TEN-YEAR NETWORK DEVELOPMENT PLAN

2024

ANNEX D2
Hydrogen Infrastructure Gaps Identification Methodology

Publisher ENTSOG AISBL
Avenue de Cortenbergh 100
1000 Brussels, Belgium

Cover picture Courtesy of Astora

Content

Abbreviations

The list of abbreviations of the TYNDP 2024 Implementation Guidelines[1] is also valid for this document. Additionally, the following abbreviations apply:

ENNOH	European Network of Network Operators for Hydrogen
BEMIP Hydrogen	Hydrogen and electrolyser priority corridor containing Denmark, Germany, Estonia, Latvia, Lithuania, Poland, Finland, Sweden
GHR	Regulation of the European Parliament and of the Council on the internal markets for renewable gas, natural gas and hydrogen, amending Regulations (EU) No 1227/2011, (EU) 2017/1938, (EU) 2019/942 and (EU) 2022/869 and Decision (EU) 2017/684 and repealing Regulation (EC) No 715/2009 (recast)
HI East	Hydrogen and electrolyser priority corridor containing Bulgaria, Czechia, Germany, Greece, Croatia, Italy, Cyprus, Hungary, Austria, Poland, Romania, Slovenia, Slovakia
HI West	Hydrogen and electrolyser priority corridor containing Belgium, Czechia, Denmark, Germany, Ireland, Spain, France, Italy, Luxembourg, Malta, Netherlands, Austria, Portugal
IGI indicator	Infrastructure Gaps Identification Indicator

1. Introduction

The objective of this Hydrogen Infrastructure Gaps Identification (IGI) methodology is to provide guidance on the different elements of relevance for the IGI report as part of the 2024 TYNDP cycle. The TYNDP 2024 IGI methodology thereby builds on the TYNDP 2024 Implementation Guidelines through cross-references. The TYNDP 2024 Implementation Guidelines specify the required elements of the project-specific cost-benefit analysis (PS-CBA) as part of the 2024 TYNDP cycle.

The draft TYNDP 2024 IGI methodology (TNYPD 2024 Annex D.1) and the draft TYNDP 2024 Implementation Guidelines (TYNDP 2024 Annex D.2) are consulted along a third draft methodology document, the draft TYNDP 2024 System Assessment methodology (TYNDP 2024 Annex D.3[2]), that covers the methodology of TYNDP 2024 sections that are not of relevance for the PS-CBA process and the IGI report. Further details about the timeline can be found in section 1 of the draft TYNDP 2024 Implementation Guidelines.

2. Legal background

Article 60 of the Regulation on the internal markets for renewable gas, natural gas and hydrogen (GHR) stipulates that *"The Union-wide network development plan for hydrogen shall include the modelling of the integrated hydrogen network, scenario development, a European supply adequacy outlook and an*

[1] Link to draft TYNDP 2024 Implementation Guidelines: link
[2] Link to draft Annex D.3: link

assessment of the resilience of the system. The Union-wide network development plan for hydrogen shall, in particular: […] c) identify investment gaps, in particular with respect to the necessary cross-border capacities, to implement the priority corridors for hydrogen and electrolysers as referred to in point 3 of Annex I to [the TEN-E Regulation].”

Point 3 of Annex I of the TEN-E Regulation defines the priority corridors for hydrogen and electrolysers: *“[…] Hydrogen interconnections […]:* ***hydrogen infrastructure and the repurposing of gas infrastructure, enabling the emergence of an integrated hydrogen backbone, directly or indirectly (via interconnection with a third country), connecting the countries of the region and addressing their specific infrastructure needs for hydrogen supporting the emergence of an Union-wide network for hydrogen transport****, and, in addition,* ***as regards islands and island systems, decreasing energy isolation, supporting innovative and other solutions involving at least two Member States with a significant positive impact on the Union’s 2030 targets for energy and climate and its 2050 climate neutrality objective, and contributing significantly to the sustainability of the island energy system and that of the Union.***

Electrolysers: supporting the deployment of power-to-gas applications aiming to enable greenhouse gas reductions and contributing to secure, efficient and reliable system operation and smart energy system integration and, in addition, as regards islands and island systems, supporting innovative and other solutions involving at least two Member States with a significant positive impact on the Union’s 2030 targets for energy and climate and its 2050 climate neutrality objective, and contributing significantly to the sustainability of the island energy system and that of the Union.”

Three such priority corridors are defined in the TEN-E Regulation:

- HI West: Belgium, Czechia, Denmark, Germany, Ireland, Spain, France, Italy, Luxembourg, Malta, Netherlands, Austria, Portugal.
- HI East: Bulgaria, Czechia, Germany, Greece, Croatia, Italy, Cyprus, Hungary, Austria, Poland, Romania, Slovenia, Slovakia.
- BEMIP Hydrogen: Denmark, Germany, Estonia, Latvia, Lithuania, Poland, Finland, Sweden.

In line with Article 60 of the GHR, the focus of ENTSOG’s infrastructure gaps identification exercise is on the needed hydrogen interconnectors within the priority corridors for hydrogen and electrolysers.

The infrastructure gaps identification is complementarily addressed by Article 13 of the TEN-E Regulation. An identified infrastructure gap thereby translates into an equivalent infrastructure need. The identified infrastructure gaps shall be reported as a part of the TYNDP and follow the procedural requirements of Article 13 of the TEN-E Regulation.

Article 13(1) of the TEN-E Regulation directs the focus of the analysis at system level to the effect of possible infrastructure gaps on the completion of the EU’s 2030 climate and energy targets and 2050 climate-neutrality objective. The TYNDP scenarios, established in line with Article 12 of the TEN-E

Regulation, thereby comply with this requirement. In line with Article 13(1) of the TEN-E Regulation, these scenarios form the basis of the infrastructure gaps identification.

3. Model description

The model description contained in section 2 of the draft TYNDP 2024 Implementation Guidelines is also valid for this draft TYNDP 2024 IGI methodology. Exceptions from this validity and specifications are described in this section:

> While as for the PS-CBA process the Dual Hydrogen/Electricity Model (DHEM) and Dual Gas Model (DGM) are used, the same TYNDP 2024 scenario is considered (i.e., National Trends+), and the same years are modelled (i.e., 2030 and 2040), the benefit indicators described in the TYNDP 2024 Implementation Guidelines are not computed within the IGI. The IGI report is based on own indicators.
> For the DGM, the same natural gas infrastructure level will be chosen in the final TYNDP 2024 Implementation Guidelines as in the final TYNDP 2024 IGI methodology depending on the public consultation.
> In contrast to the PS-CBA process, both hydrogen infrastructure levels (i.e., PCI/PMI hydrogen infrastructure level and Advanced hydrogen infrastructure level) are assessed within the TYNDP 2024 IGI report.

The DHEM market assumptions listed in section 3.2.4 and Annex III as well as the infrastructure information provided by Annex I and II of the draft TYNDP 2024 Implementation Guidelines are also valid for this draft TYNDP 2024 IGI methodology. However, the alternative fuel approach detailed in section 3.2.5 of the draft TYNDP 2024 Implementation Guidelines is not considered for all IGI indicators as detailed in section 5. The same stressful weather year is used for the curtailed hydrogen demand IGI indicator (see section 5.2) as detailed in section 3.2.11 of the draft TYNDP 2024 Implementation Guidelines. The remaining parts of section 3 as well as section 4, section 5, section 6.2, Annex IV, and Annex V of the draft TYNDP 2024 Implementation Guidelines are not relevant for this draft IGI methodology as they are related to project-specific assessments.

All hydrogen-related values specified in this draft TYNDP 2024 IGI methodology are considering the GCV[3].

4. General approach

To identify the infrastructure gaps, the following elements must be defined:

> Already defined in the draft TYNDP 2024 Implementation Guidelines in combination with the previous section:
  - General modelling concepts.

[3] The TYNDP 2024 scenarios are using the NCV. For hydrogen, the NCV can be transferred into the GCV by multiplication with 1.18.

  - The simulation tools and models to be used.
  - The TYNDP scenario(s) and years to be used.
  - The level of the network development (infrastructure level) to be considered as a reasonable counterfactual situation on which to assess the system and identify possible infrastructure gaps.
- Not defined in the draft TYNDP 2024 Implementation Guidelines:
  - The indicators on the basis of which infrastructure gaps will be identified (see section 5).
  - The threshold value for each infrastructure gap indicator. The comparison of the indicator result with its threshold value allows the judgement whether i) an infrastructure gap does not exist or is less relevant, or ii) an infrastructure gap does exist (see section 5).
  - The methodology to compare the results for different hydrogen infrastructure levels to derive project-related information about infrastructure gaps (see section 6).

The results of the TYNDP 2024 IGI report are only related to infrastructure gaps that are based on the considered infrastructure levels. Therefore, the TYNDP 2024 IGI report cannot find that an infrastructure that is part of the smallest considered infrastructure level (i.e., the PCI/PMI hydrogen infrastructure level) is not addressing any infrastructure gap.

Infrastructure gaps identified in ENTSOG's hydrogen-related TYNDP 2024 IGI report may in some cases also be addressed by energy infrastructure solutions in other sectors like the electricity sector[4] or the natural gas sector. This is the case for any infrastructure gaps identification that is focused on a specific energy vector.

No generic hydrogen infrastructure projects are used in this draft TYNDP 2024 IGI methodology. Instead, only real projects that were submitted by project promoters are considered.

5. Infrastructure Gaps Identification Indicators

The Infrastructure Gaps Identification indicators (IGI indicators) identify the existence of an infrastructure gap through the existence of effects of such infrastructure gap. The effect of this infrastructure gap is either expressed at a border for IGI indicator 1 (see section 5.1) or at a country for IGI indicator 2 (see section 5.2). The reason for an infrastructure gap is an infrastructure bottleneck. An infrastructure bottleneck is a physical congestion of the network that can be observed based on full utilization rates of all relevant transmission infrastructure during certain periods of time. If a limited cooperation mode is used among countries in situations of hydrogen scarcity (see section 3.2.4 of the draft TYNDP 2024 Implementation Guidelines), the dominant infrastructure bottleneck is not necessarily

[4] While for example imports of hydrogen produced from natural gas with CCS from Norway or renewable energy imports by ship from distant production locations cannot be achieved by the electricity sector.

located at a border of the country through which the IGI indicators demonstrated the existence of an infrastructure gap (see examples below). Also, besides the dominant bottleneck, non-dominant bottlenecks may exist at other locations that only unfold their effect once the dominant bottleneck is addressed. Additionally, an infrastructure bottleneck can in principle be solved by different projects and via different routes. Therefore, the infrastructure gaps identified by the IGI indicators identify regional infrastructure gaps, as the potential solution to it is not limited to the border of IGI indicator 1 or the country of IGI indicator 2. The regional aspect of the infrastructure gap can be further investigated at project level (see section 6).

5.1. IGI indicator 1: Hydrogen market clearing price spreads in DHEM

The indicator aims at identifying hydrogen infrastructure gaps by assessing Zone 2 nodes of different countries based on differences in hydrogen market clearing prices between these nodes.

The indicator is established

- based on outputs of the objective function of the DHEM,
- for each considered scenario (i.e., NT+),
- for each considered year of assessment (i.e., 2030 and 2040),
- for the reference weather year (i.e., 2009),
- for each considered combination of hydrogen and electricity infrastructure levels (i.e., PCI/PMI hydrogen infrastructure level coupled with the electricity infrastructure level from the NT+ scenario; Advanced hydrogen infrastructure level coupled with the electricity infrastructure level from the NT+ scenario), and
- without consideration of the alternative fuel approach[5].

The DHEM thereby provides hourly hydrogen market clearing prices per hydrogen node.

The hydrogen market clearing price spreads between different hydrogen nodes thereby allows to internalise information about several aspects that are listed below:

- Competition and market integration:
    - Undersized hydrogen cross-border capacities are cross-border trade barriers. These trade barriers limit the access of the hydrogen producers with the lowest marginal

[5] The alternative fuel approach helps to measure how projects can help to enable the switch of end users from an incumbent fuel like natural gas or oil towards hydrogen, and to thereby contribute to the realisation of the situation described in the TYNDP scenarios. The alternative fuel approach is useful to be considered if individual projects are assessed with the incremental approach. If an assessment is only based on the reference simulation of a certain infrastructure level, the alternative fuel approach would remove a share of the hydrogen demand of the TYNDP scenarios from the assessment, preventing the IGI report to identify related hydrogen infrastructure gaps. Therefore, the alternative fuel approach will not be considered for the hydrogen market clearing price spread indicator. An overview of the results of this indicator under consideration of the alternative fuel approach may still be provided in the TYNDP 2024 IGI report.

production cost to hydrogen consumers. This results in hydrogen market clearing price spreads. On the other hand, a perfect market integration would result in a full hydrogen market clearing price convergence between Member States.

- Hydrogen demand curtailment[6] :
    - Hydrogen demand curtailment in a certain node is a last resort. It is characterized by a hydrogen market clearing price at the level of the willingness to pay for hydrogen (WTP_{H2}). The WTP_{H2} is higher than the price of the most expensive hydrogen supply source. This creates hydrogen market clearing price spreads between nodes with and nodes without hydrogen demand curtailment.
- Curtailed electrolytic hydrogen production within the EU:
    - Curtailed renewable electricity production would as a symptom show an electricity market clearing price of 0. Thus, there would be a business case for producing electrolytic hydrogen from this curtailed renewable electricity at a very low marginal cost if in another country more expensive hydrogen sources were used (e.g., hydrogen production from electricity produced by nuclear power plants, hydrogen production from natural gas, hydrogen imports from non-EU countries, etc.). If there was insufficient hydrogen transport capacity between the country with the curtailed renewable electricity production and a country that uses more expensive hydrogen sources, this will be displayed as a hydrogen market clearing price spread.
- Renewable hydrogen or low-carbon hydrogen import options:
    - Hydrogen price spreads can also be calculated between the hydrogen market clearing price in a Member State and relevant import prices of import options of renewable hydrogen (e.g., imports by ship or hydrogen from North Africa or Ukraine) or of low-carbon hydrogen (e.g., hydrogen from Norway) as established in the NT+ scenario. Such price spread shows which non-EU country or region could be an attractive potential supply source.

To define which hydrogen market clearing price spreads are a significant indication of an hydrogen infrastructure gap, one of the following thresholds must be passed:

- Threshold 1: A hydrogen market clearing price spread as the yearly average of the absolute hourly hydrogen market clearing price spread between two Zone 2 nodes of different countries of more than 4 €/MWh_{H2}[7]; OR

---

[6] Selecting the curtailed hydrogen demand as single indicator would not allow to consider other listed aspects of relevance for the identification of hydrogen infrastructure gaps.

7 In ENTSO-E's implementation guidelines for TYNDP 2024 of 4 March 2024, several interconnection target recommendations to contribute to EU energy targets are listed. Amongst them is the price differential: "Market studies simulations will serve to account price differentials per border as the yearly average of absolute hourly price differentials. This indicator is computed per border in €/MWh. In those borders where this indicator is greater than 2 €/MWh will mean that further interconnectors should urgently be investigated." The hydrogen market clearing price spreads indicator allows for a similar approach, while a more conservative threshold value is chosen.

> Threshold 2: A hydrogen market clearing price spread as the absolute average daily[8] hydrogen market clearing price spread between two Zone 2 nodes of different countries of more than 20 €/MWh$_{H2}$ for more than 40 days per year.

If there is a hydrogen market clearing price spread above one of the thresholds, this indicates an infrastructure gap for the given assumptions. **The exact threshold values will be established after consideration of the public consultation of this draft document.**

Example 1 of the application of the thresholds: > Case: Country A is neighboring country B. There is no direct or indirect hydrogen transport capacity between them. Country A is producing all its hydrogen with electrolysers from renewable electricity at a marginal cost of 30 €/MWh$_{H2}$ along the whole year. Country B is producing hydrogen with electrolysers from nuclear power at a marginal cost of 40 €/MWh$_{H2}$ along the whole year. o Result for Threshold 1: The yearly average of the absolute hourly hydrogen market clearing price spread between country A and country B is 10 €/MWh$_{H2}$. As this is more than 4 €/MWh$_{H2}$Threshold 1 is passed. o Result for Threshold 2: The absolute average daily hydrogen market clearing price spread between country A and country B is above 20 €/MWh$_{H2}$ for 0 days. Therefore, Threshold 2 is not passed. o Result: As one of the thresholds is passed, an infrastructure gap is identified based on the IGI indicator 1 between country A and country B.
Example 2 of the application of thresholds: > Case: Country D is an island and cannot produce sufficient hydrogen in any hour along the year to satisfy its hydrogen demand. The hydrogen market clearing price is therefore equivalent to the WTP$_{H2}$, e.g. 154 €/MWh$_{H2}$. Hydrogen import by ship is assumed to cost 116.5 €/MWh$_{H2}$ and to be available along the whole year. o Result: Both thresholds are passed. As at least one threshold is passed, an infrastructure gap is identified based on the IGI indicator 1.

Addressing an identified infrastructure gap by addressing the underlying dominant infrastructure bottleneck does not exclude the existence of non-dominant infrastructure gaps based on non-dominant infrastructure bottlenecks that would unfold an effect on other nodes once the identified dominant infrastructure gap was addressed. This is explained by the following example.

[8] By using daily average values, intra-day changes of the transport direction are tending to equalize each other, being more conservative than working with absolute average hourly hydrogen market clearing price spreads.

Example of a non-dominant infrastructure gap:

- Initial case: Country A is neighboring country B, country B is neighboring country A and country C, and country C is neighboring country B. There is no hydrogen transport capacity between these three countries. Country A has surplus hydrogen supply options while country B and country C have no hydrogen supply option but hydrogen demand.
    - Result of the hydrogen market clearing price spread indicator: The hydrogen market price spread indicator will indicate an infrastructure gap based on the IGI indicator 1 between country A and country B. There is no such indication between country B and country C as both show the high hydrogen market clearing price associated with hydrogen shortage.
- Case after identified infrastructure gap was addressed: There would still be the non-dominant infrastructure gap between country B and country C as there is still no connection between them, so the non-dominant infrastructure bottleneck remains, and country C remains with the high hydrogen market clearing price associated with hydrogen shortage.

The approach to investigate the role of projects is described in section 6.

5.2. IGI indicator 2: Curtailed hydrogen demand in DHEM and DGM

This IGI indicator identifies infrastructure gaps by measuring the hydrogen demand curtailments of individual nodes under certain stress cases. Thereby, two different types of stress cases are assessed: A stressful weather year and S-1 cases.

The stressful weather year data is aligned with the stressful weather year proposed to be used for the calculation of the reduction in exposure to curtailed hydrogen demand indicator (B5) within the draft TYNDP 2024 Implementation Guidelines. The following simulation logic is applied for each combination of simulation year and hydrogen infrastructure level:

1. A DHEM simulation is run with the stressful weather year data.
2. The DHEM outputs from step 1 that influence the natural gas demand, hydrogen production, and hydrogen consumption are transferred into the DGM (see sections 2.4.5 and 2.4.6 of the draft TYNDP 2024 Implementation Guidelines).
3. A DGM simulation is run on the basis of step 2.
4. Per node, the combined hydrogen demand curtailment from the DHEM simulation and the additional hydrogen demand curtailment from the DGM are provided.

The S-1 cases consider the unavailability of a certain non-European hydrogen supply source, e.g., ammonia imports by ship, Ukraine, Norway, North Africa. The following simulation logic is applied for each combination of simulation year and hydrogen infrastructure level:

1. A DHEM simulation is run with the reference weather year data (same as used for the hydrogen market clearing price spread indicator).

2. The DHEM outputs from step 1 that influence the natural gas demand, hydrogen production, and hydrogen consumption are transferred into the DGM (see sections 2.4.5 and 2.4.6 of the draft TYNDP 2024 Implementation Guidelines).
3. A DGM simulation is run on the basis of step 2 but considering the unavailability of a certain hydrogen supply source.
4. Per node, the combined hydrogen demand curtailment from the DHEM simulation and the additional hydrogen demand curtailment from the DGM are provided.

To define which hydrogen demand curtailments are a significant indication of an hydrogen infrastructure gap, one of the following thresholds must be passed:

- Threshold 1: A yearly average hydrogen demand curtailment rate of more than x %; OR
- Threshold 2: A hydrogen demand curtailment rate of more than y % for at least one month per year.

If there is a hydrogen demand curtailment above one of the thresholds, this indicates an infrastructure gap for the given assumptions. **The exact threshold values will be established after consideration of the public consultation of this draft document.**

As there is only a limited cooperation mode considered for hydrogen in the DHEM and in the DGM (see section 3.2.4 of the draft TYNDP 2024 Implementation Guidelines), the infrastructure bottleneck causing the hydrogen demand curtailment rate to be above one of the thresholds defined above in a certain country does not need to be located at the border between this country and its direct neighbors. This is explained by the following examples

Example of the identification of an infrastructure bottleneck under full cooperation mode:

Country A is neighboring country B, country B is neighboring country A and country C, and country C is neighboring country B. Country A has a surplus of hydrogen supply options, while country B and country C are depending on supplies from country A. Under a full cooperation mode, the model will try to reach equal hydrogen demand curtailment rates in all three countries. Under this full cooperation mode, a difference between hydrogen demand curtailment rates between neighboring countries can only be caused by fully utilized (or non-existing) infrastructure. The infrastructure that was fully utilized (or was non-existing) and thereby caused this difference is defined as the dominant infrastructure bottleneck. If as a result of this cooperation country B and country C have the same hydrogen demand curtailment rates, which are higher than the one of country A, the dominant infrastructure bottleneck is located between country A and country B. If country A and country B have the same hydrogen demand curtailment rates, which are higher than the one of country C, the dominant infrastructure bottleneck is located between country B and country C. If country A has a lower hydrogen demand curtailment rate than country B and the one of country B is lower than the one of country C, there are dominant infrastructure bottlenecks between country A and country B as well as between country B and country C.

Example of the identification of an infrastructure bottleneck under the limited cooperation mode applied for the hydrogen infrastructure gaps identification:
Country A is neighboring country B, country B is neighboring country A and country C, and country C is neighboring country B. Country A has a surplus of hydrogen supply options, while country B and country C are depending on supplies from country A and have no potential access to hydrogen import options. Under the limited cooperation mode, the model will try to first satisfy the hydrogen demand of country A, then of country B, and only then of country C (as cross-border flows are penalized with a small hurdle cost). If only country C is curtailed, this does not mean that the infrastructure bottleneck, defined as the fully utilized (or non-existing) infrastructure causing the curtailment, is located at the border between country B and country C. While this is a possible explanation, the infrastructure bottleneck could also be linked to the infrastructure from country A to country B. In latter case, not sufficient hydrogen can be send out of country A to satisfy the hydrogen demand of both country B and country C. This would then be the dominant infrastructure bottleneck. If it was not, the total supply options of the three countries would be too limited, so the dominant infrastructure bottleneck would be import infrastructure into country A.

The example above shows that the infrastructure bottleneck with a limited cooperative mode does not need to be at the node where the infrastructure gap is identified. The approach to investigate the role of projects is described in section 6.

6. Comparison of the indicator results for different hydrogen infrastructure levels

As stated in previous sections, the two IGI indicators are used to identify regional infrastructure gaps that are indicated by the passing of one threshold of one IGI indicator.

By comparing the results of different hydrogen infrastructure levels for simulations that are identical concerning all other parameters, the effect of including additional infrastructure can be identified. The Advanced hydrogen infrastructure level contains the exact PCI/PMI hydrogen infrastructure level as well as additional projects.

If an infrastructure gap is indicated in the PCI/PMI hydrogen infrastructure level but is not observed in the Advanced hydrogen infrastructure level, the additional projects contained in latter infrastructure level removed it. Thereby, they addressed a certain infrastructure bottleneck.

To identify which of the additional projects removed the infrastructure bottleneck that caused the infrastructure gap, the results of the IGI indicator simulations are interpreted. Thereby, infrastructure bottlenecks are identified by assessing which hydrogen demand curtailments are caused by all relevant transmission infrastructure being used at their maximum capacity (i.e., infrastructure bottleneck). Then, it can be stated that one solution to address the respective infrastructure gap is described by the identified projects (in addition to the PCI/PMI infrastructure level) with their respective capacities. This does not falsify the fact that various combinations of additional infrastructure at various locations may be able to address this gap.

An infrastructure gap can also be reduced by bringing the threshold values closer to the threshold. In this case, the comparison is following the same steps, but the projects and their respective capacities were not sufficient to remove the relevant infrastructure bottlenecks. Nevertheless, they partially address the identified regional infrastructure gap.

Based on the public consultation of the draft TYNDP 2024 IGI methodology, it is an option to further investigate project-related solutions by adding a third hydrogen infrastructure level that contains all hydrogen projects that were accepted for the TYNDP 2024, i.e. also less-advanced ones that are no PCI or PMI.

If an infrastructure bottleneck is identified, this is an indication that projects addressing the respective transport need and that are part of the assessed infrastructure level are not in competition. This information may be used for the PS-CBA process.

7. Overview of simulation cases for the Infrastructure Gaps Identification report

Table 1: Combinations of scenarios, years, infrastructure levels, cases, models, and indicators for the infrastructure gaps identification of hydrogen infrastructure.

No.	Scenario	Infrastructure levels			Case	Model / IGI indicator
		Electricity	Hydrogen	Natural gas[9]		
1	NT+ 2030	NT+ 2030	PCI/PMI	None	Reference year	DHEM / price input for no. 4
2	NT+ 2030	NT+ 2030	PCI/PMI	None	Stressful year	DHEM / curtailment input for no. 3
3	NT+ 2030	None	PCI/PMI	Yes	Stressful year	DGM / curtailment
4	NT+ 2030	None	PCI/PMI	Yes	S-1 Shipping	DGM / curtailment
5	NT+ 2030	NT+ 2030	Advanced	None	Reference year	DHEM / price input for no. 8, 9
6	NT+ 2030	NT+ 2030	Advanced	None	Stressful year	DHEM / curtailment input for no. 7

[9] The natural gas infrastructure level will be chosen based on the public consultation. This is further detailed in the draft TYNDP 2024 Implementation Guidelines.

7	NT+ 2030	None	Advanced	Yes	Stressful year	DGM / curtailment
8	NT+ 2030	None	Advanced	Yes	S-1 Ukraine	DGM / curtailment
9	NT+ 2030	None	Advanced	Yes	S-1 Shipping	DGM / curtailment
10	NT+ 2030	None	Advanced	Yes	S-1 North Africa	DGM / curtailment
11	NT+ 2040	NT+ 2040	PCI/PMI	None	Reference year	DHEM / price input for no. 13-15
12	NT+ 2040	NT+ 2040	PCI/PMI	None	Stressful year	DHEM / curtailment input for no. 13
13	NT+ 2040	None	PCI/PMI	Yes	Stressful year	DGM / curtailment
14	NT+ 2040	None	PCI/PMI	Yes	S-1 Shipping	DGM / curtailment
15	NT+ 2040	None	PCI/PMI	Yes	S-1 Norway	DGM / curtailment
16	NT+ 2040	NT+ 2040	Advanced	None	Reference year	DHEM / price input for no. 19-22
17	NT+ 2040	NT+ 2040	Advanced	None	Stressful year	DHEM / curtailment input for no. 18
18	NT+ 2040	None	Advanced	Yes	Stressful year	DGM / curtailment
19	NT+ 2040	None	Advanced	Yes	S-1 Ukraine	DGM / curtailment
20	NT+ 2040	None	Advanced	Yes	S-1 Shipping	DGM / curtailment
21	NT+ 2040	None	Advanced	Yes	S-1 Norway	DGM / curtailment
22	NT+ 2040	None	Advanced	Yes	S-1 North Africa	DGM / curtailment

8. Implementation of the energy efficiency first principle in the infrastructure gaps identification

The introduction part of section 6 as well as section 6.1 of the draft TYNDP 2024 Implementation Guidelines are also valid for this draft TYNDP 2024 IGI methodology.

> Inclusion of options for better utilisation of existing infrastructure
  - The existing infrastructure considered in the TYNDP 2024 topology is updated with information that is provided by the infrastructure operators. This provides the option to update the underlying energy infrastructure capacities which are the main parameter capturing the ability of better utilisation through operational improvements, including by digital solutions. Also, the consideration of infrastructure of multiple energy sectors like hydrogen, electricity, and natural gas allows an optimisation of the utilisation of the existing infrastructure's capacities in the model through flexibility provisions across energy sectors.

> Inclusion of options to include more energy-efficient technologies
  - The TYNDP 2024 IGI report is prepared on the basis of the NT+ scenario that includes energy efficiency measures as described in the section 6.1 of the draft TYNDP 2024 Implementation Guidelines. Thereby, a decisive share of the measures (e.g., renovations of buildings) have been set at the highest level that can be considered as feasible and realistic under current targets, policies, and expected technological advancements. Thereby, in line with the energy efficiency first principle, the most energy efficient solution does not have to prevail but should be considered within the decision making process and be preferred if being similarly cost-efficient, and beneficial for security of supply. By already being part of the NT+ scenario, the selected energy efficiency measures are not associated with additional investments in the simulations for the TYNDP 2024 IGI report and their usage is always an option alongside the identification of infrastructure gaps.

> Inclusion of options to make better use of the market mechanisms
  - By considering perfect competition only limited by infrastructure constraints between nodes, as well as by allowing demand side response to be acting without infrastructure or market restrictions (e.g., if the demand side response is located at DSO level) within a whole zone, the market behaviour is optimistic regarding the effects of demand side management. Several demand side responses are therefore considered. The pattern of the total demand is not simply transferred from the NT+ scenario to the TYNDP, but the underlying assets are considered to be used within their specifications to allow their optimised utilisation.
  - Concerning the DHEM-based assessments, this relates to
    - assets coupling the sectors through conversion (i.e., electrolysers and hydrogen-fired power plants);
    - demand shedding (e.g., reduction of industrial demand for a limited time that is triggered by a certain market clearing price).

- Concerning the DGM-based assessments, this relates to
  - the calculation of monthly profiles for the DGM, which is not only a simplification, but also assumes the possibility of significant temporal flexibility of natural gas and hydrogen demand, interpretable as demand-shifting possibilities within a sector and/or additional availability of storage options and/or further optimisation of existing infrastructure's utilisation. This prioritises all relevant alternatives to new infrastructure, while being agnostic concerning the actual solution;
  - assets coupling the sectors through conversion (i.e., hydrogen production from natural gas);
  - the model being allowed to investigate the optimal solution for each stress case with several degrees of freedom (i.e., usage of hydrogen supply sources and natural gas supply sources).

> Aiming at balancing security of supply, quality of energy supplied, and cost-efficiency

- The wider benefits of investments are addressed from a system efficiency and societal perspective.
- Concerning the DHEM-based assessments, this relates to
  - monetising unserved energy demand (i.e.., VoLL, WTP, and CODH);
  - penalising energy losses contributing negatively to life cycle efficiencies (e.g., reflection in marginal costs of fuels, conversion losses of electrolysers, conversion losses of power plants, efficiencies of energy storages);
  - penalising of emissions (e.g., reflection in marginal costs of fuels and thereby in the merit order);
  - simulating with an integrated model covering the hydrogen and the electricity sector.
- Concerning the DGM-based assessments, this relates to
  - monetising unserved energy demand (i.e., CODH);
  - penalising energy losses contributing negatively to life cycle efficiencies and emissions (e.g., conversion losses of hydrogen production from natural gas, reflection in merit order);
  - simulating with an integrated model covering the hydrogen and the natural gas sector.

ENTSOG AISBL
Avenue de Cortenbergh 100 | 1000 Brussels, Belgium
Tel. +32 2 894 51 00

info@entsog.eu | www.entsog.eu