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Harmonised system-wide cost-benefit analysis for candidate hydrogen projects

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Contact information
Name: Tilemahos EFTHIMIADIS
Address: European Commission – JRC, P.O. Box 2, 1755 ZG, Petten, the Netherlands
Email: tilemahos.efthimiadis@ec.europa.eu

Name : Cristobal IRAZOQUI
Address : European Commission – DG ENER, 1049 Brussels, Belgium
Email: cristobal.irazoqui@ec.europa.eu
Tel : +3222982103

EU Science Hub
https://joint-research-centre.ec.europa.eu

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Contents

Abstract

This report presents the Cost-Benefit Analysis (CBA) methodology for candidate hydrogen projects developed by the European Commission in compliance with the requirements set in the Regulation (EU) 2022/869 and to be used for the identification of the first Union list of projects of common interest and of projects of mutual interest established pursuant to Regulation (EU) 2022/869.

1 Introduction and scope

Cost–benefit analysis (CBA) is a systematic evaluation tool aimed at determining whether an action/decision/investment is socio-economically desirable namely, if its prospective or potential system benefits (referred in the following as "benefits") outweigh its costs, with the aim of comparing different actions/decisions/investments. A CBA methodology must describe the common principles for undertaking a CBA as well as clarifying the different steps a user must carry out to perform the exercise.

This CBA methodology for candidate hydrogen projects (in the following, "hydrogen CBA methodology") has been developed by the European Commission (the "Commission") in compliance with the requirements set in Article 11(8) of the revised Regulation (EU) 2022/869 (in the following, "TEN-E Regulation") [1]. In particular, the hydrogen CBA methodology has been developed to ensure a harmonised energy system-wide cost-benefit analysis at Union level and it is compatible in terms of benefits and costs with the methodologies developed by the ENTSO for Electricity and the ENTSO for Gas pursuant to Article 11 to TEN-E Regulation[1].

Article 11 of the TEN-E Regulation mandates ENTSOG to develop a draft CBA hydrogen methodology by April 2023, followed by Member States' and ACER opinion and finally the Commission approval, resulting in a final hydrogen CBA methodology no earlier than end of 2023. This requirement does not meet the timeline of the 1st PCI/PMI process under the revised TEN-E Regulation, which should end in the adoption of the first Union list of PCI/PMI by November 2023.

Taking these time limitations into consideration, the Commission has tasked JRC to elaborate a hydrogen CBA methodology. This considered the input received from ENTSOG and ACER. This hydrogen methodology has, therefore, the purpose to bridge the gap between the 1st hydrogen PMI/PCI process under the revised TEN-E Regulation and the ENTSOG methodology to come in time for the next PCI/PMI process.

This hydrogen CBA methodology has been developed in a transparent manner, including extensive consultation of Member States and all relevant stakeholders.

1.1 The TEN-E Regulation

The Trans-European Networks for Energy (TEN-E) is a policy instrument focused on developing and linking the energy infrastructure of European Union (EU) Member States[2]. A well-planned and integrated energy infrastructure is essential to achieve such objectives: energy infrastructure is the part of the system that enables renewable energy to be incorporated into the grid, and then transmits and distributes energy across the EU from the supply source (whether imported or generated within the EU) to the end user, or stores energy until it is needed. Energy infrastructure provides for a reliable and secure energy system that helps to keep energy prices in check[3].

The revised TEN-E Regulation, entered into force in June 2022, lays down guidelines for the timely development and interoperability of the priority corridors and areas of trans-European energy infrastructure contributing at mitigating climate change by supporting the achievement of the EU climate and energy 2030 targets and the EU climate neutrality objective by 2050 at the latest:, and to ensuring interconnections, energy security, market and system integration and competition that benefits all Member States, as well as affordability of energy prices.
More specifically, the TEN-E Regulation:

- provides for the identification of projects on the Union list of projects of common interest (PCIs) and of projects of mutual interests (PMIs);
- facilitates the timely implementation of the Union list by streamlining, coordinating more closely and accelerating permit granting processes, and by enhancing transparency and public participation;
- provides rules for the cross-border allocation of costs and risk-related incentives for projects on the Union list.

(1) At the time of writing, the following methodologies developed by the ENTSOs are under public consultation:
- 4th ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects: draft version 4.0 for public consultation (20 December 2022); and
- ENTSOG Single-Sector Cost-Benefit Analysis (CBA) Methodology – Preliminary draft (28 February 2023).

(2) https://energy.ec.europa.eu/topics/infrastructure/trans-european-networks-energy_en

(3) https://ec.europa.eu/info/news/in-focus-making-eus-energy-infrastructure-fit-climate-neutrality-2021-jun-15_en

1.2 General criteria for candidate hydrogen projects

In its assessment of applications received, the Commission shall check the compliance with respect to the general criteria foreseen in Article 4(1) to TEN-E Regulation. In particular, the application for the candidate projects shall clearly show that:

- the project is necessary for at least one priority corridor for hydrogen and, as described in Article 4(1)(a) to TEN-E Regulation;
- the potential overall benefits of the candidate project, assessed in accordance with the relevant specific criteria, outweigh its costs, including in the longer term, in line with the provisions set in Article 4(1)(b) to TEN-E Regulation.

Pursuant to Article 4(1)(c) to TEN-E Regulation, the candidate project shall either:

- involve at least two Member States by directly or indirectly, via interconnection with a third country, crossing the border of two or more Member States; or
- be located in the territory of one Member State, either inland or offshore, including islands, and has a significant cross-border impact as set out in point (1)(d) of Annex IV to TEN-E Regulation: "*for hydrogen transmission, the project enables the transmission of hydrogen across the borders of the Member States concerned, or increases existing cross-border hydrogen transport capacity at a border between two Member States by at least 10 % compared to the situation prior to the commissioning of the project, and the project sufficiently demonstrates that it is an essential part of a planned cross-border hydrogen network and provides sufficient proof of existing plans and cooperation with neighbouring countries and network operators or, for projects decreasing energy isolation of non-interconnected systems in one or more Member States, the project aims to supply, directly or indirectly, at least two Member States*;", and in point (1)(e) of Annex IV to TEN-E Regulation: "*for hydrogen storage or hydrogen reception facilities referred to in point (3) of Annex II, the project aims to supply, directly or indirectly, at least two Member States;*"

According to the aforementioned options, the application shall clearly describe the Member States directly or indirectly involved, the increase of existing cross-border capacity achievable thanks to the project, the importance of the project as part of a priority corridor for hydrogen and, if applicable, the Member States directly or indirectly supplied.

In particular, project promoters must ensure that their applications belong to the following hydrogen infrastructure categories as stated in point (3) of the Annex II to TEN-E Regulation:

- pipelines for the transport, mainly at high pressure, of hydrogen, including repurposed natural gas infrastructure, giving access to multiple network users on a transparent and non-discriminatory basis;
- storage facilities connected to the high-pressure hydrogen pipelines;
- reception, storage and regasification or decompression facilities for liquefied hydrogen or hydrogen embedded in other chemical substances with the objective of injecting the hydrogen, where applicable, into the grid;
- any equipment or installation essential for the hydrogen system to operate safely, securely and efficiently or to enable bi-directional capacity, including compressor stations; and
- any equipment or installation allowing for hydrogen or hydrogen-derived fuels use in the transport sector within the TEN-T core network identified in accordance with Chapter III of Regulation (EU) No 1315/2013 of the European Parliament and of the Council [2].

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

To verify the compliance with general and specific criteria, project promoters shall provide all the necessary underlying information and details.

1.3 Specific criteria for candidate hydrogen projects

The contribution of the candidate projects to the specific criteria foreseen in Article 4(3) of TEN-E Regulation needs to be demonstrated.

Pursuant to Article 4(3)(d) of TEN-E Regulation, project promoters shall clearly show that the project contributes significantly to:

— sustainability, including by reducing greenhouse gas emissions, by enhancing the deployment of renewable or low carbon hydrogen, with an emphasis on hydrogen from renewable sources in particular in hard-to-abate end-use applications in the industry and transport sectors, in which more energy efficient solutions are not feasible, and supporting variable renewable power generation by offering flexibility, storage solutions, or both,

and the project contributes significantly to at least one of the following specific criteria:

— market integration, including by connecting existing or emerging hydrogen networks of Member States, or otherwise contributing to the emergence of an Union-wide network for the transport and storage of hydrogen, and ensuring interoperability of connected systems;

— security of supply and flexibility, including through appropriate connections and facilitating secure and reliable system operation;

— competition, including by allowing access to multiple supply sources and network users on a transparent and non-discriminatory basis.

2 General approach

Similarly to the methodological approach exploited for candidate electricity transmission projects [3] and gas infrastructure projects [4], the assessment of candidate hydrogen projects shall take into consideration pertinent assumptions concerning future scenarios, the definition of the reference network used to assess the impact of the project; and the techniques to be used in calculating costs and benefits for the candidate hydrogen project.

Scenarios are a description of contrasted, yet plausible futures that can be characterised by a combination of demand and supply assumptions. With reference to the assessment of candidate hydrogen projects, such scenarios shall consider possible development for the electricity, gas and hydrogen systems as well as energy changes within the modelled systems (according to the different level of detail, it can encompass the geographical area immediately affected by the project or a wider area). These different future developments can be used as input parameter sets for subsequent simulations and analyses.

Benefits stemming from the realisation of candidate hydrogen projects should as much as possible be evaluated by using an interlinked model (or more coupled models) of electricity, gas and hydrogen systems. Such modelling framework should have an adequate resolution (to capture, for instance, the dynamics of renewable energy sources and electrolysers), and should explicitly include all relevant assets consistently with the developed scenarios.

This methodology is based on the multi-criteria approach, which allows to consider and combine monetised, quantified and qualitative benefits. This approach is also consistent with the ENTSOs methodologies.

The steps for applying the hydrogen CBA methodology to be carried out by ENTSOG are described below:

- clear identification of input information for the consistent assessment of candidate hydrogen projects, in compliance with general indications on common scenarios and assumptions, the latest TYNDP scenarios developed by the ENTSOs and other complementary information provided by ENTSOG, project promoters (see section 2.1);
- description of relevant modelling frameworks[4] used for the evaluation of benefits (see section 3.1) and description of the impact of any simplified assumption on the pertinent calculations;
- calculation of benefits (see section 3.1) within the study horizon in both "with" and "without" cases

(4) While ENTSOG is free to select any modelling tool for the assessment of the benefits of candidate hydrogen projects, it is recommended, when possible and relevant, the use of an open source tool (for instance, PyPSA [5]) to foster transparency.

- **calculation of costs (see section 3.2) within the study horizon; and**
- **calculation of the Economic Net Present Value and benefit-cost ratio.**

2.1 Scenarios and assumptions

A list of common parameters and assumptions ensures consistency across all candidate hydrogen projects. Some information are provided in the templates for candidate PCI projects; other assumptions and input parameters should be aligned with the latest joint TYNDP scenarios. Project promoters can introduce complementary assumptions, in line with the scope of the candidate hydrogen project: any choice of parameters and assumption from project promoters deviating from values described in joint TYNDP scenarios shall be clearly described and justified.

Below a list of key parameters and assumptions for candidate hydrogen projects is provided:

— duration of the study horizon. As a general assumption, the duration of the study horizon should be the minimum between a) the longest technical lifetime of any equipment and b) the maximum reference period for energy projects as referred to in Article 15(2) and Annex I to Commission Delegated Regulation (EU) No 480/2014[5] [6]. The duration of the study horizon shall not be in any case higher than the study horizon of the harmonised energy system-wide cost-benefit analysis methodology for projects on the Union list falling under the energy infrastructure categories set out in point (1)(a), (b), (d) and (f) and point (3) of Annex II to TEN-E Regulation. The study horizon shall start the year after the commissioning year

— hydrogen demand: for each Member State and for each year within the study horizon. Hydrogen demand should be netted by the amount of hydrogen not affecting the hydrogen grid infrastructure (for instance when hydrogen transport is covered via freight transport, trucks, etc.) Simplification related to the geographical scope are allowed, consistently with the geographical scope of the project;

— natural gas demand: for each Member State and for each year within the study horizon. Simplification related to the geographical scope are allowed, consistently with the geographical scope of the project;

— other fuel demands for each Member State and for each year within the study horizon. Simplification related to the geographical scope are allowed, consistently with the geographical scope of the project;

— hydrogen price: for each Member State, for each hydrogen production technology and for each year within the study horizon. This assumption should be consistent with the most updated TYNDP scenarios and, if available, the latest Commission data, where relevant;

— natural gas price: for each Member State and for each year within the study horizon. This assumption should be consistent with the most updated TYNDP scenarios and, if available, the latest Commission data, where relevant;

— other fuel prices for each Member State and for each year within the study horizon. This assumption should be consistent with the most updated TYNDP scenarios and, if available, the latest Commission data, where relevant;

— shadow cost of carbon for each year within the study horizon. As a general assumption, values for the shadow cost of carbon within the study horizon should be aligned, where applicable, to the most updated ones[6]; and

— emission and monetisation factors for non GHG emissions: for each Member State and for each year within the CBA horizon. This assumption should be consistent with the most updated TYNDP scenarios. Examples of reference monetisation values for select pollutants as found in [7] are reported here below:

(5) 25 years.
(6) In particular Tables 5 and 6 of Commission Notice 2021/C 373/01 [13], in line with the most updated EIB estimates. A review of the current values for shadow cost of carbon is expected in a future EIB Group Climate Bank Roadmap progress report [8].

Table 1. Reference monetisation values for select pollutants

€2015/kg	NOx	NH3	SO2	PM2.5	PM10	VOC
low	24.10	19.70	17.70	56.80	31.80	1.61
middle	34.70	30.50	24.90	79.50	44.60	2.10
high	53.70	48.80	38.70	122.00	69.10	3.15

Source: [7]

- discount rate. As a general assumption, a 4% discount rate should be assumed, in agreement with the current value assumed for other PCI energy infrastructure categories. The discount rate should in any case be compatible with the same value defined in the harmonised energy system-wide cost-benefit analysis methodology for projects on the Union list falling under the energy infrastructure categories set out in point (1)(a), (b), (d) and (f) and point (3) of Annex II to TEN-E Regulation.

To increase the validity of CBA results, sensitivity analyses shall be carried out by ENTSOG to evaluate the impact that the variation of parameters has on the socio-economic desirability of candidate hydrogen projects. It is important to note that the aim of such sensitivity analyses is not to introduce complete and different scenarios but to understand the resilience of the CBA evaluation with respect to few changes in critical parameters.

The parameters listed below can be subjected to sensitivity analyses carried out by ENTSG for candidate hydrogen projects. The list is not exhaustive and it shall be complemented with relevant information provided in the templates for PCI candidate submission:

- fuel and CO_2 prices;
- climate year: different climatic years result in different temperatures and, consequently, different values demand values;
- natural gas and hydrogen demand, as result of different techno-socio-economic conditions;
- commissioning date of projects: delays in any phase of the realisation of a project might its impact socio-economic desirability. A sensitivity analysis on the commissioning date increases the robustness of the CBA assessment;
- CAPEX and OPEX; and
- discount rate.

2.2 Project implementation status

In order to support the process for establishing the regional list of projects pursuant to Annex III to the TEN-E Regulation, project promoters for candidate PCI process shall declare in their applications the level of maturity of the relevant projects, in line with the following stages, consistent with PCI monitoring reports developed by ACER[7]:

- projects “Under consideration”
- projects “Planned but not yet in permitting”;
- projects “Permitting”; and
- projects “Under construction”

[7] *PCI monitoring* | www.acer.europa.eu. (2023). https://www.acer.europa.eu/gas/infrastructure/ten-e/pci-monitoring.

3 Project CBA for candidate PCIs

The assessment of candidate PCI hydrogen project shall be carried out considering the social perspective: Candidate projects would be considered sustainable from a social perspective if, in line with the provisions set in Article 4(1) to TEN-E Regulation, their potential overall benefits, assessed in accordance with the relevant specific criteria, outweigh their costs.

Benefits of a candidate hydrogen project must be calculated taking into consideration two configurations:

- "with case", where the candidate project is realised, it is inserted in the system and, if socio-economically desirable, realizes during its lifetime system benefits that are larger than total costs; and
- "without case" where the candidate project is not realised.

As said above, the calculation of the difference of indicators between the "with" and the "without" cases allow to calculate benefits. For instance, the variation of greenhouse gas (GHG) emissions achievable thanks to the realisation of candidate hydrogen projects is equal to the difference in the "with" case (i.e. the hydrogen project is built) and the "without case" (i.e. the hydrogen project is not built).

In some cases, the calculation of benefits does not need a complex modelling exercise representing the whole system, while in others extensive modelling activities are required. In some cases, simplifications might be introduced to reduce the modelling complexity, although there is trade-off between modelling complexity and accuracy of the assumption.

Benefits and non-capital costs are calculated for each year of operation of the project, throughout the duration of the study horizon of the equipment and installation constituting a candidate hydrogen project. Consequently, to compare the total benefits generated by the candidate project during its corresponding study horizon with the related total costs, this hydrogen CBA methodology requires the use of the discounted cash-flow method for the calculation of the *Economic New Present Value* (ENPV) of the candidate hydrogen project: in particular, annual cash flows considering costs and benefits in nominal terms shall be discounted using the discount rate as defined in section 2.1 of this hydrogen CBA methodology.

3.1 Benefits

While the calculation of each benefit should preferably aim for a monetary value, the lack of a fully operational EU hydrogen market, data and models may impede the full monetization of some benefits. Such monetization may be feasible in future assessments. Where monetization is not possible, the quantitative/qualitative assessment of the benefits are to be considered. In general, the indicators can be:

- **monetised**: they are expressed in monetary terms;
- **(non-monetised) quantified**: they are quantified but not expressed in monetary terms; and
- **qualitative**: they are expressed in qualitative terms (for instance, "++", "+", "0", etc.).

Table 1. Summary of benefits considered in the hydrogen CBA methodology

Benefit [unit]	Specific criterion - Article TEN-E
B1 - Variation of GHG emissions [€/a]	Sustainability - Article 4(3)(d), Annex IV (5)(a)
B2 - Variation of non-GHG emissions [€/a]	Sustainability - Article 4(3)(d), Annex IV (5)(a)
B3 - Integration of renewable and low-carbon hydrogen potential into the system [%]	Sustainability - Article 4(3)(d), Annex IV (5)(a)
B4 – Substitution effect – Fuel switching [€/a]	Competition - Article 4(3)(d)(iii), Annex IV (5)(d)

B5 - Reduction of curtailed hydrogen demand [GWh/a]	Security of supply and flexibility - Article 4(3)(d)(ii) and Annex IV 5(c)
B6 – Improvement of market integration [qualitative]	Market integration: Article 4(3)(d)(i) and Annex IV 5(b)
B7 - Increase of cross-sectoral flexibility [€/a]	Sustainability - Article 4(3)(d), Annex IV (5)(a)

The following sections describe how benefit indicators must be calculated in line with the specific criteria set in Article 4(3) of TEN-E Regulation.

Member States impacted by the benefits achievable thanks to the candidate hydrogen project should be identified and disaggregated benefits at Member State level should be provided.

All the benefits should be calculated in the way to avoid double counting. In this respect, ENTSOG shall clearly describe how this in ensured in the calculation of each benefit.

3.1.1 B1 – Variation of GHG emissions

Benefit Definition:

- Definition: economic valorisation of the variation of greenhouse gas emissions achievable thanks to the candidate hydrogen project.
- Relevance: Hydrogen projects are key infrastructural projects for integrating and enabling the consumption of renewable and low carbon hydrogen, for replacing the use of non-renewable hydrogen, natural gas and, under the proper socio-economic and technological conditions, enabling a cost effective solution to provide flexibility and, if need be, store energy (directly via compressed or liquefied hydrogen or indirectly via other mediums such as ammonia, methanol, solid-state systems, etc.). It will be measured as the contribution of a project to GHG emission reductions in various end-use applications in hard-to-abate sectors, such as industry or transport; flexibility and seasonal storage options for renewable electricity generation, as stated in the Annex IV (5)(a) to TEN-E Regulation.

Benefit Calculation:

- Modelling needs: Modelling needs shall be compatible with the methodology used by ENTSOG for calculating GHG emission savings (see 'Calculation process').
- Data needs: Data needs shall be compatible with the methodology used by ENTSOG for calculating GHG emission savings (see 'Calculation process').
- How the benefit is expressed: First, the benefit is expressed in quantitative terms as tons of equivalent carbon emission savings. Then, the benefit is finally expressed in monetary terms when the tons of CO2 emission savings are multiplied by the shadow cost of carbon. As a simplification in the absence of widely available and undisputed cost data, applying the shadow cost of carbon to all GHG emissions is in line with Commission Notice 2021/C 373/01.

Link with specific criteria TEN-E Regulation

- Sustainability: Article 4(3)(d) and Annex IV (5)(a) of TEN-E Regulation.

EU energy policy aims at reducing greenhouse gas (GHG) emissions by achieving intermediate targets towards Union's carbon neutrality by 2050. In this respect, infrastructural projects are key in achieving potential GHG emission reductions and in lowering the EU carbon footprint. Integrating low-carbon and renewable hydrogen[8] in the system can reduce GHG emissions due to substitution effects enabled by the reduction of the use of fuels of fossil origin, in particular in end-use applications such as hard-to-abate sectors. Moreover, such projects can support variable renewable power generation by offering flexibility and energy storage solutions.

Calculation process

1. ENTSOG shall calculate GHG emissions savings achievable thanks to the candidate hydrogen project from increase of low-carbon and renewable hydrogen deployed in the system, with an emphasis on hydrogen from renewable sources. In line with the Commission technical guidance on climate proofing of infrastructure [9], project promoters should follow, where applicable, the most updated version of the EIB Project Carbon Footprint Methodology [10] to quantify GHG emissions.
2. GHG emission savings achievable thanks to the candidate hydrogen project are evaluated by comparing two situations:
   - GHG emissions in the "with case", $emission|_{with}$, and
   - GHG emissions in the "without case", $emission|_{without}$

(8) At the time of writing, the definition of low-carbon and renewable gases in this methodology are intended to be consistent with the Hydrogen and decarbonised gas market package, proposed by the European Commission in December 2021 and currently being negotiated by the co-legislators. After the entry into force of the Hydrogen and decarbonised market package, the official definitions will apply.

3. The variation of GHG emissions achievable thanks to the candidate project, expressed in CO_2 equivalent emissions, are converted in monetary terms by using the shadow cost of carbon:

$$B_1 = \sum \left[emission_{CO_{2equiv}} \Big|_{without} - emission_{CO_{2equiv}} \Big|_{with} \right] \cdot ShCost_{CO_2}$$

1. **The economic present value of the variation of GHG emissions achievable thanks to the project is calculated within the study horizon using the discounted cash-flow approach.**

4. Upon justification (including bearing in mind the scope of GHG emissions captured by the methodologies below), ENTSOG might complement the calculations pursuant to the EIB Project Carbon Footprint Methodology with results from the following approaches:
   a. the standard ISO 14067 "Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification"[9];
   b. the standard ISO 14064-1 "Greenhouse gases — Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals"[10]; and
   c. the most updated version of the Innovation Fund methodology for GHG emission avoidance calculation [11].

<u>Main elements to consider:</u>

— Carbon footprint of the renewable and\or low-carbon hydrogen integrated in the system thanks to the candidate hydrogen project

— Operational data of the candidate hydrogen project: efficiency, technical constraints, etc.

— CO2 price is an input to the calculation and it is subject to sensitivity analysis (see section 2.1).

(9) https://www.iso.org/standard/71206.html
(10) https://www.iso.org/standard/66453.html

3.1.2 B2 – Variation of non-GHG emissions

Benefit Definition:

- Definition: economic valorisation of the variation of non-greenhouse gases emission achievable thanks to the project.
- Relevance: hydrogen projects are key infrastructural assets for integrating and enabling the consumption of low-carbon and renewable gases. By reducing the usage of polluting fuels, they can reduce the system environmental footprint by reducing non-greenhouse gases emissions.

Benefit Calculation:

- Modelling needs: accurate assessment would require a detailed modelling exercise simulating a larger portion of the hydrogen system (both transmission and distribution levels) beyond the project and, if any, of the systems (e.g. electricity and gas) involved in the production and integration of low carbon and renewable gases resulting in the reduction of non-GHG emissions. An alternative solution without significant modelling requirements would be based on project assumptions and relative calculations, using reputable methodologies.
- Data needs: if detailed modelling is introduced, extensive data to simulate a sufficiently large portion of the hydrogen system and, if any, of the systems involved in the production of renewable gases, are needed. In absence of extensive modelling, the benefit can be calculated but using operative data about the estimated amount of equivalent reduced greenhouse gases emissions.
- How the benefit is expressed: first, the benefit is expressed in quantitative terms as tons of non-GHG emission savings. Then, the benefit is finally expressed in monetary terms when the tons of non-GHG emission savings are multiplied by the relevant monetisation values (see reference values in Table 1).

Link with specific criteria TEN-E Regulation

- Sustainability: Article 4(3)(d) of TEN-E Regulation.

Further benefits from hydrogen projects can be realised thanks to the reduction of non-GHG emissions that also contribute to climate change. Non-GHG emissions include direct emissions like particulate matter, or indirect methods that trigger chemical reactions leading to pollution, such as acid rain, also increase pollution levels. To ensure that eventual mitigation effects introduced by candidate hydrogen projects are accurately evaluated, special attention must be paid to these non-CO2 emissions. This should involve at least addressing the primary emission types of CO, NO_2 (including NO that forms NO_2 in the atmosphere), SO_2, and various particulates (such as PM_2, PM_5, and PM_{10}).

By optimising the use of fossil fuels, hydrogen projects can reduce such emissions. As elaborated below, effects of potential differences in the assumed social costs of pollutants should be investigated through sensitivity analyses.

Calculation process

1. Evaluation of the amount of non-GHG emissions avoided thanks to the candidate hydrogen project is based on the following approach:
   a. a detailed modelling exercise is carried out by ENTSOG, based on the emission factors per pollutant of the various technologies displaced, in which the amount of polluting generation is evaluated in both the "with" and "without" cases. Given the objective function of the optimisation algorithm and the combination of the active constraints of the problem, the model provides as output the variation in non- GHG emissions achievable thanks to the project.
   b. If detailed modelling is not feasible, the approach with simplified assumptions should be followed:
      i. ENTSOG calculates the emission factor difference based on the most granular emission intensity data available, and the amount of polluting generation displaced based on

their knowledge of the operational capability of the project. Prospective emission intensities can be imputed by interacting such data with installed generation capacities in the scenarios considered, as compliant with TYNDP scenarios.

2. The variation of emissions for the *g*-th non-GHG pollutant achievable in the *z*-th zone of the modelled/represented system thanks to the candidate hydrogen project is converted into monetary terms by using the social cost of the pertinent emissions provided in the information set accompanying the project submission template.

$$B_2 = \sum_g \left[emission_{g,z}\big|_{without} - emission_{g,z}\big|_{with} \right] \cdot emission\_cost_g$$

3. The economic present value of indicator B_2 is calculated within the CBA horizon using the discounted cash-flow approach.

Sensitivity analyses shall be run to check the monetary values of benefits from avoided non-GHG emissions under different assumptions about their social costs (see Annex V(2) of the TEN-E Regulation).

3.1.3 B3 – Integration of renewable and low-carbon hydrogen potential into the system

Benefit Definition:

- Definition: Integration of renewable and low-carbon hydrogen potential achievable thanks to the candidate hydrogen project.
- Relevance: The integration of low-carbon and particularly renewable hydrogen in the system, achievable thanks to the candidate hydrogen projects, can support the decarbonisation of the EU energy system. This is particularly relevant for hard-to-decarbonise sectors, such as industry and transport.

Benefit Calculation:

- Modelling needs: Accurate assessment of the amount of renewable and low-carbon hydrogen integrated in the system would require a detailed modelling exercise simulating a larger portion of the electricity, gas, hydrogen, industrial and transport systems beyond the project (i.e. up to the European level). An alternative solution without significant modelling requirements would be based on project assumptions and relative calculations.
- Data needs: If detailed modelling is introduced, extensive data requirement to simulate the whole electricity, gas, hydrogen, industrial and transport systems (i.e. simulations up to the European level would require data requirements similar to the ones for ENTSOs TYNDPs). In absence of extensive modelling, the benefit can be calculated but using operative data about the estimated amount of low-carbon and particularly renewable hydrogen produced, hypotheses on the amount of fuel replaced and the related fuel cost prices.
- How the benefit is expressed: First, the benefit is expressed in quantitative terms as the amount of hydrogen produced from fossil origin which is replaced by renewable or low-carbon hydrogen. Then, the benefit is finally expressed in relative and, therefore, qualitative terms.
- The analysis should provide a breakdown in low-carbon and renewable hydrogen integrated in the system thanks to candidate hydrogen projects.

Link with specific criteria TEN-E Regulation

- Sustainability: Article 4(3)(d) and Annex IV (5)(a) of the TEN-E Regulation

A candidate hydrogen project can bring benefits stemming from the substitution of fuels with low-carbon and particularly renewable alternatives. This happens, for instance, when low-carbon and particularly renewable hydrogen replace fossil-fuel based hydrogen produced via Steam Methane Reforming (SMR) for industrial uses. Low-carbon and particularly renewable hydrogen produced as fuel substitute can be consumed locally, stored and shipped from production to the consumption point in different forms or, when dedicated transportation infrastructure will be available, injected into the hydrogen grid. It is important to highlight that this benefit shall not be monetised as the economic impact of the variation of the share of renewable and low-carbon gases integrated into the system is already internalised in the indicator "B1 - Variation of GHG emissions [€/a]"

Calculation process

1. By assuming that the hydrogen demand does not change[11] between the "with" and the "without" case, (i.e. hydrogen demand is a scenario variable), the amount of replaced hydrogen is equal to the increased amount of low-carbon and particularly renewable hydrogen $\Delta H2_{RES} + \Delta H2_{lowcarbon}$.
2. Evaluate the increased amount of renewable hydrogen integrated into the system thanks to the candidate hydrogen project following one of the two approaches below:

(11) While this indicator captures the benefit from substituting fossil-fuel based hydrogen with low carbon and renewable hydrogen, this does not account for the full amount of fossil fuels displaced by low carbon and renewable hydrogen or hydrogen-based alternatives, which is accounted in the benefit B4 "Substitution effect – Fuel switching".

a. In case a detailed modelling exercise is carried out, it must evaluate the operation of the modelled electricity, gas and hydrogen systems in both “with” and “without” cases. Given the objective function of the optimisation algorithm and the combination of the active constraints of the problem, the model provides as output the variation in renewable hydrogen production achievable thanks to the project as well as, if any, of the related production costs.

b. In case of simplified assumptions, the assessment must calculate the input data required to calculate the indicator using assumptions based on its knowledge of the operational capability of the project as well as of general assumptions about the relevant portion of the EU electricity, gas and hydrogen systems concerned by the candidate hydrogen project. All the assumptions must be duly justified and referenced.

3. The variation of the share of renewable and low-carbon hydrogen integrated into the system is expressed as described below:

$$share_{H2,renewable} = \frac{\mathrm{QH2}_{renewable}}{\mathrm{QH2}}$$

$$share_{H2,low-carbon} = \frac{\mathrm{QH2}_{low-carbon}}{\mathrm{QH2}}$$

$$B_{3,H2,renewable} = share_{H2,renewable}|_{with} - share_{H2,renewable}|_{without}$$

$$B_{3,H2,low-carbon} = share_{H2,low-carbon}|_{with} - share_{H2,low-carbon}|_{without}$$

$$B_3 = B_{3,H2,renewable} + B_{3,H2,low-carbon}$$

Project promoters shall provide the values of the benefit B_3 and the sub-indicators $B_{3,H2,renewable}$ and $B_{3,H2,low-carbon}$, as well as all the information needed to check and replicate their calculation.

Main elements to consider

— Data requirement and data granularity are comparable to the ones concerning ENTSOs TYNDPs, if quantities are evaluated as output of a detailed modelling exercise of the electricity, gas and hydrogen EU systems. Specific data requirement might differ according to the different modelling formulation;

3.1.4 B4 – Substitution effect – Fuel switching

Benefit Definition:

- Definition: Economic impact of substitution effect (fuel switching) enabled by the candidate hydrogen project.
- Relevance: The integration of low-carbon and particularly renewable hydrogen in the system, achievable thanks to the candidate hydrogen projects, can support EU supply diversification by facilitating the access to indigenous sources of hydrogen supply.

Benefit Calculation:

- Modelling needs: Accurate assessment of the amount of renewable and low-carbon hydrogen integrated in the system would require a detailed modelling exercise simulating a larger portion of the electricity, gas, oil and hydrogen systems beyond the project (i.e. up to the European level). An alternative solution without significant modelling requirements would be based on project assumptions and relative calculations.
- Data needs: If detailed modelling is introduced, extensive data requirement to simulate the whole electricity, gas, oil and hydrogen systems (i.e. simulations up to the European level would require data requirements similar to the ones for ENTSOs TYNDPs). In absence of extensive modelling, the benefit can be calculated but using operative data about the estimated amount of low-carbon and particularly renewable hydrogen produced, hypotheses on the amount of fuel replaced and the related fuel cost prices.
- How the benefit is expressed: The benefit is expressed in quantitative terms and is monetised as the potential cost saving resulting from the replacement of fuels of fossil origin with low carbon and particularly renewable hydrogen and/or hydrogen based fuels.
- The analysis should provide a breakdown in low-carbon and renewable hydrogen integrated in the system thanks to candidate hydrogen projects.

Link with specific criteria TEN-E Regulation

- Competition: Article 4(3)(d)(iii) and Annex IV (5)(d) to TEN-E Regulation

A candidate hydrogen project can bring benefits stemming from the substitution of fuels with alternatives produced starting from renewable and/or low carbon hydrogen, especially when produced in the EU. While substituting fuels enabled by hydrogen projects might not currently be cost-competitive compared to fossil-fuel alternatives, learning curve effects, economy of scale and massive RES installed capacity might gradually make renewable and/or low carbon based alternatives cheaper. Renewable and/or low carbon fuels produced as fuel substitute can be either consumed locally, stored and shipped from production to the consumption point in different forms or, when dedicated transportation infrastructure will be available, injected into the hydrogen grid. This benefit is conceptually similar to the benefit “Fuel cost savings” considered in the ENTSOG methodology [4].

Calculation process

This benefit is calculated as replacement of fuels with hydrogen or hydrogen derived fuels:

$$B_4 = \sum_{i=1}^{n} \left(Q_{fossil\ fuel\ i}\big|_{without} * P_{fossil\ fuel\ i} - Q_{from\ H2\ fuel\ i}\big|_{with} * P_{from\ H2\ fuel\ i} \right) +$$

$$-\Delta QH2_{RENEW} * P_{RENEW\ H2} - \Delta QH2_{LC} * P_{LC\ H2}$$

where:

- Q is the quantity of $fuel_i$ (fossil origin) expressed in energy terms (such as GWh) used in the "without" case and the quantity of fuel (H2 based) in the "with" case. All quantities need to be expressed in the same units.
- $fuel_{i=1\ to\ n}$ is any fuel replaced by hydrogen or hydrogen-based corresponding alternative driven by the new project;
- P_{fuel} is the price of the specific replaced fuel (in €/GWh);
- $\Delta QH2_{RENEW}/\Delta QH2_{LC}$ are the amount of low-carbon and renewable hydrogen which are replacing the use of fossil-based fuels in "with" case (in GWh); and
- $P_{RENEW\ H2}/P_{LC\ H2}$ are the prices of low-carbon and renewable hydrogen which are replacing the use of fossil-based fuels in "with" case (in €/GWh)

Values should always be showed both in quantities of switched fuel and monetised terms.

3.1.5 B5 – Reduction of curtailed hydrogen demand

Benefit Definition:

- Definition: Reduction of curtailed hydrogen demand that cannot be satisfied in a given area.
- Relevance: When an internal EU market for hydrogen will be established, the higher integration of hydrogen stemming from candidate hydrogen projects could mitigate the risk of curtailment of hydrogen demand that could occur in moments when the demand of hydrogen is higher than the supply, when storages are insufficient and/or when there is not enough transportation capacity in the hydrogen network to allow hydrogen to flow to local consumption nodes. In this respect, the integration of hydrogen infrastructure devoted to reduce curtailed hydrogen demand can increase security of energy supply in the Union.

Benefit Calculation:

- Modelling needs: An accurate assessment would require a detailed modelling exercise simulating a larger portion of the electricity, gas (distribution and/or transmission levels) and hydrogen systems affected by the candidate hydrogen project, potentially up to the European level. Simplified approaches might be allowed considering the scale of the candidate hydrogen project and the related impact on cross-border hydrogen flows and/or the more efficient electrolyser operations.
- Data needs: Extensive data requirement to simulate a significant portion of the electricity, gas and hydrogen systems is required in case of an accurate modelling exercise. In absence of extensive modelling, the benefit can be calculated by using operative data about additional amount of hydrogen unlocked by the candidate hydrogen project, the timing and the location of unserved hydrogen demand and/or benefits from the ability to optimise electrolyser operations.
- How the benefit is expressed: The benefit is expressed in quantitative terms as avoided hydrogen demand curtailment (expressed in GWh/a) achievable thanks to the candidate hydrogen project.

Link with specific criteria TEN-E Regulation:

- Security of supply and flexibility - Article 4(3)(d)(ii) and Annex IV 5(c) of the TEN-E Regulation

Hydrogen security of supply can be considered by looking at whether there are countries in EU that risk any hydrogen demand curtailment: in this respect, candidate hydrogen project may play a role in increasing security of supply by mitigating such occurrences thanks to their production.

Calculation process

The benefit B_5, conceptually similar to the benefit “Avoided curtailment demand” considered in the ENTSOG methodology [4], can be calculated as follows:

1. Evaluate the operation of the modelled the electricity, gas and hydrogen systems in both “with” and “without” cases. Given the objective function of the optimisation algorithm and the balance hydrogen demand constraints, the model provides as output the level of unserved, then curtailed, hydrogen demand, in each modelled zone.
2. The benefit related to the reduction of hydrogen demand curtailment in each Member State achievable thanks to the candidate hydrogen project can be calculated by project promoters as follows.

$$B_5 = \sum_z (Demand\_curtailment_z|_{without} - Demand\_curtailment_z|_{with})$$

Main elements to consider

- Reduction of curtailed hydrogen demand:

- the accurate evaluation of unserved hydrogen demand on the relevant portion of the hydrogen system affected by the candidate hydrogen project requires running a hydraulic model simulation;
- Probabilistic approaches can be used to calculate hydrogen demand curtailment in different demand situations, also significant of different climatic stress conditions. For the calculation of B_5, it is recommended to use the average value of demand curtailment calculated as value in each demand situation multiplied by probability of occurrence of situation;
- using assumptions on the operation of the hydrogen system achieved thanks to the candidate hydrogen project eases the need of running a modelling exercise but it decreases accuracy of the assessment.

3.1.6 B6 – Improvement of market integration

Benefit Definition:

- Definition: Improvements in connecting existing or emerging hydrogen networks of Member States achievable thanks to the candidate hydrogen project.
- Relevance: The completion of the EU energy market requires the removal of technical barriers preventing the efficient use of energy assets across the EU. This is particularly relevant for the upcoming EU hydrogen system, which, in its inception, might strongly rely on bottom-up initiatives (such as "hydrogen valleys" or "hydrogen islands"). In this respect, the candidate hydrogen project can support the integration of the EU hydrogen market at the level of interconnections among EU Member States.

Benefit Calculation:

- Modelling needs: An accurate assessment of the improvement in market integration in terms of price convergence would require a detailed modelling exercise simulating the European hydrogen market. The use of a simplified approach would not require any specific modelling capability.
- Data needs: An accurate assessment of the improvement in market integration in terms of price convergence would require extensive data requirements (price and quantities for hydrogen demand and supply, transportation and storage capacities, etc.) to allow the simulation of the (future) European hydrogen system. The use of a simplified approach would not require specific data requirements besides the number of hydrogen subsystems connected thanks to the candidate hydrogen project.
- How the benefit is expressed: The benefit is expressed in qualitative terms (see 'Calculation process' section for further details).

Link with specific criteria TEN-E Regulation:

- Market integration: Article 4(3)(d)(i) of TEN-E Regulation

The development of an efficient EU hydrogen market is a key element of EU energy policy towards the 2050 objective of carbon neutrality. The capability of enabling the decarbonisation of hard-to-abate sectors as well as its importance in several industrial processes picked the interest of many countries which recently released ambitious national hydrogen strategies. In this framework, one the leading development models imagined in the EU and worldwide is represented by the so-called "hydrogen valleys" or "hydrogen islands", with several uncorrelated bottom-up initiatives supporting the initial development of the hydrogen supply chain[12].

In this respect, a candidate hydrogen project can (also) support the development of an EU-wide hydrogen system by being part of the interconnecting infrastructure linking, across borders, these separate initiatives. By fostering the level of market integration of the EU hydrogen system in its incipience, a candidate hydrogen project can reinforce collaboration between EU Member States, and neighbouring countries, towards the achievement of their decarbonisation targets.

The improvement in market integration as a result of the realization of candidate hydrogen projects could be measured in terms of price convergence once the internal EU hydrogen market becomes mature enough. A difference in marginal price between two connected countries can be the result of a transmission tariff, an infrastructure limitation, or both. In this respect, local hydrogen marginal prices would be expected to converge as a result of the availability of increased cross-border hydrogen interconnection capacity. This approach is conceptually similar to the indicator "Weighted Marginal Price Deviation" described ENTSOG TYNPD 2020 CBA methodology [12].

Calculation process

The benefit B_6 can be calculated using one of the following two approaches:

(12) https://h2v.eu/

a. Simplified approach:

1. Evaluate the number of countries connected by the hydrogen infrastructure in question, $N_{countries}$, in both "with" and "without" cases.
2. The improvement of market integration achievable thanks to the candidate hydrogen project, can be calculated as follows:

$$B_6 = (N_{countries}|_{with} - N_{countries}|_{without})$$

b. *Detailed approach* (prerequisite: establishment of a mature EU hydrogen market):

1. Run simulations of the operation of the EU hydrogen market in both "with" and "without" cases.
2. As output of the simulation, calculate the Weighted Marginal Price Deviation (WMPD) as follows:

$$WMPD = \sum_{t}^{N} \sum_{z=1}^{Z} \left(|MP_z(\mathrm{t}) - REF\ EX(\mathrm{t})| * \frac{D_i(\mathrm{t})}{D_{EU}(\mathrm{t})} \right)$$

where:

— N is the number of analysed points in time[13];

— Z is the number of countries modelled in the simulation;

— $MP_z(t)$ is the hydrogen marginal price in the *z*-th country in the specific point in time;

— $REF\ EX(t)$ is the demand-weighted average of EU marginal Prices in the specific point in time;

— $D_z(t)$ is the hydrogen demand in the *z*-th country in the specific point in time; and

— $D_{EU}(t)$ is a total hydrogen demand in Europe in the specific point in time

3. Calculate the benefit B_5 as follows:

$$B_6 = \frac{(WMPD|_{without} - WMPD|_{with})}{WMPD|_{without}}$$

B_6 can assume any value between 0 and 1: low values of B_6 would result in higher levels of price convergence and, consequently, in improved levels of market integration.

(13) Points in time are representations of operating points of the system. They could represent the totality of occurrences simulated in the modelling framework or a significant and representative subset of it.

3.1.7 B7 Increase of cross-sectoral flexibility

Benefit Definition:

- Definition: increase of cross-system flexibility enabled by the candidate hydrogen project.
- Relevance: by offering flexibility and/or storage solutions in support to variable renewable power generation, candidate hydrogen projects can realize total savings (both capital and operative savings), creating synergies and benefits for the Union.

Benefit Calculation:

- Modelling needs: in order to fully capture the cost savings enabled by candidate hydrogen projects, a detailed modelling exercise encompassing all the relevant sectors (for instance but not limited to, power, gas, hydrogen, heat, transport and industry) is necessary. The level of representation shall be consistent with the specific characteristics of the project as well as the necessary temporal and spatial granularity and the cross-sectoral interactions among the sectors. Different modelling approaches are possible taking into consideration with the alternatives in terms of interaction among the different dimensions of the energy system, leading to different trade-off levels between complexity and accuracy.
- Data needs: extensive data requirement to allow the simulation of the operation of the integrated energy system, with a level of detail, in principle, considerably higher than the one necessary for the simulations of electricity, hydrogen and gas sectors alone.
- How the benefit is expressed: the benefit is expressed in monetary terms as difference between total costs in "without" case and the "with" case.

Link with specific criteria TEN-E Regulation

- Sustainability: Article 4(3)(d) TEN-E Regulation

To ensure a cost-efficient, fair and inclusive energy transition, it is necessary that all relevant sectors, such as gas, electricity, industry, transport, and heat are considered in a more integrated perspective: the transition to a more integrated, holistic and optimised system can be achieved only if the role of assets able to act along different dimensions of the one energy systems is emphasized, creating opportunities for cross-sectoral cost efficiencies arising by stressing the "energy efficiency first" principle.

In this respect, candidate hydrogen projects play a key role in unlocking such efficiencies, by enabling flexibility and storage services – for instance, but not limited to, the hydrogen linepack - facilitating links among the different energy carriers and supporting decarbonisation of hard-to-abate sectors. Such increase of cross-sectoral flexibility can either materialize in increases of social welfare in several sectors positively affected by candidate hydrogen projects as well as in reduction of capital expenses.

A proper characterisation of cost savings cannot neglect the required level of detail of needed modelling exercises and data gatherings, which can increase more than linearly with the number of sectors represented and potentially be more extended and cumbersome than the one related to the integrated model as referred in Article 11(10) of TEN-E Regulation.

Calculation process

For each year within the study horizon, the increase of cross-sectoral flexibility achievable thanks to candidate projects shall be evaluated as follows:

1. **In case of complete integrated model, including investment decisions, calculate the benefit as the variation of the social welfare objective function maximised by the optimisation problem, which can be directly calculated by the integrated model from both "without" and "with" simulations:**

$$B_7 = SEW(s)|_{with} - SEW(s)|_{without} +$$

2. **In case of separate simulation of different systems, the assessment shall identify proper values for boundary conditions necessary to ensure consistency between the results calculate by the separate models: such values might come as output of *s* separate models. In this case, the benefit is calculated as the estimated variation of social welfare objective functions maximised by the *s* separate models:**

$$B_7 = \sum\nolimits_s [Total\ cost_s|_{without} - Total\ cost_s|_{with}]$$

3. **If no simulations are carried out (of for the sub-systems not simulated), the assessment may estimate the benefit as the estimated variation of annual total costs (both operational and capital, if the models can also be used for investment decision) of the used models that can be achieved thanks to the candidate hydrogen project in all the sectors. Exogenous information must be duly justified and referenced:**

$$B_7 = \sum\nolimits_s [Total\ cost_s|_{without} - Total\ cost_s|_{with}]$$

1. **The economic present value of the indicator B_7 is calculated within the study horizon using the discounted cash-flow approach.**

Given the fact that this indicator can, in principle, encompass all the others, it is important that no double counting with the latter exists: in this case, the assessment shall clearly identify these risks and remove the share of the indicator which is already accounted in another one.

3.2 Costs

Project promoters shall provide relevant costs for each year analysed in the study horizon accompanied with assumptions on the duration of authorisation, construction time and decommissioning phases. In particular, project promoters shall take into account the following cost elements:

- capital expenditure costs;
- operational and maintenance expenditure costs;
- costs induced for the related system over the technical lifecycle of the project;
- decommissioning and waste management costs; and
- other external costs.

Project promoters shall clearly describe what cost elements are incurring within the study horizon, taking into consideration the specificities of equipment and installations constituting the pertinent candidate hydrogen project.

Costs occurred before the study horizon shall be actualised at using as reference year the year after the adoption of the relevant Union list of PCIs and PMIs (e.g. 2024 is the reference year for the first Union list of PCIs and PMIs under the revised TEN-E Regulation, see section 3.4).

Member States impacted by the costs related to a candidate hydrogen project should be identified and disaggregated costs at Member State level should be provided.

Information shall be provided in a format allowing the Commission to check and verify the impact of the assumptions and the relevant calculations (e.g., Excel spreadsheet). Confidentiality of sensitive information must be ensured in line with the provisions of TEN-E Regulation.

3.3 Residual impacts

When dealing with the potential adverse impacts of a project, the primary approach is to prevent such impacts from occurring in the first place, for instance by optimising the routing of the project. When this is not possible, mitigation measures can be put in place and, in certain cases, compensatory measures may be legally mandated. When the project planning has advanced enough, the expenses associated with these measures can be accurately estimated and are included in the overall project costs (see section 3.2). When the required information for such cost internalisation is not available yet, however, residual impact must be evaluated, in line with the approaches developed by the ENTSOs in their respective methodologies in line with Article 11 of the TEN-E Regulation (see footnote 1). In particular, project promoters for candidate hydrogen projects shall evaluate, when relevant:

— S1 (Residual Environmental Impact);

— S2 (Residual Social Impact); and

— S3 (Other Impacts).

3.3.1 S1 – Residual Environmental Impact

In line with the approach developed by ENTSO-E in its CBA methodology (see footnote 1), the residual environmental impact of a candidate hydrogen project shall be evaluated by identifying:

— stage of the candidate project, in line with the project implementation status, see section 2.2;

— potential impact, i.e. to what extent the candidate hydrogen project impacts on nature and biodiversity (length and surface area of infrastructure located within an environmental sensitive area); and

— type of sensitivity, i.e. rationale on why the area is considered sensitive (e.g. biodiversity, habitat, etc.).

For candidate hydrogen projects in the "permitting" or "under construction", the elements listed should be reported based on the current data of the project promoter, also referencing the environmental impact assessment performed to identify those elements. When a project is not sufficiently mature ("planned, but not yet in permitting"' or "under consideration") and when the aforementioned elements are not available the project promoter shall clearly state that an environmental assessment is not yet available due to the low degree of maturity of the candidate project and that the actual routing of the project is not defined yet.

3.3.2 S2 – Residual Social Impact

Similarly to what described in section 3.3.1 and in line with the approach developed by ENTSO-E in its CBA methodology (see footnote 1), the residual social impact of a candidate hydrogen project shall be evaluated by identifying:

— stage of the candidate project, in line with the project implementation status, see section 2.2;

— potential impact, i.e. to what extent the candidate hydrogen project impacts on densely populated areas or protected areas (length and surface area of infrastructure located within an socially sensitive area); and

— type of sensitivity, i.e. rationale on why the area is considered sensitive (i.e. population density, landscape, etc.)

For candidate hydrogen projects in the "permitting" or "under construction", the elements listed should be reported based on the current data of the project promoter, also referencing a social impact assessment performed to identify those elements, when required by the legislative framework. When a project is not sufficiently mature ("planned, but not yet in permitting"' or "under consideration") and when the aforementioned elements are not available, the application shall clearly state that a social assessment is not yet available due to the low degree of maturity of the candidate project and that the actual routing of the project is not defined yet.

3.3.3 S3 – Other impacts

Any other impact (positive or negative) not covered in S1 and S2 shall be included in S3. Any impact already accounted in S1 and S2 shall not be considered in this indicator.

3.4 Project value – NPV and B/C – calculation

The Economic Net Present Value (ENPV) represents the difference between the present value of all monetised benefits and the present value of all costs, discounted using the discount rate.

$$ENPV = \sum_{y=0}^{T} \frac{TotB_{mon,y} - TotC_{,y}}{(1+r)^y}$$

where:

- T is the study horizon;
- y represent the year within the study horizon when benefits and costs occur;
- $TotB_{mon,y}$ is the sum of monetized benefits for the *y*-th year;
- $TotC_y$ is the sum of total costs for the *y*-th year;
- r is the social discount rate;

Another indicator to be calculated is the benefit-cost ratio (BCR), which is the ratio between the present value of all monetised benefits divided by the present value of all costs[14]

$$BCR = \sum_{y=0}^{T} \frac{TotB_{mon,y}}{(1+r)^y} \Bigg/ \sum_{y=0}^{T} \frac{C_y}{(1+r)^y}$$

Benefits and costs shall be actualised at using as reference year the year after the adoption of the relevant Union list of PCIs and PMIs (e.g. 2024 is the reference year for the first Union list of PCIs and PMIs under the revised TEN-E Regulation).

3.5 Transparency and confidentiality

In submitting their CBA, project promoters for candidate hydrogen projects must provide all the necessary information with the appropriate level of transparency, also taking into consideration the provisions of the TEN-E Regulation, to allow the Commission to be able to rebuild the NPV and BCR calculations.

Confidentiality of sensitive information is ensured in line with the provisions of the TEN-E Regulation.

([14]) More detailed information on the project value calculation can be found in the latest CBA methodology developed by the ENTSOs [3], [4].

References

[1] Regulation (EU) 2022/869 of the European Parliament and of the Council of 30 May 2022 on guidelines for trans-European energy infrastructure, amending Regulations (EC) No 715/2009, (EU) 2019/942 and (EU) 2019/943 and Directives 2009/73/EC and (EU) 2019/944, and repealing Regulation (EU) No 347/2013.

[2] Regulation (EU) No 1315/2013 of the European Parliament and of the Council of 11 December 2013 on Union guidelines for the development of the trans-European transport network, and repealing Decision No 661/2010/EU.

[3] 3rd ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects – Draft version – 28 January 2020.

[4] 2nd ENTSOG Methodology for Cost-Benefit Analysis of Gas Infrastructure Projects – October 2018.

[5] T. Brown, J. Hörsch, D. Schlachtberger, PyPSA: Python for Power System Analysis, 2018, Journal of Open Research Software, 6(1), arXiv:1707.09913, DOI:10.5334/jors.188.

[6] Commission Delegated Regulation (EU) No 480/2014 of 3 March 2014 supplementing Regulation (EU) No 1303/2013 of the European Parliament and of the Council laying down common provisions on the European Regional Development Fund, the European Social Fund, the Cohesion Fund, the European Agricultural Fund for Rural Development and the European Maritime and Fisheries Fund and laying down general provisions on the European Regional Development Fund, the European Social Fund, the Cohesion Fund and the European Maritime and Fisheries Fund.

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[8] European Investment Bank, EIB Group 2021Climate Bank Roadmap Progress Report. 28 July 2022.

[9] Commission Notice - Technical guidance on the climate proofing of infrastructure in the period 2021-2027 (2021/C 373/01).

[10] European Investment Bank. Methodologies for the assessment of project greenhouse gas emissions and emission variations. Version 11.3. January 2023.

[11] European Commission. Methodology for GHG emission Avoidance Calculation. Innovation Fund Small Scale Projects. Version 2.0. November 2022.

[12] ENTSOG. Ten Year Network Development Plan 2020. Annex D – Methodology. July 2021.

[13] Commission Notice — Technical guidance on the climate proofing of infrastructure in the period 2021-2027 C/2021/5430.

List of abbreviations and definitions

BCR	benefit-cost ratio
CBA	Cost-benefit analysis
EC	European Commission
EIB	European Investment Bank
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSOG	European Network of Transmission System Operators for Gas
GHG	Greenhouse gasses
JRC	Joint Research Centre
NPV	Net Present Value
SMR	Steam Methane Reforming
WMPD	Weighted Marginal Price Deviation

List of tables

Annex 1. Modification of the methodology due to the contributions received from the public consultation.

1. Introduction

The consultation on the draft hydrogen CBA methodology is part of the process for development of methodologies for a harmonised energy system-wide cost-benefit analysis at Union level pursuant to Article 11(8) of the revised TEN-E Regulation. Concerning the hydrogen CBA methodology, the consultation started on 16 November 2022 and ended on 20 January 2023. The consultation has been carried out through EUSurvey[15], the European Commission's official survey management tool.

The objective of this consultation was to seek input from stakeholders on the draft hydrogen CBA methodology published on 16 November 2022, who were invited to answer questions for the overall approach of the methodology as well as questions for each individual indicator of the methodology.

The public was consulted on the following general question:

— *In your view, to what extent does the draft methodology allow for a harmonised energy system-wide cost-benefits analysis at Union level?*

— *Do you have any feedback regarding the assumptions considered in the draft methodology? (Section 2.1)?*

Concerning the specific indicators proposed, the public was consulted on the following questions for each individual indicator, respectively:

— *In your view, is the benefit well described in line with the legal base?*

— *Do you have suggestions for data sources which could be used for the calculation of this benefit?*

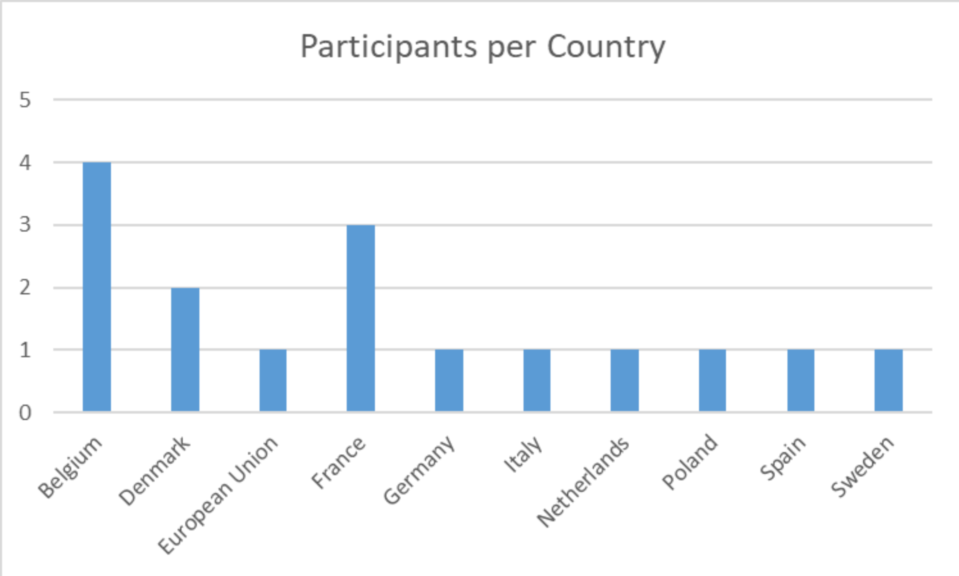
— *Suggestions for data sources which could be used for the calculation of this benefit?*

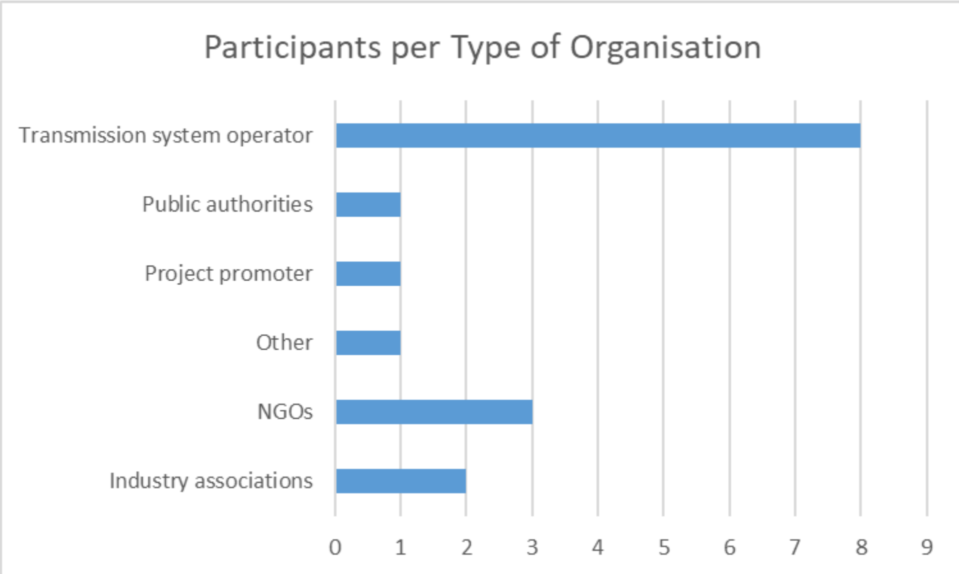
2. Consultation results

Sixteen participants responded to the consultation via EUSurvey. Most of the replies came from Belgium and France. In terms of categories, the replies from transmission system operators and citizens, were followed by those from NGOs and industry associations. In several cases, respondents made identical comments to the same question. Even though this could indicate a certain level of stakeholder engagement in that specific case, it did not necessarily bring further merit to the arguments presented. These cases are indicated in the summary below.

A joint ACER-NRAs document have been submitted to the Commission via email in response to the public consultation on the draft hydrogen CBA methodology. This document was complemented with another one raising horizontal elements for all CBA methodologies developed by the Commission pursuant to Article 11(8) of the revised TEN-E Regulation.

(15) https://ec.europa.eu/eusurvey/home/about





3. Summary of changes due to input received from the public consultation

Number Comment	Respondent's comment	Outcomes
A1	The methodology should stress the use of interlinked models (several respondents).	Improved the text accordingly in section 2 accordingly.
A2	Clustering shall consider at least the project level aggregation (several respondents).	The comment does not strictly apply to the hydrogen CBA methodology.
A3	Unclear how monetised, non-monetised and qualitative indicators are combined (several respondents).	The approach for combining different type of indicators is part of the assessment methodology.

Number Comment	Respondent's comment	Outcomes
A4	Benefits and costs should be calculated for each year of operation within the study horizon (several respondents)	Improved the text by further clarifying this in the text of the hydrogen CBA methodology.
A5	The lack of hydrogen infrastructure poses a risk of underestimating projects benefits.	The comment does not strictly apply to the hydrogen CBA methodology.
A6	The CBA should accommodate integrated projects of both gaseous and liquid H2.	The hydrogen CBA methodology does not discriminate any project compliant with Annex II of the revised TEN-E Regulation.
A7	Important to ensure adequate input data and scenarios as they affect the quality of the CBA results (several respondents)	The quality level of input data and scenarios is beyond the scope of the hydrogen CBA methodology.
A8	The methodology could be improved by adding more cross-sectoral benefits (several respondents).	Improved the hydrogen methodology by adding the benefit "Increase of cross-sectoral flexibility".
A9	The methodology allows different approaches for calculating benefits, which might create comparability problems (several respondents).	improved the text in section 3 to reduce methodological ambiguity. At the same time, the aim of this methodological framework is to be, in principle, as wide as possible to allow the characterizations of benefits according to the improvements concerning the availability of data and modelling tools in time. In this respect, a more focused approach should be used in the implementation of generalised methodological frameworks in each specific PCI/PMI process.
A10	Hydrogen projects do not necessary decrease GHG emissions or have a positive impact on sustainability (i.e production of blue hydrogen can have higher GHG emissions that burning natural gas).	The sustainability of candidate hydrogen projects must be evaluated in the application of a CBA methodology. In this respect, if the evaluation of an application shows that a candidate project increases GHG emissions, this would be reflected in the value of the benefit B1. At the same time, the Commission observes that the scope of the CBA methodology is to provide methodological tools for assessing candidate projects and their merits (i.e. system benefits outweighing costs) in line with the provisions of the revised TEN-E Regulation.
A11	The methodology could be improved by including benefits measuring the positive impact of candidate hydrogen projects in "supporting variable renewable power generation by offering flexibility and/or storage solutions pursuant to Art. 4(3) of the revised TEN-E Regulation.	improved the hydrogen methodology by adding the benefit "Increase of cross-sectoral flexibility".
A12	The same social discount rate shall be used	The comment is in line with the text of the

Number Comment	Respondent's comment	Outcomes
	(several respondents)	hydrogen CBA methodology.
A13	An approach for residual value to account the benefit of a project beyond the study horizon shall be introduced. Alternatively, the duration of the study horizon could be extended to account the full technical lifetime of assets part of a candidate hydrogen project (several respondents). The duration of the study horizon should be the same for all projects within the same category (i.e. transmission, terminals or storages)	in line with other best practices in EU energy infrastructure development we did not introduce any residual value in the hydrogen CBA methodology,
A14	Although assumptions should be aligned with the latest TYNDP scenarios, project promoters should be allowed to provide their own project assumptions (several respondents).	We believe it is consistent with its proposal.
A15	We suggest clarifying whether the 4% discount rate is pre-tax or post-tax, and if the rate is nominal or real.	We take note of the comment received and it observes that such decision would also have to be consistent with the practices to be used for other methodologies referred to Article 11 of the revised TEN-E Regulation and the related timelines.
A16	Hydrogen production cost is highly variable depending on the chosen technology. Even if ensuring some level of alignment across Member States is good in principle, project promoters should be given some flexibility with regards to using their own project-specific assumptions.	Such parameter could be subject to sensitivity analysis.
A17	TYNDP might not be always the most updated source of information (several respondents).	We acknowledge that TYNDP scenarios are sometimes not fully aligned with the most recent energy policy development, due to the different timelines. However represent a key source of information to ensure consistency among all energy infrastructure projects.
A18	Negative externalities of hydrogen infrastructure projects shall be considered	Included a section concerning impacts, in line with the best practice for other CBA methodologies pursuant to Art. 11 of the revised TEN-E Regulation.
A19	There should be zero support for hydrogen based on fossil fuels	We take note of the comment received but it also observes that it goes beyond the scope of the hydrogen CBA methodology.
A20	The draft text doesn't explain whether the CBA methodology applies to the Projects of Mutual Interest (so-called PMIs)	Amended the text to reflect that the methodology applies to both PCIs and PMIs.
A21	The description of benefits may be further improved by making a reference to renewable	Amended the text accordingly in section

Number Comment	Respondent's comment	Outcomes
	and low carbon hydrogen replacing not only non-renewable hydrogen and natural gas but also other energy sources (several respondents).	3.1.1.
A22	The GHG emission indicator (that could be considered as avoided CO2 emissions) could be calculated both in a static and dynamic way. Static: What are the impacts on CO2 emissions thanks to operational changes enabled by the infrastructure project? Dynamic: What are the impacts on CO2 emissions thanks to the changes in investments enabled by the infrastructure project. (several respondents).	if project specific, any "dynamic" variation of GHG emissions should be considered in the evaluation of "with" and "without" cases.
A23	Indirect GHG impact of hydrogen emissions due to leakage shall be considered.	The list of greenhouse gases provided in section 3.1.1. is consistent with the updated Kyoto Protocol. If the context in scientific literature were to change, the Commission is open to re-evaluate its position on the matter.
A24	Assess GHG emissions intensity and climate impact on multiple timescales using different values of GWP.	GWP100 is, as also recognised in the comment received, the most commonly used metric. If the context in scientific literature were to change, the Commission is open to re-evaluate its position on the matter.
A25	The draft methodology also fails to state a reasoning why scope 1 and 2 but not scope 3 emissions are included.	In the most updated EIB methodology, scope 3 emissions from outside the boundary defined by the physical limits of the project are included in the relative emissions calculation where they are considered significant.
A26	The CBA should consider and monetise also the reduction of other non-CO2 negative externalities (e.g. NOx, SOx, PM, etc.) stemming from the project. Useful data for the computation of this benefit could be gathered from promoters, ENTSOG and widely recognised institution operating in this field (several respondents).	Amended the hydrogen CBA methodology accordingly.
A27	Several indicators are missing, among which: a) Reduction of RES curtailment enabled by the project (static indicator) b) Cost savings, even in the absence of fuel switch (static indicator) c) Avoided investments in other technologies (e.g. if you have more flexible gas infrastructure, you can avoid oversizing the electricity generation technologies to meet seasonal demand variations), etc. (dynamic indicator).	Such benefits could be included only if there would be a direct causality with the realisation of the project.

Number Comment	Respondent's comment	Outcomes
A28	The benefit "Integration of renewable and low-carbon hydrogen into the system" could be better explained.	Amended the hydrogen CBA methodology accordingly.
A29	The reduction of curtailed hydrogen demand shall be monetised, eventually using the Cost of Disrupted Gas (CODG) as proxy value.	Such monetization shall be introduced when a clear framework about hydrogen security of supply will introduced in EU energy policy framework. We take note of the suggestion to use CODG as proxy value for Cost of Disrupted Hydrogen (CODH) but it believes the former is not an appropriate proxy for the latter.
A30	The "Reduction of curtailed hydrogen demand" is a very speculative benefit at this point in time in our opinion. Large uncertainties prevail both around demand as well as around supply, particularly in this very early stage of a hydrogen network and hydrogen economy.	This comment goes beyond the scope of the hydrogen CBA methodology.
A31	Fossil gas-based hydrogen is not acceptable, even more now given the current scarcity of fossil gas is having negative repercussions on prices, cost of living and the global access to LNG for third countries. Supporting fossil gas-based (blue) hydrogen, which is an inefficient, wasteful and emission-heavy fuel.	This comment goes beyond the scope of the hydrogen CBA methodology.
A32	Additionality, i.e. only using additional renewable energy to generate renewable hydrogen, is crucial.	This comment pertains mainly to assets devoted to the production of hydrogen (i.e. electrolysers).
A33	Useful data for the computation of curtailed hydrogen demand could be gathered from project promoters and ENTSOG.	Amended the text accordingly.
A34	On top of the curtailed hydrogen demand, additional benefits should be considered, such as avoided RES curtailment, avoided high electricity prices, higher share of clean hydrogen, lower electricity grid congestion costs, lower LCOH, share of hydrogen supply routes and electrolysis load factor.	Amended the text accordingly by adding the benefit "Increase of cross-sectoral flexibility".
A35	The draft proposal can be enriched with additional elements so that the value generated by an H2 asset in terms of sector integration is fully internalized and recognized.	Amended the text accordingly by adding the benefit "Increase of cross-sectoral flexibility".
A36	Market integration is a key criterion according to TEN-E Regulation; thus, it should be monetised.	The proposed detailed approach is in line with the methodology
A37	Is it correctly understood, that the market integration benefit assumes that prices are the	When hydrogen market design foresees hydrogen market zones, even within Member

Number Comment	Respondent’s comment	Outcomes
	same within each country and might differ between countries? If this is the case, then B5 does not consider that there could be developed different disconnected zones within countries but also zones across borders. That is, price integration might be relevant within countries. It could be relevant to look at zones instead of countries. Also, it might be difficult to establish a hydrogen marginal price.	States, the benefit in terms of price convergence achieved thanks to candidate hydrogen project could be evaluated according to the proposed detailed approach.
A38	The gas (methane and hydrogen) transport infrastructure offers an intrinsic flexibility, called linepack. This flexibility should be part of the “with and without” analyses of transport infrastructure.	Amended the text accordingly by adding the benefit “Increase of cross-sectoral flexibility”.
A39	Please consider adding the following benefits - System-value: Levelised cost of hydrogen - Arbitrage value: Share of H2 supply routes and electrolyser load factor - Insurance value: Hydrogen production capacities - Kick-start value: Investment in on-site renewables and electrolysers - Environmental value: Carbon footprint of H2.	Most of the proposed indicators are benefits *per se*.
A40	Single largest infrastructure disruption case (how does the project improve the disruption scenario) should be included.	The Commission takes note of the comment received and it observes that hydrogen disruption scenarios can be considered in benefit evaluation, provided that they are evaluated considering the related probability of occurrence.
A41	All PP should use same “common” assumptions, best if clearly specified in the methodology the values or reference which should be used in the calculations.	Improvedthe text by specifying that assumptions should other come from TYNDP scenarios or information provided in the template for the project submission. At the same time, the project promoters can introduce complementary assumptions and use pertinent calculations approaches, in line with the scope of the candidate hydrogen project, provided that such deviations and modelling/simplification assumptions are clearly described and justified.
A42	Demand for hydrogen used to assess infrastructure project should be netted from the amount of hydrogen demand not impacting the grid. For example, some hydrogen demand could be covered through freight transport (like gasoline/oil these days/LNG trucks), especially in transport and also for certain types of industry use. In this case, some percentage should be	Agree.

Number Comment	Respondent's comment	Outcomes
	deducted from the initial hydrogen demand estimations.	
A43	Suggestion to use common assumptions	See comment A41.
A44	Clear rules on the study horizon and discount rate: 25 years from the start of the operation of the project and 4%. Recommendable to give guideline on how to treat years before the start of operation of the project (in particular concerning already incurred costs).	The text already supported the use of the values 25 years and 4%. The benefits shall be accounted from the year after the commissioning year (first full year of system benefits). The text included guidance on how to actualise costs occurring before the start of operation of the project.
A45	Improve terminology: a. refer to "socio-economically desirable" rather than "profitable", as later is more a term used in business analysis **b.** refer to Economic Net Present Value (ENPV) as CBA is an economic analysis of a project and not a financial analysis	Improved the text accordingly.
A46	For qualitative indicators no methodology is proposed to apply an "appreciation scale" making impossible to compare different projects.	The proposed qualitative indicators are expressed as percentage, which inherently allows an appreciation to compare different projects.
A47	The potential benefits of H2 projects on security of supply are not that well captured with the proposed indicators. Monetizing the impact of the H2 project in case of a supply disruption of natural gas could be used as a way to assess the benefits in terms of SoS.	The impact of candidate hydrogen projects on security of supply shall be considered by analysing the impact on the reduction of curtailed hydrogen demand.
A48	Where possible, the cost distribution and socioeconomic impacts per Member State should be provided. The impacted Member States should be identified.	Improved the text accordingly.
A49	Avoiding double counting is mentioned in the proposed methodology, anyhow description of the verification process for double counting seems to be missing.	The verification process of non-double counting shall be carried out in line with the provisions set in point (2) of Annex III to the revised TEN-E Regulation.
A50	There are no definitions nor references of low carbon gases (reference to REDII / REDIII Delegated acts)	Improved the text accordingly via footnote in section 3.1.1.
A51	With respect to the benefit "Reduction of curtailed hydrogen demand", the methodology should define in which demand situation this indicator should be computed (e.g. yearly demand vs peak day with 1/20 years probability) and, possibly, also in which import disruption condition(s). When calculating demand curtailment, we believe approach taken in	The text already aligns the proposed indicator with ENTSOG's 2nd CBA Gas Methodology. In addition, the text has been improved in "Main elements to consider" to explicit the use probabilistic approaches to calculate gas demand curtailment in different demand situations, also resulting in different climatic stress conditions.

Number Comment	Respondent's comment	Outcomes
	ENTSOG 2nd CBA methodology should be followed in respect to the climatic stress conditions analysis..	
A52	Concerning the benefit "Improvement of market integration [qualitative]", there is a difference in unit outcome of simplified and detailed approach for calculation of the same indicator. There should be a guidance how to translate the indicator initial calculation result in qualitative indicator units, seems very unclear at the moment.	The units of measures between the two approaches are different as they measure different aspects of hydrogen market integration. In this respect, the simplified approach shall not be used to simplify the calculations for the detailed approach.
A53	The methodology says: "A difference in marginal price between two connected countries can be the result of a transmission tariff, an infrastructure limitation, or both.". To be able to distinguish between infrastructure bottlenecks and tariff, an assessment should be performed with/without the project.	With/without comparison applies to any CBA benefit.
A54	The definition of Costs is aligned with Regulation 2022/869, Annex V, also to ensure a harmonised approach among all the CBA methodologies.	improved the text accordingly in section 3.2.
A55	The formula of the Economic Benefit/Cost ratio is missing.	improved the text accordingly in section 3.4.

Short view of the changes due to input received from the public consultation

Number Comment	Type of comment	Actions after consultation
A1	Clarification request	Clarified
A2	Improvement request	No action
A3	Improvement request	No action
A4	Clarification request	Clarified
A5	Observation	No action
A6	Observation	No action
A7	Observation	No action
A8	Improvement request	Improvement accepted
A9	Improvement request	Clarified/no action

Number Comment	Type of comment	Actions after consultation
A10	Observation	No action
A11	Improvement request	Improvement accepted
A12	Observation	No action needed
A13	Observation	No action needed
A14	Observation	No action needed
A15	Improvement request	No action (future clarification will be provided for all energy infrastructure categories)
A16	Improvement request	No action
A17	Observation	No action
A18	Improvement request	Improvement accepted
A19	Observation	No action needed (beyond the scope)
A20	Improvement request	Clarification provided
A21	Improvement request	Improvement accepted
A22	Observation	No action
A23	Improvement request	No action
A24	Improvement request	No action
A25	Improvement request	Clarification provided
A26	Improvement request	Improvement accepted
A27	Improvement request	No action
A28	Improvement request	Clarification provided
A29	Improvement request	No action
A30	Observation	No action
A31	Observation	No action
A32	Observation	No action
A33	Improvement request	Clarification provided
A34	Improvement request	Improvement accepted
A35	Improvement request	Improvement accepted

Number Comment	Type of comment	Actions after consultation
A36	Improvement request	No action needed
A37	Improvement request	No action
A38	Improvement request	Improvement accepted
A39	Improvement request	No action
A40	Improvement request	No action
A41	Improvement request	Improvement accepted
A42	Observation	No action needed
A43	Improvement request	Improvement accepted
A44	Improvement request	No action needed
A45	Improvement request	Improvement accepted
A46	Improvement request	No action needed
A47	Improvement request	No action needed
A48	Improvement request	Improvement accepted
A49	Improvement request	No action needed
A50	Improvement request	Improvement accepted
A51	Improvement request	No action needed
A52	Improvement request	No action needed
A53	Improvement request	No action needed
A54	Improvement request	Improvement accepted
A55	Improvement request	Improvement accepted

4. Other important changes

This section outlines important changes implemented by the Commission to the text of SGG CBA methodology, compared to the version submitted for public consultation. These changes have been introduced to increase consistency with other TEN-E methodologies, in line with the provisions of Article 11(8) of the Regulation;

- introduction of the benefit "B2 - Variation of non-GHG emissions";
- introduction of the benefit "B7 - Increase of cross-sectoral flexibility"; and
- introduction of approaches for the evaluation of residual impacts (see section 3.3).

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