european network
of transmission system operators
for gas

ENTSOG SINGLE-SECTOR COST-BENEFIT ANALYSIS (CBA) METHODOLOGY

DRAFT

Contents

Foreword

This draft single-sector Cost-Benefit Analysis (CBA) methodology is created on the basis of Article 11 of the Regulation (EU) 2022/869 on guidelines for trans-European energy infrastructure (TEN-E Regulation). It aims at establishing the 3rd ENTSOG CBA Methodology with a focus on hydrogen infrastructure. It was prepared under consideration of the feedback received during the extensive consultation of its preliminary version. This document is published by ENTSOG and is at the same time submitted to the Member States (MSs), the European Commission (EC), and the Agency for the Cooperation of Energy Regulators (ACER) for opinion. Within three months after receipt of the opinion of ACER and MSs on this draft CBA methodology, ENTSOG will amend its methodology an submit it to the EC for approval. In 2025, the CBA methodology will be again upgraded to reflect a progressively integrated model between electricity, gas, and hydrogen.

Introduction and CBA methodology objective

The objective of this CBA methodology is to provide **guidelines to be applied to the CBA of projects (project-specific CBA or PS-CBA) and more generally of the overall gas and hydrogen infrastructure (System Assessment)**. It also contains interlinkages with the electricity infrastructure. This methodology reflects the specific provisions from the TEN-E Regulation and aims to ensure their consistent application by all parties involved. The CBA methodology will be complemented by dedicated input data specifications for each TYNDP cycle (Implementation Guidelines) that interpret the rules defined in the CBA methodology**.** Additionally, the Scenario Report specifies scenario details that are not covered by the CBA methodology. **CBA methodology, Implementation Guidelines and Scenario Report therefore are complementary documents providing exhaustive guidance on the performance of PS-CBAs for a certain TYNDP.** On this basis, the concrete projects that are submitted to ENTSO-E and ENTSOG during the TYNDP process determine the outputs.

The 1st ENTSOG CBA methodology[1] was approved by the EC in February 2015. The 2nd ENTSOG CBA methodology was established in February 2019[2]. The CBA methodology is in general applied to the European-wide Network Development Plans for gas (TYNDP), the subsequent Project of Common Interest (PCI) and Project of Mutual Interest (PMI) selection processes, PCIs' and PMIs' Cross-Border Cost Allocation (CBCA) procedures, and certain eligibility checks of PCIs and PMIs for Union financial assistance.

The previous ENTSOG CBA methodologies were in line with the repealed TEN-E Regulation (EU) 347/2013 considering mainly natural gas infrastructure, while other sectors were captured through the scenarios. The 3rd ENTSOG CBA methodology will however focus on hydrogen infrastructure as defined in Annex II (3) of the revised TEN-E Regulation and will be consistent with ENTSO-E's single-sector CBA methodology which is established in parallel.
The TYNDP comprises of an assessment of the energy system and the energy infrastructure projects. As per Regulation (EC) 715/2009 and Article 13 of the TEN-E Regulation, the TYNDP has the role of identifying the remaining infrastructure gaps through the assessment of the overall gas infrastructure. It defines the basis against which the project-specific CBA (PS-CBA) of PCI and PMI candidates is run. Therefore, the definition of relevant input data must be clearly defined.

The CBA methodology is based on a multi-criteria analysis, combining monetised and non-monetised elements to measure the achievement of relevant EU energy and climate policy targets.

Generally, the PS-CBA should follow the steps below that are reflected by the structure of this methodology:

- Define the assessment framework (chapter 2)
- Assess the overall system, including the identification of the infrastructure gaps (chapter 3)
- Assess projects through an incremental approach and a CBA (chapter 4)

[1]https://entsog.eu/sites/default/files/entsog-migration/publications/CBA/2015/INV0175-150213_Adapted_ESW-CBA_Methodology.pdf
[2]https://entsog.eu/sites/default/files/2019-03/1.%20ADAPTED_2nd%20CBA%20Methodology_Main%20document_EC%20APPROVED.pdf

1. Legal Requirements

ENTSOG prepared this draft CBA methodology based on Article 11 of the TEN-E Regulation. Article 11(1) states that ENTSOG's CBA methodology covers energy infrastructure set out in Annex II (3).

Annex II (3) concerns following hydrogen infrastructure categories:

(a) pipelines for the transport, mainly at high pressure, of hydrogen, including repurposed natural gas infrastructure, giving access to multiple network users on a transparent and non-discriminatory basis;
(b) storage facilities connected to the high-pressure hydrogen pipelines referred to in point (a);
(c) reception, storage and regasification or decompression facilities for liquefied hydrogen or hydrogen embedded in other chemical substances with the objective of injecting the hydrogen, where applicable, into the grid;
(d) any equipment or installation essential for the hydrogen system to operate safely, securely and efficiently or to enable bi-directional capacity, including compressor stations;
(e) any equipment or installation allowing for hydrogen or hydrogen-derived fuels use in the transport sector within the TEN-T core network identified in accordance with Chapter III of Regulation (EU) No 1315/2013 of the European Parliament and of the Council.

Any of the assets listed in points (a) to (d) may be newly constructed or repurposed from natural gas to hydrogen, or a combination of the two.

ENTSOG's CBA methodology shall be drawn up in line with the principles laid down in Annex V, be based on common assumptions allowing for project comparison, and be consistent with the Union's 2030 targets for energy and climate and its 2050 climate neutrality objectives, as well as with the rules and indicators set out in Annex IV.

Annex V sets up principles for the energy system-wide CBAs:
The methodologies for cost-benefit analyses developed by the ENTSO for Electricity and the ENTSO for Gas shall be consistent with each other, taking into account sectorial specificities. The methodologies for a harmonised and transparent energy system-wide cost-benefit

analysis for projects on the Union list shall be uniform for all infrastructure categories, unless specific divergences are justified. They shall address costs in the broader sense, including externalities, in view of the Union's 2030 targets for energy and climate and its 2050 climate neutrality objective and shall comply with the following principles:

(1) the area for the analysis of an individual project shall cover all Member States and third countries, on whose territory the project is located, all directly neighbouring Member States and all other Member States in which the project has a significant impact. For this purpose, ENTSO for Electricity and ENTSO for Gas shall cooperate with all the relevant system operators in the relevant third countries. In the case of projects falling under the energy infrastructure category set out at point (3) of Annex II, the ENTSO for Electricity and the ENTSO for Gas shall cooperate with the project promoter, including where it is not a system operator;

(2) each cost-benefit analysis shall include sensitivity analyses concerning the input data set, including the cost of generation and greenhouse gases as well as the expected development of demand and supply, including with regard to renewable energy sources, and including the flexibility of both, and the availability of storage, the commissioning date of various projects in the same area of analysis, climate impacts and other relevant parameters;

(3) they shall establish the analysis to be carried out, based on the relevant multi-sectorial input data set by determining the impact with and without each project and shall include the relevant interdependencies with other projects;

(4) they shall give guidance for the development and use of energy network and market modelling necessary for the cost-benefit analysis. The modelling shall allow for a full assessment of economic benefits, including market integration, security of supply and competition, as well as lifting energy isolation, social and environmental and climate impacts, including the cross-sectorial impacts. The methodology shall be fully transparent including details on why, what and how each of the benefits and costs are calculated;

(5) they shall include an explanation on how the energy efficiency first principle is implemented in all the steps of the Union-wide ten-year network development plans;

(6) they shall explain that the development and deployment of renewable energy will not be hampered by the project;

(7) they shall ensure that the Member States on which the project has a net positive impact, the beneficiaries, the Member States on which the project has a net negative impact, and the cost bearers, which may be Members States other than those on which territory the infrastructure is constructed, are identified;

(8) they shall take into account, at least, the capital expenditure, operational and maintenance expenditure costs, as well as the costs induced for the related system over the technical lifecycle of the project as a whole, such as decommissioning and waste management costs,

including external costs. The methodologies shall give guidance on discount rates, technical lifetime and residual value to be used for the cost- benefit calculations. They shall furthermore include a mandatory methodology to calculate benefit-to-cost ratio and the net present value, as well as a differentiation of benefits in accordance with the level of reliability of their estimation methods. Methods to calculate the climate and environmental impacts of the projects and the contribution to Union energy targets, such as renewable penetrations, energy efficiency and interconnection targets shall also be taken into account;
(9) they shall ensure that the climate adaptation measures taken for each project are assessed and reflect the cost of greenhouse gas emissions and that the assessment is robust and consistent with other Union policies in order to enable comparison with other solutions which do not require new infrastructures.

Annex IV sets up rules and indicators concerning criteria for projects:

(1) A project of common interest with a significant cross-border impact shall be a project on the territory of a Member State and shall fulfil the following conditions: (…)
(d) for hydrogen transmission, the project enables the transmission of hydrogen across the borders of the Member States concerned, or increases existing cross-border hydrogen transport capacity at a border between two Member States by at least 10 % compared to the situation prior to the commissioning of the project, and the project sufficiently demonstrates that it is an essential part of a planned cross-border hydrogen network and provides sufficient proof of existing plans and cooperation with neighbouring countries and network operators or, for projects decreasing energy isolation of non-interconnected systems in one or more Member States, the project aims to supply, directly or indirectly, at least two Member States;
(e) for hydrogen storage or hydrogen reception facilities referred to in point (3) of Annex II, the project aims to supply, directly or indirectly, at least two Member States;
(…)
(2) A project of mutual interest with significant cross-border impact shall be a project and shall fulfil the following conditions: (…)
(b) for projects of mutual interest in the category set out in point (3) of Annex II, the hydrogen project enables the transmission of hydrogen across at the border of a Member State with one or more third countries and proves bringing significant benefits, either directly or indirectly (via interconnection with a third country) under the specific criteria listed in Article 4(3), at Union level. The calculation of the benefits for the Member States shall be performed and published by the ENTSO for Gas in the frame of Union-wide ten-year network development plan;

(…)
(5) Concerning hydrogen falling under the energy infrastructure category set out in point (3) of Annex II, the criteria listed in Article 4 shall be evaluated as follows:
(a) sustainability, measured as the contribution of a project to greenhouse gas emission reductions in various end-use applications in hard-to-abate sectors, such as industry or transport; flexibility and seasonal storage options for renewable electricity generation; or the integration of renewable and low-carbon hydrogen with a view to consider market needs and promote renewable hydrogen;
(b) market integration and interoperability, measured by calculating the additional value of the project to the integration of market areas and price convergence to the overall flexibility of the system;
(c) security of supply and flexibility, measured by calculating the additional value of the project to the resilience, diversity and flexibility of hydrogen supply;
(d) competition, measured by assessing the project's contribution to supply diversification, including the facilitation of access to indigenous sources of hydrogen supply

Table 1: Coverage of TEN-E requirements in CBA methodology

TEN-E requirement	Coverage in CBA methodology
Annex IV(1)(d)	B6 indicator
Annex IV(1)(e)	Connection to cross-border hydrogen infrastructure
Annex IV(2)(b)	Captured by the proposed indicators
Annex IV(5)(a)	B1 indicator, B3 indicator, B4 indicator
Annex IV(5)(b)	B2 indicator, B6 indicator
Annex IV(5)(c)	B5 indicator
Annex IV(5)(d)	B2 indicator, B5 indicator, B6 indicator
Annex V introduction	Fulfilled
Annex V(1)	Fulfilled
Annex V(2)	Fulfilled through sensitivities
Annex V(3)	Fulfilled, especially through indicators and grouping
Annex V(4)	Fulfilled with details to be specified in complementary documents
Annex V(5)	Fulfilled, especially through scenario section
Annex V(6)	Fulfilled, especially through B3 indicator
Annex V(7)	Fulfilled, especially through section 3.2.2 indicators

Annex V(8)	Fulfilled, especially through section 3.3. project costs
Annex V(9)	Fulfilled, especially through indicator B1

2. Assessment framework

Network operators must prepare their systems for future challenges.

This requires the identification of infrastructure gaps that may hamper the achievement of the Union energy or climate policies. This CBA methodology provides guidance for such identification to be performed as part of the TYNDP process and for the assessment of projects that may allow for the mitigation of those infrastructure gaps. Over the last years, demand and supply patterns have shown some volatility subject to different and, sometimes unexpected, events. Over the coming years and decades, the European commitment to move towards a decarbonised energy system could materialise in different ways. For the assessment of infrastructure projects, the context to be considered shall cover possible evolutions in terms of demand and supply patterns and the development of the overall energy infrastructure.

The input data set necessary for the implementation of a proper CBA assessment at system and project-specific level requires regular update. It is therefore built through the TYNDP every two years ensuring stakeholders involvement. This data set must be made publicly available as part of the TYNDP process. This TYNDP input data set is used when applying the CBA methodology to the TYNDP. It also constitutes a robust input data source for other fields of application of the CBA methodology. It is therefore recommended to use the latest available TYNDP input data set whenever performing PS-CBAs.

Table 2: Complementary information to be provided by TYNDP-specific implementation guidelines (IG) or Practical Implementation Document (PID).

Simulation tools used to perform the assessment (IG)	List of tools used for market, network, and redispatch simulations.
Plausibility check for commissioning year of projects (PID, data submission handbook)	For TYNDP 2024, project promoters must submit a justification of their project schedule. For subsequent TYNDPs, a validation mechanism might be established.
Additional rules for clustering of projects (IG)	If required, additional grouping guidelines to be applied in the PS-CBA phase.

Hydrogen infrastructure level for PS-CBA (IG)	Selection of advanced or PCI hydrogen infrastructure level as reference network for the PS-CBAs.
Consistency check of project information (PID, data submission handbook)	A phase of consistency checking by ENTSOG of project data submitted by project promoters may be introduced.
Project data requirements (PID, data submission handbook)	Definition of the mandatory data submissions by projects promoters.
Definition of advanced infrastructure (PID, data submission handbook)	For the allocation of projects to the different infrastructure levels.
Natural gas infrastructure level for PS-CBA (IG)	Selection of FID natural gas infrastructure level or advanced infrastructure level for the PS-CBAs.
Thresholds for infrastructure gaps (IG)	
Ranking of hydrogen vs. natural gas demand curtailment (IG)	For the calculation of B5 indicator.
Probability of disruption and climatic stress cases to be used (IG)	For the calculation of B5 indicator.
Sensitivity on project-specific data (IG)	Details required to calculate the chosen sensitivities for a given TYNDP.
Interlinkage indication between natural gas and hydrogen infrastructure projects (PID)	

2.1. Scenarios

The Scenarios for the TYNDPs are established in line with Article 12 of the TEN-E Regulation. The ENTSO for Electricity and ENTSO for Gas shall follow ACER's framework guidelines when developing the joint scenarios to be used for the Union-wide ten-year network development plans. The joint scenarios shall also include a long-term perspective until 2050 and include intermediary steps as appropriate.

ACER's guidelines shall establish criteria for a transparent, non-discriminatory and robust development of scenarios taking into account best practices in the field of infrastructures assessment and network development planning. The guidelines shall also aim to ensure that the underlying ENTSO-E and ENTSOG scenarios are fully in line with the energy efficiency first principle and with the Union's 2030 targets for energy and climate and its 2050 climate neutrality objective and shall take into account the latest available Commission scenarios, as well as, when relevant, the national energy and climate plans.

Therefore, this section of the CBA methodology is of informative nature. The relevant information will be defined in the scenario report of ENTSO-E and ENTSOG.

From the scenario report, the following information is needed for the application of ENTSOG's CBA methodology:

Table 3: Interactions between scenario data and CBA methodology

Time horizon	Years (e.g., 2030, 2040, 2050) for which data is prepared.
Multiple scenarios	To capture contrasted possible futures, especially in the long term, multiple scenarios must be prepared and used for the System Assessment and PS-CBA.
Demand	Including peak demand cases and (seasonal) profiles. The scenarios are constructed so that they are in line with the energy efficiency targets as it is defined in the Energy Efficiency Directive (EU) 2018/2002 (EED) and its subsequent revisions. This ensures that subsequent

	steps of the TYNDP process are also in line with the energy efficiency first principle. Regarding alternative fuels replace by hydrogen in the different sectors, scenario report will be used as basis for identification of the shares of replaced alternative fuels per demand sector and subsector.
Supply	Potentials, flexibilities, and profiles of sources of electricity (e.g., power plant fleet), hydrogen (e.g., import, blue hydrogen production facilities, electrolysers), and natural gas (e.g., national production, biomethane production, import).
Commodity and CO2 prices, emission factors	To calculate the system behaviour, calculate benefit indicators and monetize results.
Market assumptions	Market assumptions needed for the ILM.

In case not all scenarios are used for the assessment of projects of other infrastructure categories than hydrogen, this shall not limit the assessment and benefit calculation of hydrogen infrastructure projects to the scenarios used for other infrastructure categories. All scenarios shall be used for the System Assessment and the PS-CBA. If a national trend scenario based on NECPs should not cover the full time horizon until 2050, for the PS-CBAs it shall be coupled with the 2050 data of a scenario with another storyline.

If a required information was not provided by the scenario process, another high quality data source should be used and referenced, preferably in the implementation guidelines.

2.2. Network and Market modelling assumptions

Approach to modelling

Modelling of hydrogen infrastructure will require network and/or market modelling of different energy carriers such as natural gas and electricity, given the foreseen interlinkages between the energy carriers.

Figure 1: Representation of the future EU integrated energy system (source: European Commission).

Joint modelling of the above-mentioned energy carriers will be captured as follows:

- Interlinkages between hydrogen and electricity through a network and market modelling of the joint hydrogen/electricity systems. This model will be used for indicators B1, B2, B3, B4.
- Interlinkages between hydrogen and natural gas networks through a dual hydrogen/natural gas network modelling. This model will be used for indicator B5.

The analysis can be performed through several modelling software tools. Additionally, network and market modelling for the different energy carriers may be performed with either the same tool, or with different tools, as needed. The tools to be used will be clarified in the implementation guidelines. The modelling tools must allow for the calculation of the different CBA indicators. Depending on the CBA indicator to be calculated, one or the other modelling tool will be used. For more information on the calculation of CBA indicators see section 3.

To perform a robust and complete assessment of the infrastructure levels and projects when modelling joint hydrogen/electricity systems, it is important to ensure that calibration of the model is consistent with the electricity system in terms of:

> Reference grid: The reference grid of ENTSO-E's TYNDP will be used. The hydrogen infrastructure level to be used for PS-CBA will be defined in the implementation guidelines. It will be either the hydrogen infrastructure level Advanced or PCI. For the System Assessment, all hydrogen infrastructure levels will be used.
> Hydrogen CCGTs: There is a direct connection between the hydrogen node and the electricity node, in respect to the supply of hydrogen to power plants. The electricity system can thereby access the hydrogen system's seasonal storage, allowing for cheaper electricity prices at various times during the year, and hydrogen-based transport options.
> Electrolysers: The electrolysers are the antithesis of the CCGTs. The electrolyser acts as a major supply source to the hydrogen system, converting electricity from non-CO2 emitting sources to hydrogen through electrolysis.

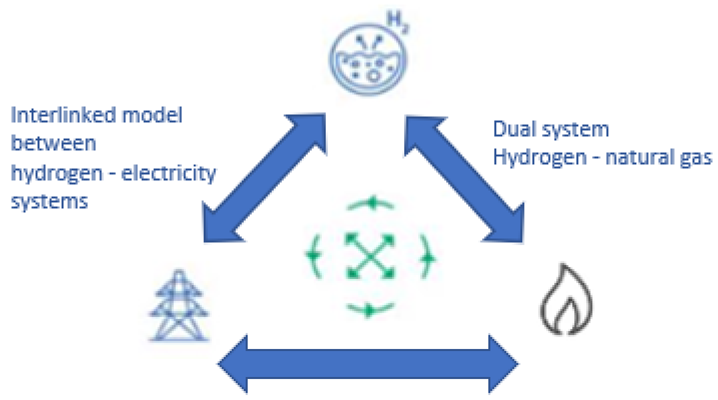


Figure 2: Representation of the interlinkages between hydrogen, electricity, and natural gas systems.

Specific information on modelling assumptions and market assumptions used for developing the TYNDP System Assessment and the PS-CBA assessments must be publicly available as part of the TYNDP development process (if not restricted due to confidentiality).

The dual hydrogen/natural gas model is operated by ENTSOG. The interlinked hydrogen/electricity model for the purpose of this CBA methodology is operated by ENTSOG and governed by the Steering Group of ENTSO-E's and ENTSOG's joint Interlinked Model (ILM) Task Force.

In case a group consists of different infrastructure categories, e.g. a hydrogen pipeline and an electrolyser, benefits will be divided between the different assets in a way that all assets show the same cost-benefit indication.

2.2.1. Network assumptions and description of future hydrogen infrastructure

Future hydrogen infrastructure will connect hydrogen supplies with demand. Being at early stages of the infrastructure planning, it is still unclear however, how and at what pace it will evolve within the different countries in Europe.

Therefore, it is of vital importance to build a robust assessment framework that will capture the future possible status of development of the future hydrogen network also considered for the hydrogen demand and supply evolution included in the Scenarios. This representation of the hydrogen network is an input to the network and market modelling exercise underpinning the determination of projects' benefits.

The topology of the hydrogen infrastructure will emerge as a simplified topology, and progressively evolve with regular updates expected as part of the TYNDP process. The resulting capacities should be made publicly available as part of the TYNDP development process to allow for its use in further fields of application of the CBA methodology.

Existing hydrogen infrastructure

Currently, the topology refers only to planned infrastructure as there is no public European hydrogen network in place. In the future, following the implementation of hydrogen projects, the topology will consider both existing infrastructure and planned projects.

Planned hydrogen projects

The identification of projects requires reliable and detailed information. The TYNDP has a role to collect all projects that aim to contribute to the emergence of a European hydrogen network. In particular, the TEN-E Regulation defines that all hydrogen projects intending to apply for the PCI status should be part of the latest available TYNDP. The TYNDP should therefore collect all relevant information for the CBA assessment of projects intending to apply for the PCI status.

It is the project promoters' responsibility to provide their projects' information. However, a consistency check phase in the data collection may be conducted by ENTSOG to ensure as reliable information as possible. This phase will be further detailed in the PID and data submission handbook.

Hydrogen reference networks

Future hydrogen reference network(s) will be used as a basis for the System Assessment and the PS-CBA. Given the current high degree of uncertainty related to hydrogen infrastructure development and its importance, several contrasted reference networks must be defined (under section *Assumptions to consider when building the hydrogen reference network*), to increase the robustness of the assessment and decrease the level of uncertainty.

The EU-level topology should at least reflect the following items for the future European hydrogen infrastructure, which encompasses the infrastructures that can apply for the PCI or PMI status as listed in Annex II(3) of the TEN-E Regulation. Also infrastructure that is not eligible for PCI or PMI status must however be represented to allow for a proper infrastructure assessment. The category defined in Annex II(3)(d)[3] can be reflected in the infrastructure category below that it effects. Hydrogen infrastructure of any category can be within completely unconnected hydrogen valleys of any size within one country (internal projects). If a hydrogen infrastructure project however is not such an internal project, it is considered to be part of the cross-border infrastructure.

- For hydrogen transmission infrastructure (Annex II(3)(a)):
    - Cross-border capacities between countries
    - Cross-border off-shore capacities
    - Expected capacities for production (including production type) and demand enabled by the transmission project (limited to scenario values per country)
    - Expected location of enabled supply and demand and its connection to the transmission grid
    - Meaningful transmission constraints within one country or area (i.e., internal projects or bottlenecks defining a more granular network within a country, where the connected sub-country nodes are linked to expected enabled production and demand (as part of the cross-border projects))
- For hydrogen storage infrastructure (Annex II(3)(b)):
    - Expected connection to the (future) hydrogen grid
    - The working gas volume
    - The withdrawal and injection capacities
    - The withdrawal and injection curves that define their ability to withdraw or inject gas depending on the filling level
- For LH2 (or hydrogen embedded in other chemical substances) import terminals (Annex II(3)(c)):

[3] Any equipment or installation essential for the hydrogen system to operate safely, securely and efficiently or to enable bi-directional capacity, including compressor stations.

  - Expected connection to the (future) hydrogen grid
  - Injection capacities into the (future) hydrogen grid (along the year and during high demand situations if applicable)
  - Storage volumes (converted to hydrogen)
- For LH2 (or hydrogen embedded in other chemical substances) export terminals that are a joint project with a respective import terminal:
  - Expected connection to the (future) hydrogen grid or hydrogen production facility
  - Expected production capacities
  - Expected efficiency of the process of LH2 production or LOHC loading
  - Storage volumes (converted to hydrogen)
- For hydrogen production facilities:
  - Expected capacity of the production facility (e.g., electrolyser, SMR with CCS, ATM with CCS)
  - Expected efficiency of the production facility (e.g., electrolyser, SMR with CCS, ATM with CCS)
  - Hydrogen grid connection capacity from the production facility on hourly and daily basis
  - Connection of electrolyser to dedicated RES or electricity grid (and respective grid connection capacity on hourly and daily basis)
- For infrastructure enabling hydrogen (or hydrogen-derived fuels) demand in the transport sector (Annex II(3)(e)):
  - Expected enabled hydrogen demand in the transport sector
  - Loading Capacity (when relevant)
  - Share of alternative fuel(s) expected to be replaced per country sector and subsector

The geographical perimeter must be clearly defined. In line with the TEN-E Regulation, it should cover at least the European Union, all Energy Community countries (i.e., from the European Economic Area) where a submitted hydrogen project may have a cross-border impact on the hydrogen system in the European Union.

Assumptions to consider when building the hydrogen reference network:

A **FID hydrogen infrastructure level** that contains only the existing infrastructure and hydrogen projects that have already taken the Final Investment Decision (FID) is not proposed due to the current state of the hydrogen system development. This might change when the CBA methodology is updated in 2025.

An advanced hydrogen infrastructure level will be based on the existing network together with those **projects whose status of implementation its more advanced and, therefore, with a higher likelihood of being successfully implemented. Conditions to be considered as advanced project will be defined in the TYNDP Implementation Guidelines as well as in Practical Implementation Document of each TYNDP cycle.**

As an example, projects could be considered as advanced when a FID has been taken, they are part of the National Development Plan or projects have concluded a Market consultation or Market Open season procedure.

A PCI hydrogen infrastructure level will consist of the advanced hydrogen infrastructure level and will additionally contain **the latest list of hydrogen infrastructure projects of common interest** (starting from the sixth PCI list, i.e., the first PCI list under the revised TEN-E Regulation once adopted).

A TYNDP **hydrogen infrastructure level** will consist of the PCI hydrogen infrastructure level as well as **all remaining projects submitted to the TYNDP**. For the System Assessment, all three hydrogen infrastructure levels will be used. However, for the PS-CBAs only advanced or PCI hydrogen infrastructure level will be used. The choice will be defined in the PID.

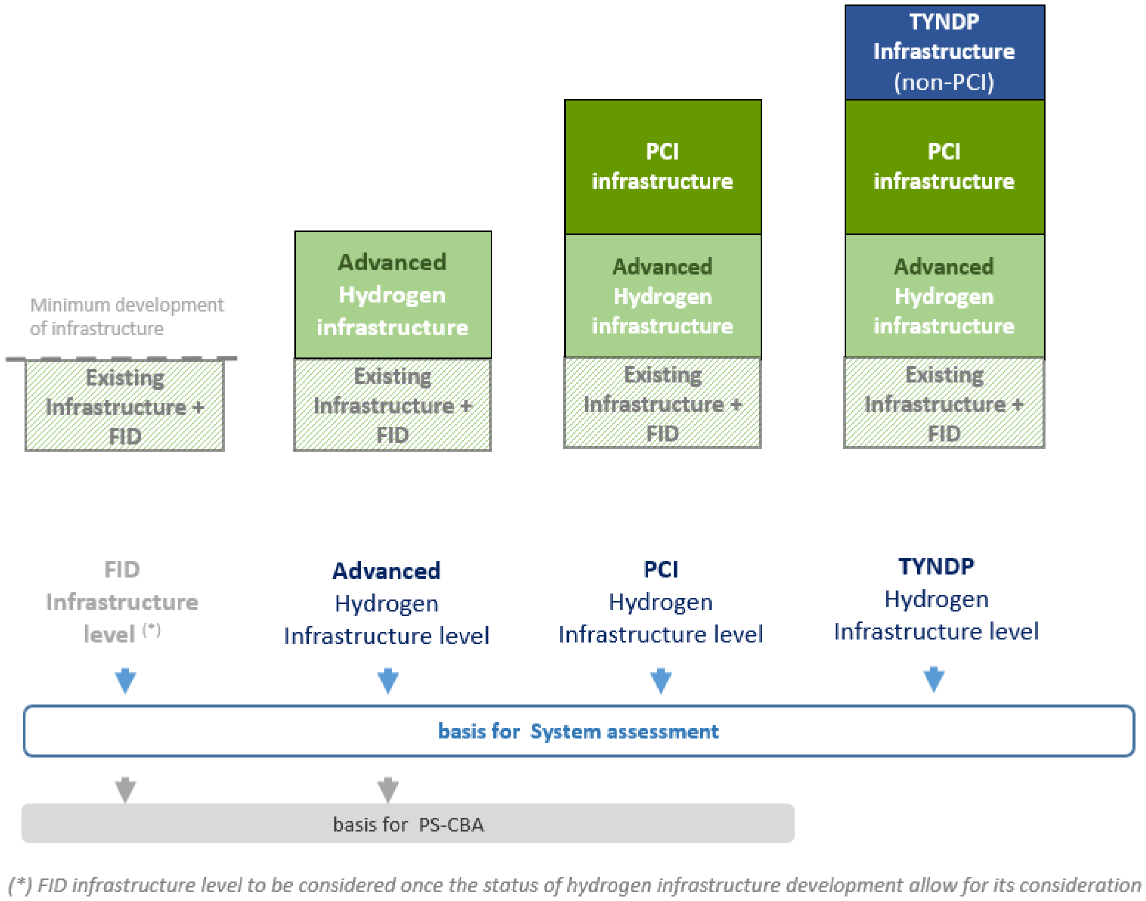


Figure 3: Consideration of hydrogen infrastructure levels as a basis for System and PS-CBA assessments.

2.2.2. Network assumptions and description of natural gas infrastructure

Interlinkage between Hydrogen and Natural Gas infrastructure

An important share of hydrogen supply is produced from natural gas with thermal processes such as steam methane reforming or partial oxidation. Until green hydrogen production ramps up, blue hydrogen supply will be needed to satisfy hydrogen demand. Hydrogen and natural gas reference networks considered in the assessment should properly reflect this interlinkage.

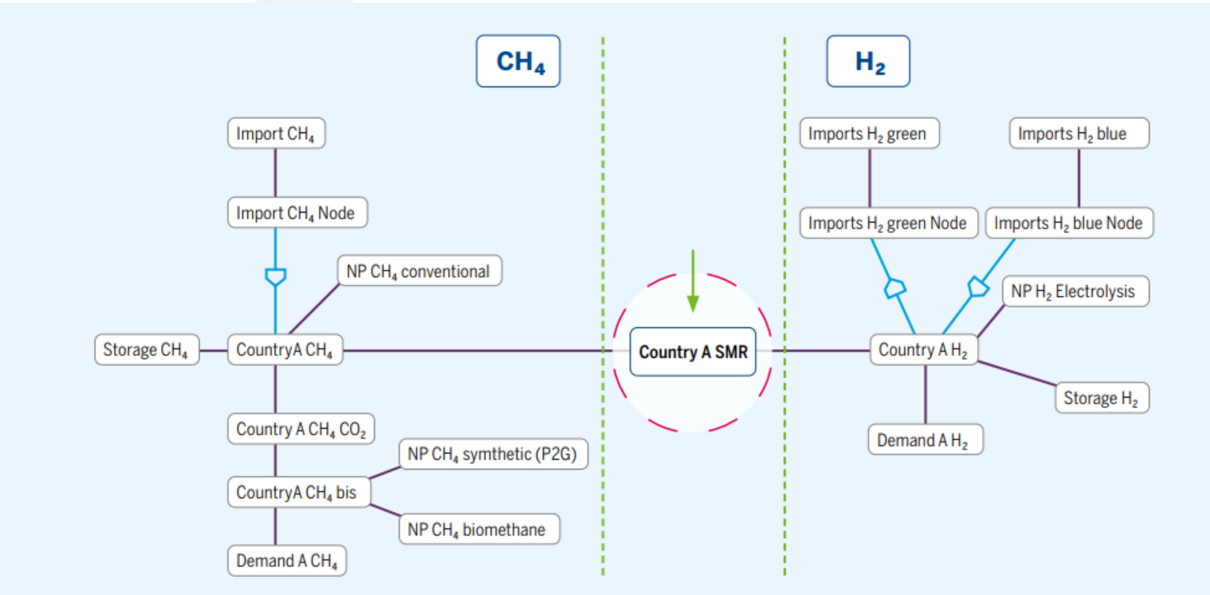


Figure 4: Interlinkage between exemplary hydrogen and natural gas networks.

Hydrogen infrastructure will be composed of newly built hydrogen infrastructure and hydrogen infrastructure repurposed from natural gas infrastructure.

It is necessary for the modelling tool and natural gas reference network to consider the potential impact of repurposing of natural gas to hydrogen infrastructure for the different years of the assessment.

In addition to the consideration of the two interlinkages defined above, a robust assessment framework must provide a sufficiently accurate representation of the natural gas infrastructure, both in regard to the existing infrastructure and to its possible evolution. This representation will be an input to the network and market modelling exercise underpinning the determination of projects´ benefits. Thus, gas TSOs must continue to submit their natural gas projects to the TYNDP and keep them up to date.

The geographical perimeter must be clearly defined. In line with the TEN-E Regulation, it should cover at least the European Union, all Energy Community countries (i.e. from the European Economic Area) where a submitted hydrogen project may have a cross-border impact on the hydrogen system in the European Union.

The level of detail to represent the natural gas infrastructure should strike a balance between the accuracy and complexity of the modelling and the availability and complexity of the underlying network information.

The topology of the natural gas infrastructure as developed and regularly updated by ENTSOG, is used in the TYNDP process. The topology refers to both existing and planned infrastructure. The corresponding capacities should be made publicly available as part of the TYNDP development process to allow for its use in further fields of application of the CBA Methodology.

The EU-level network modelling should be able to reflect market areas' transmission, storage, and LNG capacities as well as internal specificities, if relevant, from an infrastructure assessment perspective. Capacities as provided by network operators and project promoters to ENTSOG for the description of the gas infrastructure should be calculated based on hydraulic modelling.[4]

The EU-level topology should at least reflect the following European natural gas infrastructure:

- Transmission infrastructure:
    - Cross-border capacities between countries (including complex interconnections between more than two TSOs)structure
    - Cross-border capacities between countries (including complex interconnections between more than two TSOs)
    - Intra-country capacities between market areas
    - Meaningful intra-market areas constraints, where relevant

[4] Based also on the stakeholders feedback received during public consultation process of ENTSOG CBA Methodology 2.0, there is no strong recommendation on using EU-level hydraulic modelling since it would require collecting and maintaining a cumbersome amount of mostly non-public information, that may differ among network operators and over time. This, together with the complexity related to the need for building a reliable tool at European level, would complexify the accuracy and readability of the results by the users and may in turn hinder the interpretation of the CBA assessment.

- LNG terminals infrastructure:
    - Regasification capacities both along the year and during high demand situations
    - The tank volumes' characteristics, including a flexibility factor defining the share of the tank volume expected to be available during high demand situations[5]
- Underground storage infrastructure:
    - Connection to the gas grid
    - The working gas volume
    - The withdrawal and injection capacities
    - The withdrawal and injection curves that define their ability to withdraw or inject gas depending on the filling level[6]
- Connection to indigenous production infrastructure, including renewable gases such as biomethane.
- Reduction of natural gas capacities for transmission, storage and LNG terminals as a consequence of the implementation of hydrogen infrastructure projects from repurposed natural gas infrastructure including a link to the hydrogen project causing this reduction.
- The gas infrastructure in countries adjacent to the EU, as much as the infrastructure in these countries contribute to imports to or exports from Europe.

Natural gas existing infrastructure

A proper description of the existing infrastructures is essential as a basis for defining a further development of the grid and for accurate project assessment.

Natural gas projects

The identification of projects requires reliable and detailed information. The TYNDP has a role to collect all projects of EU relevance. It is the project promoters' responsibility to provide their projects' information. However, in order to ensure as reliable information as possible for both hydrogen and natural gas project submissions, a consistency check phase in the data collection may be conducted by ENTSOG.

Depending on their level of maturity, projects can be categorised along different natural gas infrastructure status. Those status are a prerequisite for the definition of the natural gas infrastructure levels to be used as counterfactual situations when performing the PS-CBA. Each project status should be derived from the information provided by its promoter.

[5] For each TYNDP ENTSOG revises those values in cooperation with GLE.

[6] For each TYNDP ENTSOG revises those curves in cooperation with GSE.

Natural gas reference network

The FID natural gas infrastructure level should at least consider all the existing infrastructures together with projects having an FID status . The FID status was defined by in Art. 2.3 of Regulation (EC) 256/2014 as follows: 'final investment decision' means the decision taken at the level of an undertaking to definitively earmark funds for the investment phase of a project […]'. In addition, in order to provide a wider perspective regarding the consideration of non-FID projects, an Advanced infrastructure level should be established with the required maturity of projects to be defined in the PID[7].

While the reference network as well as the advanced infrastructure level shall be used for the System Assessment, only one of them may be used for the PS-CBAs. This choice will be defined in the PID. When coupled with a hydrogen infrastructure level, the natural gas infrastructure levels' capacities can differ due to the effect of repurposing projects contained in the respective hydrogen infrastructure level.

2.2.3. Network assumptions and description of electricity infrastructure[8]

Interlinkage between hydrogen and electricity infrastructure

An important share of the hydrogen supply will be produced by electrolysis from the electricity grid or from dedicated renewables. The electrolysers can provide additional support to the electricity system through participation in ancillary service markets such as upwards and downwards regulation. In addition, hydrogen transmission and storage infrastructure could significantly support the electricity sector by providing seasonal and large-scale storage, transport options, as well as by increasing the use of renewables. This enables the integration of renewable and low-carbon hydrogen produced, helping to avoid RES curtailment. Similarly, the electricity network can support the integration of green hydrogen through extending capacity across borders, allowing otherwise curtailed energy to be distributed around Europe and providing additional energy for direct or indirect electricity usage.

---

[7] Definition of maturity status are updated according to the corresponding TYNDP process.
In TYNDP 2022 Practical Implementation Document Advanced Project is detailed as it follows:

- Project commissioning year expected at the latest by 31st December of the year of the TYNDP project data collection + 6 (e.g. 2028 in case of TYNDP 2022, for which projects were collected in 2022) and
    - or whose permitting phase has started ahead of the TYNDP project data collection OR
    - FEED has started (or the project has been selected for receiving CEF grants for FEED ahead of the TYNDP project data collection).

The definition of the project maturity status is regularly updated as part of the TYNDP process and published in the Practical Implementation Document.

[8] ENTSO-E and ENTSOG are currently working on an updated, comprehensive ILM report.

Considering the strong interlinkages between electricity and hydrogen systems, the best way to capture all potential benefits of hydrogen infrastructure will be through joint modelling of at least these two energy carriers.

As defined in 2.2, the assessment of hydrogen projects will also require market modelling for electricity and hydrogen systems. This could be achieved through a dispatch modelling. It will be necessary to model the electricity and hydrogen system at European scale at an hourly granularity to properly reflect its dynamics.

Interlinked modelling of a hydrogen-electricity interlinked energy system:

The electricity part of the model reflects the EU bidding zones, which currently primarily includes one node per country with the exceptions of Italy, Norway, and Sweden. Each country includes demand profiles, generation capacities, and storage capacities in alignment with the scenarios.
The electricity grid is an important factor. The electricity grid in the interlinked model reflects the reference grid used in the TYNDP developed by ENTSOE's TYNDP Study Team.
The electricity sector is modelled on an hourly basis which is a necessary requirement to capture the dynamics of variable renewables in each country, this can vastly change over the period of a day.

Several asset classes are added to the model. The hydrogen reference network(s) which includes hydrogen pipelines and storages, will be defined as in section 2.2.1. These hydrogen network(s) are linked to the reference grid used in the electricity part of the model. Additionally, SMR capacities, which are taken from the scenarios, act as an additional domestic supply source for the production of hydrogen. Finally, import potentials from outside of the EU are considered in the model.
The hydrogen system is modelled at a daily frequency. Unlike in the electricity system where supply and demand must be balanced instantaneously, the hydrogen system has inherent storage capacity within the actual pipelines (line pack). This enables an additional dimension of flexibility that is not afforded to the electricity system.

The two sides of the interlinked model are joined by two connections.

1 **Electrolysers** act as a load in the electricity system that is used to convert water to hydrogen through the process of electrolysis. It is assumed that the hydrogen is produced from carbon free electricity. The hydrogen that is produced from the electrolysers is sent into the hydrogen system where it has access to the pipeline and storage infrastructure and is used to meet the hydrogen demand.

2 **Hydrogen used in combined cycle gas turbines (CCGTs).** The hydrogen nodes are linked to the CCGTs in the electricity system in order to create electricity. This allows the CCGTs to take the real price of hydrogen that will be used to determine the marginal price of the powerplants. It will also enable real life limitations of hydrogen volumes.

Electricity reference network

The reference network of the electricity system will be defined as per ENTSO-E reference network for the relevant TYNDP and PS-CBA processes. As defined in the *4th ENTSO-E Guideline for Cost-Benefit Analysis of grid development projects*, the electricity reference network comprises the already existing electricity grid, and the projects most likely implemented by the dates considered in the scenarios.

Market assumptions

This CBA methodology focusses on the most relevant market assumptions for the identification of cross-sectoral benefits in the electricity and hydrogen systems. They are typically provided by the TYNDP scenarios. Therefore, the following elements should be considered for modelling purposes:

> Market assumptions for the electricity system to be based on marginal costs of generation plants, and demand-side response. These electricity costs are transferred to the hydrogen commodity through the electrolysers. Additional costs in the hydrogen system come from imports and hydrogen production from natural gas (such as SMR or partial oxidation).

> The cost of curtailed demand in the electricity and hydrogen systems are important parameters. The cost used in the electricity system is called the 'Value of Lost Load' and describes the price at which consumers are no longer willing to pay for electricity. In the gas system it is called the 'Cost of Hydrogen disruption' (CODH) which describes the same phenomena in the hydrogen system.

> When jointly modelling electricity and hydrogen, it is necessary to consistently define the value of lost load (VOLL) of each energy carrier to avoid undue "non-served energy" of a given carrier. For this reason, the CODH has been established at a parity level with electricity taking into account the efficiency of electrolysers.

> In the hydrogen system, the cost of hydrogen disruption is set at a price below the cheapest CO2 emitting generator, typically CCGTs. The reason for this price is so that the electrolyser does not use energy from CO2 emitting generators that will result in hydrogen that is not green (i.e., produced from renewable energy) or pink (i.e.,

produced from nuclear energy). The model has preference to use SMR or imports based on prices and availability or to ultimately curtail the demand.

3. System Assessment: Identification of infrastructure gaps

The analysis at system level should allow to verify how and up to what extent, the possible hydrogen infrastructure will contribute to the completion of Europe's 2030 climate and energy targets and 2050 climate-neutrality objective.[9]

The TEN-E Regulation has identified four main criteria: sustainability, security of supply and flexibility, competition, and market integration. In the System Assessment, hydrogen reference network(s) will be assessed to the extent possible against these criteria[10].

Consideration of the energy efficiency first principle in the System Assessment is already included as part of the scenarios and thereby in the basis for the infrastructure gaps identification[11] (more details are included in section

Given a certain level of infrastructure assumed in place along the considered time-horizon, the analysis of the system may reveal the need for further development. In such case, projects will be then assessed to determine if the situation is mitigated or completely solved.

Infrastructure gaps

An infrastructure gap can be identified as a situation where an infrastructure may be needed to meet the criteria defined in the TEN-E Regulation.

In accordance with Art. 8(10)(c) of Regulation (EC) 715/2009, the TYNDP "shall […] identify investment gaps". This represents the basis for the identification of infrastructure needs. The identified infrastructure gaps should be reported as a specific section of the TYNDP report.
To identify the infrastructure gaps, the following definitions apply:

- The threshold value beyond which an infrastructure gap does not exist or is less relevant.
- 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.

[9] As set by Art. 13 of TEN-E Regulation.
[10] As set by Art. 4 of the TEN-E Regulation.
[11] As set by Art. 13 of TEN-E Regulation.

Thresholds

The identification of the infrastructure gaps will be performed along the different CBA indicators. For a given indicator, and for the different countries, the existence of an infrastructure gap relates to a threshold[12] value that - if not achieved - signals an infrastructure gap. The threshold is the value beyond which the infrastructure gap disappears or is considered less relevant. The same threshold should be used both for evaluating the possible infrastructure gaps and for evaluating how projects mitigate or solve these gaps, to ensure comparability of results.

As an example, in case of an indicator measuring how projects solve or mitigate demand curtailment, the minimum threshold to be considered is 100%. In this case, below this threshold the demand cannot be fully satisfied, resulting in an infrastructure gap that can be solved or mitigated by the realisation of one or more projects.

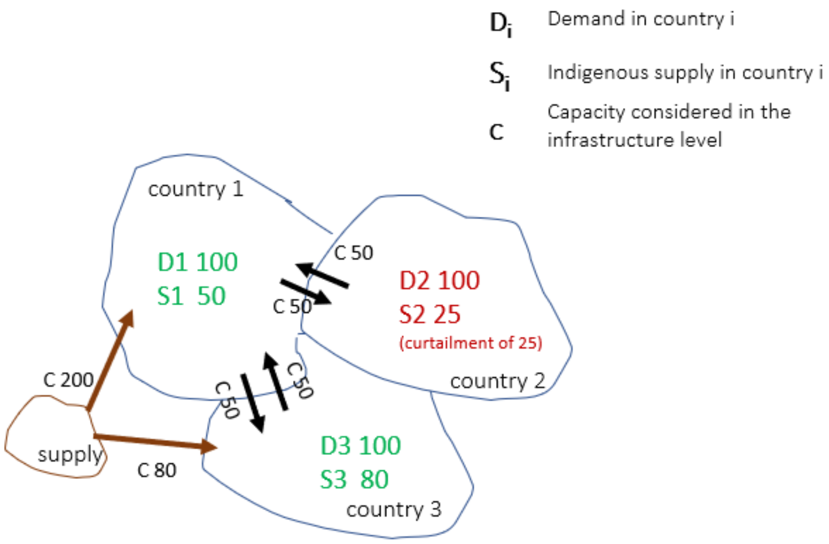


Figure 5: Practical example of infrastructure gap identified in Country 2.

12 Fixing such a threshold is not in the scope of the CBA methodology, but should be defined in the Implementation Guidelines for each TYNDP/PS-CBA processes.

Infrastructure levels

The selection of the proper level of development of infrastructure is vital for the identification of infrastructure gaps and a reliable system and project assessment.

An infrastructure level is defined as the potential level of development of the European hydrogen network. It represents the level of infrastructure assumed to be in place along the considered analysis time horizon. Therefore, the identification of infrastructure gaps and the need for further development are strictly dependent on the definition of the infrastructure level.

Infrastructure levels represent counterfactual situations:

- On which to identify infrastructure gaps and to perform the system assessment.
- Against which projects are assessed.

More details on infrastructure levels for the System Assessment can be found in section 2.2. Additionally, a comparison between the infrastructure levels and the topology derived from the expansion model within the scenario process may be provided, analysing where submitted projects result in less capacity than in the expanded grid.

4. Project-Specific Assessment

4.1. Frame for the project-specific assessment

This CBA methodology combines monetary elements pertaining to the CBA approach, as well as non-monetary and/or qualitative elements referring to the **Multi-Criteria Analysis (MCA)** approach. Its perimeter is wider than the pure monetary assessment, as the reality of the gas market and its effect for the European economy and society generally require that non-monetary effects are also considered. Quantitative indicators provide detailed, understandable and comparable information independently from their potential monetary value.

The project-specific assessment is performed as part of the TYNDP process, as this allows for:

- The assessment of projects on a comparable basis
- Consistent results to be provided to promoters
- High transparency towards stakeholders on the projects assessment

The CBA Methodology is a guidance document that describes the common principles and recommendations for undertaking the CBA of hydrogen infrastructure ensuring that project assessment is performed in a fair and consistent way. In addition and considering ACER's recommendations on the consistency of CBA Methodologies, each TYNDP and PS-CBA process will be supplemented by a complementary document named 'Implementation Guidelines' (IG).

Results will be published in the TYNDP in the form of a **Project Fiche** that is meant to display all relevant results of the PS-CBA, especially the benefit indicators and economic parameters. This allows provision of technical support to promoters while ensuring a level playing field and a transparent assessment towards all stakeholders. Presenting the cost-benefit analysis of a project in a project fiche using a standardised template ensures the provision of relevant project information and PS-CBA results in a harmonised, synthetic and comparable manner.

Project grouping

Often, a number of functionally-related projects needs to be implemented for their benefit(s) to materialise. The cost-benefit analysis should in this case be performed jointly for these strictly functionally-related projects, ensuring consistency between the considered benefits and costs.

For example:

> In case of a hydrogen interconnector connecting two countries, two different promoters are usually involved.

> A new hydrogen import terminal or hydrogen storage may need a new evacuation pipeline to connect them to the hydrogen network.

> Projects connecting with extra-EU supply sources are composed by different projects whose full realisation is a prerequisite to connect the new source and enable the development of a given hydrogen corridor.

In such cases those projects need to be **grouped together** to perform their cost-benefit analysis. In other cases, groups may correspond to a single project.

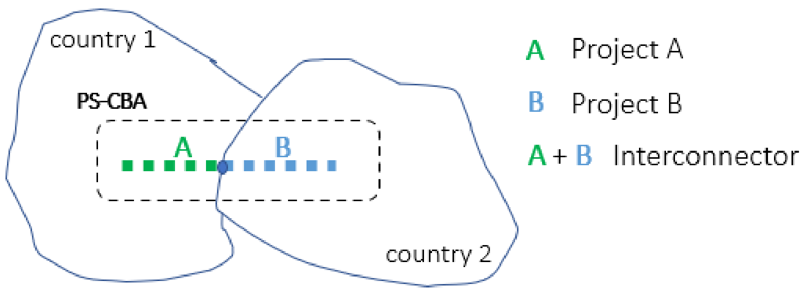


Figure 6: Example of project grouping in case of an interconnection formed by two projects.

At minimum, the following grouping is necessary:

> Hydrogen interconnection between two (or more) countries

> Import terminal and connecting pipeline to the hydrogen grid

> Underground storage and connecting pipeline to the hydrogen grid

> A connection to an extra-EU hydrogen supply source

Grouping principles

The following grouping principles shall be applied:

- **Competing projects** need to be assessed separately and as many groups as projects in competition should be established, with only the competing project amended while the rest of the group stays unchanged.
- The **enhancer(s)** need to be grouped and assessed together with the enhanced project (the main investment); an additional group separating the main investment from the enhancers should also be assessed separately, if needed to better capture the impact of the enhancer project.

  Regarding enhancer or complementary projects, it should be noted that, in order to be grouped together with the main investment, the enhancer project should contribute to the realisation of the full potential (i.e., investments cannot be grouped together if they only contribute marginally to the full potential of the main investment to be realised).
- The **enabler(s)** need to be grouped and assessed together with the enabled projects (assessed investment).
- In case of a project consisting of **several phases**, each phase should be assessed separately in order to evaluate the incremental impact of all phases (e.g., in case of a project composed of two different phases, one group should consider only phase 1 while a second group should consider phase 1 and phase 2).

Where:

- **Enabler** is a project which is indispensable for the realisation of the assessed investment/project in order for the latter to start operating and show any benefit. The enabler itself might not bring any direct capacity increment at any IP.[13]

[13] If a hydrogen project should be enabled by a natural gas project (e.g., disconnection of natural gas users that cannot convert to hydrogen from a natural gas pipeline and re-connection to another natural gas pipeline to allow for cost-optimal repurposing of a pipeline), the natural gas project will still not be grouped together with the hydrogen projects. This is to avoid any unclarity about natural gas projects' non-eligibility to the PCI and PMI status. However, such interdependencies must be submitted by project promoters and communicated in a transparent manner.

> **Enhancer** (or complementary) is a project that would allow the main project to operate at higher rate or creating synergies compared to the main project operating on its own basis, increasing the benefits stemming from the realisation of the main investment. An enhancer, unlike an enabler, is not strictly required for the realisation of the main project.

> **Competing** projects are projects with similar characteristics that tackle the same objective/infrastructure gap in the same geographical area. The competition between projects might be an observation from the intermediate PS-CBA results. This could be visible when removing (TOOT) or adding (PINT) both projects at the same time does not result in significantly different benefits.[14]

Other considerations for grouping

When grouping projects, other elements may be considered as a secondary input to check groups' consistency, such as the projects' implementation status (e.g., under consideration vs. under construction, etc.) and the expected commissioning year. For example, grouping together projects expected to be commissioned far apart in time may introduce the risk that eventually one or more investments are not realised.
Grouping principles should be flexible enough to consider the evolving nature of hydrogen infrastructure. More detailed clustering rules may be introduced in the IG and the rules may be reviewed in the next CBA methodology update.

In addition to the grouping principles, the following additional considerations will apply when clustering the projects:

> Investments can only be grouped together if they are at maximum two advancement status apart from each other. This limitation is applied to avoid excessive clustering of investments.

[14] While the capacity created in the expansion model of the scenario building process could indicate a reasonable level of interconnection, the project-based capacities at other borders could describe the existence or non-existence of alternative routes. Thus, the infrastructure need at a border could be higher or lower than estimated by the expansion model.

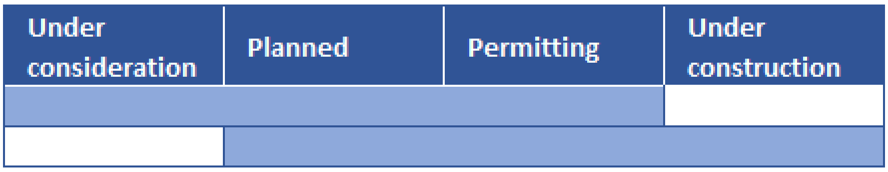


Figure 7: Illustration of the clustering of investments according to the status of implementation of projects.

> Enhancing projects and main investments can be grouped with a main investment only if their expected commissioning years are less than 10 years apart. (e.g. Phase 1 and 2 of a cross-border interconnection between two countries)

> For clustering of groups including an enabler project(s), investments can only be grouped together if the expected commissioning year of the enabler project(s) is prior or equal to the expected commissioning year of the enabled project and at a maximum 5 years in advance.

> If an enabler project is still under consideration, all enabled projects as well as a group containing the enabler project is considered as under consideration, even if individual projects should be more mature.

The incremental approach

Estimating benefits associated with projects require comparison of the two situations “*with project*” and “*without project*”. This is the incremental approach. It is at the core of the analysis, and is based on the differences in indicators and monetary values between the situation “*with the project*” and the situation “*without the project*”.

The counterfactual situation is the level of development of the hydrogen infrastructure against which the project is assessed (the hydrogen infrastructure level, as described in section *Network assumptions and description of future hydrogen infrastructure*). It should be consistent across the different projects assessed.

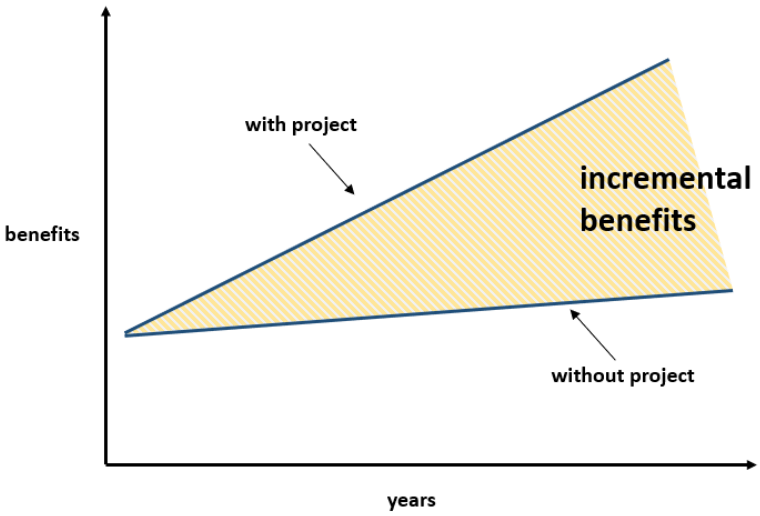


Figure 8: Incremental approach (adapted from Belli (ed.) et al.).

The counterfactual situation against which the project[15] is assessed will impact the value given to the project. It is therefore recommended that the benefits of an infrastructure project are assessed against different infrastructure levels in order to get a comprehensive view of what could be the impact of the project:

- Main assessment against the reference network(s)
- Additional assessment against the extended network(s)

Indeed, assessing the benefits of projects against different grids provides a complementary perspective that allows reflection on different kinds of interactions among projects when calculating the differences between the situation with the project and the situation without the project. In fact, the higher the number of projects included in the reference grid, the lower the marginal impact brought by the assessed project will be when applying the incremental approach. This approach may also allow identification if synergies with projects that are not part of the assessed group but belong to the infrastructure level used as counterfactual. The extended network allows consideration of project interaction occurring under such level of development of the infrastructure.

[15] The term project should be understood as referring to the related group of projects (in line with the section on project grouping), when applicable.

According to the counterfactual situation against which the project is assessed, the literature makes available two methods for the application of the incremental approach:

> **Put IN one at a time** (PINT) implies that the incremental benefit is calculated by adding the project compared to the considered counterfactual, in order to measure the impact of implementing the project compared to the corresponding infrastructure situation. Following this approach each project is assessed as if it was the very next one to be commissioned.
> **Take OUT one at a time** (TOOT) implies that the incremental benefit is calculated by removing the project compared to the counterfactual, in order to measure the impact of implementing projects compared to the corresponding infrastructure situation. Compared to the PINT approach, the application of TOOT considers the project as if it is the very last one to be implemented.

As shown in the example below based on the reference grid, depending on the status of the assessed project, the project will be assessed with **either one or the other** of the two approaches.

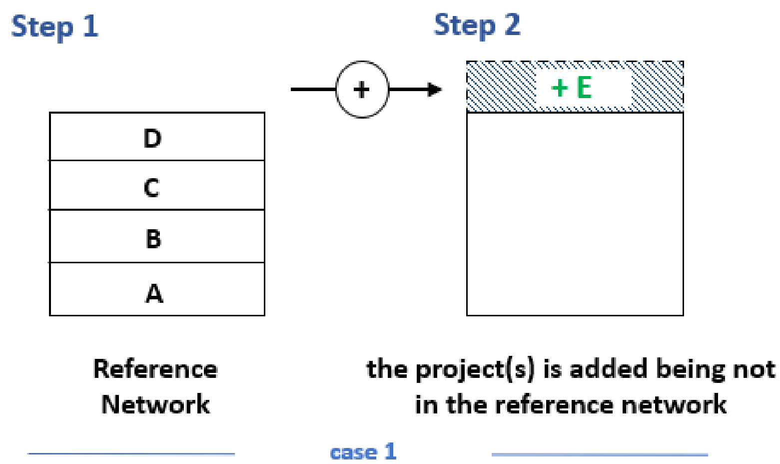


Figure 9: Incremental approach with PINT of project E.

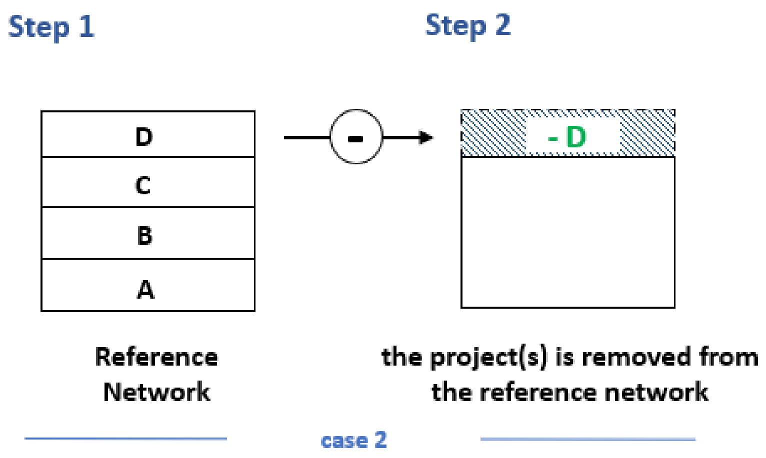


Figure 10: Incremental approach with TOOT of project D.

Infrastructure gaps as basis for project-specific assessment

Identification of infrastructure gaps on the basis of the reference grid should be used to ensure a level-playing field project-specific assessment focused on evaluating how projects contribute to solving the gaps: in cases where a specific infrastructure gap is identified, all projects should be assessed against this gap, and the project-specific assessment should show if and to which extent a specific project allows to mitigate this infrastructure gap.

The infrastructure gaps are measured compared to **threshold** values beyond which the infrastructure gaps disappear or are considered less relevant (as mentioned in section 2. *System Assessment: Identification of infrastructure gaps*). The same threshold should be used for both evaluating the possible infrastructure gaps and for evaluating how projects mitigate or solve these gaps, to ensure comparability of results.

It is expected that hydrogen infrastructure gaps will progressively emerge across Europe to the extent permitted by supply and demand increase along the mid and long-term horizon in order to contribute to the fulfilment of the 2050 climate neutrality objective.

4.2. Project benefits

The TEN-E Regulation has identified four main criteria: sustainability, security of supply and flexibility, competition, and market integration. Hydrogen projects should be assessed against these criteria. According to Art. 4 of the TEN-E Regulation, hydrogen PCI projects should contribute significantly to the sustainability criteria and in addition should contribute to at least one of the three remaining criteria.
In line with those criteria, hydrogen infrastructure projects' potential benefits to Europe and Member States are listed below:

- **Social economic welfare (B2)** from wholesale energy market integration
- Additional **societal benefit due to GHG emissions variation (B1),** related to
  - Integration of renewable energy
  - And/or substitution of higher-carbon energy sources
- Additional **societal benefit due to non-GHG emissions variation (B4),** related to
  - Integration of renewable energy
  - And/or substitution of higher-carbon energy sources
- **Renewable Energy integration (B3)**
- Contribution to **security of supply (B5)**
- **Significance of cross-border impact of hydrogen transmission projects (B6)**

The above-mentioned benefits can be:

- Quantified, measured through specific indicators.
- Quantified and monetised, assigning monetary value to be then considered in the calculation of the economic performance indicators together with the cost information.
- Qualitative, when benefits cannot be quantified.

This methodology is based on a multi-criteria analysis, combining a monetised CBA with non-monetised elements. In line with this concept, the above benefits are therefore taken into account in this methodology along with cost information, allowing for a level-playing field and comprehensive assessment of projects on all criteria.

This can be summarised in the table below.

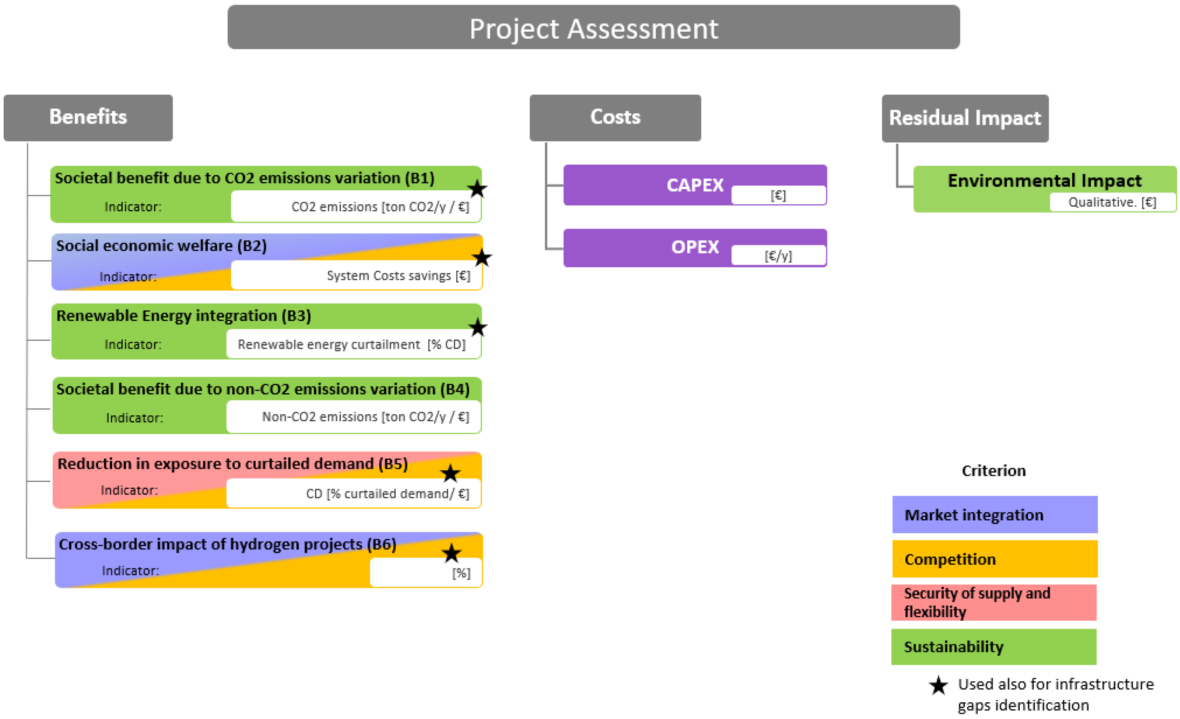


Figure 11: CBA metric and TEN-E Regulation criteria.

The indicators are explained in the section below. The details on how the indicators are calculated should be part of the TYNDP report in form of an Annex, as well as part of the Implementation Guidelines of the corresponding TYNDP and PS-CBA process. Changes will be subject to advice from the European Commission, ACER and public consultation.

4.3. Quantification and monetisation of benefits

The definition of a common set of project assessment metrics ensures comparability between projects and reflects in an aggregated form their impact along the different policy criteria identified by the TEN-E Regulation. These metrics should be analysed all together, not giving undue priority to one of them.
When it comes to monetisation, it is important to identify all possible double-counting of benefits in the assessment.

Monetisation should only be performed when reliable monetisation is ensured, to avoid non-robust conclusions when comparing monetised benefits to project costs. Without it, (non-monetised) quantitative benefits should be maintained. Over time, specific investigations outside of the scope of this methodology may allow identification of meaningful and reliable ways to monetise an increased number of quantified benefits. Further monetisation should then be proposed and consulted as part of the TYNDP process.

4.4. Indicators

The below set of indicators covers all specific criteria of the TEN-E Regulation and all the benefits identified in section 4.2. All indicators should be used as part of the incremental approach (as per section 4.1) in order to evaluate the contribution of a project along the specific criteria set by the Regulation.

B1: Societal benefit due to GHG emissions variation

Definition	This indicator measures the reduction in GHG emissions as a result of implementing a new project, based on the GHG emissions comparison with/without the project.
Indicator Calculation	The indicator considers the change of GHG emissions as a result of changing the generation mix of the electricity sector or the supply source used to meet hydrogen demand (including GHG emissions savings from replacement of alternative fuels in non-power sectors). This indicator is first expressed in quantitative terms in tonnes of CO2 equivalent emissions savings. Then, the benefit is finally expressed in monetary terms (€/y or M€/y) when the tons of CO2e emission savings are multiplied by the shadow cost of carbon of the corresponding simulated year.
Model	Interlinked hydrogen/electricity model Ex-post allocation of TYNDP scenario GHG emissions savings
Interlinkage with other indicators	B2 Social economic welfare Fuel cost savings are not included to avoid double counting with B2 (SEW)

Introduction

Hydrogen infrastructure could reduce overall greenhouse gas emissions of the EU's energy system and consequently contribute to the achievement of climate-neutrality.

To fully capture in the assessment the benefits resulting from the reduction of GHG emissions due to a new project, this indicator follows a two-step approach:

Step 1: Quantitative terms

This indicator is first expressed in quantitative terms, calculated as the variation in CO2e emissions of the system with and without the assessed project.
Unit: tonnes of CO2 equivalent per year.

Calculation of GHG emissions follows a two-step approach:

1.1 Calculate the GHG emissions reduction thanks to the implementation of the project in the electricity sector.
Variation of GHG emissions in the electricity system is calculated through the interlinked model by comparing system emissions with and without the implementation of the project.

1.2 Calculate the GHG emissions reduction thanks to the implementation of the project in non-power sectors.
The TYNDP scenario process should deliver an assumed average GHG emission factor for all hydrogen consumers outside of the power sector in case the incumbent (alternative) fuel would be used. It will be assumed that if insufficient hydrogen was available, the alternative fuel with its respective GHG emission factor is used instead.
Variation of GHG emissions outside of the electricity system is calculated through an ex-post treatment of the interlinked model results by comparing the satisfied hydrogen demand with and without the implementation of the project.

Resulting GHG emissions savings will be the sum of Step 1 and Step 2.

Step 2: Monetization

The resulting amount of generated/avoided GHG emissions in tonnes of carbon dioxide equivalent (CO2e) derived in step 1 shall be valued in monetary terms.
Unit: € or M€

There are several approaches to monetise the economic cost of CO2:

- The shadow costs of carbon represent the economic costs required to drive the economy to meet the 1.5˚C global temperature target
- The social cost of carbon represents the economic cost as a result of an additional tonne of carbon dioxide emissions or its equivalent

The monetary part of CO2 is partly taken into consideration within the Social Economic Welfare (B2) through energy production costs. The production costs are considered for electricity generation and hydrogen production from natural gas. The marginal cost for each supply source is the sum of the fuel cost, variable operation and maintenance costs and the

CO2 market price. This CO2 price, which is paid for by the producers, is the forecast of the CO2 price over the Emission Trading Scheme (ETS). Depending on the level of this market price, the forecasted price signal may be too low to give a sufficient price signal to lead to the investment level required to reach Europe's climate goal.

Thus, in order to appropriately assess investments in accordance with the European objective of GHG emission reduction, a specific indicator for monetising this additional impact is designed. For this purpose, and as indicated in the EC guidelines on CBA and sector applications[16], it is recommended that for the monetisation of indicator B1, the shadow cost of carbon will be the minimum value to be used to monetise GHG emissions and reductions. The reference source regarding Shadow Cost of Carbon, in line with EC general principles for cost-benefit analysis, is the European Investment Bank. As the shadow cost of carbon is normally calculated with yearly granularity, yearly values should be considered for monetization of GHG emissions through B1 indicator.

Methodology

This indicator measures the reduction in GHG emissions due to the implementation of a new project. Therefore, the GHG emissions of the electricity and hydrogen systems are computed with and without the project.

The variations that are considered for this indicator are:

- Variations resulting from changing the generation mix of the electricity sector
- Variations resulting from changing the supply sources used to meet hydrogen demand
- Variations resulting from the replacement of an alternative fuel

In the electricity system, an asset such as the electricity grid can be used to allow generation with lower GHG emissions to replace higher GHG emitting generation in a neighbouring country. This will in turn reduce the overall GHG emissions. Additionally, as the electricity and hydrogen systems are connected through CCGTs, it is possible that hydrogen created from renewable or nuclear can be used in these CCGTs. It is likely that this will be stored hydrogen and used when energy prices in the electricity system are high.

---

[16] https://jaspers.eib.org/LibraryNP/EC%20Reports/Economic%20Appraisal%20Vademecum%202021-2027%20-%20General%20Principles%20and%20Sector%20Applications.pdf

In the hydrogen system, domestically produced hydrogen can be used to replace hydrogen produced using natural gas (such as SMR in combination with CC(U)S) which comes with a GHG emission. Depending on prices, pipelines can be used to distribute cleaner hydrogen within Europe replacing SMR or imports and storages can be used to store cleaner energy and dispatch this energy when green hydrogen is not available.
In addition, hydrogen infrastructure will also enable additional GHG emissions savings from the replacement of more polluting fuels in non-power sectors. These savings can be retrieved from the interlinked model by comparing the enabled usage of hydrogen with and without the project.

$$
\begin{aligned}
B1 = {} & \left| GHG\ Emissions\ ILM_{without\ project} - GHG\ Emissions\ ILM_{with\ project} \right| \\
& \cdot (Societal\ cost\ of\ CO_2 - ETS\ price) \\
& + \left| Unserved\ hydrogen\ demand_{without\ project} \right. \\
& \left. - Unserved\ hydrogen\ demand_{with\ project} \right| \\
& \cdot Average\ GHG\ Emission\ Factor_{alternative\ fuel} \cdot (Societal\ cost\ of\ CO_2)
\end{aligned}
$$

Double-counting

To prevent any double counting, any reduction in system cost associated with emissions reduction must be considered and removed from this indicator. The CO2 price considered externally in the model reflects an emission trading scheme price.

B2: Social Economic Welfare for hydrogen sector

Definition	In the integrated system model, socio-economic welfare is defined as the sum of the short-run economic surpluses of consumers, producers, transmission owners (congestion rent) and cross sectoral rents.
Indicator Calculation	The indicator considers the change of total generation costs with and without a project. This indicator is first expressed in monetised terms (€/y or M€/y)
Model	Interlinked hydrogen/electricity model
Interlinkage with other indicators	B1 Societal benefit due to CO2 emissions variation

Introduction

In the integrated system model, socio-economic welfare is defined as the sum of the short-run economic surpluses of electricity consumers, producers, transmission owners (congestion rent) and cross-sectoral rents. Investments in generation, transmission capacities and storage typically increase the sum of these surpluses through matching demand with cheaper supply sources which may not have been possible due to limitation in the system.

A set of base case energy landscapes are determined through the joint scenario development process that describe various demand profiles and generation mixes. The reference infrastructure levels for electricity, hydrogen, and natural gas are obtained from data collections by European TSOs and project promoters.

Methodology

In the interlinked model, two different approaches can be used for calculating the variation in socio-economic welfare.

The first is the generation cost approach, which compares the total generation costs with and without a project. Generation costs consist of the marginal cost of a generation, which is a function of the fuel cost, variable operation and maintenance costs and the CO2 market price, per unit energy delivered to the market. If inelastic demand is assumed, this approach is appropriate to use when considering the total system benefits.

The second is the total surplus approach, which compares the producer and consumer surpluses for both bidding areas, congestion rent between them and cross-sector rents because of the interlinkage between the sectors, with and without the project. When assessing individual sectoral benefits (electricity and hydrogen), it is necessary to explain the system benefits using the total surplus approach.

The delta SEW is the difference between the base case simulation without the project the simulation with the project:

$$\Delta SEW_{H2} = SEW_{H2}^{with\ Project} - SEW_{H2}^{without\ Project}$$

In an interlinked model the SEW must be decomposed in order to consider the cross-sectoral links between the electricity and hydrogen systems. As the electricity system produces energy to create hydrogen, production costs are increased. However, the benefits of the hydrogen produced are mainly reaped in the hydrogen system (if there are H_2 CCGTs this creates a storage style operation). Therefore, for this energy produced, the producer surplus and consumer surplus are attributed to different sectors.

$$SEW_{H2} = R_{Producer}^{H2} + R_{Consumer}^{H2} + R_{Grid\ congestion}^{H2} + R_{Cross-sector}^{H2\leftrightarrow elec}$$

With:

- R can be the producer', consumers', grid congestion, and cross-sector rent
- $R_{Producer}^{H2}$
  - The producer surplus is the difference between the marginal cost of generation and the market clearing price
- $R_{Consumer}^{H2}$
  - The consumer surplus is the difference between the price consumers are willing to pay for energy and the market clearing price
- $R_{Grid\ congestion}^{H2}$
  - The congestion rent is the difference in the market clearing price at each interconnection point of a hydrogen pipeline.
- $R_{Cross-sector}^{H2\leftrightarrow elec}$
  - The cross sector rent is the difference in the market clearing price within the electricity market and the hydrogen market

The cross-sector rent (CSR) can be calculated separately and split across the electricity and hydrogen sectors. Here, the CSR is split in equal shares:

$$R_{CSR}^{H2\leftrightarrow elec} = \left(\sum_{a \in A} \sum_{c \in C} \left| mcp_{H2}^{a} p_{H2}^{a,c} - mcp_{elec}^{a} p_{elec}^{a,c} \right| \right) / 2$$

- $mcp_{H2}^{a} p_{H2}^{a,c}$
  - This represents the market clearing price in the hydrogen sector multiplied by the energy transfer.
- $mcp_{elec}^{a} p_{elec}^{a,c}$
  - This represents the market clearing price in the electricity sector multiplied by the energy transfer.
- The cross sectoral rent must be calculated for all electricity/hydrogen connection points individually.
- In this case the cross sector rent is split between sectors equally. A proportional split can also be used e.g. (40% electricity – 60% hydrogen).

Double-counting

When considering the monetisation of benefits such as renewable integration and CO2 emissions reduction, it is important to consider that these benefits will be included in the cross-sectoral Social Economic Welfare calculations. Therefore, if a separate methodology is to be used, these benefits will need to be removed from the Social Economic Welfare calculation or reported as additional information, not to be added to the final Social Economic Welfare figure.

B3: Renewable Energy integration

Definition	This indicator measures the reduction of renewable generation curtailment in MWh (avoided spillage) and/or the additional amount of RES generation that is connected by the project in MW.
Indicator Calculation	This indicator is expressed in quantitative terms (Unit: MWh/y) Monetisation: Already monetised as part of B1.
Model	Interlinked hydrogen/electricity model
Interlinkage with other indicators	B1 Societal benefit due to RES variation

Introduction

All decarbonisation and renewable technologies are needed to reach net zero by 2050. The EC revises its renewable integration targets, often resulting in more ambitious goals. European renewable energy will be essential to:

- Ensure that long term climatic targets can be achieved through sustained growth and substantial investment in all European renewable energy sources including wind, solar, and biomethane.
- Foster renewable energy production at consumer level (e. g., prosumers, energy positive buildings, etc.) will contribute to scaling up and embracing clean energy supply.
- Plan transmission infrastructure needed to connect areas of high renewable energy potential to the high demand centres.

Hydrogen can unlock the full potential of renewable electricity resources. It will contribute to a higher European energy autonomy.
A European hydrogen market is an opportunity for the EU to take part in a global clean energy market and import decarbonised energy.

Methodology

The RES Integration Benefit indicator assesses the difference between RES, which was curtailed in the base case simulation, that is now able to be used to meet demand due to the inclusion of an asset and is measured in MWh/y.

$$B_3 = \sum_z \left(RES\_curtailment_z|_{without\ project} - RES_{curtailment_z}|_{with\ project} \right)$$

The integration of RES can be triggered by but not limited to:

- Increasing the electricity capacity between one area with excess RES generation to another
- Increasing electrolyser capacity in an area with additional RES
- Increasing hydrogen capacity between two areas that may allow RES to be converted to hydrogen and integrated into a system. This can be used to replace other hydrogen supply sources such as SMR or imports. Additionally, it can be used to integrate hydrogen into a zone with additional storage capacity.
- Increased hydrogen storage capacity

Two types of projects can be assessed in relation to the RES integration indicator:

- The direct connection of RES to the main system as contained in a project
- Projects that increase the capacity in the main system itself

If B1 and B3 should both not be positive, B4 should be considered as providing 0 benefit since non-GHG emissions alone should not justify a passing of the sustainability criterion.

B4: Societal benefit due to non-GHG emissions variation

Definition	This indicator measures the reduction in non-GHG emissions as a result of implementing a new project, based on the non-GHG emissions comparison with/without the project.
Indicator Calculation	The indicator considers the change of non-GHG emissions as a result of changing the generation mix of the electricity sector or the supply source used to meet hydrogen demand (including non-GHG emissions savings from replacement of alternative fuels in the industrial, transport and residential sectors). This indicator is first expressed in quantitative terms in tonnes of non-GHG emissions savings (NOx, SO2, PM, ….). Then, the benefit is finally expressed in monetary terms (€/y or M€/y) when the tons of non-GHG emission savings are multiplied by the shadow cost of air pollutants.
Model	Interlinked hydrogen/electricity model Ex-post allocation of TYNDP Scenario non-GHG emissions savings
Interlinkage with other indicators	No interlinkage

Introduction

In the EU, the National Emissions Ceilings Directive sets national emissions reduction commitments for five different air pollutants: nitrogen oxides (NOx), sulphur dioxides (SO2), fine particulate matter, non-methane volatile organic compounds and ammonia.
In addition, the European Commission has set in the European Green Deal the zero-pollution ambition for a toxic-free environment[17], in addition to 2030 targets for the reduction of air pollution set in the zero-pollution Action Plan[18].
These pollutants contribute to poor air quality, leading to significant negative impacts on human health and the environment. Energy use in transport, industry and in power sectors, as well as in heat generation are major sources of emissions especially for NOx and SO2.
In this context, hydrogen infrastructure could significantly contribute to the fulfilment of the above-mentioned targets, as hydrogen does not emit CO2 and almost no air pollution when used.

[17] EC Communication: Pathway to a Healthy Planet for All (link)
[18] EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil' (link)

Methodology

This indicator quantifies the different emissions of the above-mentioned air pollutants through a post process by applying the relevant emission factor (tonne of pollutant/MWh) applicable to the corresponding (generation unit). In addition, for sectorial non-GHG emissions savings. total non-GHG emissions savings from TYNDP Scenario process at country level will be used as basis for an ex-post allocation of benefits according to the hydrogen demand enabled by the project implementation.

The emissions factors greatly differ depending on the use of the fuel, and in particular depending on the combustion techniques and abatement techniques. Ideally, each power plant of the electricity system would have a different emission factor for each air pollutant considered in the assessment. To simplify the computation of the indicator it is recommended to consider one emission factor per pollutant and technology type.

Sectorial non-GHG emissions savings are mainly driven by the alternative fuel that will be replaced by hydrogen. Average sectorial/sub-sectorial emissions factors will be used based on the share of replaced fuel(s) per sector/subsector.

Similar to the calculation of indicator B1 Societal benefit due to CO2 emissions variation, a two-step approach is required to fully capture in the assessment the benefits due to the reduction of non-greenhouse gases emissions of a new project, this indicator also follows a two-step approach:

Step 1: Indicator is expressed in quantitative terms as tonne of pollutant (nitrogen oxides, sulphur dioxides, fine particulate matter, non-methane volatile organic compounds and ammonia).

Step 2: indicator is expressed in monetary terms by multiplying by damage costs of the different air pollutants considered.

Monetisation

Monetisation of the avoided emissions from the different air pollutants are monetised by multiplying by the damage cost of the pollutant as it follows:

$$B4 \; = \sum_i (Non - GHG\ emission_{pollutant\ i, without\ project} - Non - GHG\ emission_{pollutant\ i, with\ project}) \cdot Damage\ cost_{pollutant\ i})$$

It is recommended to favour transparent and preferably publicly available sources of information (such as European Environment Agency[19]) regarding the damage costs of pollutants. In addition, the sources of data must be referenced.

Double-counting

Since there are no interlinkages to other indicators for this indicator, no double accounting can occur.

[19] European Environment Agency, Costs of air pollution from European industrial facilities 2008–2012

B5: Reduction in exposure to curtailed demand

Definition	The curtailed demand is the demand that cannot be satisfied in a given area as a result of simulating any of the below specified conditions. The indicator measures the reduction on curtailed demand in a given area thanks to the implementation of the project. It covers both hydrogen as well as natural gas.
Indicator Calculation	The indicator is calculated under climatic stress cases and supply and/or infrastructure disruption cases. Even in the absence of a mature H2 market, this indicator can also be expressed in monetised terms (€/y or M€/y), by making assumptions on the estimation of future Cost of Disrupted Hydrogen (CODH) that, as a conservative proxy, could be aligned to the values adopted for the Cost of Disrupted Gas (CODG).
Model	Dual hydrogen/natural gas model
Interlinkage with other indicators	No interlinkage since other indicators are calculated under normal conditions, i.e. in the absence of climatic stress and disruption cases.

Introduction

To achieve the energy pillars of Security of Supply and Competition it is important to identify whether there are countries in Europe that risk to facing any demand curtailment (i.e., to be not fully supplied). Curtailed demand may occur in case of the lack of appropriate connections, endangering the secure and reliable system operation, or insufficient supply or production.

Methodology

The analysis should allow identification where projects provide benefits coming from mitigating possible demand curtailment.

Identification of demand curtailment risks should be performed individually for:

> Climatic stress conditions, in case of extreme temperatures with lower probability of occurrence than normal conditions (e.g., occurring with a statistical probability of once in 20 years, 1/20)

> Supply stress conditions, in case of supply stress due to specific route/origin disruptions (e.g., hydrogen import disruption from a certain corridor)

> Infrastructure stress conditions, in case of disruption of the single largest capacity[20] of a country

Quantification of the avoided demand curtailment:

The curtailed demand is the demand that cannot be satisfied in a given area as a result of simulating any of the above-mentioned conditions.

Several cooperation assumptions among countries could be considered, in order to better reflect the possible interactions between countries when coping with stress conditions or supply disruptions. Therefore, this indicator could be calculated considering cooperation among regions or hydrogen valleys, in addition to cooperation across all European countries.

To facilitate the understanding of the results, it is recommended that the amount of curtailed demand for a given area is provided:

> In energy (such as GWh)

> As relative share / percentage

These options represent two alternative ways of displaying the same result.

Monetisation

The benefit of avoided demand curtailment shall be monetised as follows:

$$B5 = \sum_i (probability\ of\ occurence_i * (avoided\ hydrogen\ curtailed\ demand_i * \mathrm{CODH} + avoided\ natural\ gas\ curtailed\ demand_i * CODG))$$

Where

> i is the number of assessed cases

> Probability of occurrence is defined in the IG.

> Avoided curtailed demand is the difference (in GWh) between the curtailed demand without the project and the resulting curtailed demand considering the project implementation.

> CODH is the “cost of hydrogen disruption” expressed in €/GWh.

> CODG is the cost of natural gas disruption expressed in €/GWh.

[20] Hydrogen infrastructure does not consider single largest infrastructure disruption, but single largest capacity disruption since the hydrogen network is still under planning and not in operation.

> The preference regarding the satisfaction of natural gas or hydrogen customers must be defined in the IG (e.g., natural gas customers could (partially) share the burden by getting curtailed to allow for blue hydrogen production to mitigate hydrogen supply disruptions).

With the definition of an EU hydrogen security of supply policy for the definition of a Cost of Disrupted Hydrogen (CODH), a harmonised reference value at EU level will be introduced to be used as monetisation factor (eventually differentiated by country considering specific peculiarities). Until such value is identified, as a conservative proxy, values adopted for the CODG should be used, allowing project promoters to provide evidence of higher values to be used in the evaluation.

Double-counting

When the impact of a combination of different stress conditions is assessed (e.g., climatic and supply stresses), it is necessary to identify which conditions are responsible for the demand curtailment. If results show demand curtailment in a specific area under climatic stress conditions, without any supply or infrastructure stress conditions, it is expected that the assessment of a supply or infrastructure disruption impacting this specific area in the same climatic conditions will show a higher (or at least equal) level of curtailed demand.

In this case, only the additional demand curtailment will be considered as the impact of the additional stress. This is of utmost relevance to avoid double counting when monetising the benefit stemming from avoided demand curtailment in a different situation.

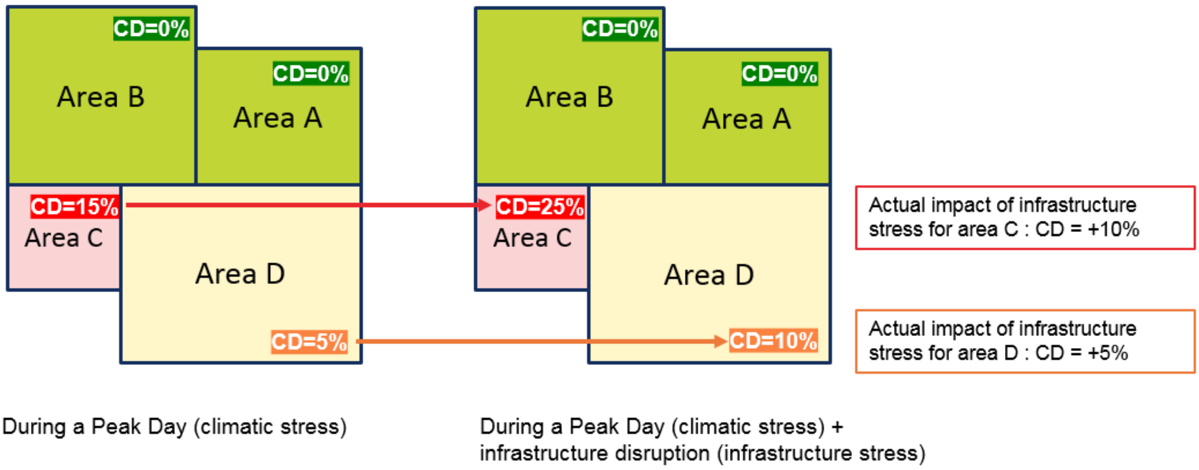


Figure 12: Example of curtailed demand indicator during a peak-day compared to a combination of supply route disruption during peak-day.

B6: Cross-border impact of hydrogen transmission projects

Definition	The indicator measures the cross-border hydrogen capacity increase enabled by the project compared to the situation prior to the implementation of the project.
Indicator Calculation	The indicator is a capacity-based indicator: - For countries where no cross-border capacity is available before commissioning year of the project. It is assumed that capacity increase is equal to 100%, as the prior situation is two isolated countries. - For countries where cross-border capacity is already available before commissioning year of the project, indicator is calculated as the increase of capacity related to the project divided by the cross-border capacity available prior to the commissioning of the project.
Model	Capacity-based (not modelled)
Interlinkage with other indicators	No interlinkage

Introduction

This indicator intends to look at the cross-border impact of hydrogen projects in terms of cross-border capacity increase enabled by a given project. According to Annex IV(3) of the TEN-E Regulation, hydrogen transmission projects should increase by at least 10% compared to the situation prior to the commissioning of the project. If this threshold is passed, the cross-border significance of the project is considered as given. If not, other provisions of Annex IV(3) could still qualify the project as having significant cross-border impact.

Methodology

Cross-border impact for hydrogen transmission projects is measured through a capacity-based indicator. Therefore the cross-border capacity between two countries is calculated without the implementation of the project group and once the project group is implemented.

If the countries were not interconnected, and this interconnection will be the first hydrogen cross-border capacity between these two countries, capacity increase will be considered as 100%.

Once the first interconnection between two countries is implemented, cross-border impact of hydrogen transmission projects should be measured by the ratio between the cross-border capacity increase enabled by the project and the cross-border capacity prior to the implementation of the project. As required by Annex IV (3) of the TEN-E regulation this ratio should be equal or higher to 10%.

$$Cross-border\ capacity = \frac{\left[\sum_{i=0}^{n} Cross\text{–}border\ Country\ i\right]_{with\ project} - \left[\sum_{i=0}^{n} Cross\text{–}border\ Country\ i\right]_{without\ project}}{\left[\sum_{i=0}^{n} Cross\text{–}border\ Country\ i\right]_{without\ project}} \cdot 100(\%)$$

Double-counting

Since there are no interlinkages to other indicators for this indicator, no double accounting can occur.

Environmental Impact

Similarly to other energy infrastructure categories, each hydrogen infrastructure has an impact on its surroundings. This impact is of particular relevance when crossing some environmentally sensitive areas, such as Natura 2000[21], namely on biodiversity.

Mitigation measures are taken by the promoters to reduce or even fully mitigate this impact and comply with the EU Environmental Regulation and European Commission biodiversity strategy.

In order to give a comparable measure of project effects, the fields described in the table will be filled in by the promoter as a minimum.

Table 4: Minimum set of information to be included in the PS-CBA assessment phase regarding the environmental impact of a hydrogen project.

Project	Type of infrastructure	Surface of impact	Environment-ally sensitive area	Potential impact	Mitigation measures	Related costs included in project CAPEX and OPEX per year	Justification of costs
Section 1							
Section 2							

Where:

- The section of the project may be used to geographically identify the concerned part of the project (e.g., section point A to point B of the project routing)
- Type of infrastructure identifies the nature of the section (e.g., compressor station, hydrogen transmission pipeline, etc.)
- Surface of impact is the area covered by the section in linear meters and nominal diameter for pipe, as well as in square meters, although this last value should not be used for comparison as it may depend on the national framework
- Environmentally sensitive area, such as Natura 2000, as described in the relevant legislations (including where possible the quantification of the concerned surface)
- Potential impact, as the potential consequence on the environmentally sensitive area stemming from the realisation of the concerned project
- Mitigation measures, that are the actions undertaken by the promoter to compensate or reduce the impact of the section (e.g., they can be related to the Environmental impact assessment which is carried out by the promoter)

[21] https://ec.europa.eu/environment/nature/natura2000/index_en.htm

> Related costs: The promoter shall indicate the expected related CAPEX and OPEX per year which must be part of the CAPEX and OPEX used for the calculation of the economic performance indicators. Promoters shall also provide adequate justification of these costs. If such costs are not included in the economic performance indicators used for other TEN-E infrastructure categories like electricity, they shall also not be considered for hydrogen infrastructure projects when comparing these infrastructure projects.

In case of any other environmental impact not covered by the CBA assessment undertaken by ENTSOG or via the table above, it is the responsibility of the project promoter to submit these in form of qualitative or quantitative information. These other impacts will be included and displayed in the TYNDP assessment results together with the other indicators.

Overlapping indicators

ENTSOG's CBA Methodology for the assessment of hydrogen infrastructure is based on a multi-criteria analysis, combining a monetised CBA with non-monetised elements. The indicators defined in this methodology aim at providing relevant and quantified information not always possible to be monetised.

The figure below shows the criteria addressed by the different CBA indicators and the possible overlaps that will be considered when applying the methodology.

Each indicator defined in the methodology measure the contribution of the project to the specific criteria independently from the others and is considered as non-overlapping with the others. In addition, more information regarding the different interlinkages and potential overlapping of indicators is detailed in section 4.2. The security of supply and flexibility indicators thereby can be used as proxy indicators for competition, since it captures a surplus of supply quantities, supply sources and/or supply routes which are also a prerequisite for effective competition.

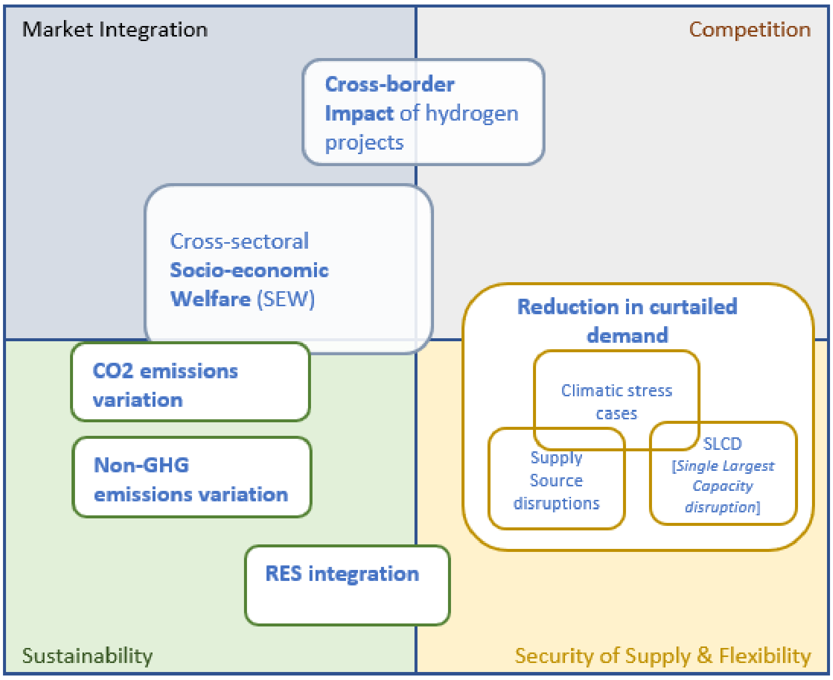


Figure 13: description of CBA indicators' interlinkages and potential areas of overlapping.

4.5. Projects costs

Costs represent an inherent element of a CBA analysis. According to Annex V (8) of the TEN-E Regulation, the CBA "*shall, at least, take into account the following costs: capital expenditure, operational and maintenance expenditure costs, as well as the costs induced for the related system over the technical lifecycle of the project as a whole, such as decommissioning and waste management costs, including external costs*".

Investment costs are therefore classified[22] by:

> **Capital expenditure** (CAPEX)
  - **Initial investment cost**, that corresponds to the cost effectively incurred by the promoter to build and start operation of the hydrogen infrastructure. CAPEX should consider the costs of both off-shore and on-shore infrastructure related to obtaining permits, feasibility studies, obtaining rights-of-way, groundwork, preparatory work, designing, dismantling, equipment purchase and installation.[23]
  - **Replacement costs** are the costs borne to ensure that the infrastructure remains operational by changing specific parts of it.[24]

> **Operational and maintenance expenditure** (OPEX) corresponds to costs that are incurred after the commissioning of an asset and which are not of an investment nature, such as direct operating and maintenance costs, administrative and general expenditures, etc.

All cost data should be considered at constant (real) prices . As part of the TYNDP and PCI processes, it is recommended that constant prices refer to the year of the TYNDP project collection.

When available and based on a significant amount of infrastructure projects, unit investment costs for hydrogen infrastructure (as required by Article 11(9) of the Regulation) will be used for comparison in the IG of the corresponding TYNDP process.

Only cost related to hydrogen infrastructure should be considered, while it shall be transparently displayed which additional costs might be required (e.g., in the natural gas

---

[22] This classification is in line with the EC Guide to Cost-Benefit Analysis of Investment Projects.
[23] Costs already incurred at the time of running the project cost-benefit analysis should be generally considered in the assessment, while in case of expansion projects only the costs related to the expansion should be taken into account since the costs incurred before already allowed the project to be functional.
[24] Over the project assessment period.

system) to enable the hydrogen infrastructure by linking it to natural gas projects. This will be further detailed in the PID and/or IG.

4.6. Economic Net Present Value and other Economic Performance Indicators

Economic Performance Indicators are based on project costs as well as the part of the benefits that are monetised. Economic performance indicators are sensitive to the assessment period, the retained Social Discount Rate and therefore to the distribution of benefits and costs over the assessment period.

The CBA methodology builds on Multi-Criteria Analysis, on the basis that not all benefits of projects can be monetised. For this reason, Economic performance indicators, and in particular Economic Net Present Value, only represent a part of the balance between project costs and benefits.

Economic performance indicators are therefore useful to compare projects. However, when considering if the potential overall benefits of a project outweigh its costs, as per Art. 4.1(b) of the Regulation, the Regional Group members should also consider non-monetised benefits in addition to the Economic performance indicators.

The forecasted costs and benefits for each investment are to be represented annually.

The year of commissioning is the year that the investment is expected to come into first operation. The benefits are accounted for from the first full operational year after commissioning.

To evaluate projects on a common basis, benefits should be aggregated across the years, as follows:

- For years from the first year after commissioning (i.e. the start of benefits) to the first mid-term: extend the first mid-term benefits backwards;
- For years between different mid-term, long-term and very long-term (if any): linearly interpolate benefits between the time horizons;
- For years beyond the farthest time horizon: maintain benefits of this farthest time horizon. To assess a project that is comprised of multiple investments, the annualised benefits, losses and operational costs for the project are accounted for from the commissioning of the latest investment, thus the commissioning of the complete project.

This chapter focuses mostly on the Economic Net Present Value (ENPV). Other Economic Performance Indicators are explained in Annex II.

4.6.1. Economic Parameters

Constant (real) prices

In order to ensure transparency and comparability, the analysis of socio-economic benefits and costs should be carried out at **constant (real) prices**, i.e. considering fixed prices at a base year[25]. By doing so, one neutralises the effect of inflation.

As part of the TYNDP and PCI processes, it is recommended that constant prices refer to the year of the TYNDP project collection.

Socio-Economic discount rate

The concept of "socio-economic discount rate" (SDR) corresponds to the rate that ensures the comparability of benefits and costs incurred at different points in time.
The social discount rate is applied to economic benefits and costs of the project (both CAPEX and OPEX). It allows to consideration of the time value of money.

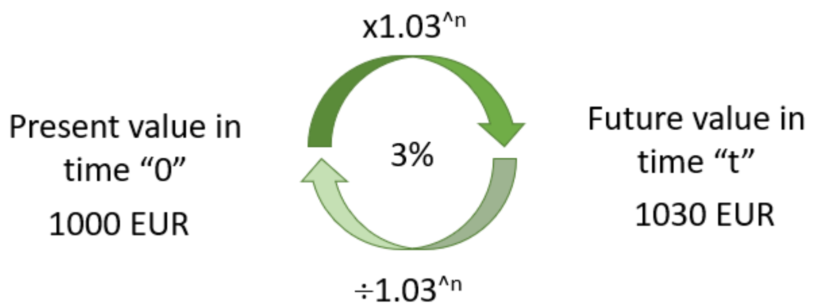


Figure 14 – Example of how the social discount rate works.

It can be interpreted as the minimum profitability that should be reached by a hydrogen infrastructure project to achieve net economic benefits. It can also be interpreted as the economic interest rate provided by the best alternative project, following the principle of

[25] In order to ensure consistency throughout the time horizon, the already incurred costs (investment) shall be considered as constant prices for the year of occurrence.

opportunity costs. This discount rate represents the weight that society attributes to benefits, with future benefits having a lower value than present ones.

A zero SDR means that current and future benefits are indifferent to the society point of view. A positive discount rate, on the other hand, indicates a preference for current over future benefits, whereas the opposite is true if the discount rate is negative.

The literature offers different approaches on how to estimate the socio-economic discount rate. For the cost-benefit analysis of projects, a same **SDR equal to 3% will be used for all projects**. It corresponds to the reference value for EU-funded projects for the period 2021–2027[26]. This value is also recommended by the European Advisory Board on Climate Change in its publication *Towards a decarbonised and climate-resilient EU energy infrastructure: recommendations on an energy system-wide cost-benefit analysis* [27]. It therefore provides a fair basis for the comparison of projects, unbiased by the location of the projects. Indeed, it would be possible to use different social discount rates. However, in order to guarantee comparability of project assessments and results consistency, this methodology recommends using one social discount rate for all projects.

The SDR has to be considered in real terms, in line with the recommendations that the analysis of socio-economic benefits and costs should be carried out at constant (real) prices.

Economic life and physical life of project

The reference period should correspond to the project's economic life to allow its likely long-term impacts to materialise. The project's economic life is defined as the expected time during which the project remains useful (i.e. capable of providing goods/services) to the promoter, and it could be different than the physical or technical life of the project.

It is important to consider when estimating the reference period for hydrogen projects, that these projects are expected to produce benefits in the long-term, as hydrogen infrastructure is currently at early stages of implementation. A very important share of the project benefits are expected under sustainability criteria, contributing to the achievement of the climate

[26] European Commission - Guide to Cost-Benefit Analysis of Investment Projects, page 55.
[27] Towards a decarbonised and climate-resilient EU energy infrastructure: recommendations on an energy system-wide cost-benefit analysis, page

neutrality 2050 objective. Therefore, the reference period should be long enough to include long-term benefit of the projects.

In line with EC recommendations on CBA guidelines and principles, it is recommended to set the reference period as the value-weighted average lifetime of the different assets of the project. However, restricted to a reasonable time limit to enable future forecasting of the net future economic cash flows, this is usually no longer than 50 years. European Scientific Advisory Board on Climate change also recommends to apply in the CBA methodology assessment periods that reflect realistic project lifetimes.

According to the available literature the physical lifetime of hydrogen projects is estimated up to 50 years, whereas economic lifetime of hydrogen system has been estimated to be in 40 years[28].

This methodology recommends the consideration of an **economic life of 40 years**, and that this same reference economic life should be retained for all projects assessed to ensure comparability in the analysis of the results.

4.6.2. Economic Net Present Value (ENPV)

The ENPV is the difference between the discounted monetised benefits and the discounted costs expressed in real terms for the basis year of the analysis (discounted economic cash-flow of the project).

The ENPV reflects the performance of a project in absolute values and it is considered the main performance indicator.

If the ENPV is positive the project generates a net monetary benefit and it is beneficial from a socio-economic perspective. As not all benefits are monetised, a project may be beneficial even if ENPV is not positive.

$$\mathrm{ENPV} = \sum_{t=f}^{c+39} \frac{B_t - C_t}{(1+r)^{t-n}}$$

[28] The techno-economics potential of hydrogen interconnectors for electrical energy transmission and storage (Max Patel, Sumit Roy, Anthony, Paul Roskilly, Andrew Smallbone), 2022

Where:

- ***c*** is the first full year of operation
- $\mathbf{B_t}$ is the monetised benefits (SEW) induced by the project on year *t*
- $\mathbf{C_t}$ is the sum of CAPEX and OPEX on the year *t*
- ***n*** is the year of analysis (common for all projects)
- ***r*** is the Social Discount Rate of the project
- ***f*** is the first year where costs are incurred

In order to ensure consistent and comparable results, it is extremely important that, when computing the NPV the same approach in terms of economic lifetime, residual value and social discount rate should be applied to the different projects assessed.

Residual Value

In their "Economic Appraisal of Investment Projects"[29] (page 41), European Investment Bank indicates "*In line with sound banking practice, the Bank ensures that the maturity of its loans is shorter than the underlying project life. When the Bank is lending to guaranteed public sector projects, the main reason for capping the maturity of the loan is to make beneficiaries pay for the project, avoiding potential inter-generational transfers that may arise in detriment of future generations*".

As the reference period in this CBA methodology is estimated according to the expected economic life of hydrogen projects, the residual value at the end of the reference period will be normally very low.

As regards the estimation of the residual value, "Economic Appraisal Vademecum 2021-2027 – General Principles and sector applications" recommends the approach to calculate the remaining value of the assets/components based on a standard accounting depreciation formula.

In line with this approach and in order to provide a conservative approach, it is recommended as a basis approach that projects are **assessed without residual value**.

[29] http://www.eib.org/attachments/thematic/economic_appraisal_of_investment_projects_en.pdf

In addition, in the case that the technical lifetime of the asset is shorter than the assessment period, economic analysis will be performed based on the technical lifetime of the asset.

4.7. Sensitivity analyses

Sensitivity analyses enable the identification of those elements most affecting the performance of projects. Critical factors can be divided into the following categories:

> **Sensitivity on hydrogen market factors**, where the concerned elements are:
> demand evolutions
> renewables penetration
> climatic impact, including extreme weather events if Scenario report includes sufficient data to allow for its consideration
> commodity and GHG prices
> supply potentials
> supply generation patterns

Those elements are already captured by the different demand and supply scenarios considered (see section 2.1).

It is recommended to have a scenario-based approach for such sensitivity analyses, as some of the elements (such as gas demand and prices) are interdependent over time, and to keep CBA results to a manageable level.

> **Sensitivity on project-specific data** that should be reflected in the project-specific assessment (to be detailed in the IG):

- Commissioning year, which is of particular importance when assessing multi-phase projects or groups of projects
- CAPEX and OPEX
- Avoided decommissioning cost of natural gas infrastructure for repurposing hydrogen infrastructure

> **Sensitivity on monetary parameters,** directly impacting the calculation of the monetised benefits and Economic performance indicators:

- Social discount rate (higher and lower SDR, to be defined in the IG)

> Residual value and economic lifetime (calculation of economic performance indicators with consideration of 25 years of economic lifetime and inclusion of residual value)

Annex I: Residual Value

As part of the project's economic analysis, the residual value should be calculated as part of the sensitivity analysis for an assessment period of 25 years, according to the following depreciation formula using the social discount rate:

$$R_v = \sum_{t=e+1}^{t=w} \frac{Dep_t}{(1+r)^{t-n}}$$

Where:

- R_v is the Residual value
- n is the year of analysis (common to all projects)
- Dep_t is the nominal value of depreciation for year t, including the replacement costs of the asset, if any
- c is the commissioning year of the project
- e is the last year of the considered economic life (assumed to be the 25th year of operations, i.e. 24 years post-commissioning: *e=c+24*)
- w is the last year of the considered life for the asset
- r is the social discount rate

In the special case where straight-line depreciation is used, with no replacement costs after commissioning of the project, *Dep* is constant and defined by the ratio of total *CAPEX* divided by the number of years *(w-c+1)* in technical life. The formula becomes:

$$R_v = \frac{CAPEX}{w-c+1} \sum_{t=e+1}^{t=w} \frac{1}{(1+r)^{t-n}}$$

Using the formula of the sum of geometric series, the residual value boils down to the following equation:

$$R_v = \left(\frac{CAPEX}{w-c+1}\right)\left[(1+r)^{n-e-1}\right]\left[\frac{1-(1+r)^{e-w}}{1-(1+r)^{-1}}\right]$$

Annex II: Other Economic Performance Indicators

Economic Benefit/Cost ratio

It represents the ratio between the discounted monetised benefits and the discounted costs. It is the present value of project benefits divided by the present value of project costs.

$$EB/C = \frac{\sum_{t=f}^{c+39} \frac{B_t}{(1+r)^{t-n}}}{\sum_{t=f}^{c+39} \frac{C_t}{(1+r)^{t-n}}}$$

Where:

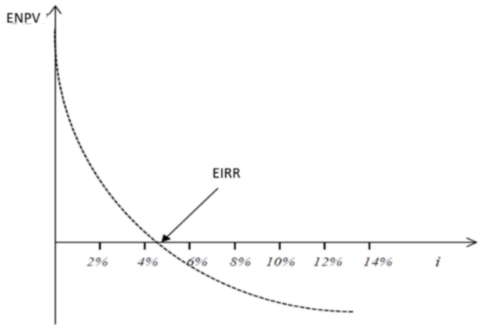
- ***c*** is the first full year of operation
- $\mathbf{B_t}$ is the monetised benefits induced by the project on year *t* (this includes the Residual Value at the end of the project economic lifetime, when considered)
- $\mathbf{C_t}$ is the sum of CAPEX and OPEX on the year *t*
- ***n*** is the year of analysis (common to all projects)
- ***r*** is the Social Discount Rate of the project
- ***f*** is the first year where costs are incurred

If EB/C exceeds 1, the project is considered as economically efficient as the monetised benefits outweigh the costs on the economic life. This indicator has the advantage of not being influenced by the size of projects, not disadvantaging small ones. This performance indicator should therefore be seen as complementary to ENPV and as a way to compare projects of different sizes (different level of costs and benefits).

This performance indicator allows to compare projects even in case of EB/C lower than 1.
It is not appropriate for mutually exclusive projects. Being a ratio, the indicator does not consider the total amount of net benefits and therefore the ranking can reward more projects that contribute less to the overall increase in public welfare.

Economic Internal rate of return (EIRR)

The indicator is defined as the discount rate that produces a zero ENPV.



A project is considered economically desirable if the EIRR exceeds its socio-economic Discount Rate. Mathematically, the EIRR is calculated as the value of the discount rate that satisfies the following formula.

$$0 = \sum_{t=f}^{c+39} \frac{B_t - C_t}{(1 + \mathrm{EIRR})^{t-n}}$$

Where:

> ***c*** is the first full year of operation

> $\mathbf{B_t}$ is the monetised benefits (SEW) induced by the project on year *t* (this includes the Residual Value at the end of the project economic lifetime, when considered)

> $\mathbf{C_t}$ is the sum of CAPEX and OPEX on the year *t*

> ***n*** is the year of analysis (common to all projects)

> ***f*** is the first year where costs are incurred

There are several shortcomings related to the use of the EIRR:

> If the "sign" of the benefits changes in the different years of the assessed time horizon, there may be multiple EIRRs for a single project. In these cases, the indicator will be impossible to implement;

> It is highly sensitive to the assumed economic life: when projects with different economic lives are to be compared, the IRR approach inflates benefits of a short-life project because IRR is a function both of the time period and of the size of the investment incurred;

> It is highly sensitive to the timing of benefits: in case of projects not producing benefits for many years, the EIRR tends to be lower compared to projects with a more "constant"

distribution of benefits over time, even though the net present value of the former may be higher;

> It cannot be used with time-varying discount rates.

For all the above-mentioned shortcomings, in case of contrasted results between the ENPV and the EIRR, the ENPV decision rule shall always be preferred.

Annex III: Recommendation on time horizon and EPI interpolation

For the Economic Performance Indicators and based on CBA results for simulated years, the economic cash flow for each year should be calculated in the following way:

- From the first full year of operation until the next simulated year the monetised benefits should be considered equal to the monetised benefits of the simulated year
- The monetised results as coming from the simulations and used to build the EPI will be **linearly interpolated** between two simulated years (e.g. n+10 and n+20)
- The monetised benefits will be kept constant until the 39th year of life of the project after the last simulated year
- The assessment of all the projects should take place at the same year of analysis (*n*) and take into consideration an economic life of 40 years. For example, projects may be commissioned in 2029 or 2033, their benefits and costs will be considered for the following 40 years but all discounted in the same year (e.g. 2023). Following this approach:

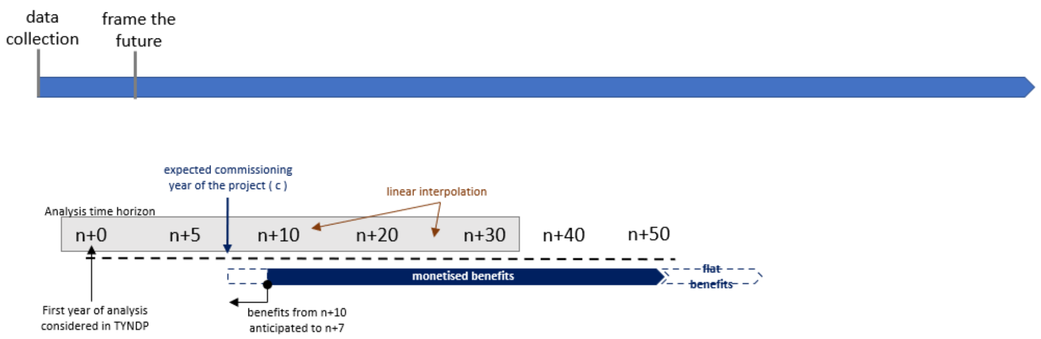


Figure 15 – Representation of economic cash flow assessment in case of projects to be commissioned between two assessed years

For multi-phase projects or group of projects the benefits will be counted according to the year of the first phase/project to be commissioned. This allows to take into account projects or group of projects where the implementation of the first phase/project already brings benefits and contributes as the enhancers to the other phases/projects of the group.
Furthermore, in case of the assessment of multi-phase projects or group of projects the residual value (when considered) of each phase/project should be indicated accordingly to the commissioning year of the considered phase/project.

A table representing both the situation of a single phase and a multiphase project is given below.

TYNDP-horizon	n+0	…	n+4	n+5	n+6	n+7	…	n+16	…	n+24	*Constant benefit*			*Input for residual value (yrs.)*
Economic cash flow	**Single phase project**			**c**	c+1	c+2	…	c+11	…	c+15	c+16	…	c+39	**40**
	Multiphase project – Phase 1			**c**	c+1	c+2	…	c+11	…	c+15	c+16	…	c+39	**40**
	Multiphase project – Phase 2					**c**	…	C+9	…	C+13	C+14	…	C+37	**38**
				Common time horizon of 40 years of operation for EPI calculation *For multi-phase projects the Time Horizon for the whole project ends with the 40 years of operation of the first phase/commissioned project*										

(*) n is the first year of analysis
(**) c is the commissioning year
(***) number of years of operation to be considered for the depreciation of the asset in the calculation of the Residual Value

Table 5 – Illustration of the economic cash flow assessment

At the same time, in order not to overestimate the benefits and in line with section 4.7, a sensitivity analysis on the commissioning year should be considered, starting this time by taking into account the benefits from the full operational year of the last phase/project to be commissioned. In this way, the total benefits, when discounted, will be lower since happening further in the future. This allows to take into consideration the situation where the first phase/project are enablers of the other phases/project of the group and the benefits do not appear before the full implementation of the project/group of projects.
Continuing with the example above this time we start calculating the benefits of the overall project from the commissioning year of the last phase to become operational. Therefore, benefits stemming from the realisation of the first phase will be considered from c+2.