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

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Abstract

This report presents the developed Cost-Benefit Analysis (CBA) methodology for candidate electrolysers projects, developed in compliance with the requirements set in the Regulation (EU) 2022/869.

1 Introduction and scope

The cost–benefit analysis (CBA) is a systematic evaluation tool aimed at determining whether an action/decision/investment is profitable (namely, if its benefits outweigh its costs) or to provide a base for 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 electrolysers projects (in the following, "electrolysers CBA methodology") has been developed by the JRC, the European Commission (the "Commission") science and knowledge service, in compliance with the requirements set in Article 11(8) of Regulation (EU) 2022/869 (in the following, "TEN-E Regulation") [1]. In particular the electrolysers 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(1) of TEN-E Regulation.

This electrolysers 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) countries[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.

1.2 General criteria for candidate electrolyser projects

In its assessment of applications received, the Commission shall check the compliance with respect to the general criteria foreseen in Article 4(1) of 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) of 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) of TEN-E Regulation. In particular, to verify compliance with this criterion, the application must include the calculation of the Net Present Value (NPV) of the candidate project along the whole duration of the technical lifetime of the project.

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

i. 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

ii. 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)(f) of Annex IV to TEN-E Regulation: "*the project provides at least 50 MW installed capacity provided by a single electrolyser or by a set of electrolysers that form a single, coordinated project and brings benefits directly or indirectly to at least two Member States, and, specifically, as regards projects on islands and island systems, supports innovative and other solutions involving at least two Member States with a significant positive impact on the Union's 2030 targets for energy and climate and its 2050 climate neutrality objective, and contributes significantly to the sustainability of the island energy system and that of the Union*".

According to the aforementioned options, the application shall clearly describe the level of benefits to different Member States, the direct and indirect benefits brought by the candidate project and, for islands and island systems, the significant positive impact on EU's 2030 climate target, the contribution to 2030 and 2050 EU's carbon neutrality objective and the significant contribution to the sustainability of the energy island and the EU as a whole.

In particular, project promoters must ensure that their applications are compliant with the following rules:

i. the proposed project includes a single electrolyser or a set of electrolysers forming a single, coordinated project with a capacity of at least 50 MW;
    a. hydrogen production must comply with the life cycle greenhouse gas emissions savings requirement of 70 % relative to a fossil fuel comparator of 94 g CO2eq/MJ as set out in Article 25(2) and Annex V to Directive (EU) 2018/2001. In addition;
    b. life cycle greenhouse gas emissions savings are calculated using the methodology referred to in Article 28(5) of Directive (EU) 2018/2001 or, alternatively, using ISO 14067 or ISO 14064-1;
    c. the life-cycle greenhouse gas emissions include indirect emissions;
    d. quantified life-cycle greenhouse gas emission savings are verified in line with Article 30 of Directive (EU) 2018/2001 where applicable, or by an independent third party

ii. the single electrolyser or the set of electrolysers forming a single, coordinated project must have a network-related function. In this respect, project promoters shall describe how their candidate projects contribute to overall system flexibility and overall system efficiency of electricity or hydrogen networks.

iii. when relevant, the proposed project can include related equipment, including pipeline connection to the network.

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

1.3 Specific criteria for candidate electrolyser projects

Pursuant article 4(3)(e) of the TEN-E Regulation, project promoters shall clearly show compliance with all of the following specific criteria:

— sustainability, including by reducing greenhouse gas emissions and enhancing the deployment of renewable or low carbon hydrogen in particular from renewable sources, as well as synthetic fuels of those origins;

— security of supply, including by contributing to secure, efficient and reliable system operation, or by offering storage, flexibility solutions, or both, such as demand side response and balancing services;

— enabling flexibility services such as demand response and storage by facilitating smart energy sector integration through the creation of links to other energy carriers and sectors.

2 General approach

In line with the provisions set in Article 11 of TEN-E Regulation and similarly to the methodological approach exploited for candidate electricity transmission projects [2] and gas infrastructure projects [3], the assessment of candidate electrolyser 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 electrolyser 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 electrolyser projects, such scenarios shall consider possible development for the electricity, gas and hydrogen systems, energy exchanges within the modelled system (according to the different level of detail, it can encompass the geographical area immediately affected by the project or a wider area) and with the modelled systems. These different future developments can be used as input parameter sets for subsequent simulations and analyses.

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.

2.1 Assumptions

A list of common parameters and assumptions used in the methodology is provided below. Assumptions should be aligned with the latest TYNDP scenarios:

- thresholds for identifying whether a project has a significant positive impact on the Union’s 2030 targets for energy and climate and its 2050 climate neutrality objective, and contributes significantly to the sustainability of the island energy system and that of the Union impact as defined in paragraph (1)(f) in Annex IV to TEN-E Regulation;
- 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 [4]. 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;
- hydrogen price for each Member State and for each year within the study horizon;
- ETS carbon price for each year within the study horizon;
- 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 shadow cost of carbon values in Tables 5 and 6 of Commission Notice 2021/C 373/01 [5];
- 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;
- Natural gas demand: for each Member State and for each year within the CBA horizon;
- Hydrogen demand;
- Classification of greenhouse gases (see B1) and relative GWP factors;
- if a legislative and regulatory frameworks would allow the establishment of an EU hydrogen security of supply policy, suitable values for Cost of Disruption of Hydrogen Supply (CODH) for each Member State and for each year within the study horizon;
- monetization factors for RES curtailment for each Member State and for each year within the study horizon.

3 Project CBA for candidate PCIs

The assessment of candidate PCI electrolyser 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) of TEN-E Regulation, their potential overall benefits, assessed in accordance with the relevant specific criteria, outweigh their costs.

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

- the "with case", where the candidate project is realised, it is inserted in the system and, if profitable, realizes during its lifetime benefits that are larger than total costs; and
- the "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 amount of hydrogen produced by a candidate electrolyser projects is equal to the difference in production in the "with" case (i.e. the electrolyser is built) and the "without case" (i.e. the electrolyser is not built so there is no production).

In some cases, the calculation of benefits does not need a complex modelling exercise representing the whole system (see aforementioned example with the benefit "amount of hydrogen produced"): in other cases, however, system modelling activities are required in case of indicators capturing system properties. For instance, an accurate assessment of the benefit "reduction of RES curtailment" would require an exhaustive modelling of the electricity system if the electrolyser is directly interconnected to the electricity system, as the candidate electrolyser project might affect RES curtailment in function of different operating characteristics of the system (i.e. availability of transmission capacity to transfer RES curtailment from its origin to the electricity node where the electrolyser is connected). In some cases, simplifications might be introduced to reduce the modelling complexity (for instance, analysis in specific snapshots extended through duration curves to the whole year of operation), although there is trade-off between modelling complexity and accuracy of the assumption.

Benefits and costs are calculated for one year of operation, although the technical lifetime of a candidate electrolyser project is higher. Consequently, to fully capture the net benefits created by the candidate project in time, this electrolysers CBA methodology require the use of the discounted cash-flow method: in particular, annual cash flows considering costs and benefits for the system in nominal terms will be discounted using the discount rate.

3.1 Benefits

While the calculation of each benefit should aim for a monetary value, the lack of data and models may impede the full monetization of some benefits, although such monetization may be feasible in future assessments. In such cases 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 electrolyser CBA methodology

Benefit [unit]	Specific criterion - Article TEN-E
B1- Variation of GHG emissions [€/a]	Sustainability - Article 4(3)(e)(i)
B2 - Variation of the share of renewable and low-carbon hydrogen integrated into the system	Sustainability - Article 4(3)(e)(i)

B3 – Increased deployment and integration of synthetic fuels	Sustainability - Article 4(3)(e)(i)
B4 – Reduction of curtailed hydrogen demand [€/a]	Security of supply - Article 4(3)(e)(ii)
B5 – Variation of electricity RES curtailment [€/a]	Security of supply - Article 4(3)(e)(ii)
B6 – Variation of socio-economic welfare in electricity markets [€/a]	Smart energy sector integration - Article 4(3)(e)(iii)
B7 – Cross sectoral cost savings [€/a]	Smart energy sector integration - Article 4(3)(e)(iii)

Source: Own elaboration.

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

3.1.1 B1 - Variation of GHG emissions [€/a]

Benefit Definition:

- Definition: economic valorisation of the variation of greenhouse gases emission achievable thanks to the project.
- Relevance: electrolysers are key infrastructural projects for producing low carbon and particularly renewable hydrogen, for replacing the use of non-renewable hydrogen, natural gas and, under the proper socio-economic and technological conditions, it can enable a cost-efficient solution to store energy (directly via compressed or liquefied hydrogen or indirectly via other mediums such as ammonia, methanol, solid-state systems, etc.).

Benefit Calculation:

- Modelling needs: modelling requirements for the calculation of the benefit must be compliant with the provisions set in point (4)(a)(ii) of Annex II to TEN-E Regulation.
- Data needs: data requirements for the calculation of the benefit must be compliant with the provisions set in point (4)(a)(ii) of Annex II to TEN-E Regulation.
- 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 CO_2 emission savings are multiplied by the shadow cost of carbon.

Link with specific criteria TEN-E Regulation

- Sustainability: Article 4(3)(e)(i) TEN-E Regulation

Notes

- Fuel cost savings are not included to avoid double counting with B2-B3.

The whole EU energy policy is based upon the objective of reducing greenhouse gases (GHG) emissions by achieving intermediate targets towards Union's carbon neutrality in 2050. In this respect, infrastructural projects are key in achieving potential GHG emission reductions and in lowering EU carbon footprint.

The whole life cycle assessment of hydrogen production and consumption via electrolysis can reduce GHG emissions, according to the carbon footprint of the electricity used to feed the electrolyser. In this respect, the Greenhouse Gas Protocol[1], the most widely used international accounting tool for quantifying and measuring GHG emissions, breaks down emissions in three categories:

- scope 1 emissions, that are defined as those caused directly by an activity;
- scope 2 emissions, which count indirect emissions resulting from energy consumption; and
- scope 3 emissions, defined as all other indirect emissions caused along the whole value chain.

According to the carbon footprint of the energy used to feed the electrolyser, the scope 2 emissions of the electrolysis process might significantly vary. For instance, for hydrogen produced from dedicated renewable energy source, scope 2 emissions are close to zero. At the same time, for hydrogen produced from electricity absorbed from the grid, scope 2 emissions can be calculated assuming the average country-level CO_2 equivalent emission per kWh of electricity feeding the electrolyser.

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(1) https://www.ghgprotocol.org/

Calculation process

1. Pursuant to the provisions set in point (4)(a)(ii) of Annex II to TEN-E Regulation, project promoters must calculate life cycle greenhouse gas emissions savings using one of the following three approaches:
   a. methodology referred to in Article 28(5) of Directive (EU) 2018/2001 [6];
   b. the standard ISO 14067 "Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification"[2]; and
   c. 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"[3].

The life-cycle greenhouse gas emissions must include all indirect emissions. Any of aforementioned alternative approaches allows to calculate the GHG emission savings achievable by comparing two situations:

— GHG emissions in the "with case", $emission|_{with}$, and

— GHG emissions in the "without case", $emission|_{without}$

2. The variation of GHG emissions achievable thanks to the candidate project converted in monetary terms by using the social cost of carbon

$$B_1 = \sum \left[emission|_{without} - emission|_{with}\right] \cdot ShCost_{CO_2}$$

3. 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.

Main elements to consider

— carbon footprint electricity feeding the candidate electrolyser project;

— operational data of the candidate electrolyser project: efficiency, technical constraints, etc.

— specific information required as input information for the alternative approaches described in point 1 above.

— CO_2 price is an input to the calculation and it might be subject to sensitivity analysis.

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(2) https://www.iso.org/standard/71206.html

(3) https://www.iso.org/standard/66453.html

3.1.2 B2 - Variation of the share of renewable and low-carbon hydrogen integrated into the system

Benefit Definition:

- Definition: increase of the share of renewable or low-carbon hydrogen, in particular from renewable sources, achievable thanks to the candidate electrolyser project.
- Relevance: low carbon and particularly renewable hydrogen produced via electrolysis can reduce extra-EU fuel dependency (for instance, by reducing the consumption of imported natural gas converted in hydrogen via SMR) increasing security of supply and foster cross-sectoral flexibility.

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-hydrogen system 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-hydrogen system (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 electrolyser projects.

Link with specific criteria TEN-E Regulation

- Sustainability: Article 4(3)(e)(i) TEN-E Regulation

Notes

- Economic effect of GHG reduction is not included to avoid double counting with B1.

A candidate electrolyser project can bring benefits stemming from the substitution of other fuels low carbon and particularly renewable hydrogen. 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. While they might not be currently cost-competitive compared to hydrogen produced via SMR, learning curve effects, economies of scale and massive increase in RES installed capacity are expected to gradually make them cheaper than a fossil fuel based one. Low carbon and particularly renewable hydrogen produced as fuel substitute can be either consumed locally (for instance, if the electrolyser facility is close to an industrial facility), stored and shipped from production to the consumption point in different forms or, when dedicated transmission 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 [3].

Calculation process

1. By assuming that the hydrogen demand does not change between the “with” and the “without” case, the amount of replaced hydrogen is equal to the increased amount of low carbon and particularly renewable hydrogen $\Delta H2_{RES} + \Delta H2_{low\quad carbon}$.
2. The project promoter evaluates the increased amount of renewable hydrogen produced thanks to the candidate electrolyser project following one of the two approaches below:

   a. In case a detailed modelling exercise is carried out, the project promoter must evaluate the operation of the modelled electricity and hydrogen system 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 project promoter shall 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 and hydrogen system concerned by the candidate electrolyser 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:

$$share_{H2,renewable} = \frac{QH2_{renewable}}{QH2}$$

$$share_{H2,low\ carbon} = \frac{QH2_{low\ carbon}}{QH2}$$

$$B_{2,H2,renewable} = share_{H2,renewable}\big|_{with} - share_{H2,renewable}\big|_{without}$$

$$B_{2,H2,low\ carbon} = share_{H2,low\ carbon}\big|_{with} - share_{H2,low\ carbon}\big|_{without}$$

$$B_2 = B_{2,H2,renewable} + B_{2,H2,low\ carbon}$$

Project promoters shall provide the values of the benefit B_2 and the sub-indicators $B_{2,renewable}$ and $B_{2,low\ carbon}$ as well as all the information needed to check and replicate their calculation.

Main elements to consider

— Increased production of renewable and low-carbon hydrogen:

- 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-hydrogen EU system. Specific data requirement might differ according to the different modelling formulation;
- no extensive data requirements if project promoters use assumptions on the operation of the electricity and hydrogen system achieved thanks to the candidate electrolyser project.

3.1.3 B3 – Increased deployment and integration of synthetic fuels

Benefit Definition:

- Definition: increased deployment and integration of synthetic fuels achievable thanks to the candidate electrolyser project.
- Relevance: power-to-X (P2X) is a process that incorporates electrolysis to produce hydrogen as an intermediate product, which is then used in another chemical process downstream to produce different fuels. Such fuels can then be locally used, stored or, when possible, injected in the gas system. While the multiple energy conversion reduces the round-trip efficiency of the whole P2X cycle, the process can be justifiable from an economic perspective if synthetic fuels are produced low carbon and particularly renewable hydrogen with low marginal costs of production. Increased availability of synthetic fuels can reduce extra-EU fuel dependency, increasing security of supply and foster cross-sectoral flexibility.

Benefit Calculation:

- Modelling needs: an accurate assessment would require a detailed modelling exercise simulating a larger portion of the electricity-gas-hydrogen system 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 system (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 synthetic fuels that can be produced starting from hydrogen, hypotheses on the amount of fuels replaced and the related fuel cost prices.
- How the benefit is expressed: first, the benefit is expressed in quantitative terms as the amount of synthetic fuels produced starting from renewable or low-carbon hydrogen. Then, the benefit is finally expressed in relative and, therefore, qualitative terms.
- The analysis should provide a breakdown of the synthetic fuels produced from low-carbon and renewable hydrogen.

Link with specific criteria TEN-E Regulation

- Sustainability: Article 4(3)(e)(i) TEN-E Regulation

Notes

- Economic effect of GHG reduction is not included to avoid double counting with B1.

Similarly for the case of benefit B_2, a candidate electrolyser project can create value for the system by supporting the production of synthetic fuels, developed from electrolysed hydrogen, able to substitute other fuels such as methane, gasoline, diesel, kerosene, etc. Synthetic fuels produced as fuel substitutes can be either consumed locally (for instance, if the electrolyser facility is close to an industrial facility), stored and shipped from production to the consumption point in different forms or, if quality standard allow it and if in gaseous form, injected into gas grid. This benefit is conceptually similar to the benefit “Fuel cost savings” considered in the ENTSOG methodology [3].

Calculation process

1. By assuming that demand does not change between the “with” and the “without” case, the amount of replaced fuel is equal to the increased amount of synthetic fuel.
2. The project promoter evaluates the increased amount of synthetic fuel produced thanks to the candidate electrolyser project following one of the two approaches below:

a. In case a detailed modelling exercise is carried out, the project promoter must evaluate the operation of the modelled electricity-gas-hydrogen- system 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 production of each different synthetic fuel achievable thanks to the candidate electrolyser project as well as, if any, of the related production costs.

b. In case of simplified assumptions, the project promoter shall 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 assumptions on the system demand and supply of other fuels. All the assumptions must be duly justified and referenced.

3. The relative increase in the deployment of the g-th synthetic fuel produced starting from renewable and low carbon hydrogen is calculated as described below:

$$share_{g,renewable\ H2} = \frac{Qsyn\ gas_{g,renewable\ H2}}{Qsyn\ gas_g}$$

$$share_{g,low\ carbon\ H2} = \frac{Qsyn\ gas_{g,low\ carbon\ H2}}{Qsyn\ gas_g}$$

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

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

$$B_{3,g} = B_{3,g,renewable\ H2} + B_{3,g,low\ carbon\ H2}$$

$$B_{3,renewable\ H2} = \frac{\sum_g \left(B_{3,g,renewable\ H2}\right) \cdot Qsyn\ gas_g}{\sum_g Qsyn\ gas_g}$$

$$B_{3,low\ carbon\ H2} = \frac{\sum_g \left(B_{3,g,low\ carbon\ H2}\right) \cdot Qsyn\ gas_g}{\sum_g Qsyn\ gas_g}$$

$$B_3 = \frac{\sum_g \left(B_{3,g,renewable\ H2} + B_{3,g,low\ carbon\ H2}\right) \cdot Qgas_g}{\sum_g Qgas_g}$$

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

Main elements to consider

— Increased production of synthetic fuels:

- 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-hydrogen EU system. Specific data requirement might differ according to the different modelling formulation.
- No extensive data requirements if project promoters use assumptions on the operation of the electricity and hydrogen system achieved thanks to the candidate electrolyser project.

3.1.4 B4 – Reduction of curtailed hydrogen demand [€/a]

Benefit Definition:

- Definition: reduction of curtailed hydrogen demand that cannot be satisfied in a given area.
- Relevance: when an internal market for hydrogen will be established, the production of hydrogen from candidate electrolysers 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 transmission capacity in the hydrogen network to allow hydrogen to flow to local consumption nodes. In this respect, production of hydrogen devoted to reduce curtailed hydrogen demand from candidate electrolyser project can increase security of energy supply in the Union.

Benefit Calculation:

- Modelling needs: accurate assessment would require a detailed modelling exercise simulating a larger portion of the electricity-hydrogen system beyond the project (i.e. up to the European level).
- Data needs: extensive data requirement to simulate the whole electricity- hydrogen system (i.e. simulations up to the European level would require data requirements similar to the ones for ENTSOs TYNDPs).
- How the benefit is expressed: first, the benefit is expressed in quantitative terms as avoided hydrogen demand curtailment (expressed in ton/a or in GWh/a) achievable thanks to the candidate electrolyser project. Then, the benefit is finally expressed in monetary terms when avoided hydrogen demand curtailment is multiplied with values of Cost of Disruption of Hydrogen Supply (*CODH*) for each Member State.

Link with specific criteria TEN-E Regulation

- Security of supply: Article 4(3)(e)(ii) TEN-E Regulation.

Notes

- A prerequisite for the calculation of this indicator is the establishment of an internal hydrogen market, legislation concerning hydrogen security of supply and the availability of suitable values for CODH.

Under the proper legislative framework and market conditions, hydrogen security of supply can be ensured by identifying whether there are countries in EU that risk to face any hydrogen demand curtailment: in this respect, candidate electrolyser project may play a role in increasing security of supply by mitigating, thanks to their production, such occurrences.

Calculation process

Provided that the proper regulatory, legislative and market frameworks are established, the benefit B_4, conceptually similar to the benefit “Avoided curtailment demand” considered in the ENTSOG methodology [3], can be calculated as follows:

1. project promoters evaluate the operation of the modelled electricity and hydrogen system 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 monetized benefit related to the reduction of hydrogen demand curtailment in each Member State achievable thanks to the candidate electrolyser project can be calculated by project promoters as follows.

$$B_4 = \sum_z (Demand\_curtailment_z|_{without} - Demand\_curtailment_z|_{with}) \cdot CODH_z$$

3. The economic present value of the indicator B_4 is calculated within the study horizon using the discounted cash-flow approach.

<u>Main elements to consider</u>

— Avoided hydrogen demand curtailment:

  - running a detailed EU hydrogen and electricity model might correspond to data requirement and data granularity comparable to the ones concerning ENTSOs TYNDPs.
  - No extensive data requirements if project promoters use assumptions on the operation of the electricity and hydrogen system achieved thanks to the candidate electrolyser project.

3.1.5 B5 – Reduction of RES curtailment [€/a]

Indicator Definition:

- Definition: reduction of RES curtailment in the electricity system achievable thanks to the candidate electrolyser project.
- Relevance: reduction of RES curtailment by using the RES surplus to feed electrolysers connected to the electricity network increases security of supply of the Union.

Indicator Calculation:

- Modelling needs: if the project is connected to the electricity network and not to a dedicated and exclusive RES infeed, the accurate assessment would require a detailed modelling exercise simulating a larger portion of the electricity system beyond the project (i.e. up to the European level). An alternative solution without significant modelling requirements would be based on project and system assumptions and relative calculations.
- Data needs: extensive data requirement to simulate the whole electricity system (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 by using operative data about the estimated amount of additional RES that can be used to produce renewable hydrogen thanks to the candidate electrolyser project as well as about the amount of avoided RES curtailment.
- How the benefit is expressed: the benefit can be expressed in quantitative terms as avoided RES curtailment in the electricity system (in GWh/a) achievable thanks to the candidate project and in monetary terms, by multiplying the avoided RES curtailment for the relevant monetisation factors.

Link with specific criteria TEN-E Regulation

- Security of supply: Article 4(3)(e)(ii) TEN-E Regulation

Notes

- Economic effect of the related GHG reduction is not included to avoid double counting with B1.

RES curtailment arises in the electricity system when the instantaneous production of renewable energy sources exceeds the instantaneous electricity demand, taking also in consideration inflexibility of certain component of the electricity system (for instance, minimum up time and downwards ramp constraints of dispatchable thermal power plants). In this occurrence, if the electricity system is not able to store or transmit such surplus in other areas of the system, system operators might force RES to reduce their output to ensure system security: consequently, the system is not exploiting cheap and clean energy output.

While electrolysers might have technical operational constraints, they can still provide additional flexibility to the energy system as a whole, increasing their energy intake in RES surplus moments to produce renewable hydrogen. This capability can be beneficial under different perspectives:

- by reducing the curtailment of renewable energy that it is instead stored in hydrogen to be used on a second stage, candidate electrolyser projects can enable additional decarbonisation of end-uses increasing the sustainability of the whole energy system;
- the reduction of curtailment for RES generation contributes at increasing the safety and the stability of network operation, enhancing security of supply; and
- the flexibility provided by candidate electrolyser projects can be seen as a measure of demand response in the electricity system enabling energy storage: consequently, candidate electrolysers contributing at reducing RES curtailment facilitate smart energy sector integration by reinforcing links among energy carriers (i.e. electricity and hydrogen) and sectors (i.e. electricity, hydrogen, industry, transport, etc.), ultimately unlocking cost savings for the Union.

Calculation process

The benefit B_5, conceptually similar to part of the benefit B3 "RES Integration Benefit" considered in the ENTSO-E methodology [2], can be calculated as follows:

1. Project promoters evaluate the reduction of RES curtailment following one of the two approaches below:
    a. in case a detailed modelling exercise is carried out, the project promoter must evaluate the operation of the modelled electricity system in both "with" and "without" cases. Given the objective function of the optimisation algorithm and the balance demand constraints, the model provides as output the level of curtailed RES generation, in each modelled zone;
    b. in case of simplified assumptions, the project promoter shall calculate the estimated amount of RES curtailment that can be avoided by redirecting such infeed to the candidate electrolyser project. All the assumptions must be duly justified and referenced.
2. The monetized benefit related to the reduction of avoided RES curtailment in the *z*-th zone of the modelled electricity system can be calculated by project promoters by multiplying avoided RES curtailment for proper monetisation factors for RES curtailment (expressed in €/MWh).

$$B_5 = \sum_z (RES\_curtailment_z|_{without} - RES\_curtailment_z|_{with}) \cdot K_{RES\_curtailment}{}_z$$

3. The economic present value of the indicator B_5 is calculated within the study horizon using the discounted cash-flow approach.

Main elements to consider

— Avoided RES curtailment
- running a full EU electricity model to calculate avoided RES curtailment might correspond to data requirement and data granularity comparable to the ones concerning ENTSO-E TYNDP.
- no extensive data requirements might be needed if project promoters use estimation about the amount of avoided RES curtailment that can be avoided thanks to the candidate electrolyser project.

— Monetisation factors for RES curtailment: such factors (in theory different for each EU Member State) could be subject to sensitivity analysis.

4.

3.1.6 B6 – Variation of socio-economic welfare in electricity markets [€/a]

Benefit Definition:

- Definition: variation of Social Economic Welfare (SEW) in electricity markets achievable thanks to the candidate electrolyser project.
- Relevance: candidate electrolyser projects can enhance flexibility and efficiency of electricity markets, resulting in an increase of SEW for the Union.

Benefit Calculation:

- Modelling needs: if the project is connected to the electricity network and not to a dedicated and exclusive RES infeed, the accurate assessment would require a detailed modelling exercise simulating a larger portion of the electricity system beyond the project (i.e. up to the European level). The modelling shall be able to capture different phases of electricity markets, in particular closer to the real-time (for instance, balancing markets and ancillary services markets), giving the flexibility capability and related benefits that a candidate electrolyser projects can offer to such markets: for instance, modelling of balancing markets would require higher temporal granularity (i.e. intra-hour modelling.
- Data needs: extensive data requirement to simulate the whole electricity system (i.e. simulations up to the European level would require data requirements similar to the ones for ENTSOs TYNDPs) with a level of detail sufficient enough to represent market session close to the real time. Level of detail of data should be consistent and compatible with the modelling exercise.
- How the benefit is expressed: the benefit is expressed in monetary terms either by using the generation cost approach or the total surplus approach.

Link with specific criteria TEN-E Regulation

- Smart energy sector integration: Article 4(3)(e)(i) TEN-E Regulation.

Notes

- Economic effect of the related GHG reduction is not included to avoid double counting with B1.

Socio-economic welfare (SEW) is defined in economics via the concept of utility, i.e. the value that different actors in the market associate to a particular good or service. Individuals tend to maximize their utility through their actions and consumption choices and the interactions of buyers/consumers and sellers/producers through the laws of supply and demand in competitive markets yield to consumer and producer surplus. A natural equilibrium point is achieved when the highest overall (social) level of satisfaction is created among the different actors.

In power system economics, SEW is often defined as the short-run economic surpluses of electricity consumers, producers and, given the nature of the transportation problem, transmission operators (collecting congestion rents). Any infrastructural project inserted in the system affects either the generation or the consumption mix or the transmission capacity, resulting into a variation and/or redistribution of SEW within the modelled system (between different actors and/or among different modelled zones).

Current EU electricity market design offer the following opportunities to electrolysers [7]:

- participating in day-ahead electricity market, acting as implicit (price-based) demand response. In this respect, electrolyser can vary their consumption according to price signal: for instance, they can quickly ramp–up their consumption at times where there is RES surplus (reducing RES curtailment, see benefit B_5) and especially in hours where operational constraints on inflexible generation might result in negative prices, increasing SEW for EU society;
- participating in intraday electricity market: electrolyser might adjust their consumption profile in continuous trading, matching buy or sell orders in order to balance positions: in this respect, electrolysers might act as additional flexibility resource in intraday electricity markets, contributing at increasing SEW for EU society;

- participating in electricity balancing markets: in this respect and whether allowed by the pertinent regulatory framework, electrolysers could be controlled to quickly ramp-up or ramp-down their consumption participating either individually (if sufficiently large) or through aggregators in electricity balancing markets by providing, for instance, Frequency Containment Reserve (FCR) and/or automatic/manual Frequency Restoration Reserve (aFRR/mFRR). If such services are remunerated in the zone where the electrolyser is connected, a cost-efficient flexibility service provided by the electrolyser would result in an increase of SEW for the system.
- participation in other (non-frequency) ancillary services markets: ancillary services are defined as "those services necessary to support the transmission of electric power from seller to purchaser, given the obligations of control areas and transmitting utilities within those control areas, to maintain reliable operations of the interconnected transmission system". Given the fact that electrolysers act as loads in the electricity markets, they can provide the following ancillary services:
    - reactive power and voltage control: electrolysers exploit AC/DC converters that can be used as STATCOMs, providing reactive power and voltage control [7].
    - scheduling and dispatch: given their flexibility, electrolysers might increase efficiency of scheduling (i.e change status of a generation unit) and dispatch (i.e. change output of a scheduled generation unit) carried out by system operator with the aim of maintaining adequate levels of security for the system while increase the SEW of the system.
- participating in the market based procurement of congestion management.

<u>Calculation process</u>

The benefit B_6, whose part of it is conceptually similar to the benefit B1 "SEW benefit" considered in the ENTSO-E methodology [2], can be calculated as follows:

1. If the candidate electrolyser is connected to the power system, project promoters evaluate the increase of SEW following one of the two approaches below:
    a. generation approach, where the benefit for the system is calculated by assessing the difference between total operating cost of the power system in both "without" and "with" cases;
    b. total surplus approach: , where the benefit for the system is calculated by assessing the difference between total SEW (sum of consumer and producer surpluses and congestion rent) of the power system in both "with" and "without" cases;
2. In case a detailed modelling exercise is carried out, given the objective function of the optimisation algorithm representing the different phases of the electricity market the project promoter can calculate the benefit as sum of the difference of total costs in each modelled market *m* (i.e. day-ahead, intraday, balancing, other ancillary services markets);

$$B_6 = \sum_m (Total\ cost\ ele_m|_{without} - Total\ cost\ ele_m|_{with})$$

or

$$\begin{aligned} B_6 = \sum_m &(Consumer\ surplus_m|_{with} - Consumer\ surplus_m|_{without}) \\ &+ (Producer\ surplus_m|_{with} - Producer\ surplus_m|_{without}) \\ &+ (Congestion\ rent_m|_{with} - Congestion\ rent_m|_{without}) \end{aligned}$$

    a. in case of simplified assumptions, the project promoter shall calculate the estimated amount of RES curtailment that can be avoided by redirecting such infeed to the candidate electrolyser project. All the assumptions must be duly justified and referenced.

3. In case of simplified assumptions, the project promoter shall calculate the estimated amount of increase of SEW that can be achieved in each step of the electricity market thanks to the market efficiency brought by the candidate electrolyser project. All the assumptions must be duly justified and referenced.

5.

4. The economic present value of the indicator B_6 is calculated within the study horizon using the discounted cash-flow approach.

Main elements to consider

- An accurate characterization of the different steps of EU electricity markets would require extensive modelling and data requirement, both in terms of temporal granularity (e.g. intra-hour modelling for electricity balancing markets), spatial granularity (e.g. nodal formulation to account re-dispatch) and problem formulation (e.g. AC modelling to account participation to voltage control and ancillary services markets). Consequently, modelling and corresponding data requirements could significantly vary according to the level of accuracy and detail chosen by project promoters.

3.1.7 B7 – Cross sectoral cost savings [€/a]

Benefit Definition:

- Definition: cost savings achieved thanks to candidate electrolyser projects by enabling cross-sectoral flexibility.
- Relevance: by enabling services such as demand response and energy storage, candidate electrolyser 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 electrolyser projects, a detailed modelling exercise encompassing several other 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 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

- Smart energy sector integration: Article 4(3)(e)(iii) TEN-E Regulation

Notes

- Double counting with other indicators shall be avoided.

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, electrolysers play a key role in unlocking such efficiencies, by enabling flexibility services facilitating links among the different energy carriers and sectors: trivially, electrolysers use electricity to create hydrogen, which is a key resource for certain industries and that can be potentially used as a fuel for both transport and heating system. Cost savings can also arise in terms of reduction of capital expenses in several sectors enabled by candidate electrolyser projects.

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. In this respect, the level of detail used by project promoters shall reflect the level of implementation of the best practice developed by the ENTSOs with respect the implementation of the integrated (electricity, gas and hydrogen) energy model.

Calculation process

For each year within the study horizon, project promoter shall evaluate the cross-sectoral cost savings achievable thanks to candidate projects as follows:

1. In case of complete integrated model, project promoters of candidate projects shall calculate the benefit as variation of annual total costs (both operational and capital, if the model can also be used for investment decision) that can be achieved thanks to the candidate electrolyser project in all the s sectors which is directly calculate by the integrated model from both “without” and “with” simulations of the integrated model;

$$B_7 = \sum [Total\ cost(s)|_{without} - Total\ cost(s)|_{with}]$$

2. In case of separate simulation of different systems, project promoters of candidate electrolyser projects 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 a simplified integrated model from separate studies or assumptions from project promoters: in case of separate studies or assumptions from project promoters, exogenous information must be duly justified and referenced by project promoters. For project promoters following this approach, the benefit is calculated 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 electrolyser project in all the sectors

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

3. If no simulations are carried out, project promoters of candidate electrolyser projects may estimate cost 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 electrolyser project in all the sectors. Exogenous information must be duly justified and referenced by project promoters

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

5. 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, project promoter should clearly identify these risks and remove the share of the indicator which is already accounted in another one.

Main elements to consider

An accurate characterization of this indicator would require extensive modelling and data requirement, similar if not exceeding the requirements set for the integrated model pursuant to Article 11(10) of TEN-E Regulation.. Consequently, modelling and corresponding data requirements could significantly vary according to the level of accuracy and detail chosen by project promoters.

3.2 Costs

The project promoter shall provide CAPEX and OPEX for each year analysed in the study horizon, assumptions on authorisation, construction time and decommissioning (if relevant). 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).

3.3 Project value calculation

The Net Present Value (NPV) represents the difference between the present value of all monetised benefits and the present value of all costs, discounted using the 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.[1]

3.4 Transparency and confidentiality

In submitting their CBA, project promoters for candidate electrolyser 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.

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[1] More detailed information on the project value calculation can be found in the latest CBA methodology developed by the ENTSOs.

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

[3] 2nd ENTSOG Methodology for Cost-Benefit Analysis of Gas Infrastructure Projects – October 2018.

[4] 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.

[5] COMMISSION NOTICE - Technical guidance on the climate proofing of infrastructure in the period 2021-2027 (2021/C 373/01)

[6] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast).

[7] Dumont, A., *Impacts of day-ahead power market conditions on flexible grid-connected water electrolysis in Europe*. Louvain School of Management, Université catholique de Louvain, 2022. Prom. : Johannes Mauritzen. http://hdl.handle.net/2078.1/thesis:34769

[8] Chiesa, N., Korpås, M., Kongstein, O. E. and Ødegård, A. *Dynamic control of an electrolyser for voltage quality enhancement*. In proceedings of the International Conference on Power Systems Transients, Delft, The Netherlands, 14–17 June 2011; p. 8.

List of abbreviations and definitions

CBA	Cost Benefit Analysis
EIB	European Investment Bank
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSOG	European Network of Transmission System Operators for Gas
EU	European Union
JRC	Joint Research Centre
PCI	Project of Common Interest
SMR	Steam Methane Reforming

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