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

PRELIMINARY DRAFT

Contents

Foreword

This preliminary draft single-sector Cost-Benefit Analysis (CBA) methodology is created on the basis of Article 11 of the Regulation (EU) 2022/869 (TEN-E Regulation). It aims at establishing the 3rd ENTSOG CBA Methodology with a focus on hydrogen infrastructure. Under consideration of the feedback received to this preliminary draft version, a draft version will be submitted by ENTSOG to the Member States, the European Commission (EC), and the Agency for the Cooperation of Energy Regulators (ACER). 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 and more generally of the overall gas and hydrogen infrastructure**. 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 specific input data specifications for each TYNDP cycle.

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,

[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

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The previous ENTSOG CBA methodologies were in line with the repealed TEN-E Regulation (EU) 347/2013 considering mainly natural gas infrastructure, while other sectors were captured through the scenarios.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 point (3) of the new 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 is reflected by the structure of this methodology:

- Define the assessment framework
- Assess the overall system, including the identification of the infrastructure gaps
- Assess projects through an incremental approach and a CBA

1. 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 guidelines 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, supply patterns and 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.

1.1 Scenarios

The Scenarios for the TYNDPs are established in line with Article 12 of the TEN-E Regulation.

Time horizon

The reference time horizon to be used in the assessment will be defined by the common ENTSO-E and ENTSOG scenarios.

In order to enable evaluation of projects' impacts against the targets set by the European policies while keeping the number of results reasonable, the assessment framework will set the minimum number of years for which the analysis will be performed.

> For the mid- and long-term horizon, it will be defined by 10-year-rounded years (e.g., 2030, 2040, 2050, etc.), using interpolated values for years within this time interval.

> For the mid-term horizon, additional assessment years could be considered defined by 5-year-rounded-years (e.g., 2025, 2030, 2035).

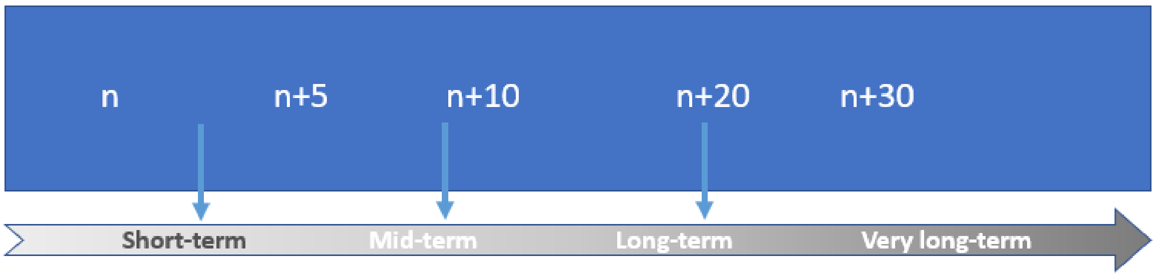


Figure 1: Assessed years according to the different time horizons.

Possible contrasted futures

The realistic identification of infrastructure gaps and the assessment of projects require the consideration of contrasted possible futures. This involves consideration of the storylines based on demand and supply assumptions reflecting the possible range of the future energy supply mix and demand evolutions. Each storyline is then developed in quantitative scenarios that cover different situations, reflecting how uncertain aspects of the future could materialise. Consideration of different energy scenarios may support decision makers' strategies and policies in circumstances of unknown outcomes, with scenarios describing how alternative energy conditions could develop in the future.

Scenarios are described using parameters of technologies, energy prices, emission prices, etc. Energy and environmental policies defined at national or European level, and related targets, are relevant in building those scenarios. Contrasted yet consistent assumptions will be retained for these different parameters, each set of assumptions corresponding to a scenario storyline.

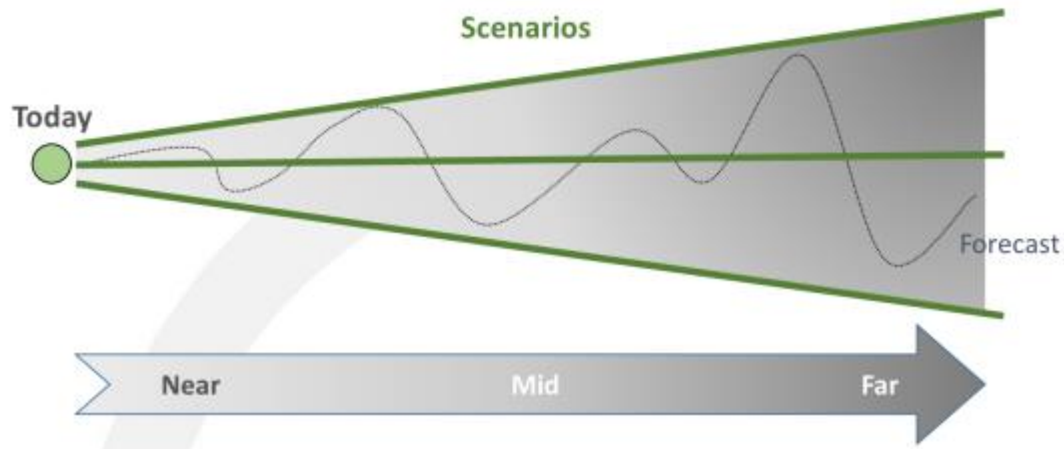


Figure 2: Scenarios to set the range of possible futures.

Demand

The common ENTSO-E / ENTSOG Scenario Report includes hydrogen, natural gas, and electricity demand information that will be considered for the System and PS-CBA (project-specific Cost-Benefit Analysis) assessments.

The following elements should be considered when building the storylines for demand scenarios.

- **Energy policies and regulation**: The demand scenarios should be realistically defined, reflecting actual energy policies and regulations set by decision makers to the extent possible. For example, any energy and environmental regulations at national or EU level should be considered.
- **Economic conditions**: Current economic trends as well as future evolutions should be carefully considered in order to define demand scenarios.
- **Commodity and CO2 prices evolution**: Contrasted views are also needed for commodity and CO2 prices, as they may have a direct influence on energy demand.
- **Energy efficiency**: Energy efficiency results from the combination of policy-driven measures and individual behaviour. Therefore, different assumptions regarding the capacity of stakeholders to achieve energy efficiency goals may be considered for demand scenarios.
- **Demand evolution in the different sectors**: The demand evolution in the different sectors is impacted by parameters such as the evolution of technologies, macroeconomic parameters, etc. Such parameters influence energy switching dynamics and in turn energy demand.

It is important for the assessment of hydrogen infrastructure that demand scenarios cover not only a yearly volumetric perspective but also **peak demand** and **seasonal profile** perspectives.

Seasonal patterns will become more important in the mid- to long-term, if the demand of hydrogen progressively increases in the heating and power sectors. Therefore, peak demand situations may well emerge as a key parameter for the network design and operation. **Peak demand cases**, on a single day or over a sustained period, are to be considered to reflect the capacity that the hydrogen infrastructure must be able to provide.
Thus, consideration of the hydrogen demand’s **seasonal profile** is also key for a realistic assessment of the hydrogen infrastructure.

This information is vital to assess the role that transmission systems, underground storages or LH2 terminals play as part of the hydrogen system. It is of specific interest how this infrastructure contributes to increasing flexibility and ensuring a safe, secure and sustainable operation of the hydrogen and electricity systems. High demand situations in particular, though the probability of their occurrence may be low, are critical for assessing security of supply.

In addition, for a comprehensive assessment of hydrogen projects at the European and national level, demand data must be defined at least with a **country level granularity** and on a daily basis **for hydrogen and natural gas systems**. As demand for sources of energy may evolve differently for different demand sectors (residential and commercial, industrial, transport, power), the development of demand scenarios must **sufficiently detail a sectorial breakdown** to capture the various sectorial trends.

The dynamic of the electricity system is such that supply, and demand must be met instantaneously in order to achieve the three market structures that are typical within Europe (day-ahead, intraday and balancing markets). The day ahead market predicts hourly supply and demand patterns for the following day. The other market (intraday and balancing) operates at a higher frequency of data availability but are not considered in the framework of the ENTSOG and ENTSO-E modelling exercises. This means the electricity system must be cleared on an hourly basis, which allows the systems to capture wind and solar patterns which fluctuate on a continuous basis. Operating at an hourly basis means that peak and seasonal cases can inherently be seen within the demand profiles model.
The frequency at which both the electricity and hydrogen data is available means that there is adequate information to determine whether there is sufficient renewable and nuclear capacity to meet demand for domestic hydrogen, whilst decarbonising the electricity sector simultaneously.

The need for renewable energy is exacerbated by the push for electrification of heating, transport, and in some cases industry. Heating of residential and tertiary buildings may result in a bigger technological shift to heat pumps, increasing the seasonal dependency of electricity supply. Electric vehicles will not greatly affect the seasonal pattern of electricity demand but will increase the base load electricity demand across Europe.

Consideration of Energy Efficiency first principle as part of Scenario process

Energy efficiency is one of the key pillars of EU energy policy, not only to meet EU's climate objectives, but also, to reduce dependence on fossil fuels from extra-EU countries and increase security of supply and the use of renewable energy.

By ensuring the implementation of the energy efficiency principle in the scenarios, it will also ensure its implementation in the subsequent steps of the TYNDP process, such as System assessment and PS-CBA, as both processes use demand and supply as input data from Scenarios.

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 can for example be observed in the level of energy demand. The scenarios aim to be in line with the final energy levels as it is defined in the EED or based on the latest figures available. Detailed information on the joint ENTSOG and ENTSO-E scenarios can be found in the respective scenario reports[3].

[3] https://www.entsog.eu/sites/default/files/2022-04/entsoe_entsog_TYNDP2022_Joint_Scenario_Report_Version_April2022_220411.pdf

Commodity and CO2 prices

Commodity and CO2 prices are important contextual elements that must be considered when developing possible future scenarios, as both will have an effect the energy mix and may impact hydrogen and natural gas demand.

In terms of CO2, market prices and the Social Cost of Carbon (SCC) represent two different approaches to CO2 prices. The CO2 market prices will drive market behaviour. In this respect, CO2 market prices are more accurate as a parameter influencing demand, which should be therefore taken into account for scenario building and modelling. The Social Cost of Carbon includes the full social cost of emitting one further ton of CO2, once external effects are also integrated. It represents the full economic marginal cost of emitting an additional ton of CO2 and may be relevant when assessing the benefits in terms of sustainability stemming from the realisation of a project.

The IEA World Energy Outlook can be one relevant source of information for possible future commodity prices and CO2 market prices, whereas it is recommended to use EIB as the source for the Social Cost of Carbon, in line with the EC's general principles for cost-benefit analyses.

Supplies

The common ENTSO-E / ENTSOG Scenario Report will be the source of the hydrogen, natural gas and electricity supply data that will be considered for the System and PS-CBA assessments.

A hydrogen and natural gas supply assessment is key to measure the contribution of a hydrogen infrastructure project to the European energy system. Scenarios should integrate differentiated evolutions for green ambitions and potential development of renewables and low-carbon sources in order to cover possible futures. They should also consider targets set by Member States and the European Union.

Supply patterns may evolve significantly over the coming decades. When assessing the European hydrogen and natural gas markets, it is necessary to capture the uncertainty in the development of supplies, by defining minimum and maximum supply potentials per supply source. These assumed minimum and maximum potentials for each source should be used as lower and upper limits for supply imports. Import capacities along the different import routes also have to be considered since they may represent a limit to the use of the supply potential.

The supply pattern of hydrogen might differ from the methane supply pattern. It is likely that relatively more hydrogen will be produced within the EU using various technologies (e.g., Steam Methane Reforming/Autothermal reforming or electrolysers/power-to-gas), when compared to the natural gas supply.

In addition, the supply pattern of the domestically produced hydrogen is considerably different compared to the conventional natural gas production. While the conventional natural gas production is almost constant, the hydrogen production using electrolysers fluctuates over the year. This is because the hydrogen production greatly relies on the availability and price of renewable electricity as main input. As a consequence, it is important for the assessment of hydrogen infrastructure that hydrogen supply profiles cover not only annual volumes but also assumptions on **daily and seasonal supply flexibility** induced by the different renewable production according to various climatic years.

The granularity of the supply source data must be, at least, differentiated among EU production (per EU country and production technology), imports via pipeline and imports via shipping. The level of granularity must also reflect the possible evolution over time in the types of hydrogen and natural gas transported within the hydrogen and natural gas grids.

LH2/LNG terminals allow various sources of gas to access the network. One single LH2/LNG regasification terminal may handle hydrogen or LNG coming from different basins across the world. This feature makes LH2/LNG terminals a significant factor for the diversity of supply sources. Therefore, with regard to LH2/LNG it must be considered, where relevant as part of the supply assumptions, that LH2/LNG is supplied from different sources. This must be duly reflected in the assessment, where relevant. More details can be found in chapter 3.2.2.

If additional sources other than the common ENTSO-E / ENTSOG Scenario Report are needed for the assessment, it is recommended to use transparent and preferably publicly available sources of information for supply data. The sources of data must be referenced.

1.2 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 3: Representation of the future EU integrated energy system (source: European Commission).

In the proposed ENTSOG single-sector preliminary methodology, joint modelling of the above-mentioned energy carriers is proposed to be captured:

- Interlinkages between hydrogen and electricity through a market modelling of the joint electricity-hydrogen systems.
- Interlinkages between hydrogen and natural gas networks through a dual hydrogen-natural gas network (and possible market) modelling.

This 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.

To perform a robust a complete assessment of the evaluated 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: Different methodologies are used within ENTSO-E and ENTSOG, therefore definitions may change slightly. The reference grids of the electricity and gas sectors are evaluated to determine which hydrogen infrastructure level matches the electricity reference grid, in terms of methodological approach.
- Hydrogen CCGTs: there is a direct connection between the gas node and the electricity node, in respect of the supply of hydrogen for use in gas turbines. The electricity system can access the hydrogen systems seasonal storage, allowing for cheaper electricity prices at various times during the year.
- Electrolysers: the electrolysers are the antithesis of the CCGTs, where hydrogen is converted to electricity through combustion. The electrolyser acts as a major supply source to the hydrogen system, converting non-CO2 emitting sources of electricity to hydrogen through electrolysis.

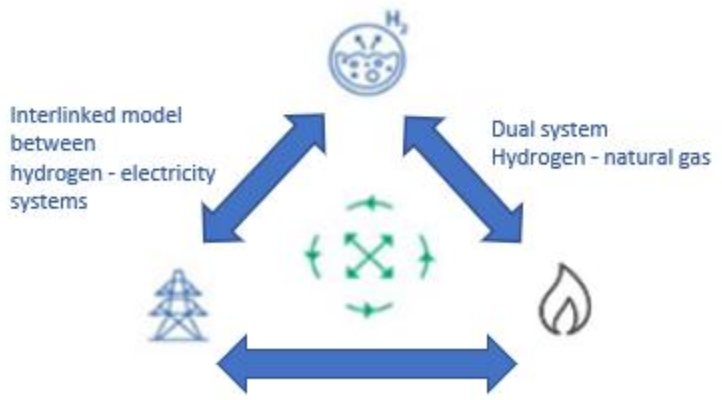


Figure 4: Representation of the interlinkages between hydrogen, electricity, and natural gas systems.

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. PS-CBA assessment.
Specific information on modelling assumptions and market assumptions used for developing the System and PS-CBA assessments must be publicly available as part of the TYNDP development process.

1.2.1 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.

Hydrogen existing infrastructure

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

Hydrogen planned 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 projects intending to apply for the PCI label should be part of the latest available Ten-Year Network Development Plan. 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.

Hydrogen reference network(s)

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

In addition, an upper limit of maximum three reference network(s) should be defined to keep project-specific results at a manageable number.

The EU-level topology should at least reflect the following items for the future European hydrogen infrastructure, which encompasses the infrastructures that can apply as PCI /PMI as listed in Annex II(3) of the TEN-E Regulation:

For hydrogen transmission infrastructure:

- Cross-border capacities between countries
- Cross-border off-shore capacities
- Meaningful transmission constraints within one country or area

For hydrogen storage infrastructure:

- 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:

- Expected connection to the future hydrogen grid
- Injection capacities into the hydrogen grid (along the year and during high demand situations if applicable)
- Storage volumes (converted to hydrogen)

For hydrogen production facilities:

- Expected capacity of the electrolyser
- Expected efficiency of the electrolyser
- Grid-connection capacity to/from the production facility on hourly and daily basis

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 majority of hydrogen projects are at an early stage of development In Europe, and most are considered as less mature projects – it is not known how many will reach an FID in the upcoming years. For this reason, the creation of infrastructure levels based on the maturity status of the projects will provide limited added value to the System and PS-CBA assessment phase. Gradually, once the implementation of hydrogen infrastructure starts, infrastructure levels based on their maturity or level of project advancement may be considered.

Assumptions to consider when building the hydrogen reference network:

It is foreseen that hydrogen infrastructure in Europe will progressively evolve, connecting diverse hydrogen supplies with consumption nodes or areas. Consideration of hydrogen reference network should capture the uncertainty inherent to hydrogen supply and demand evolution, therefore, it is recommended to consider at least two different hydrogen reference networks.

Considering two different and contrasted reference networks will allow definition of a robust and reliable assessment framework. Whereas, at the same time, it also decreases the uncertainty intrinsic to development of hydrogen infrastructure. Nonetheless, it is important to restrict the number of possible reference networks to allow for a manageable number of simulation cases during the System and PS-CBA assessment phases.

In accordance with the TEN-E Regulation, this CBA methodology will be applied for the preparation of each subsequent TYNDP developed by ENTSOG, and additionally for the PS-CBA of hydrogen infrastructure PCI projects.

The first and following PCI list(s) under the revised TEN-E Regulation for hydrogen infrastructure will set the foundations for hydrogen cross-border infrastructure in Europe. Considering the objectives and purpose of the amended TEN-E Regulation, it is foreseeable that hydrogen projects granted with the PCI label will benefit from an accelerated permitting procedure at national and EU level, as well as from a streamlined environmental assessment procedure at national level.

It may be the case that in the first PCI process under the revised TEN-E, the PCI status is not granted to hydrogen infrastructure in all European countries. Nevertheless, PCI infrastructure might progressively expand across Europe with the subsequent PCI processes, as hydrogen markets in Europe will emerge and evolve into more mature markets.

The **first hydrogen reference network** or configuration should be **based on 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 once adopted). This will enable comparison of projects in the PS-CBA phase, considering the minimum level of infrastructure that will probably be in place in the mid-term.

In addition, one additional extended hydrogen reference network will be considered**.**

For this purpose, additional non-PCI hydrogen infrastructure projects submitted to TYNDP will be considered as part of the second hydrogen extended network. However, in order to enable supply and demand adequacy of hydrogen, it might still be necessary to adjust the capacity data.

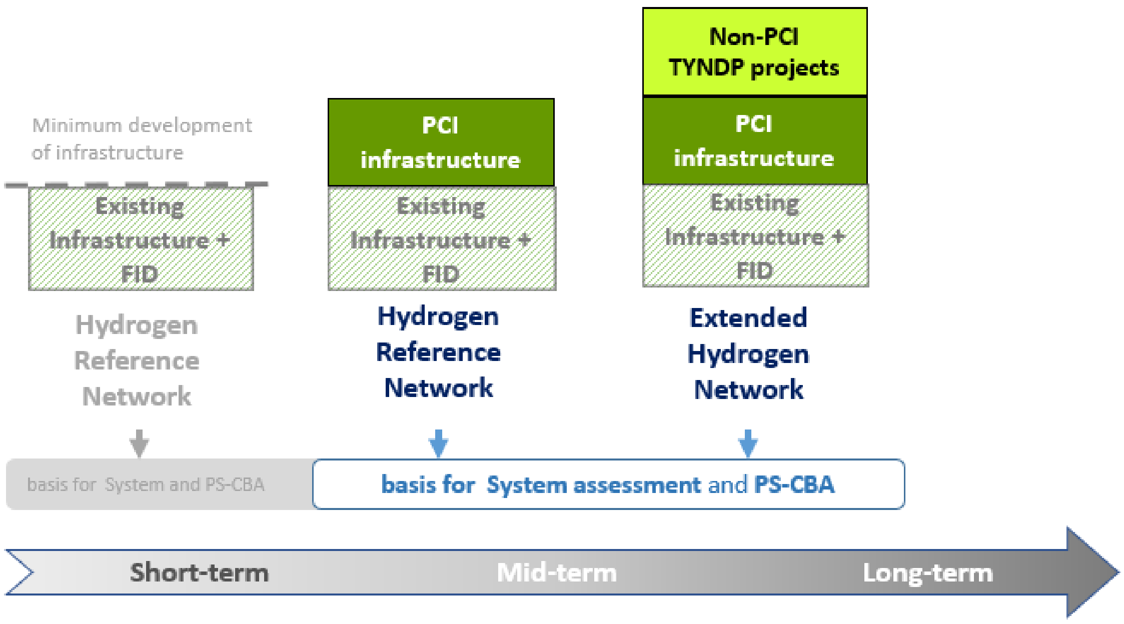


Figure 5: Consideration of Reference and extended Hydrogen networks as a basis for System and PS-CBA assessments

Once hydrogen infrastructure becomes established as part of the future European energy-system, the reference network should also consider an additional infrastructure level (especially relevant for the assessment of the short-term horizon) that could be based on the existing infrastructure and more mature projects (i.e., FID projects).

1.2.2 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. For the short- and mid-term, 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.

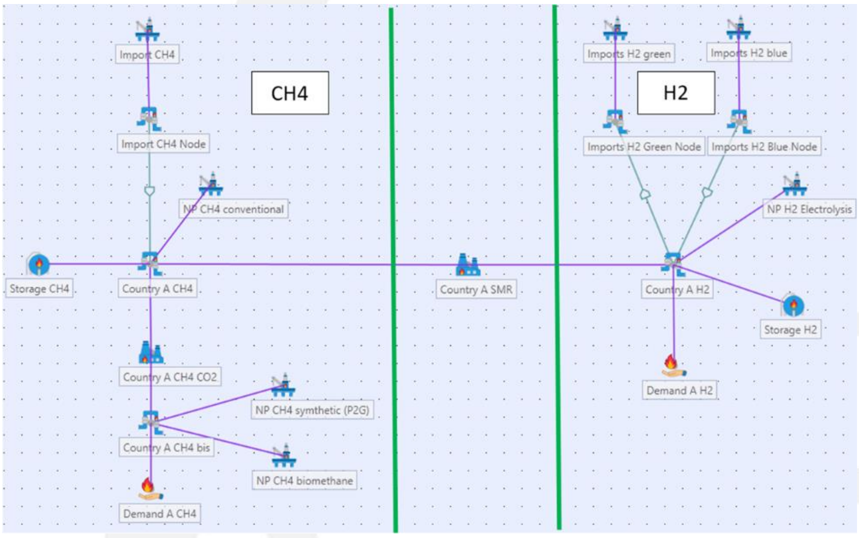


Figure 6: Interlinkage between hydrogen and natural gas networks.

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.

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)
    - Intra-country capacities between market areas
    - Meaningful intra-market areas constraints, where relevant
- LNG terminals infrastructure
    - Regasification capacities both along the year and during high demand situations

[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 maintain 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.

- 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.

> 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 represents one of the first steps to build a reliable assessment framework. This 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 reference network for natural gas should at least consider all the existing infrastructures. It is also recommended to consider projects having an FID status "all new projects for which a final investment decision has been taken […]" when defining the composition of the natural gas reference network.

In addition, in order to provide a wider perspective regarding the consideration of non-FID projects, an Advanced infrastructure level should be considered in the System Assessment.[7]

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 […]'.

1.2.3 Network assumptions and description of electricity infrastructure

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 as well as by increasing the use of renewables. This enables the integration of renewable and low-carbon H2 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 proving additional energy for direct or indirect electricity provision.

[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) o 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).

Definition of project maturity status is regularly updated as part of the TYNDP process and publish in the Practical Implementation Document.

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 these two energy carriers.

As defined in *section 1.1 Network and modelling assumptions*, 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.

Dispatch 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.

The hydrogen part of the model uses a one node per country approach since the hydrogen network has not yet been established. 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 *1.2.1Network assumptions and description of future hydrogen infrastructure*. 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.

The first connection is through electrolysers. 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. This limits the options to nuclear or renewables. 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.

The second connection is 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 section of the methodology considers the different market assumptions that should be considered. These assumptions are especially important in the long-term horizon once hydrogen markets will progressively emerge in the different European countries. However, it will require a long- to mid-term horizon to achieve a well-connected and effective market in Europe.

The current CBA methodology focusses on the most relevant market assumptions for the identification of cross-sectoral benefits in the electricity and hydrogen systems. 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 curtailed energy 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 VOLL of hydrogen 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, imports or ultimately curtail the demand.

2. 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.[8]

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 at the extent possible against these criteria[9].

Consideration of energy efficiency first principle in the System Assessment is already included as part of the scenarios and thereby in the basis for infrastructure gaps identification[10] (more details are included in section 1.1).

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

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

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.

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[11] 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.

[11] 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.

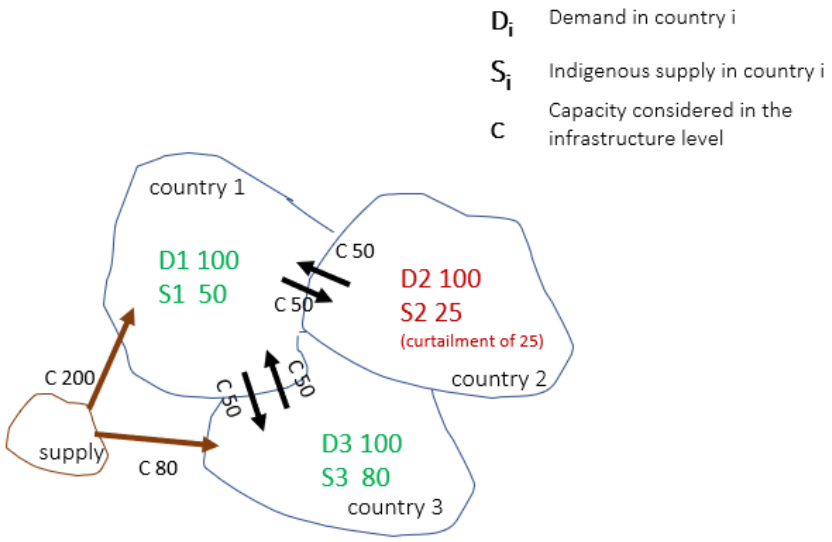


Figure 7: Practical example of infrastructure gap identified in Country 2.

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.

As detailed in the previous section *1.2.1 Network assumptions and description of future hydrogen infrastructure,* hydrogen infrastructure is still at early stages of development. It is expected that time horizon considered for System assessment is extended to the long or very long-term horizon. Therefore, a robust assessment with consideration of several potential infrastructure levels as reference networks is advisable.

Firstly, the reference network that will include the latest PCI infrastructure level and eventually, once in place, the future existing hydrogen network completed with FID projects, that will be considered as the minimum development of infrastructure.

Secondly, the extended reference network(s) that will include all hydrogen projects submitted to TYNDP should also be considered for the analysis of the European system and of the projects' impact and to ensure adequate comparison.

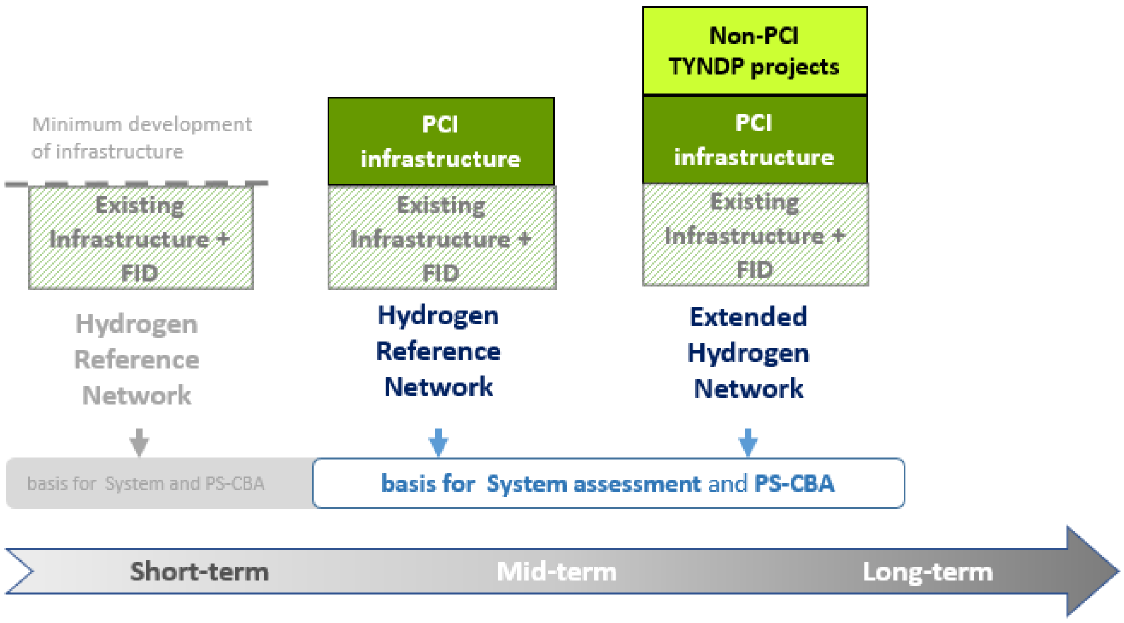


Figure 8: Consideration of the reference and extended networks in the System assessment.

3. Project-Specific Assessment

3.1 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

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 recommendations on the consistency of CBA Methodologies, each TYNDP and PS-CBA process will be supplemented by a complementary document named 'Implementation Guidelines'.

Results will be published in the TYNDP in the form of a **Project Fiche**. 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.

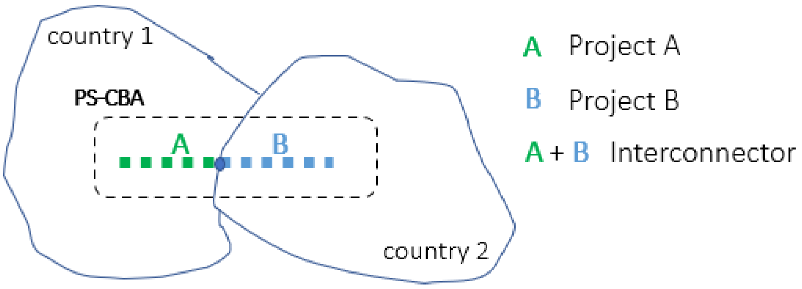


Figure 9: Example of project grouping in case of an interconnection formed by two projects.

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, 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 by 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.

- **Enhance**r (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.

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 of more investments are not realised.

Because hydrogen infrastructure is currently at early stages of development, and therefore its planning and implementation is quite dynamic and can change rapidly, grouping principles should be flexible enough to consider the evolving nature of hydrogen infrastructure.

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.

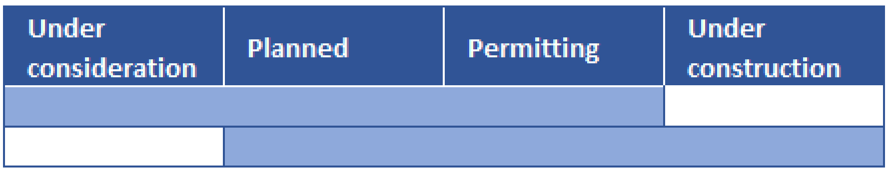


Figure 10: Illustration of the clustering of investments according to the status of implementation of projects.

- Investments can only be grouped together if their expected commissioning years are less than 10 years apart.

> 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.

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.

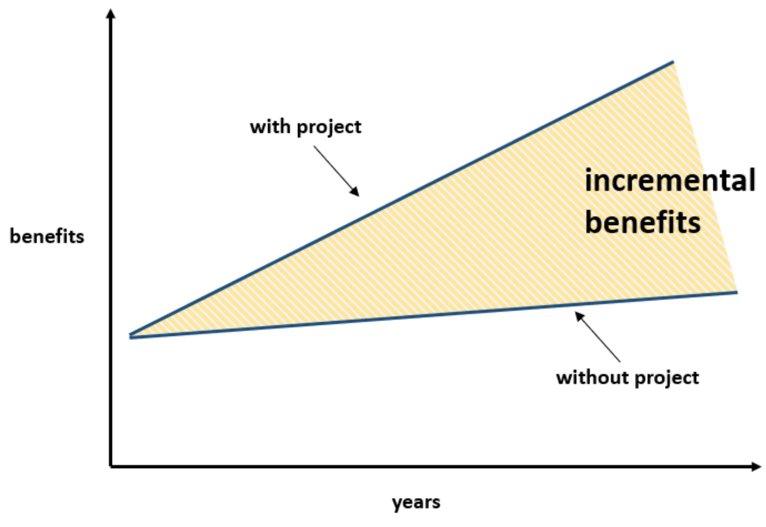


Figure 11: Incremental approach (adapted from Belli (ed.) et al.).

The counterfactual situation against which the project[12] 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.

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.

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

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.

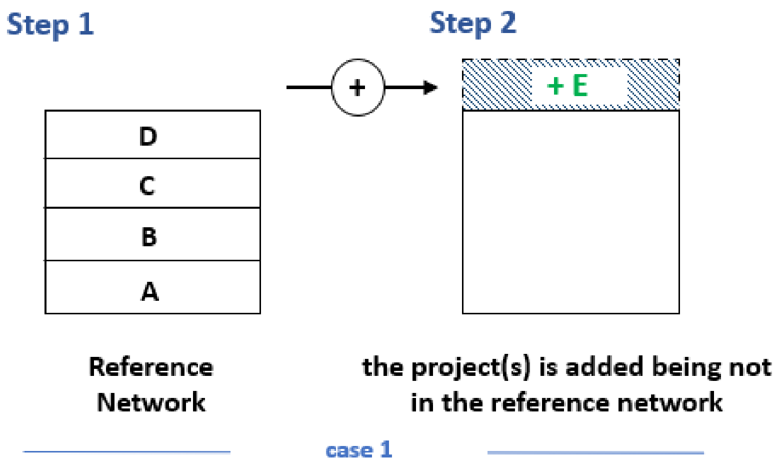


Figure 12: Incremental approach with PINT of project E.

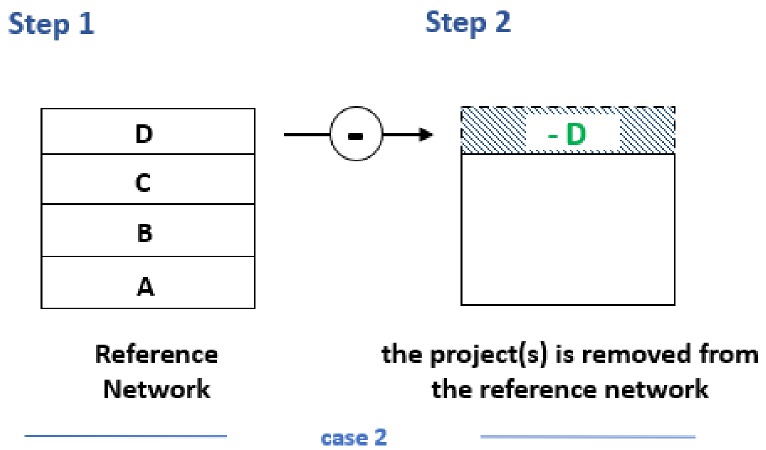


Figure 13: Incremental approach with TOOT of project D.

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.

3.2 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 CO2 emissions variation (B1),** related to
    - Integration of renewable energy
    - And/or substitution of higher-carbon energy sources
- Additional **societal benefit due to non-CO2 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)**

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.

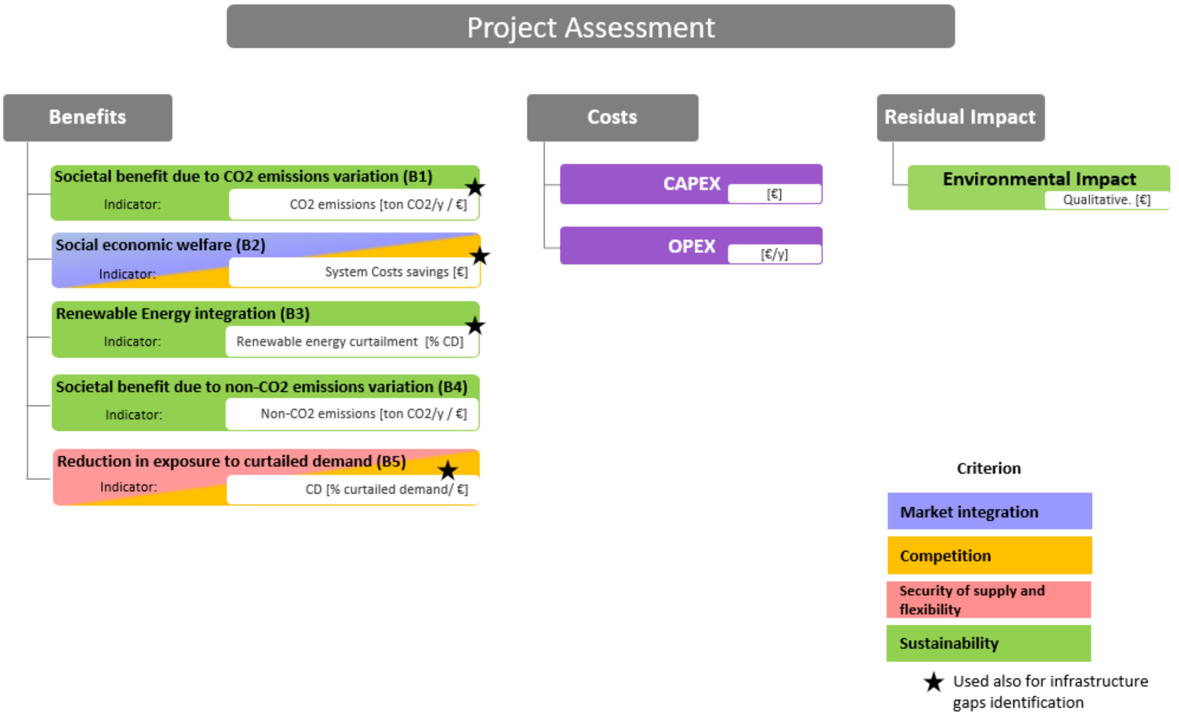


Figure 14: CBA metric and TEN-E Regulation criteria.

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.

3.2.1 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.

3.2.2 Indicators

The below set of indicators covers all specific criteria of the TEN-E Regulation and all the benefits identified in section 3.2. All indicators should be used as part of the incremental approach (as per section 3.1) in order to evaluate the contribution of a project along the specific criteria set by the Regulation.

B1: Societal benefit due to CO_2 emissions variation

Definition	This indicator measures the reduction in CO_2 emissions as a result of implementing a new project, based on the CO_2 emissions comparison with/without the project.
Indicator Calculation	The indicator considers the change of CO_2 emissions as a result of changing the generation mix of the electricity sector or the supply source used to meet hydrogen demand. This indicator is first expressed in quantitative terms in tonnes of CO_2 emissions savings. Then, the benefit is finally expressed in monetary terms (€ or M€) when the tons of CO_2 emission savings are multiplied by the shadow cost of carbon.
Model	Dispatch simulations
Interlinkage with other indicators	B2 Social economic welfare

Introduction

The EU has set itself an objective to reach carbon neutrality by 2050, which means an economy with net-zero greenhouse gas emissions. This objective is at the heart of the European Green Deal[13] and in line with the EU's commitment to global climate action under the Paris Agreement. In this context and consistently with EC's Hydrogen strategy[14], it is expected that hydrogen infrastructure will play a very important role in the decarbonisation of the EU energy system, especially in the industrial and power sectors as well as the heat and transport sectors. Hydrogen infrastructure could, therefore, 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 greenhouse gases emissions due to a new project, this indicator follows a two-step approach:

Step 1: Quantitative terms

[13] https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en
[14] https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen_en#eu-hydrogen-strategy

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

Step 2: Monetization

The resulting amount of generated/avoided GHG emissions in tonnes of carbon dioxide equivalent (CO2e) derived in step 1, should 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 Social Economic Welfare through energy production costs. The production costs are considered for electricity generation and SMR. 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 CO2 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[15], 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 greenhouse gas 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.

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

Methodology

This indicator measures the reduction in CO2 emissions due to the implementation of a new project. Therefore, the CO2 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

In the electricity system, an asset such as electricity grid can be used to allow generation with lower CO2 emissions to replace higher CO2 emitting generation in a neighbouring country. This will in turn reduce the overall CO2 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.

In the hydrogen system, domestically produced hydrogen can be used to replace hydrogen produced using natural gas (such as SMR) which comes with a CO2 emission. 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.

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.

$$B1 = CO_2 \, variation \, x \, (Societal \, \mathrm{Cos}\,t \; of \; CO_2)$$

B2: Cross-Sectoral Social Economic Welfare

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	Dispatch simulations
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.

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) Monetisation: Already monetised as part of B1 and B3
Model	Dispatch simulations
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 amount of additional 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. The integration of RES can be triggered by:

- 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 by 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 (Steam Methane Reforming) or imports. Additionally, it can be used to integrate hydrogen into a zone with additional 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.

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. 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 (M€) when the tons of non-GHG emission savings are multiplied by the shadow cost of air pollutants.
Model	Dispatch simulations
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[16], in addition to 2030 targets for the reduction of air pollution set in the zero-pollution Action Plan[17].
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.

[16] EC Communication: Pathway to a Healthy Planet for All (link)
[17] 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).

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.

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:

$$B4 = non - GHG\ emissions\ variation \cdot (Damage\ cost\ of\ pollutant)$$

It is recommended to favour transparent and preferably publicly available sources of information (such as European Environment Agency[18]) 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.

[18] 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.
Indicator Calculation	The indicator is calculated under normal conditions as well as 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, by making assumptions on the estimation of future Cost of hydrogen disruption (CODH) that, as a conservative proxy, could be aligned to the values adopted for the Cost of Disrupted Gas (CODG).
Model	Dual assessment model hydrogen-natural gas
Interlinkage with other indicators	No interlinkage

Introduction

To achieve the energy pillar of Security of Supply 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:

> Normal (climatic) conditions
> 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)
> Infrastructure stress conditions, in case of disruption of the single largest capacity[19] 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 could be monetised as follows:

$$B5 = Avoided\ curtailed\ demand(GWh) \cdot \mathrm{CODH}\ (€/\mathrm{GWh})$$

Where

> 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

With the definition of an EU hydrogen security of supply policy for the definition of a Cost of Disrupted Hydrogen (CODH), it will be introduced a harmonised reference value at EU level 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.

[19] 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.

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.

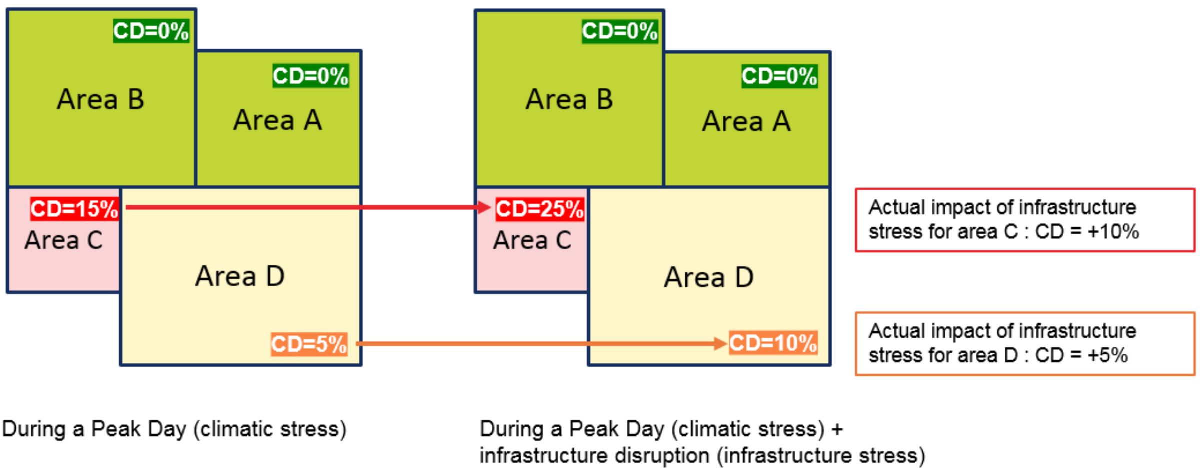


Figure 15: Example of curtailed demand indicator during a peak-day compared to a combination of supply route disruption during peak-day.

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[20], 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 1: 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	Additional expected 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)

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

- Related costs: The promoter should indicate whether this impact was already taken into account in the considered CAPEX and OPEX and provide adequate justification
- Additional expected costs: If the costs of the environmental impact were not already internalised in the CAPEX and OPEX of the projects, the promoters should indicate here the cost of such additional measures

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 3.2.2. 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.

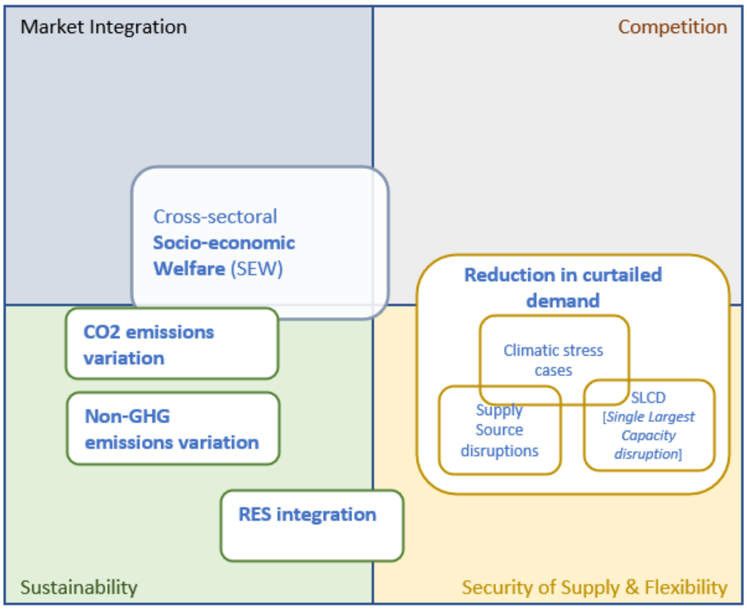


Figure 16: description of CBA indicators' interlinkages and potential areas of overlapping.

3.3 Projects costs

Costs represent an inherent element of a CBA analysis. According to Annex V(8) of the Regulation, "*the cost-benefit analysis 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[21] 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[22]
- **replacement costs**, are the costs borne to ensure that the infrastructure remains operational by changing specific parts of it[23]

> **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 (see section).
As part of the TYNDP and PCI processes, it is recommended that constant prices refer to the year of the TYNDP project collection.

Additional specifications of CAPEX and OPEX

[21] This classification is in line with the EC Guide to Cost-Benefit Analysis of Investment Projects.
[22] 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.
[23] Over the project assessment period.

3.4 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.

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

3.4.1 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[24]. 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.

[24] 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.

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.

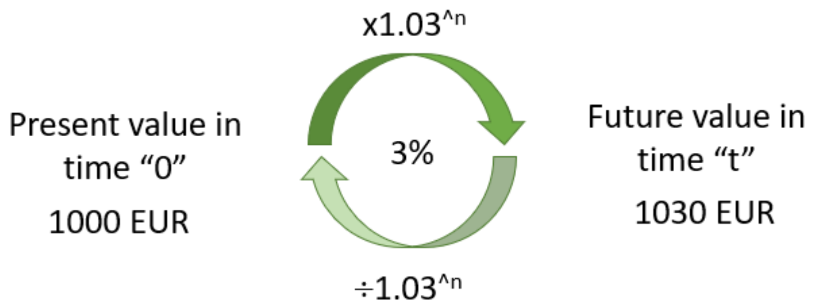


Figure 17 – Example of how the social discount rate works.

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 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[25]. It therefore provides a fair basis for the comparison of projects, unbiased by the

[25] European Commission - Guide to Cost-Benefit Analysis of Investment Projects, page 55.

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.

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 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.

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[26].

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

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.

3.4.2 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.

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

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 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"[27] (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 generation*s".

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**.

3.5 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
- commodity and CO_2 prices

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

- supply potentials
- supply generation patterns

Those elements are already captured by the different demand and supply scenarios considered (see section **Error! Reference source not found.**).

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:

- 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
- Residual value (calculation of economic performance indicators with and without residual value)

Annex I: Residual Value

As part of the project's economic analysis the residual value should be calculated 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 40th year of operations, i.e. 39 years post-commissioning: *e=c+39*)
- 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:

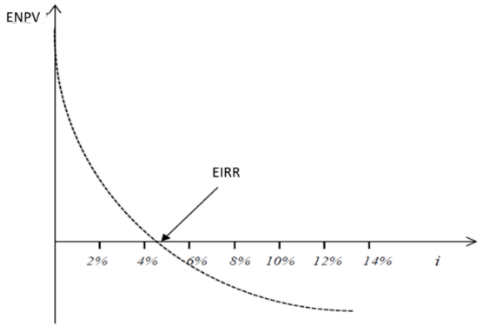
- ***c*** is the first full year of operation
- $\mathbf{B_t}$ is the monetised benefits (SEW) induced by the project on year *t* (this includes the Residual Value at the end of the project economic lifetime, when considered)
- $\mathbf{C_t}$ is the sum of CAPEX and OPEX on the year *t*
- ***n*** is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

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

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:

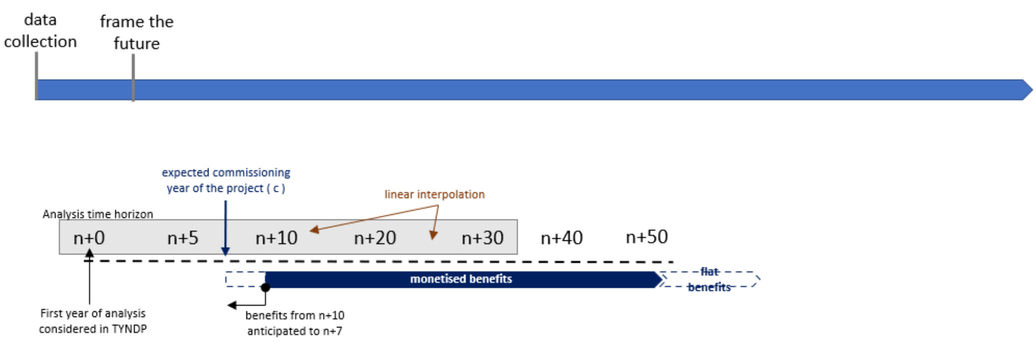


Figure 18 – Representation of economic cash flow assessment in case of projects to be commissioned between two assessed years

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 2 – Illustration of the economic cash flow assessment

At the same time, in order not to overestimate the benefits and in line with section 3.5, 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.

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Avenue de Cortenbergh 100
1000 Brussels, Belgium

Cover picture Courtesy of TAP (Trans Adriatic Pipeline)

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

info@entsog.eu | www.entsog.eu