Roadmap compliments the Working Group Scenario Building's Innovation Roadmap (WGSB Roadmap), in that the WGSB Roadmap, focuses on innovations relevant to the Joint Scenario Building process and does not consider products such as the System needs assessment or CBA, products which can be considered within the ILM Roadmap. There are some cross over in topics, such as integration of methane. Alignment will be ensured across both roadmaps.

7.3 Vision & Guiding Principles

1. **Cross-sector consistency:** Align data, assumptions, and methodologies across TYNDP planning products for electricity, natural gas, and hydrogen .

2. **Progressive integration:** Adopt a stepwise approach, starting with data harmonisation, improved data quality across sectors and improved level of granularity in all sectors. Moving toward joint cross-sector assessments beyond TYNDP scenario building and eventually integrated optimisation.

3. **Pragmatism and transparency:** Acknowledge uncertainty in energy system developments, and acknowledge multiple scenarios analysis rather than relying on a single forecast.

4. **Stakeholder involvement:** Maintain structured engagement with EC, ACER, SRG, and the broader stakeholders' community.

5. **Progression monitoring:** Progress in the implementation of the roadmap will be regularly reviewed within the cooperation between ENTSO-E, ENTSOG and ENNOH. This will include qualitative tracking of key developments related to cross-sector consistency, methodological alignment and stakeholder engagement, in order to support transparency and continuous improvement.

7.4 Key Focus Areas

- **Hydrogen modelling and assumptions:** Increase granularity and align maturity with electricity and natural gas systems.
- **Data comparability:** Critically align inputs across associations; avoid acceptance without review.
- **Methodology comparability:** This entails bringing at par the approach followed by the different associations for assessments performed for the same studies.
- **CBA consistency:** Align data assumptions for electricity, natural gas, and hydrogen across CBA assessments for electricity and hydrogen infrastructure projects, while retaining sector-specific elements where necessary. Harmonise also reference grid construction and assessment approach to the extent possible, while respecting each sector specificities. Finally harmonise CBA guidelines across associations to foster alignments across CBA products.
- **Needs assessment:** Prioritise cross-border infrastructure gaps and analysis of cross-sector interdependencies.
- **Energy carriers' expansion:** Integration of the methane system and its cross sectoral interlinkages with electricity and hydrogen. Likewise for CO_2 networks and carbon capture and storage.
- **Offshore integration:** Develop a coordinated view of electricity and hydrogen offshore infrastructure planning.
- **Industrialisation of the model development:** Understand the key requirements and key steps needed to operationalise ILM developments within TYNDP products.

7.5 Roadmap Objectives & Levels of Ambition

The roadmap provides indicative milestones across TYNDP cycles, in particular for TYNDP 2028 and TYNDP 2030, while longer-term developments beyond 2030 remain subject to further refinement.

7.5.1 Short-term (by TYNDP 2028)

- **Data-flow harmonisation:** Improve quality, consistency and comparability of assumptions across associations.
- **Hydrogen modelling:** Strengthen assumptions (electrolysers, imports, offshore hubs, regionalisation).
- **Offshore system modelling:** Strengthen assumptions on electricity and hydrogen offshore system development.
- **Methane modelling:** Integration of the methane system including the methanation process.
- **Initial steps for cross-sector needs assessment:** Activation of a joint pilot study to identify opportunities and challenges of further sector integration in the system needs assessment.
- **Geographical granularity alignment:** Improve harmonisation at country level.

7.5.2 Medium-term (until TYNDP 2030)

- **Pilot joint cross-sector needs assessment:**
  - Building on initial steps, test the feasibility and limitations of further sector integration in the system needs assessment.
  - Assess benefits and drawbacks, accuracy gains and complexity increase.
  - Harmonisation of the methodological approach used for the system needs assessment.
  - Identify extra data needs.
- **Energy carriers' expansion:** Assessment of benefits and drawbacks of further expansion in the energy carriers explicitly modelled, including methane system, heat system, CO_2 networks.
- **Harmonised CBA approach:**
  - Partial joint optimisation between electricity and hydrogen for multi-purpose projects composed of infrastructures from the 2 energy carriers.
  - Shared indicators across sectors (e.g. emissions, socio-economic welfare, RES integration).
  - Harmonisation of reference grid definition assumptions across carriers to enable consistency in assessments.
- **Geographical granularity alignment:** Progress towards finer geographical resolution as data and methodologies mature.

7.5.3 Long-term (post-2030)

- Move towards coordinated cross-sector optimisation in the needs assessment, within complexity and uncertainty limits. Apply outcomes of pilot study to define the scope and depth of integration in future TYNDPs.
  - Preceding assessment needed to identify the key steps and requirements for the industrialisation of the ILM pilot in the TYNDP products: tool development and maintenance, data provision, data control, data quality, etc.
  - The key objective is to ensure consistency in the assessments' outcomes for the various system.
- Expand energy carriers to include synthetic fuels, heat, and other relevant carriers, preceded by an upfront analysis of benefits and drawbacks.
- Roadmap to evolve based on pilot study outcomes and stakeholder feedback.

7.6 Stakeholder Engagement

Stakeholder engagement will remain central to roadmap implementation. Exchanges will involve the European Commission, ACER, and stakeholders, including through the Stakeholder Reference Group (SRG), complemented by broader consultations and pilot-specific workshops where relevant.

Particular attention will be given to engaging stakeholders on key methodological developments, including cross-sector infrastructure needs assessment and the evolution of cost-benefit analysis approaches.

Feedback will be integrated into successive roadmap iterations, ensuring that stakeholders input is considered in the progressive development of cross-sector planning methodologies.

7.7 Milestones & Timeline

2026–2027:

- Data harmonisation
- Improved hydrogen assumptions
- Activation of a joint pilot study

2028–2030:

- Pilot joint cross-sector needs assessment
- Further harmonisation of CBA approaches

Post-2030:

- Enhanced cross-sector needs assessment within TYNDPs
- Move toward integrated optimisation and expansion to additional energy carriers and offshore integration.

8 Glossary

ACER	European Union Agency for the Cooperation of Energy Regulators
ATR	Autothermal Reformer
CBA	Cost Benefit Analysis
CCGT	Combined Cycle Gas Turbine
DE	Distributed Energy
DGM	Dual Gas Model
DHEM	Dual Hydrogen Electricity Model
ENNOH	European Network of Network Operators for Hydrogen
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSOG	European Network of Transmission System Operators for Gas
ETM	Energy Transition Model
FID	Final Investment Decision
GA	Global Ambition
GHG	Greenhouse Gas
IGI	Infrastructure Gaps Identification
ILM	Interlinked Modelling
IoSN	Identification of System Needs
LNG	Liquefied Natural Gas
MedTSO	Association of Mediterranean Transmission System Operators
NECP	National Energy and Climate Plan
NH_3	Ammonia
NT	National Trends
NTC	Net Transfer Capacity
P2X	Power-to-X
PCI	Project of Common Interest
PECD	Pan-European Common Database
PEMMDB	Pan-European Market Modelling Data Base
PINT	Put In One at a Time
PMI	Project of Mutual Interest
PPA	Power Purchase Agreement
PS-CBA	Project-Specific Cost Benefit Analysis
RES	Renewable Energy Sources
SEW	Social Economic Welfare
SMR	Steam Methane Reformer
SRG	Stakeholder Reference Group
TOOT	Take One Out at a Time
TSO	Transmission System Operator
TYNDP	Ten-Year Network Development Plan
VoLL	Value of Lost Load

ANNEXES

1 Stakeholder engagement in the drafting of this report

During the preparation of this report, the European Commission (EC), the European Union Agency for the Cooperation of Energy Regulators (ACER), and the Scenario Reference Group (SRG) were consulted on this report.

Three dedicated exchanges with the EC and ACER took place during the preparation of this report, and a workshop was held with the SRG in September 2025. Some of the feedback received by these stakeholders supported an improved communication on what the ILM Framework is, what it entails and where it stands.

It is also clarified how the ILM Roadmap and the Scenario Innovation roadmap complement each other.

Following the submission of the draft report to ACER on 31 October 2025, ACER issued its Opinion (No 01/2026) on 28 January 2026. The Opinion acknowledges progress made since joint scenario development and identifies areas for continued focus, particularly regarding cross-sector consistency and the progressive operationalisation of the roadmap. These expectations are addressed through the pilot study on cross-sector system needs assessment, which has been prioritised as an immediate focus area within the roadmap (see Section 7).

2 Consultation feedback background

This section explains the purpose of the questionnaire included in the ILM 2024 Progress Report consultation. The questions are designed to confirm that the report clearly and comprehensively conveys its mandate.

The survey therefore pursues four complementary objectives:

- **Clarity and Scope:** Confirm that the report's objectives, assumptions, and information flow are sufficiently precise to allow a transparent appraisal of progress to date.
- **Modelling Choices:** Examine the suitability of the network topology, scenario selection, treatment of shared renewable energy sources, and safeguards for carbon-free hydrogen, and invite suggestions for equally consistent alternatives.
- **CBA Metrics:** Assess whether the selected cost–benefit indicators, including the new cross-sector Social Economic Welfare metric. capture the economic, environmental, and security-of-supply impacts of an integrated energy system.
- **Interpretation of Initial Findings:** Gather perspectives on the alignment of modelling tools, observed price and emissions effects, and any additional insights or data gaps that should be addressed.

3 Consultation results

The public consultation is composed by twelve questions shown in Annex 4. Designed to gather stakeholder insight, the 2024 consultation received responses from six participants, three from EU organisations and three from private entities.

3.1 Summary of Feedback

The consultation process highlighted broad recognition of the progress made in developing the Interlinked Model but also emphasized that further refinement is essential to ensure methodological robustness, transparency, and policy relevance.

Scope and Objectives

The ILM's objectives were generally considered clear, but the scope should be broadened to include a wider set of technologies (such as hydrogen storage, methane electrolysis) and additional time horizons (e.g. 2035, 2040). Hydrogen-related assumptions require stronger justification, and a more balanced treatment of different production methods and import options is needed.

Scenario Framework and Model Approach

The current scenario set was seen as too narrow to deliver robust insights. There were calls for the inclusion of additional scenarios, further harmonisation of starting assumptions across all sectors, and sensitivity testing on costs, imports, nuclear shares, and policy parameters, etc. While the overall modelling approach was judged reasonable, several important elements were considered missing or insufficiently represented, particularly gas networks, storage facilities, regasification, and the interactions between electricity, gas, and hydrogen. Any simplifications compared to scenario models should be clearly explained and justified.

Aggregation, Resolution, and Data Transparency

Stakeholders consistently requested more openness and transparency, including publication of detailed input data (demand, prices, costs) in annexes to support external review and reproducibility.

Indicators and Assessment Outputs

While current cost–benefit analysis indicators were generally seen as a good starting point, several additional indicators were recommended. These include security of supply, greenhouse gas savings, flexibility impacts, and low-carbon electricity shares. Specific attention was drawn to the inconclusive results regarding hydrogen pipeline projects, which should be further investigated to improve model alignment and data transparency.

Hydrogen Modelling

The representation of hydrogen in the model was identified as an area requiring substantial improvement. Flat pricing approaches were seen as oversimplified and not reflective of real market dynamics. Key aspects such as technology cost diversity, regional electricity prices, carbon intensity, seasonality, and import variability should be captured. In addition, the current value-of-lost-load methodology for hydrogen was viewed as distortive, and a dedicated, hydrogen-specific cost-of-disruption parameter should be developed, updated regularly, and subject to consultation.

Governance, Process, and Transparency

The need for clearer governance arrangements was strongly emphasized, including transparent allocation of responsibilities between institutions for scenario development, needs assessment, cost–benefit analysis, and data management. A clear, high-level schematic of the ILM process – from scenarios through needs analysis to CBA – was requested to support wider understanding. Finally, participants stressed that the model is still evolving, and results should be applied cautiously. Expanded opportunities for stakeholder review and ongoing refinement of assumptions will be crucial as the ILM matures in future cycles.

4 Detailed results from consultation feedback

Question 1: Clarity of Objectives, Scope, and Information Flow

Respondents generally found the ILM 2024 objectives and information flow clear, but several areas require further clarification and refinement. Stakeholders recommended expanding the scope to include additional technologies (e.g., porous reservoir hydrogen storage, methane electrolysis) and additional TYNDP scenarios, particularly those reflecting higher nuclear shares, extra-EU hydrogen imports, and broader low-carbon electricity mixes. Concerns were raised regarding the decarbonisation constraints applied exclusively to electrolytic hydrogen. Several respondents emphasised the need for a more robust approach, such as annual average emissions accounting, and called for clearer implications for investment decisions, better alignment with existing models, improved flexibility modelling (including V2G), and transparent stakeholder engagement processes.

Question 2: Model Building Approach

While most respondents agreed that the ILM's simplified model structure is a reasonable starting point, many stressed the need for improvements. Several stakeholders called for the inclusion of porous reservoirs for hydrogen storage and a broader range of hydrogen production technologies. There was a strong request to integrate natural gas infrastructure into the ILM to better reflect system interactions during the transition phase. Some respondents raised concerns about the limited transparency of the current model structure and its simplifications, particularly for representing electrolysers and hydrogen demand patterns. Overall, respondents supported the integrated approach but emphasised that business models, flexibility options, and cross-sector dependencies require more realistic representation as the ILM evolves.

Question 3: Aggregation of Nodes for CBA Modelling

Respondents generally accepted the need for aggregation to simplify the ILM for CBA purposes but expressed caution about excessive aggregation reducing model accuracy. Several participants recommended finer spatial resolution to capture local bottlenecks, infrastructure benefits, and system integration effects more effectively. Concerns were raised that the current aggregation neglects physical transport constraints and losses, resulting in uniform prices that fail to reflect cross-border price signals or locational benefits. Some stakeholders suggested introducing losses for cross-border flows to better reflect system realities. Many also emphasised that electrolyser flexibility and V2G capabilities should be properly accounted for to avoid overestimating hydrogen infrastructure benefits.

Question 4: Scenario Selection

While accepting a limited scenario set for initial model alignment, most respondents called for a broader range of scenarios to improve robustness. Stakeholders recommended using updated TYNDP 2024 scenarios, including at least 2040 and possibly 2035 horizons, given that much hydrogen infrastructure will come online after 2030. Several proposed including Global Ambition 2040 scenarios and running sensitivity analyses across key variables such as hydrogen import costs, CBAM impacts, nuclear generation shares, and retrofit rates. Such broader testing was seen as necessary to ensure the model's robustness and to better reflect the uncertainties and dynamics of the energy transition.

Question 5: Shared Renewable Energy Sources (SRES)

Most respondents disagreed with the exclusive choice of Mode 1 (system cost minimisation) for modelling Shared Renewable Energy Sources. Many argued that Mode 2, which prioritises electrolyser operations via PPAs, better reflects actual business models, regulatory flexibility, and investment realities. Multiple stakeholders emphasised that European regulation allows for multiple compliance pathways that Mode 1 fails to capture. Concerns were raised that Mode 1 leads to low electrolyser utilisation rates, undermines project viability, and creates unrepresentative system outcomes. Several called for the ILM to include multiple operating modes reflecting diverse use cases, location factors, investment logic, and market participation options to better inform both policy and system planning.

Question 6: Green Hydrogen Constraints

Respondents expressed widespread concerns about the ILM's use of Value of Lost Load (VoLL) to enforce fully decarbonised electrolytic hydrogen production. Many viewed this approach as an oversimplification that risks distorting system outcomes and artificially restricting electrolyser operations. Stakeholders advocated for applying existing EU regulations on low-carbon hydrogen more directly, allowing for compliance through PPAs, temporal correlation, and carbon intensity thresholds. Several called for a shift toward annual average emissions accounting, which would better reflect system decarbonisation while ensuring fair treatment of different hydrogen production pathways. Some respondents also urged the ILM to separate supply-demand balancing from decarbonisation enforcement and to improve transparency regarding modelling assumptions.

Question 7: Non-Linearities and CO_2 Emissions

Most respondents supported the decision not to apply strict carbon budgets within the ILM, agreeing that system-wide trade-offs are better assessed through economic optimisation combined with existing carbon pricing mechanisms like the EU Emission Trading System (ETS). Stakeholders emphasised that CO_2 emissions should remain a key model output, with greater focus on sensitivity analyses and reporting of emissions patterns. Some participants noted that non-linear constraints related to hydrogen infrastructure may affect emissions outcomes, but recommended prioritising broader system analysis over introducing rigid asset-specific constraints. Several also called for improved transparency in how CO_2 emissions are calculated and suggested exploring more comprehensive accounting of indirect emissions.

Question 8: CBA Indicator Scope

While some respondents found the existing set of CBA indicators sufficient, many proposed key additions to strengthen assessments. Several stressed the need for a dedicated security of supply indicator to capture benefits from diversifying imports and reducing external dependencies. It was recommended adding a "share of low-carbon electricity" indicator to reflect broader low-carbon pathways. Others emphasised that CO_2 impact indicators should account for hydrogen's broader role in hard-to-abate sectors beyond grey hydrogen replacement, using fossil fuel comparators consistent with the Renewable Energy Directive. Some suggested that G2P units be integrated into the model to reflect hydrogen's role in power system flexibility.

Question 9: Global SEW and SEW Split

Most respondents agreed with using Global SEW as a key system-wide metric but several, strongly argued for preserving sectoral SEW splits to inform policymakers about how benefits are distributed across electricity and hydrogen systems. Such splits were seen as particularly valuable for designing support schemes and evaluating the relative contributions of different infrastructure projects. Some stakeholders also pointed out that limited spatial granularity may lead to underestimation of sector coupling benefits, while others called for ensuring comprehensive geographical scope including third-country interconnections. Concerns were also raised that the exclusion of natural gas infrastructure may distort the overall SEW calculation.

Question 10: CBA Results and Tool Alignment

Respondents generally acknowledged good model alignment for electricity transmission and some electrolyser projects but highlighted persistent misalignments for hydrogen pipeline assessments. Many noted that hydrogen pipeline benefits often appeared marginal and within the margin of model error, making robust conclusions difficult. It was emphasised that sectoral SEW splits remain helpful in identifying projects where hydrogen sector benefits may be overstated relative to electricity system gains. Several respondents called for further investigation of discrepancies between ILM and PLEXOS/ANTARES outputs, better transparency of project-level data, and improved representation of hydrogen system seasonality, storage, and infrastructure assumptions to enhance reliability.

Question 11: Hydrogen Price Modelling

There was broad agreement that the ILM’s current flat hydrogen pricing oversimplifies real-world market dynamics. Respondents called for more varied price modelling that reflects differences in production technology, regional electricity prices, carbon intensity, electrolyser utilisation rates, and seasonal variations in both domestic production and imports. Many criticised the low-cost assumptions for SMR+CCS and imports, urging alignment with updated carbon pricing forecasts and realistic cost projections. Hydrogen Europe and others emphasised the need to incorporate regional variations in electricity carbon intensity, which strongly influence electrolyser economics across Member States. Stakeholders also advocated for including emerging production technologies and more dynamic representation of hydrogen imports.

Question 12: Insights and Recommendations

Overall, respondents recognised the valuable progress made by the ILM team and supported the model’s use as a policy development tool. However, many emphasised that current results should remain indicative given ongoing uncertainties and limitations. The majority reiterated that sectoral SEW splits remain critical for policymaking and that assumptions around electrolyser operations, hydrogen imports, and pricing require further refinement. Several respondents called for improved transparency of model input data, boundary conditions, and optimisation functions. Finally, stakeholders recommend allowing more time for review in future consultations to ensure robust feedback and continuous model improvement for subsequent CBA assessments.

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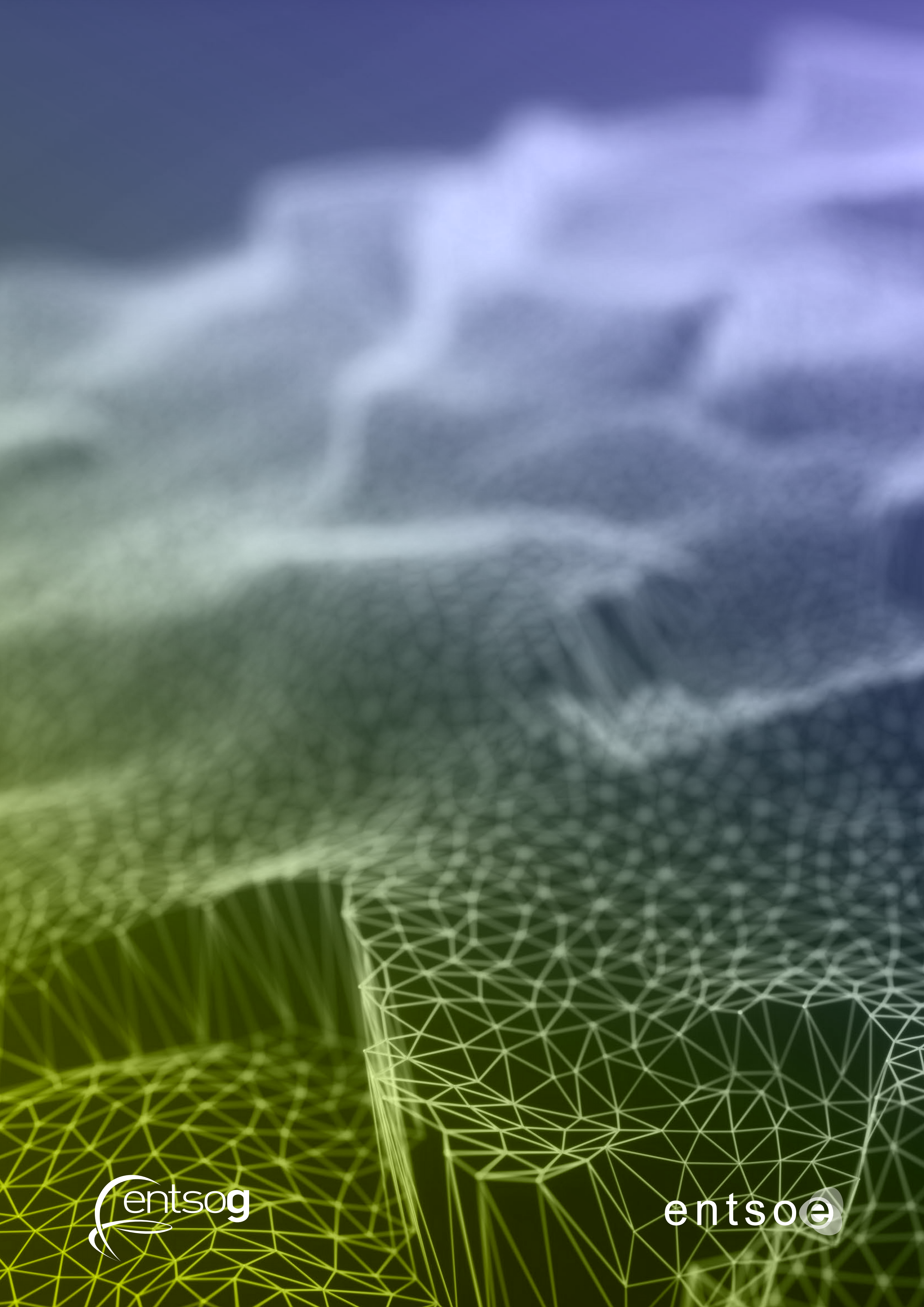

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