Levelised Cost of Hydrogen Calculator

Powered by LNEG

LNEG-LCOH
Levelised Cost of Hydrogen Calculator:
Description and Methodological Report
Version 02.2025

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Contents

Disclaimer

The aim of this document is to explain the methodology implemented for the LNEG-LCOH - Levelised Cost of Hydrogen calculator.

The default data (reference values) in the LNEG-LCOH tool are based on values obtained from different sources, including direct contact to industrial players in Europe. The values correspond mainly to the year 2024. The authors believe that the data comes from reliable sources but do not guarantee their accuracy or completeness. Reference values may be updated on an annual basis.

The information and views in this report are those of the authors and do not necessarily reflect the official opinion of LNEG, the Portuguese Government, or any other Portuguese or European Institution. No other person acting on their behalf may be held responsible for the use which may be made of the information contained herein.

This report and the tool described here were prepared within the framework of the Moving2Neutrality Agenda, Project 3.3, WP3, "Technical and economical evaluation of H_2 transport solutions for HRS networks & of liquified H_2", financed by theRecovery and Resilience Plan (RRP). The RRP is a nationally implemented programme with a development period until the end of 2025, whose objective is to implement a set of reforms and investments aimed at restoring sustained economic growth after the pandemic, strengthening the goal of convergence with the rest of Europe over the next decade.

All units used in the LNEG-LCOH tool are in SI units. The currency unit is € for the input and output of any module.

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Nomenclature

AHP	Annual hydrogen production
AHP_{nom}	Annual nominal hydrogen production - as specified by manufacturer
CAPEX	Capital expenditures
DECEX	Decommissioning expenditures
H_2	Hydrogen
HRS	Hydrogen refuelling station
LCOH	Levelised cost of hydrogen
LF	Water electrolysis plant load factor
OPEX	Operational expenditures
OPEX_{fix}	Annual fixed operational expenditures
OPEX_{var}	Annual variable operational expenditures
PPA	Power Purchase Agreement
PV	Photovoltaic
n	Year n
n_{lifetime}	Last year of operation of the assets, i.e., end of lifetime year
r	Annual discount rate
$r_{\text{degradation}}$	Annual rate of degradation

1 Introduction

1.1 The National Laboratory for Energy and Geology (LNEG)

The National Laboratory for Energy and Geology, I.P. (LNEG) is a research organisation, which carries out Science in the domains of Energy, Geology and Geological Resources with a view to its application in advanced solutions that allow the leverage of the Portuguese Economy. LNEG is under the tutelage of the Ministry of Environment and Energy of Portugal.

LNEG, under the motto "Building a cleaner, future" has, as Mission, to promote and carry out research, demonstration and knowledge transfer actions, technical and technological assistance and laboratory support for companies, in the domains of Energy and Geology (Decree-Law nr. 129/2014 of August 29).

LNEG's vision is to be a reference institution capable of contributing with excellent solutions for a decarbonised economy. The Values followed by LNEG focus on Excellence, Commitment, People, and Innovation.

In 2010, the National Laboratory for Energy and Geology adhered to the principles of the European Charter of Researchers and the Code of Conduct for the recruitment of researchers. In 2013, LNEG received the right to use the logo of Excellence in Research HR.

LNEG is scientifically organized into two main laboratories: the Laboratory of Energy (LEN) and the Laboratory of Geology and Mines (LGM). Furthermore, there is a transversal research unit named Resource Economics Unit (UER), and various administrative and management supporting units to ensure LNEG's smooth operation (e.g., Strategic Management Unit, Management and Organization Department, and others).

Grounded on the values of Excellence, Commitment, People, and Innovation, LNEG aims to contribute towards building a cleaner and better future.

1.1.1 Laboratory of Energy (LEN)

LEN operates in the areas of renewable endogenous energy resources and energy efficiency. It has the responsibility of knowing the potential of renewable energy resources and exploring innovative and strategic technologies to support the optimal use of resources. The accumulated knowledge from its research activity allows it to be in a permanent readiness to support the implementation of public policies and the business sector. LEN is divided into three main units:

- Bioenergy and Biorefineries Unit
- Renewable Energies and Energy Eficiency Unit
- Materials for Energy Unit

1.1.2 Laboratory of Geology and Mines (LGM)

LGM performs permanent functions of the State in the development of geoscientific knowledge of the emerged territory, the continental shelf and deep water zones. It is also responsible for the systematic geological survey of geological risks and resources, including geothermal energy resources, geological storage, namely CO_2, and geological heritage. It performs functions of the National Geological Service. The accumulated knowledge from its research activity allows it to be in a permanent readiness to support the implementation of public policies and the business sector. LGM is divided into four main units:

- Geology, Hydrogeology and Coastal Geology Unit
- Geoscientific Information Unit
- Mineral Resources and Geophysics Unit
- Mineral Technology and Science Unit

1.1.3 Accredited Laboratories

LNEG counts on three accredited laboratories that serve government, industry, and society:

- Laboratory of Biofuels and Biomass
- Laboratory of Materials and Coatings
- Laboratory of Solar Energy

1.1.4 LNEG as a contributor of innovation ecosystems

LNEG is part of five technological infrastructures in which close cooperation is established between public and private partners, taking advantage of existing complementary knowledge, equipment, and experimental facilities. These structures are also open to external cooperation. Some of them are listed here:

- BBRI – Biomass and Bioenergy Research Infrastructure;
- C4G – Collaboratory for Geosciences;
- INIESC – National Research Infrastructure for Concentrating Solar Energy;
- NZEB LAB – Research Infrastructure on Integration of Solar Energy Systems in Buildings;
- WindScanner – The European WindScanner Facility.

Collaborative Laboratories (CoLabs) form part of a recent approach of the Portuguese State, and LNEG develops activities within the framework of the following CoLabs:

- CoLAB BIOREF - Collaborative Laboratory for Biorefineries;
- HyLAB - Collaborative Laboratory for Green Hydrogen;
- CECOLAB – Collaborative Laboratory Towards Circular Economy; and
- GreenCoLab – Oceano Verde Association.

Collaborative Laboratories aim to have a positive effect on qualified and scientific employment in Portugal through the definition and implementation of research and innovation agendas aimed at creating economic and social value.

LNEG is also the Portuguese Geological Survey and is a full member of the European Geological Surveys, EuroGeoSurveys. Also noteworthy is the activity of the three lithotheques managed by LNEG, in which, in addition to 700 thousand meters of drilling cores, more than a hundred geological sections are also available for consultation, as well as thousands of samples, thin sections of rocks and microfossil cells. These provide valuable scientific information to researchers, students, local authorities, organisations and companies. LNEG also manages the geoPortal of Energy and Geology

The Geological Museum is also an important asset of LNEG, which provides regular public visits to its museological space. Reference collections are also available for consultation and study by researchers, both in Portugal and abroad.

1.2 The Resource Economics Units (UER)

The Resource Economics Unit (UER) is transversal to the areas of Energy and Geology of LNEG. It develops R&D&D and decision support activities for public policy makers and the private sector in energy and geological resource economics, aiming at carbon neutrality and sustainable resource exploration and use of resources. The unit applies techno-economic and social analytical approaches in the areas of (1) Sustainable energy systems, (2) Use of resources for energy production and consumption, (3) Classification of national geological deposits and energy resources in a global economy, (4) Economic and social impact of the energy transition, and (5) Circular economy, including the design of products, services, systems, and business models. UER is the unit responsible for the creation and maintenance of the LNEG-LCOH tool and serves as an interface for external users.

1.3 Purpose of the LNEG-LCOH Tool

The purpose of the LNEG-LCOH - Levelised Cost of Hydrogen Calculator (LNEG-LCOH tool) is to provide a free service for the quick estimation of costs over different components of the hydrogen value chain. The tool is envisioned to provide flexibility according to the users' needs and to provide reference values based on current trends. The tool is expected to evolve over time to consider more components and to satisfy needs that may arise from users.

LNEG is actively contributing to reducing the gap between research and the market by supporting innovation. LNEG develops high-added value tools for public use to analyse the value and supply chains associated with hydrogen and closely monitors the exchange of ideas in this emerging area.

1.4 Version

The version of this release is identified as Version 02.2025. Please visit Section 5.1 for more information about contacts and how to submit a bug report or other inquiries.

Table 1.1: Version control table.

Version	Year	Description
01.2024	2024	Initial version presenting the methodology and the tool.
02.2025	2025	Revision of text and addition of examples and excel annex with input reference values.

1.5 Exclusions

The LNEG-LCOH tool version described in this manual excludes the following variables, items, modules, ideas, or dimensions:

- Taxes, subsidies or incentives in any form.
- Decommissioning expenditures (DECEX).
- The consideration of other co- or by-products like oxygen and their economic leverage or other sustainable fuels that can be produced with green hydrogen, e.g., hydrogenated vegetable oils (HVO) or ammonia (NH_3).
- Credits associated with the reduction of Greenhouse Gas Emissions (GHG).

1.6 Structure of this Document

This document is divided into six main sections. Section 1 presents an introduction of LNEG, the objective of the LNEG-LCOH Tool, and the version control. Section 2 presents the overall LCOH computation methodology and the LNEG-LCOH Tool. Section 3 presents the reference values for a hypothetical case study. Section 4 shows some examples and comparisons with another tool. Section 5 presents information about contacts and how to report Bugs, Suggestions, and Comments.

2 Cost of Hydrogen Computation Methodology

This section presents the methodology used for the calculation of the levelised cost of hydrogen (LCOH). It starts with the main overview of the LCOH, its definition and equation, followed by a description of each of the modules LNEG-LOCH tool implemented in the current version.

2.1 What is a Levelised Cost of Hydrogen?

The levelised cost of hydrogen (LCOH) is an indicator or metric that has been widely accepted to compare options for projects involving hydrogen or other energy projects, which also serves to assess the competitiveness of such projects. It is also a method that serves to evaluate the expenses involved in hydrogen projects throughout its entire lifecycle.

The LCOH enables policymakers, investors, industrial players, and other economic agents to make better-informed decisions regarding strategies for the promotion of cost-effective, sustainable hydrogen business cases and the subsequent resource allocation.

The LCOH could be defined as a metric that relates all the expenses over the lifetime of the hydrogen assets, including capital expenditures or investment costs (CAPEX), the operational and maintenance costs (OPEX), and decommissioning expenditures (DECEX), to the production or reference amount of hydrogen. The LCOH considers all quantities (costs and amount of hydrogen) discounted over time at an annual discount rate and their contribution from the beginning until the end of the operation, i.e., the lifetime of the project.

The following general formula is used in the LNEG-LCOH tool to compute the levelised cost of hydrogen:

$$\text{LCOH} = \frac{\text{CAPEX} + \sum \frac{\text{OPEX}_{\text{fix}} + \text{OPEX}_{\text{var}}}{(1+r)^n}}{\sum \frac{\text{AHP}}{(1+r)^n}} \tag{2.1}$$

where the new variables are fixed operational and maintenance costs, OPEX_{fix} (e.g., labor, administrative costs, or other costs not dependent on variations of the amount of hydrogen), variable operational and maintenance costs, OPEX_{fix} (e.g., electricity, water for hydrogen production, electrolyser's stack replacements, fuel, or other costs dependent on the amount of hydrogen produced, liquified, stored, transported, or distributed), the discount rate, r, the year of the expense or production, n, and the annual amount produced (AHP) or equivalent amount of hydrogen (stored, transported, distributed). Equation 2.1 represents the general equation for the LCOH calculation for any of the modules implemented in the tool. The user should be aware that in the current version of the tool, DECEX are not considered, and they are not included in Equation 2.1.

The definition of LCOH adopted and presented in Equation 2.1 is equivalent to the Levelised Cost of Energy –or Electricity– (LCOE), and therefore the conversion of the LCOH expressed in €/kgH$_2$ could be easily translated to €/MWh. This allows easier comparisons between different energy projects beyond hydrogen ones.

2.2 Value Chain Components Considered for the Tool

Green hydrogen is a versatile and promising element in the Portuguese and European energy context. Hydrogen can be used as a feedstock, as fuel or as an energy carrier. As raw material, it is used in various industrial processes, many associated with the chemical industry. As a fuel, hydrogen can be used in fuel cells to generate electricity, emitting only water as a by-product, which makes it a clean and sustainable option, or it can be used in the production of other sustainable fuels such as ammonia, methanol or jet fuels, among others. As an energy carrier,
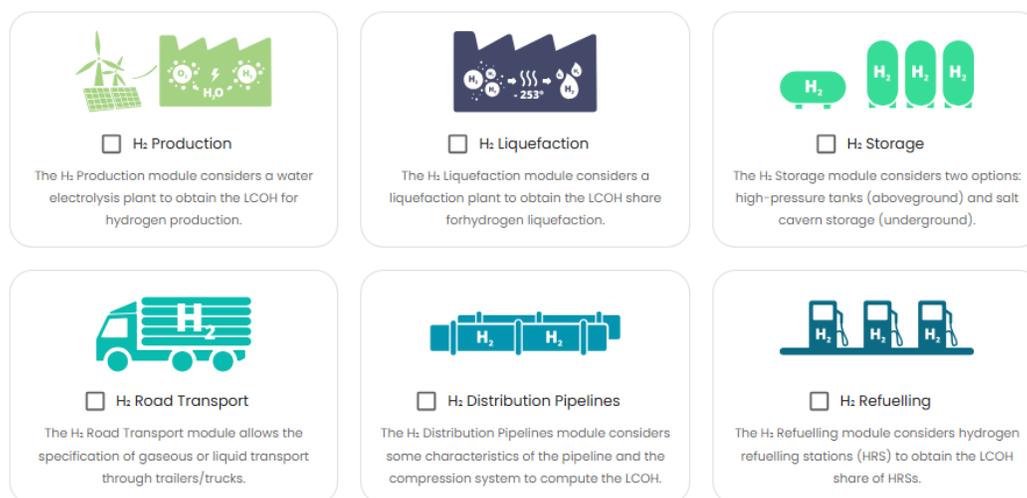
Figure 2.2: Value chain components considered in the LNEG-LCOH Tool.

hydrogen allows the storage and transport of energy, acting as a bridge between the intermittent production of renewable energies, such as solar and wind, and the need for energy demand. In addition, hydrogen can play a strategic role in the energy independence of certain regions.

Value and supply chains will consequently depend on end-use and business models. In LNEG-LCOH Tool six components were implemented. These are: i) green hydrogen production, ii) liquefaction, iii) storage, iv) road transport, v) pipeline transport, and vi) distribution through hydrogen refuelling stations (see Figure 2.2). Other uses or the transformation of hydrogen into other sustainable fuels have not been considered in the current version of the tool.

2.3 The LNEG-LCOH Tool: Overview

The LNEG-LCOH tool comprises six optional modules. They can be used individually or simultaneously, and they represent one component within the hydrogen value chain from production to transport and distribution in hydrogen refuelling stations. The hydrogen value chain is much more extensive than the six components implemented in the tool today. However, project constraints and time limitations are factors that limit the scope of the current version of the tool.

The six modules of the tool are i) H_2 Production, ii) H_2 Liquefaction, iii) H_2 Storage, iv) H_2 Road Transport, v) H_2 Distribution Pipelines, and vi) H_2 Refuelling (HRS). These are described in more detail in the following sections.

The LNEG-LCOH tool provides reference values for each of the variables used in each of the modules in the current version. The reference values considered for the H_2 Production correspond to a hypothetical water electrolysis plant of 50 MW. Although there is the option for selecting alkaline (ALK) or proton-exchange membrane (PEM) electrolisers in the tool, currently an average value is shown for the CAPEX costs of the electrolysis plant. The plant is assumed to have a technology-neutral electrolysis system (50% ALK / 50% PEM). A similar approach was adopted for the *MIBGAS IBHYX Index*. However, the user has the freedom to introduce different values.

> **!** Note: Suggested reference values are provided in a separate column for each field, based on a hypothetical 50 MW hydrogen production plant. However, users can input their own customized data if they wish, allowing flexibility in their assessment and analysis.

2.4 Production of Hydrogen Module: *H_2 Production*

The H_2 Production module considers a water electrolysis plant and uses Equation 2.1 to obtain a LCOH for hydrogen production.

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CAPEX

The CAPEX can be introduced by the user or default values can be used. The value introduced by the user should not consider the cost of the stack, which is computed internally using the CAPEX input by the user and the percentage of the cost of the stack with regard to the CAPEX (without initial stack costs). Stack replacement costs during the lifetime of the plant are better explained below because they are considered OPEX when applied after the start of operations.

OPEX

The OPEX is divided into fixed annual values and variable annual ones. The latter considers the electricity and water consumption for the electrolysis plant, as well as the stack replacement costs over the asset lifetime. Unitary costs are inputted by the user for both electricity and water.

Regarding water consumption, the user has three options: water from the public grid or network (FreshWater), water from treated wastewater (WasteWater), and desalinated water (SeaWater). In the current version, only one source of water can be used at a time. In contrast, electricity can be specified from a combination of sources. Four types of sources are possible: from the electricity network, Solar PV, Onshore Wind, and offshore wind plants. Different percentages and prices are allowed to be introduced by the user.

Stack replacement costs are computed as a percentage of the CAPEX (without stack). The percentage and the CAPEX values are input by the user. More details regarding when the stack is replaced are provided below.

H$_2$ Production

Production of hydrogen is adjusted over the year and the lifetime in two complementar ways. The first is associated with the real working hours over one year by applying a mean annual load factor (LF) input by the user. The second is associated with the stack's degradation, a known issue for which manufacturers should provide information about.

Regarding the load factor, the nominal annual capacity of the plant (AHP$_{\text{nom}}$) is multiplied by it. This load factor reflects the equivalent number of hours that the plant works in a given year at the nominal capacity (see Equation 2.2), which is always lower than 1, equivalent to 8760 hours/year.

$$\text{AHP} = \text{AHP}_{\text{nom}} \times \text{LF} \tag{2.2}$$

The stack degradation over time allows considering the reduction of the total amount of hydrogen produced after the application of the LF. The user indicates the rate of degradation of the stack, otherwise default values apply. Special attention should be put on the unit of the degradation rate required, which should be expressed annually and not hourly. In other words, every year, including the first, the nominal production of the plant experiences a decrease relative to the previous year in a fraction proportional to the degradation rate (see Equation 2.3). The first year uses as reference the nominal annual production after the application of the LF, while from year two to the lifetime of the plant (n_{lifetime}), the reference value is the previous year. The stack replacement period is specified by the user in hours; once the tool determines the stack replacement period (i.e., specific year(s)), the production is reset and that year is assumed to have the same production of year one, and the degradation progression rate starts again. A list of the input variables, their definition, and respective units considered are described in the next subsection.

$$\text{AHP}_i = \text{AHP}_{i-1} \times (1 - r_{\text{degradation}}), \quad \text{for } i = 2, 3, 4...n_{\text{lifetime}} \tag{2.3}$$

2.4.1 List of variables for the production module

Table 2.2 presents the variables considered for the production module, their units as accounted for in the tool, and description.

2.5 Liquefaction of Hydrogen Module: *H$_2$ Liquefaction*

The H$_2$ Liquefaction module considers a liquefaction plant and uses Equation 2.1 to obtain a LCOH for liquefaction of hydrogen.

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Table 2.2: Variables for hydrogen production module.

Variable Name [Unit] and Description
Electrolyser nominal capacity [MW] (self-explanatory).
Lifetime of electrolysis plant [years] (self-explanatory).
Annual discount rate [%/year]: Annual discount rate indicated as percentage per year.
Water input type [-]. Options: FreshWater, WasteWater or SeaWater.
Electrolyser type [-]. Options: Alkaline Electroliser (ALK) or Proton Exchange Membrane Electroliser (PEM).
Electrolyser stack replacement period [hours]: Electrolyser stack replacement period recommended by manufacturer in hours (of operation).
Mean annual load factor [fraction/year]: number of operational hours divided by the total number of hours in a year (8760 h).
H_2 production capacity [kgH_2/h/MW]: H_2 production capacity [kgH_2/h/MW] indicated by the manufacturer in the datasheet per each MW of electrolisers' installed.
Stack annual degradation rate [%/year]: percentage of stack degradation expected in one year affecting the production of hydrogen.
CAPEX of electrolysis plant [€/kW]: value of capital expenditures of the water electrolysis plant expressed in euros per kilowatt of total electrolyser plant capacity without cost of initial stack.
Stack cost [% CAPEX]: stack cost expressed as percentage of CAPEX with values between 0 and 100.
OPEX fixed annual [% CAPEX/year]: annual operational expenditures of fixed costs as percentage of CAPEX per year.
Electricity consumption per kgH_2 [kWh/kgH_2]: electricity consumption per kilogram of hydrogen. This quantity is used to estimate the variable portion of OPEX.
Water consumption per kgH_2 [l/kgH_2]: water consumption in liters per kilogram of hydrogen, including losses. This quantity is used to estimate the variable portion of OPEX.
Fresh water unit cost [€/m3]. This quantity is used to estimate the variable portion of OPEX.
Wastewater unit cost [€/m3]. This quantity is used to estimate the variable portion of OPEX.
Seawater unit cost [€/m3]. This quantity is used to estimate the variable portion of OPEX.
PV Solar electricity supply [%]: it corresponds to the percentage of electricity supply for electrolysis coming from PV solar generation systems with values between 0 and 100.
Onshore wind electricity supply [%]: it corresponds to the percentage of electricity supply for electrolysis coming from onshore wind generation systems with values between 0 and 100.
Offshore wind electricity supply [%]: it corresponds to the percentage of electricity supply for electrolysis coming from offshore wind generation systems with values between 0 and 100.
Network electricity supply [%]: it corresponds to the percentage of electricity supply for electrolysis coming from the electric network with values between 0 and 100.
PV Solar electricity unit cost [€/MWh]: cost of electricity production or price of electricity from PV solar generation systems.
Onshore wind electricity unit cost [€/MWh]: cost of electricity production or price of electricity from onshore wind generation systems.
Offshore wind electricity unit cost [€/MWh]: cost of electricity production or price of electricity from offshore wind generation systems.
Network electricity unit cost [€/MWh]: wholesale price of electricity.

CAPEX

The CAPEX can be introduced by the user or default values can be used.

OPEX

The OPEX is divided into fixed annual values and variable annual ones. The latter considers electricity consumption. The unitary costs of electricity are assumed to be the same as specified for the production module.

H_2 amount considered for the LCOH

The liquefaction plant has a specific capacity in tonnes per day (t/day), which the user can specify. Nevertheless, the quantity used for the computation of the LCOH in the current version is considered to be the amount of hydrogen produced, when the H_2 Production is activated. The underlying assumption is that the modules active for computation pertain to the same project, and consequently, the LCOH of each module is computed as a contribution of the total LCOH. In this way, "compatibility", "additivity", and "comparability" of the LCOH contributions are ensured. If only the H_2 Liquefaction module is activated, then the reference annual amount of hydrogen to compute the LCOH is the daily capacity of the plant times 365 days times the availability of the liquefaction plant.

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Regarding the lifetime

The lifetime of the liquefaction plant is specified by the user and could be different from that specified in the H_2 Production module. If these values are different, then only the costs of the liquefaction plant "incurred" during the H_2 Production module lifetime are considered. This assumes that a complete project LCOH metric involving various tool modules is referenced to the hydrogen production plant.

2.5.1 List of variables for liquefaction module

The following table presents the variables considered for the hydrogen liquefaction module, their units as accounted for in the tool, and their description.

Table 2.3: Variables for hydrogen liquefaction module.

Variable Name [Unit] and Description
Liquefaction plant capacity [t/day]: Liquefaction plant capacity in tonnes of hydrogen per day.
Lifetime of liquefaction plant [years] (self-explanatory).
Annual discount rate [%/year]: Annual discount rate indicated as percentage per year.
Liquefaction plant availability [%]: number of operational hours divided by the total number of hours in a year (8760 h) expressed in percentage with values between 0 and 100.
CAPEX of liquefaction plant [M€]: total value of capital expenditures of the liquefaction plant expressed in million euros.
OPEX fixed annual [€/year]: annual operational expenditures of fixed costs in euros.
Electricity annual consumption [MWh/year]: total annual electricity consumption for the liquefaction plant. Designers may express this value in terms of kilogram of hydrogen, then the total value of electricity required in one year may be obtained by multiplying the total kilograms of hydrogen liquified in one year by the unit electricity consumption per kilogram. This quantity is used to estimate the variable portion of OPEX.

2.6 Storage of Hydrogen Module: *H_2 Storage*

The H_2 Storage module considers two main types of storage in the current version. One is high-pressure tanks (aboveground) and the other is salt cavern storage (underground). To obtain the LCOH, Equation 2.1 is used.

CAPEX

The CAPEX can be introduced by the user or default values can be used.

OPEX

In this module, the annual OPEX is simplified and expressed as a percentage of the CAPEX input by the user.

H_2 amount considered for the LCOH

The storage system has a specific capacity in tonnes of hydrogen, which the user can specify. Nevertheless, the quantity used for the computation of the LCOH in the current version is considered to be the amount of hydrogen produced, when the H_2 Production is activated. The underlying assumption is that the modules active for computation pertain to the same project, and consequently, the LCOH of each module is computed as a contribution of the total LCOH. In this way, "compatibility", "additivity", and "comparability" of the LCOH contributions are ensured. If only the H_2 Storage module is activated, then the reference annual amount of hydrogen to compute the LCOH must be introduced by the user.

Regarding the lifetime

The lifetime of the storage system is specified by the user and might be different than the one specified in the other modules. If these values are different, then only the costs of the storage system "incurred" during the H_2 Production module lifetime are considered. This assumes that a complete project LCOH metric involving various tool modules is referenced to the hydrogen production plant.

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2.6.1 List of variables for storage module

The following table presents the variables considered for the hydrogen storage module, their units as accounted for in the tool, and their description.

Table 2.4: Variables for hydrogen storage module.

Variable Name [Unit] and Description
Storage capacity [t]: storage capacity in tonnes of hydrogen.
Location of storage [-]: Aboveground or Underground.
Storage method [-]: Tank (only possible in calculator for Aboveground) or SaltCavern (only possible in calculator for Underground).
CAPEX of storage system - tanks, pipes and compressors [€/t]: value of capital expenditures of the storage system in euros per tonne of hydrogen. This value must consider tank, pipes and compression system.
CAPEX of storage system - Salt caverns, pipes and compressors [€/t]: value of capital expenditures of the storage system in euros per tonne of hydrogen. This value must consider tank, pipes and compression system.
OPEX fixed annual [% CAPEX]: annual operational expenditures expressed as a percentage of CAPEX of storage with values between 0 and 100.
Annual discount rate [%/year]: Annual discount rate indicated as percentage per year.
Lifetime of storage system [years].

2.7 Distribution of Hydrogen - Road Transport Module: H_2 *Road Transport*

The H_2 Road Transport module considers some characteristics of the trailer/truck and selected performance metrics. This module allows for the specification of gaseous or liquid transport. To obtain the LCOH, Equation 2.1 is used.

CAPEX

The CAPEX can be introduced by the user or default values can be used.

OPEX

The OPEX is divided into fixed annual values and variable annual ones. The variable annual OPEX considers the fuel consumption of trailers/trucks.

H_2 amount considered for the LCOH

The quantity used for the computation of the LCOH in the current version is the amount of hydrogen produced when the H_2 Production is activated. The underlying assumption is that the modules active for computation pertain to the same project, and consequently, the LCOH of each module is computed as a contribution of the total LCOH. In this way, "compatibility", "additivity", and "comparability" of the LCOH contributions. If only the H_2 Road Transport module is activated, then the reference annual amount of hydrogen transported by the trailers/trucks is considered and must be inputted by the user.

Regarding the lifetime

The lifetime of trailers/trucks is usually lower than hydrogen production plants. if the lifetime is shorter than the one specified for the H_2 Production module, then there is a reinvestment in a new trailer/trucks, and only the costs within the lifetime of the H_2 Production are accounted for.

2.7.1 List of variables for road transport module

The following table presents the variables considered for the hydrogen distribution via road transport module and their units as accounted for in the tool, and their description.

Table 2.5: Variables for hydrogen distribution via road transport module.

Variable Name [Unit] and Description
Transport of H_2 as: options Gas or Liquid.
CAPEX of truck/trailer [€/kgH$_2$]: value of capital expenditures expressed in euros per kilogram of hydrogen transport capacity for one truck/trailer.
Truck/trailer capacity [kgH$_2$]: transport capacity of one truck/trailer expressed in kilograms of hydrogen.
Number of dispatch per day [travel/day]: averaged value of dispatch travels per day per truck/trailer expressed as travels per day.
OPEX fixed annual [€/kgH$_2$]: annual fixed operational expenditures expressed in euros per kilogram of hydrogen transported.
Fuel consumption [€/km]: average value of fuel consumption of the truck/trailer fleet expressed in euros per kilometre.
Daily mean distance per truck/trailer [km]: averaged daily distance traveled of the truck/trailer fleet expressed in kilometres.
Mean number of truck/trailer per HRS [unit/HRS]: averaged value of truck/trailers per HRS.
Annual discount rate [%/year]: Annual discount rate indicated as percentage per year.
Lifetime of truck/trailer [years] (self-explanatory).
Boil-off losses [%/day]: hydrogen evaporation losses (only applicable for liquid hydrogen transport).

2.8 Distribution of Hydrogen - Pipelines Module: *H_2 Distribution Pipelines*

The H_2 Distribution Pipelines module considers some characteristics of the pipeline and the compression system to compute the LCOH. To obtain the LCOH, Equation 2.1 is used.

CAPEX

The CAPEX can be introduced by the user or default values can be used. It is disagregated in CAPEX for the pipelines and the CAPEX associated with the compression system. This has been done recognising that the compression system is an important cost component of the system.

OPEX

The OPEX is divided into fixed annual values and variable annual values for both pipelines and compression systems. Variable annual OPEX considers the consumption of electricity for the compression system. The unitary costs of electricity are assumed to be the same as specified for the production module.

H_2 amount considered for the LCOH

The quantity used for the computation of the LCOH in the current version is considered as the amount of hydrogen produced, when the H_2 Production is activated. The underlying assumption is that the modules active for computation pertain to the same project, and consequently, the LCOH of each module is computed as a contribution of the total LCOH. In this way, "compatibility", "additivity", and "comparability" of the LCOH contributions are ensured. If only the H_2 Distribution Pipelines module is activated, then the reference annual amount of hydrogen transported by the pipelines must be indicated by the user.

Regarding the lifetime

The lifetime of pipeline systems is usually much longer than the life of water electrolysis plants, and compressors may have a similar or shorter lifetime than hydrogen production plants. Consequently, different lifetimes can be input by the user. If these values are different, then only the costs "incurred" during the H_2 Production module lifetime are considered. This assumes that a complete project LCOH metric involving various tool modules is referenced to the hydrogen production plant. In the case of compression systems, if the lifetime is shorter than the one specified for the H_2 Production module, then there is a reinvestment in a new compression system, and only the remaining years until reaching the lifetime of the H_2 Production are considered for accounting costs.

2.8.1 List of variables for pipelines module

The following table presents the variables considered for the hydrogen distribution via pipelines module, their units as accounted for in the tool, and their description.

Table 2.6: Variables for hydrogen distribution via pipelines module.

Variable Name [Unit] and Description
Pipeline length [km] (self-explanatory).
Annual discount rate [%/year]: Annual discount rate indicated as percentage per year.
Lifetime of pipeline [years]: it can be different than the electrolysis plant or different than assets in other modules.
Lifetime of compressors [years]: it can be different than the pipelines, electrolysis plant or different than assets in other modules.
CAPEX of pipelines [M€/km]: value of capital expenditures of pipelines expressed in million euros per kilometre.
CAPEX of compression system [M€/km]: value of capital expenditures of compression system expressed in million euros per kilometre.
OPEX fixed annual of pipeline [% CAPEX]: pipeline annual operational expenditures of fixed costs expressed as a percentage of CAPEX of pipelines with values between 0 and 100.
OPEX fixed annual of compressors [of CAPEX]: compression system annual operational expenditures of fixed costs expressed as a percentage of CAPEX of compression system with values between 0 and 100.
Pipeline mean annual load factor [h]: number of operational hours in a year.
Electricity annual consumption [MWh/year]: total annual electricity consumption for the compression system. This quantity is used to estimate the variable portion of OPEX and it must already consider the pipeline mean annual load factor.

2.9 Hydrogen Refuelling Stations Module: *H_2 Refuelling*

The H_2 Refuelling module considers two main types of hydrogen refuelling stations (HRS). One that receives gaseous hydrogen and dispatches gaseous hydrogen, and another that receives liquid hydrogen and dispatches gaseous hydrogen. To obtain the LCOH, Equation 2.1 is used.

CAPEX

The CAPEX can be introduced by the user or default values can be used, and it is disagregated in CAPEX for the HRS not considering the compression system, and the CAPEX associated with the compression system. This has been done recognising that the compression system is an important cost component of an HRS. However, the total cost of CAPEX can be factored into the CAPEX for HRS by the user.

OPEX

The OPEX is divided into fixed annual values and variable annual ones. The latter considers the electricity consumption for the HRS. The unitary costs of electricity are assumed to be the same as those specified for the production module.

H_2 amount considered for the LCOH

The HRS has a specific mean dispatch capacity in kilograms per day, which the user can specify. Nevertheless, the quantity used for the computation of the LCOH in the current version is considered to be the amount of hydrogen produced, when the H_2 Production is activated. The underlying assumption is that the modules active for computation pertain to the same project, and consequently, the LCOH of each module is computed as a contribution of the total LCOH. In this way, "compatibility", "additivity", and "comparability" of the LCOH contributions are ensured. If only the H_2 Refuelling module is activated, then the reference annual amount of hydrogen to compute the LCOH is the mean dispatch capacity in kilograms per day indicated by the user multiplied by the number of HRSs times 365 days times the availability of the HRSs.

Regarding the lifetime

The lifetime of the HRS is specified by the user and might be different from the one specified in the other modules. If these values are different, then only the costs of the storage system "incurred" during the H_2 Production module

lifetime are considered. This assumes that a complete project LCOH metric involving various tool modules is referenced to the hydrogen production plant. In the case of HRS, if the lifetime is shorter than the one specified for the H_2 Production module, then there is a reinvestment in a new facility, and only the remaining years until reaching the lifetime of the H_2 Production are considered for accounting costs.

2.9.1 List of variables for HRS module

The following table presents the variables considered for the hydrogen refuelling station module, their units as accounted for in the tool, and their description.

Table 2.7: Variables for hydrogen refuelling station module.

Variable Name [Unit] and Description
CAPEX of one HRS [€/HRS]: total value of capital expenditures for one HRS.
CAPEX of compression system [€/kW]: value of capital expenditures expressed in euros per kW of compression system.
Electricity consumption [kWh/kgH$_2$]: electricity consumption in HRS expressed in kilowatts-hour per kilogram of hydrogen.
OPEX fixed annual [€/kgH$_2$]: annual operational expenditures expressed in euros per kilogram of hydrogen dispensed.
HRS actual mean dispatch capacity [kgH$_2$/day]. It refers to the effective mean daily amount of hydrogen dispensed per HRS.
HRS number for analysis [unit]: total number of HRS for the analysis.
HRS annual availability [fraction/year]: number of operational hours divided by the total number of hours in a year (8760 h) expressed as percentage.
Annual discount rate [%/year]: Annual discount rate indicated as percentage per year.
Compressor number per HRS [unit/HRS] (self-explanatory).
Lifetime of HRS [years] (self-explanatory).

2.10 Individual Modules Selection and Computation of LCOH

The previous sections provided an overview of CAPEX, OPEX, and the amount of hydrogen used in each module for the computation of the LCOH. As stated above, the modules can all be activated simultaneously or can be considered individually by the user. When various modules are activated simultaneously, the H_2 Production module shall be activated too. This is because to obtain a harmonised additive value of the different LCOH components (i.e., for each module), a common reference amount of hydrogen is deemed necessary, and in this case, it is the amount of hydrogen produced. In contrast, when only one module is activated, the amount of hydrogen used and discounted using the term in the denominator of Equation 2.1 is associated with each module individually, as previously explained.

The use of different types of assets in the modules brings a new issue, which is related to the different lifetimes of the assets. It is not fair to consider, for example, the total costs during 50 years of a pipeline system to the LCOH over a period of 20 years of operation of a water electrolysis plant. This is because the pipelines could be used beyond the first 20 years of operation, and then economic leverage could be achieved afterward. In this sense, only the costs incurred during the H_2 Production module (when activated) are considered as part of the economic benefit for the hydrogen project. One potential approach, the one used in the LNEG-LOCH Tool, is to adjust the CAPEX by a factor that is computed as the ratio between the hydrogen production lifetime and the lifetime of the asset under consideration (let us assume pipelines once again); then, if the lifetime of the asset is larger than the H2 production plant, the value of this factor is lower than one and consequently the CAPEX considered in the LCOH computation is proportionally lower than the total capital expenditures for the pipeline. In this sense, it is considered a fairer estimate of the LCOH for the specific project considering different components of the hydrogen value chain. The user should acknowledge that the authors are aware that this is not the only approach, but the one adopted in the current version of the tool.

3 Reference Case and Values

The reference values considered for the H$_2$ Production correspond to a hypothetical water electrolysis plant of 50 MW. Although there is the option for selecting alkaline (ALK) or proton-exchange membrane (PEM) electrolisers in the tool, currently an average value is shown for the CAPEX costs of the electrolysis plant. The plant is assumed to have a technology-neutral electrolysis system (50% ALK / 50% PEM). However, the user has the freedom to introduce different values. Some reference values for all modules are given in the next subsection.

3.1 Reference Values

The following tables present reference values for the six modules considered in the LNEG-LCOH Tool.

Table 3.8: Variables for hydrogen production module and reference values.

Variable Name [Unit]	Value
Electrolyser capacity [MW]	50
Lifetime of electrolysis plant [years]	20
Annual discount rate [%/year]	6
Water input type	WasteWater
Electrolyser type	ALK
Electrolyser stack replacement period [hours]	80000
Mean annual load factor [fraction/year]	0.6
H2 production capacity [kgH$_2$/h/MW]	18
Stack annual degradation rate [%/year]	1.5
CAPEX of electrolysis plant [€/kW]	1600
Stack cost [% CAPEX]	15
OPEX fixed annual [% CAPEX/year]	2.5
Electricity consumption per kgH$_2$ [kWh/kgH$_2$]	52.14
Water consumption per kgH$_2$ [l/kgH$_2$]	18
Fresh water unit cost [€/m3]	3.74
Wastewater unit cost [€/m3]	3.79
Seawater unit cost [€/m3]	8.83
PV Solar electricity supply [%]	100
Onshore wind electricity supply [%]	0
Offshore wind electricity supply [%]	0
Network electricity supply [%]	0
PV Solar electricity unit cost [€/MWh]	55.14
Onshore wind electricity unit cost [€/MWh]	0
Offshore wind electricity unit cost [€/MWh]	0
Network electricity unit cost [€/MWh]	0

Table 3.9: Variables for hydrogen liquefaction module and reference values.

Variable Name [Unit]	Value
Liquefaction plant capacity [t/day]	20
Lifetime of liquefaction plant [years]	20
Annual discount rate [%/year]	6
Liquefaction plant availability [%]	98
CAPEX of liquefaction plant [M€]	105
OPEX fixed annual [€/year]	3150000
Electricity annual consumption [MWh/year]	11

Table 3.10: Variables for hydrogen storage module and reference values.

Variable Name [Unit]	Value
Storage capacity [t]	200
Location of storage	Aboveground or Underground
Storage method	Tank
CAPEX of storage system - tanks, pipes and compressors [€/t]	100000
CAPEX of storage system - Salt caverns, pipes and compressors [€/t]	2500
OPEX fixed annual - Tanks [% CAPEX]	2
OPEX fixed annual - Caverns [% CAPEX]	2
Annual discount rate [%/year]	6
Lifetime of storage system - Tanks [years]	30
Lifetime of storage system - Caverns [years]	60

Table 3.11: Variables for hydrogen distribution via road transport module and reference values.

Variable Name [Unit]	Value	Value
Transport of H2 as	Gas	Liquid
CAPEX of truck/trailer [€/kgH$_2$]	1140	400
Truck/trailer capacity [kgH$_2$]	1000	4000
Number of dispatch per day [travel/day]	1	1
OPEX fixed annual [€/kgH$_2$]	0.06	0.025
Fuel consumption [€/km]	0.6125	0.6125
Daily mean distance per truck/trailer [km]	200	200
Mean number of truck/trailer per HRS [unit/HRS]	1	0.25
Annual discount rate [%/year]	6	6
Lifetime of truck/trailer [years]	10	10
Boil-off losses [%/day]	0	1.5

Table 3.12: Variables for hydrogen distribution via pipelines module and reference values.

Variable Name [Unit]	Value
Pipeline length [km]	100
Annual discount rate [%/year]	6
Lifetime of pipeline [years]	40
Lifetime of compressors [years]	25
CAPEX of pipelines [M€/km]	1.5
CAPEX of compression system [M€/km]	0.18
OPEX fixed annual of pipeline [% CAPEX]	0.9
OPEX fixed annual of compressors [% CAPEX]	1.7
Pipeline mean annual load factor [h]	5000
Electricity annual consumption [MWh/year]	13000

Table 3.13: Variables for hydrogen refuelling station module.

Variable Name [Unit]	Value
CAPEX of one HRS [€/HRS]	5000000
CAPEX of compression system [€/kW]	0
Electricity consumption [kWh/kgH$_2$]	3.25
OPEX fixed annual [€/kgH$_2$]	0.5
HRS actual mean dispatch capacity [kgH$_2$/day]	1000
HRS number for analysis [unit]	7
HRS annual availability [%]	98
Annual discount rate [%/year]	6
Compressor number per HRS [unit/HRS]	2
Lifetime of HRS [years]	20

4 Examples and Comparisons

This section intends to briefly exemplify how to use the LNEG-LCOH Tool. Five cases are presented. The first two are a benchmark between the European Commission LCOH Tool and the LNEG-LCOH tool. The third and four cases exemplify the use of various modules. The last case shows how the *MIBGAS IBHYX Index* can be reproduced using the LNEG-LCOH tool.

4.1 Hydrogen Production: Comparisons with the EC LCOH Calculator

Two cases were computed with the European Commission LCOH Tool and the LNEG-LCOH tool. These correspond to the default values of the European Commission LCOH Tool for cases *a*) PV and Alkaline Electrolysers, and *b*) Onshore Wind and Proton-Exchange Membrane Electrolysers.

Some assumptions for both cases were adopted on the LNEG-LCOH tool because the other one does not include equivalent data as input. These were i) the water costs were assumed to be the reference value for fresh water, ii) the water consumption per hydrogen kilogram, and iii) CAPEX was adjusted to extract the initial stack in catalysers because in the LNEG-LCOH tool this value is internally added to the CAPEX input by the user, and consequently the percentages of annual OPEX and stack replacement costs were also updated. Note that based on the documentation of the European Commission LCOH Tool, the hourly capacity of the electrolysis plant was computed as the plant capacity in kW divided by the electricity consumption per hydrogen kilogram.

Case *a*: PV and Alkaline Electrolysers

Figure 4.3 shows the input data using the European Commission LCOH Tool, while Table 4.14 shows the input data used for the LNEG-LCOH tool.

The results for the European Commission LCOH Tool and the LNEG-LCOH tool showed LCOH of 6.14 and 6.15 €/kg, respectively. The difference is negligible (less than 0.2 %), and it is due mainly to the significant digits differences. The output in the LNEG-LCOH tool has three sections: i) one that shows dynamic graphs with the main information of the LCOH (see Figure 4.4), ii) a section where the user can visualise a summary of inputs (see Figure 4.5), and iii) a section where the user can visualise a summary of outputs (see Figure 4.6).

Case *b*: Onshore Wind and Proton Exchange Membrane Electrolysers

Figure 4.7 shows the input data using the European Commission LCOH Tool, while Table 4.15 shows the input data used for the LNEG-LCOH tool.

The results for the European Commission LCOH Tool and the LNEG-LCOH tool showed LCOH of 9.90 and 9.50 €/kg, respectively. The difference represents about 4%, which might be due to considerations for the exact period of stack replacement. In the LNEG-LCOH tool there was not replacement of the stack applied in this case because it was almost at year 25, and the end of life of the plant was 25 years. It is unknown if replacement of the stack was applied in the European Commission LCOH Tool, which translates in a higher LCOH.

Once again, the output in the LNEG-LCOH tool has three sections: i) one that shows dynamic graphs with the main information of the LCOH (see Figure 4.8), ii) a section where the user can visualise a summary of inputs (see Figure 4.9), and iii) a section where the user can visualise a summary of outputs (see Figure 4.10).
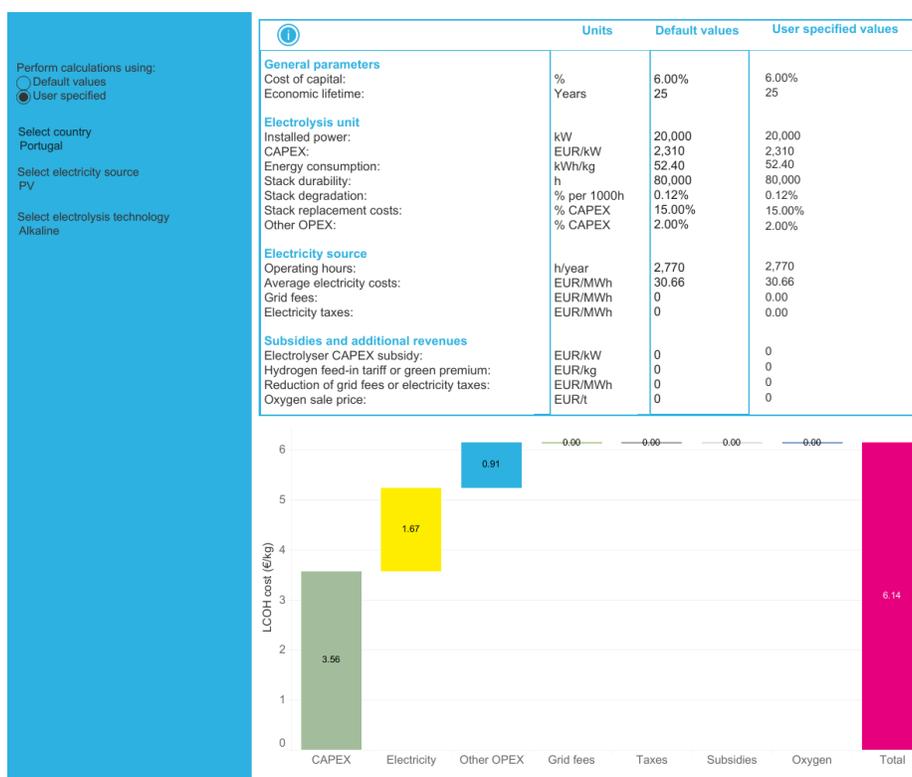
Figure 4.3: Input data and result obtained for the LCOH for the reference Case a and the European Commission LCOH Tool.

Table 4.14: Input values for the LNEG-LCOH tool for Case a.

Variable Name [Unit]	Value
Electrolyser capacity [MW]	20
Lifetime of electrolysis plant [years]	25
Annual discount rate [%/year]	6
Water input type	FreshWater
Electrolyser type	ALK
Electrolyser stack replacement period [hours]	80000
Mean annual load factor [fraction/year]	0.316
H2 production capacity [kg/h/MW]	19.08
Stack annual degradation rate [%/year]	0.3324
CAPEX of electrolysis plant [€/kW]	1963.5
Stack cost [% CAPEX]	17.7
OPEX fixed annual [% CAPEX/year]	2.35
Electricity consumption per kgH$_2$ [kWh/kgH$_2$]	52.4
Water consumption per kgH$_2$ [l/kgH$_2$]	11
Fresh water unit cost [€/m3]	3.74
Wastewater unit cost [€/m3]	0
Seawater unit cost [€/m3]	0
PV Solar electricity supply [%]	100
Onshore wind electricity supply [%]	0
Offshore wind electricity supply [%]	0
Network electricity supply [%]	0
PV Solar electricity unit cost [€/MWh]	30.66
Onshore wind electricity unit cost [€/MWh]	0
Offshore wind electricity unit cost [€/MWh]	0
Network electricity unit cost [€/MWh]	0

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![LNEG logo]

2013-2023
10 YEARS OF LOGO HRS4R
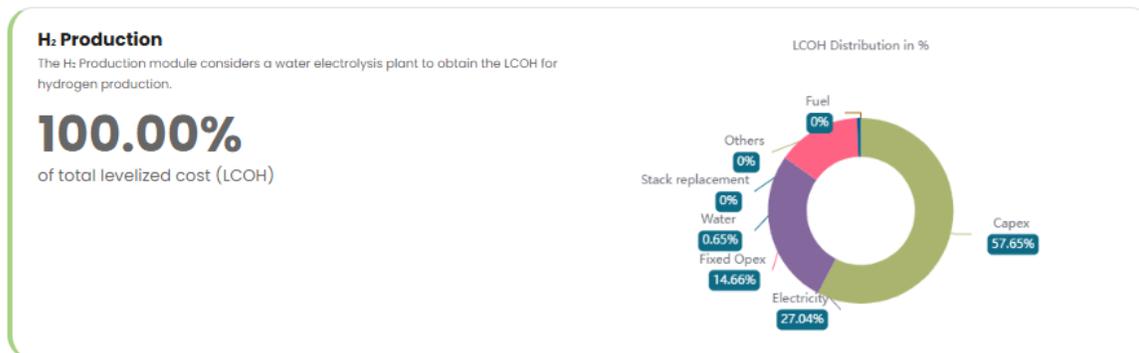HUMAN RESOURCES EXCELLENCE
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Figure 4.4: Result obtained for the LCOH for the reference Case a using the LNEG-LCOH tool. The figure shows the share of CAPEX, fixed OPEX, stack replacement, electricity, water, and fuel levelised costs regarding the total LCOH.

Figure 4.5: Summary of inputs presented by the LNEG-LCOH tool after the calculation of the LCOH for the reference Case a.

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Output summary   Hide Details

H₂ Production

Levelised cost of hydrogen (LCOH)	6.15 €/kgH₂
CAPEX share in LCOH	3.54 €/kgH₂
Fixed OPEX share in LCOH	0.90 €/kgH₂
Electricity share in LCOH	1.66 €/kgH₂
Water share in LCOH	0.04 €/kgH₂
Fuel share in LCOH	0.00 €/kgH₂
Stack replacement share in LCOH	0.00 €/kgH₂
Other OPEX share in LCOH	0.00 €/kgH₂
Net present value of total kgH₂	13061484.21 kgH₂
Net present value of CAPEX	46220790.00 €
Net present value of total OPEX	34046999.75 €
Net present value of fixed OPEX	11797056.31 €
Net present value of electricity costs	21694411.89 €
Net present value of water costs	555531.55 €
Net present value of fuel costs	0.00 €
Net present value of stack replacement costs	0.00 €
Net present value of other OPEX costs	0.00 €
Net present value of other DECEX costs	0.00 €
Annual value of kgH₂	1056329.86 €/kgH₂
Annual value of fixed OPEX	922845.00 €/year
Annual value of electricity costs	1697082.65 €/year
Annual value of water costs	43457.41 €/year
Annual value of fuel costs	0.00 €/year
Annual value of other OPEX	0.00 €/year

Figure 4.6: Summary of outputs presented by the LNEG-LCOH tool after the calculation of the LCOH for the reference Case a.

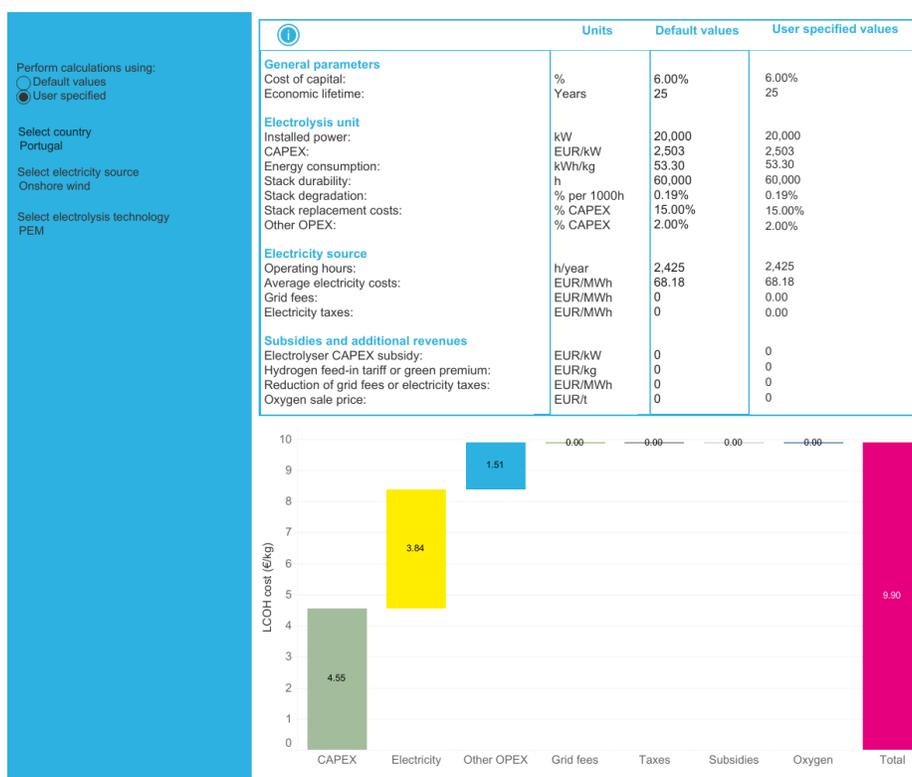REPÚBLICA
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Figure 4.7: Input data and result obtained for the LCOH for the reference Case *b* and the European Commission LCOH Tool.

Table 4.15: Input values for the LNEG-LCOH tool for Case *b*.

Variable Name [Unit]	Value
Electrolyser capacity [MW]	20
Lifetime of electrolysis plant [years]	25
Annual discount rate [%/year]	6
Water input type	FreshWater
Electrolyser type	PEM
Electrolyser stack replacement period [hours]	60000
Mean annual load factor [fraction/year]	0.277
H2 production capacity [kg/h/MW]	18.76
Stack annual degradation rate [%/year]	0.4608
CAPEX of electrolysis plant [€/kW]	2127.55
Stack cost [% CAPEX]	17.7
OPEX fixed annual [% CAPEX/year]	2.35
Electricity consumption per kgH$_2$ [kWh/kgH$_2$]	53.3
Water consumption per kgH$_2$ [l/kgH$_2$]	11
Fresh water unit cost [€/m3]	3.74
Wastewater unit cost [€/m3]	0
Seawater unit cost [€/m3]	0
PV Solar electricity supply [%]	0
Onshore wind electricity supply [%]	100
Offshore wind electricity supply [%]	0
Network electricity supply [%]	0
PV Solar electricity unit cost [€/MWh]	0
Onshore wind electricity unit cost [€/MWh]	68.18
Offshore wind electricity unit cost [€/MWh]	0
Network electricity unit cost [€/MWh]	0

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Preview results

Based on the parameters filled in, the levelized cost of hydrogen (LCOH) is **9.50 €/kgH₂**.
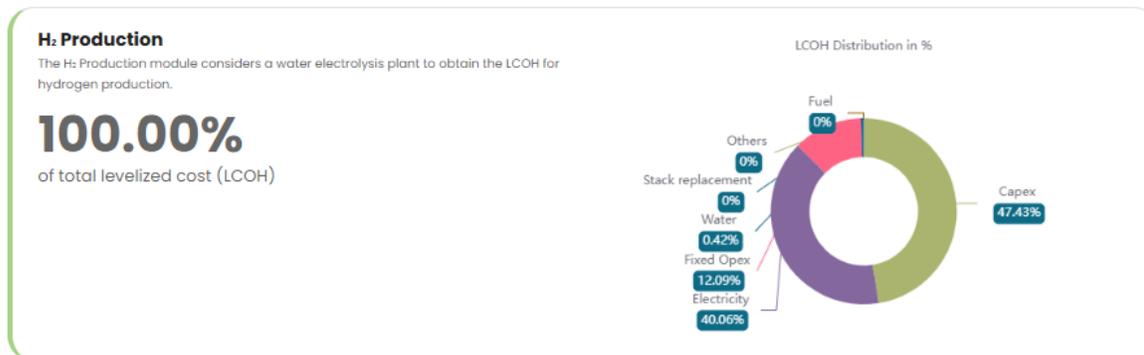This means that each kilogram of hydrogen will cost 9.50 euros.

H₂ Production

The H₂ Production module considers a water electrolysis plant to obtain the LCOH for hydrogen production.

100.00%
of total levelized cost (LCOH)

LCOH Distribution in %

Fuel 0%
Others 0%
Stack replacement 0%
Water 0.42%
Fixed Opex 12.09%
Electricity 40.06%
Capex 47.43%

Figure 4.8: Result obtained for the LCOH for the reference Case b using the LNEG-LCOH tool. The figure shows the share of CAPEX, fixed OPEX, stack replacement, electricity, water, and fuel levelised costs regarding the total LCOH.

Input summary   Hide Details

H₂ Production

Electrolyser capacity	20 MW
Lifetime of electrolysis plant	25 years
Annual discount rate	6 %/year
Water input type	Fresh water
Electrolyser type	PEM (Proton Exchange Membrane Electroliser)
Electrolyser stack replacement period	60000 h
Mean annual load factor	0.277 –/year
H₂ production capacity	18.76 kgH₂/h/MW
Stack annual degradation rate	0.4608 %/year
CAPEX of electrolysis plant	2127.55 €/kW
Stack cost	17.7 % CAPEX
OPEX fixed annual	2.35 % CAPEX/year
Electricity annual consumption	53.3 kWh/kgH₂
Water annual consumption	11 l/kgH₂
Fresh water unit cost	3.74 €/m³
Wastewater unit cost	0 €/m³
Seawater unit cost	0 €/m³
PV Solar electricity supply	0 %
Onshore wind electricity supply	100 %
Offshore wind electricity supply	0 %
Network electricity supply	0 %
PV Solar electricity unit cost	0 €/MWh
Onshore wind electricity unit cost	68.18 €/MWh
Offshore wind electricity unit cost	0 €/MWh
Network electricity unit cost	0 €/MWh

Figure 4.9: Summary of inputs presented by the LNEG-LCOH tool after the calculation of the LCOH for the reference Case b.

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Output summary   Hide Details

H₂ Production

Levelised cost of hydrogen (LCOH)	9.50 €/kgH₂
CAPEX share in LCOH	4.51 €/kgH₂
Fixed OPEX share in LCOH	1.15 €/kgH₂
Electricity share in LCOH	3.81 €/kgH₂
Water share in LCOH	0.04 €/kgH₂
Fuel share in LCOH	0.00 €/kgH₂
Stack replacement share in LCOH	0.00 €/kgH₂
Other OPEX share in LCOH	0.00 €/kgH₂
Net present value of total kgH₂	11114868.96 kgH₂
Net present value of CAPEX	50082527.00 €
Net present value of total OPEX	55555211.37 €
Net present value of fixed OPEX	12782697.82 €
Net present value of electricity costs	42293711.63 €
Net present value of water costs	478801.92 €
Net present value of fuel costs	0.00 €
Net present value of stack replacement costs	0.00 €
Net present value of other OPEX costs	0.00 €
Net present value of other DECEX costs	0.00 €
Annual value of kgH₂	910430.30 €/kgH₂
Annual value of fixed OPEX	999948.50 €/year
Annual value of electricity costs	3308498.26 €/year
Annual value of water costs	37455.10 €/year
Annual value of fuel costs	0.00 €/year
Annual value of other OPEX	0.00 €/year

Figure 4.10: Summary of outputs presented by the LNEG-LCOH tool after the calculation of the LCOH for the reference Case *b*.

4.2 HRS with Local Hydrogen Production: Case H2ProdStoHRS01

This example deals with a system that has a local water electrolysis production unit of 4 MW that has a local storage system connected to a hydrogen refuelling station (HRS) with a maximum daily dispensing capacity of 1400 kg of hydrogen, intended to supply hydrogen at 350 bar for trucks and 700 bar for passenger vehicles. An estimation of the LCOH for the whole system is required. This might assess hydrogen's minimum mean selling price at the HRS for a lifetime of 20 years. Hydrogen is in a gaseous state over all components of the system. The inputs considered for this example are presented in Tables 4.16, 4.17, and 4.18. Note that the case name is conceived to provide a proper name, and it does not come from any other document or reference. It comprises short indicators for the production stage (H2Prod), storage (Sto), and the indication that there is one HRS (HRS01).

Table 4.16: Input values for the LNEG-LCOH tool - H_2 Production module for Case H2ProdStoHRS01.

Variable Name [Unit]	Value
Electrolyser capacity [MW]	4
Lifetime of electrolysis plant [years]	20
Annual discount rate [%/year]	6
Water input type	WasteWater
Electrolyser type	ALK
Electrolyser stack replacement period [hours]	80000
Mean annual load factor [fraction/year]	0.685
H2 production capacity [kgH$_2$/h/MW]	18
Stack annual degradation rate [%/year]	1.5
CAPEX of electrolysis plant [€/kW]	1600
Stack cost [% CAPEX]	15
OPEX fixed annual [% CAPEX/year]	2.5
Electricity consumption per kgH$_2$ [kWh/kgH$_2$]	52.14
Water consumption per kgH$_2$ [l/kgH$_2$]	18
Fresh water unit cost [€/m3]	0
Wastewater unit cost [€/m3]	3.79
Seawater unit cost [€/m3]	0
PV Solar electricity supply [%]	50
Onshore wind electricity supply [%]	50
Offshore wind electricity supply [%]	0
Network electricity supply [%]	0
PV Solar electricity unit cost [€/MWh]	40.86
Onshore wind electricity unit cost [€/MWh]	60.42
Offshore wind electricity unit cost [€/MWh]	0
Network electricity unit cost [€/MWh]	0

Table 4.17: Input values for the LNEG-LCOH tool - H_2 Storage module for Case H2ProdStoHRS01.

Variable Name [Unit]	Value
Storage capacity [t]	4.5
Location of storage	Aboveground
Storage method	Tank
CAPEX of storage system - tanks, pipes and compressors [€/t]	100000
OPEX fixed annual - Tanks [% CAPEX]	3
Annual discount rate [%/year]	6
Lifetime of storage system - Tanks [years]	20

The total LCOH computed by the tool is 7.07 €/kg. The share of the total LCOH associated with the hydrogen production unit is 5.04 €/kg, the storage LCOH share is 0.13 €/kg, and the HRS LCOH share is 1.90 €/kg. Much more information can be obtained from the LNEG-LCOH tool. Figures 4.11 and 4.12 show examples of the information allowable to be extracted/downloaded. The inputs and outputs summaries are not reproduced in this document.

Table 4.18: Input values for the LNEG-LCOH tool - H_2 Refuelling module for Case H2ProdStoHRS01.

Variable Name [Unit]	Value
CAPEX of one HRS [€/HRS]	4800000
CAPEX of compression system [€/kW]	0
Electricity consumption [kWh/kgH$_2$]	3.25
OPEX fixed annual [€/kgH$_2$]	0.5
HRS actual mean dispatch capacity [kgH$_2$/day]	1400
HRS number for analysis [unit]	1
HRS annual availability [%]	98
Annual discount rate [%/year]	6
Compressor number per HRS [unit/HRS]	2
Lifetime of HRS [years]	20

③ Recolher os resultados

Com base nos parâmetros preenchidos, o custo nivelado de hidrogénio (LCOH) é de **7.07 €/kgH₂**.

Isto significa que cada quilograma de hidrogénio terá um custo de 7.07 euros.
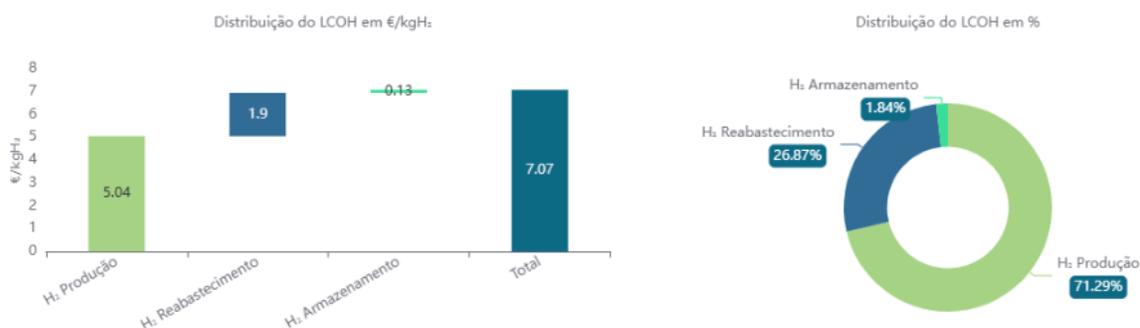
Figure 4.11: Result obtained for the LCOH for the reference Case H2ProdStoHRS01 using the LNEG-LCOH tool. The figure shows the share of the different modules contribution to the total LCOH.

4.3 Centralised Hydrogen Production and Road Transport Distribution to various HRSs: Case H2ProdStoRTHRS07

This example deals with a centralised hydrogen production plant of 25 MW with an associated local storage system that fills trailers with compressed gas. The trailers supply seven hydrogen refuelling stations (HRSs) at different distances from the production plant. These HRSs have dual dispenser types: one that supplies hydrogen to heavy-duty vehicles (trucks) at 350 bar and one to passenger vehicles at 700 bar. The lifetime of the hydrogen production plant, storage system, and HRSs is 20 years, and the truck/trailers have a lifetime of 10 years. The LCOH shall be estimated under these conditions. Hydrogen is in a gaseous state throughout the value chain. Note that the case name is conceived to provide a proper name, and it does not come from any other document or reference. It comprises short indicators for the production stage (H2Prod), storage (Sto), road transport (RT), and the indication that there are seven HRSs (HRS07).

Additional assumptions are the following:

- The total capacity of the electrolysis plant is 25 MW with a load factor of 0.8. The user should note that the electricity source distribution involves a mix, including electricity from the wholesale market.

- The total storage capacity near the water electrolysis plant is about 15 t of hydrogen, representing about 1.4 times the nominal production of the electrolysis plant in one day.

- The number of trailers/trucks estimated to supply the seven HRS is 12. The HRSs are considered at distances of 100, 200, 300, 400, 500, 600, and 800 km. This is a hypothetical case. If the capacity of each HRS is 1400 kgH$_2$/day, then the mean distance each trailer/truck must undergo every day is about 480 km.
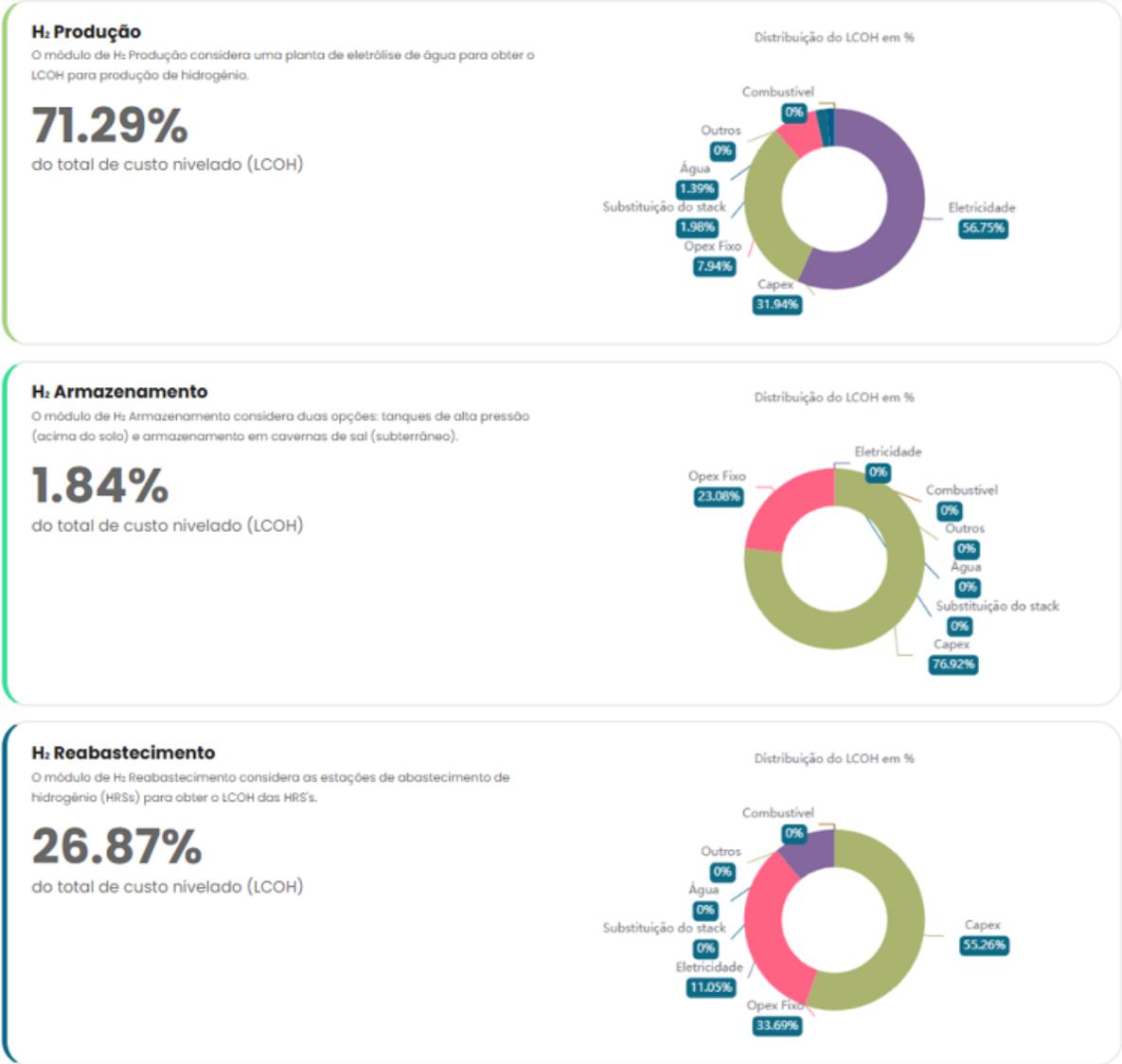
Figure 4.12: Result obtained for the LCOH for the reference Case H2ProdStoHRS01 using the LNEG-LCOH tool. The figure shows the distribution of CAPEX, fixed OPEX, stack replacement, electricity, water, and fuel levelised costs regarding the total LCOH for all modules computed.

Tables 4.19, 4.20, 4.21, 4.22 show the input data used for each of the four modules considered for this case.

Table 4.19: Input values for the LNEG-LCOH tool - H_2 Production module for Case H2ProdStoRTHRS07.

Variable Name [Unit]	Value
Electrolyser capacity [MW]	25
Lifetime of electrolysis plant [years]	20
Annual discount rate [%/year]	6
Water input type	WasteWater
Electrolyser type	ALK
Electrolyser stack replacement period [hours]	80000
Mean annual load factor [fraction/year]	0.8
H2 production capacity [kgH$_2$/h/MW]	18
Stack annual degradation rate [%/year]	1.5
CAPEX of electrolysis plant [€/kW]	2000
Stack cost [% CAPEX]	15
OPEX fixed annual [% CAPEX/year]	2.5
Electricity consumption per kgH$_2$ [kWh/kgH$_2$]	52.14
Water consumption per kgH$_2$ [l/kgH$_2$]	18
Fresh water unit cost [€/m3]	0
Wastewater unit cost [€/m3]	3.79
Seawater unit cost [€/m3]	8.83
PV Solar electricity supply [%]	40
Onshore wind electricity supply [%]	40
Offshore wind electricity supply [%]	0
Network electricity supply [%]	20
PV Solar electricity unit cost [€/MWh]	40.86
Onshore wind electricity unit cost [€/MWh]	60.42
Offshore wind electricity unit cost [€/MWh]	0
Network electricity unit cost [€/MWh]	98.1

Table 4.20: Input values for the LNEG-LCOH tool - H_2 Storage module for Case H2ProdStoRTHRS07.

Variable Name [Unit]	Value
Storage capacity [t]	15
Location of storage	Aboveground
Storage method	Tank
CAPEX of storage system - tanks, pipes and compressors [€/t]	100000
OPEX fixed annual - Tanks [% CAPEX]	3
Annual discount rate [%/year]	6
Lifetime of storage system - Tanks [years]	20

Table 4.21: Input values for the LNEG-LCOH tool - H_2 Road Transport module for Case H2ProdStoRTHRS07.

Variable Name [Unit]	Value
Transport of H2 as	Gas
CAPEX of truck/trailer [€/kgH$_2$]	1140
Truck/trailer capacity [kgH$_2$]	1000
Number of dispatch per day [travel/day]	1
OPEX fixed annual [€/kgH$_2$]	0.06
Fuel consumption [€/km]	0.6125
Daily mean distance per truck/trailer [km]	480
Mean number of truck/trailer per HRS [unit/HRS]	1.71
Annual discount rate [%/year]	6
Lifetime of truck/trailer [years]	10

Table 4.22: Input values for the LNEG-LCOH tool - H$_2$ Refuelling module for Case H2ProdStoRTHRS07.

Variable Name [Unit]	Value
CAPEX of one HRS [€/HRS]	5000000
CAPEX of compression system [€/kW]	0
Electricity consumption [kWh/kgH$_2$]	3.25
OPEX fixed annual [€/kgH$_2$]	0.5
HRS actual mean dispatch capacity [kgH$_2$/day]	1400
HRS number for analysis [unit]	7
HRS annual availability [%]	98
Annual discount rate [%/year]	6
Compressor number per HRS [unit/HRS]	2
Lifetime of HRS [years]	20

The total LCOH computed by the tool under the conditions is 8.47 €/kgH$_2$. The share of the total LCOH associated with the hydrogen production unit is 5.71 €/kgH$_2$, the storage LCOH share is 0.05 €/kgH$_2$, the road transport contribution to total LCOH is 1.21 €/kgH$_2$, and the HRS LCOH share is 1.5 €/kgH$_2$. Much more information can be obtained from the LNEG-LCOH tool. Figure 4.13 shows the results for this case. Other results may be seen directly on the tool.
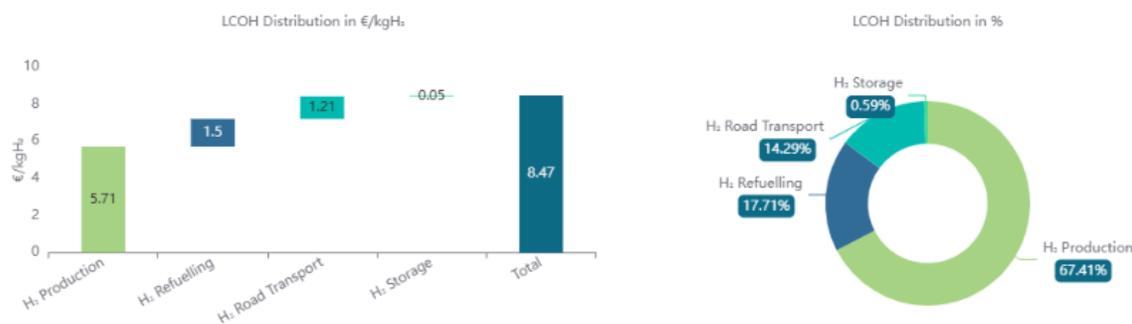

Figure 4.13: Result obtained for the LCOH for the reference Case H2ProdStoRTHRS07 using the LNEG-LCOH tool. The figure shows the share of the different modules contribution to the total LCOH.

4.4 *MIBGAS IBHYX Index* Case

This section presents how to estimate the *MIBGAS IBHYX Index* using the LNEG-LCOH tool. The *MIBGAS IBHYX Index* is a recently created index to serve as a reference for the price of green hydrogen, and it represents the levelised cost of renewable hydrogen production in accordance with the criteria established in the delegated acts for the production of RFNBO (Renewable Fuel of Non-Biological Origin). The *IBHYX Index* considers an electrolysis plant of 50 MW. The electricity is supplied by two dedicated plants, one 75 MW Solar PV facility and one onshore wind farm of 25 MW. Additionally, renewable sources' power purchase agreements (PPA) provide electricity for about 1000 hours a year. The total operating time of the electrolysis plant in a year is set to 4500 hours. A list of the parameters published to compute the *IBHYX Index* can be found on the index's website. The most recent value for the index is shown in the Figure 4.14.

The procedure to obtain equivalent data to input into LNEG-LCOH tool follows:

- Estimation of the levelised cost of energy (or electricity) LCOE of the dedicated Solar PV and Wind Plants.

- Obtain equivalent CAPEX, OPEX, and stack replacement percentage for the electrolysis plant.
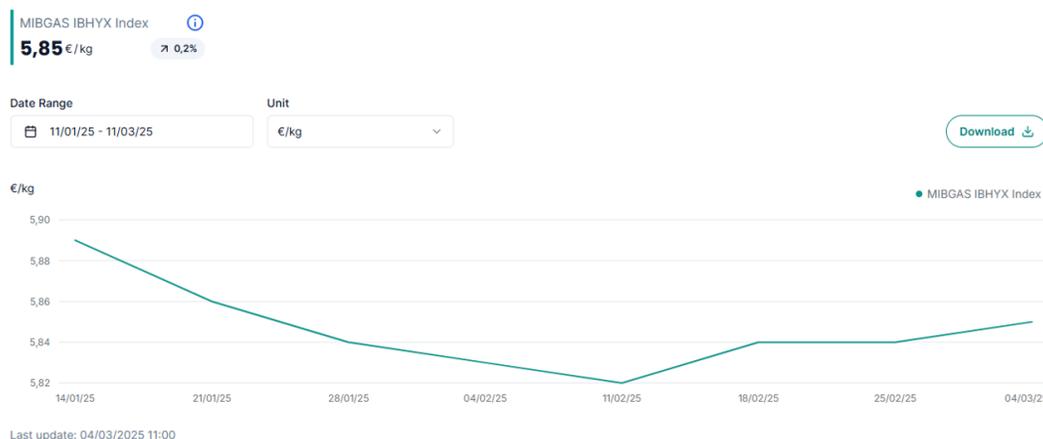
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Figure 4.14: *MIBGAS IBHYX Index* retrieved on 03/10/2025.

- Select the electricity price for the PPA.

- Assume a discount rate (or internal rate of return (IRR) or weighted average cost of capital (WACC)).

Table 4.23 presents the summary of the input data that is deemed equivalent for the LNEG-LCOH tool. It is worth noting that only the module H_2 Production was used. A discount rate of 8% was assumed. Additionally, the data for the estimation of the LCOE for the Solar PV and Wind plants is presented in Table 4.24. The estimation was done by LNEG.

Table 4.23: Input values for the LNEG-LCOH tool - H_2 Production module for the *MIBGAS IBHYX Index* Case.

Variable Name [Unit]	Value
Electrolyser capacity [MW]	50
Lifetime of electrolysis plant [years]	25
Annual discount rate [%/year]	10
Water input type	FreshWater
Electrolyser type	PEM
Electrolyser stack replacement period [hours]	80000
Mean annual load factor [fraction/year]	0.514
H2 production capacity [kg/h/MW]	19
Stack annual degradation rate [%/year]	0.5400
CAPEX of electrolysis plant [€/kW]	1360
Stack cost [% CAPEX]	17.65
OPEX fixed annual [% CAPEX/year]	4.71
Electricity consumption per kgH$_2$ [kWh/kgH$_2$]	55.5
Water consumption per kgH$_2$ [l/kgH$_2$]	11
Fresh water unit cost [€/m3]	0
Wastewater unit cost [€/m3]	0
Seawater unit cost [€/m3]	0
PV Solar electricity supply [%]	56
Onshore wind electricity supply [%]	22
Offshore wind electricity supply [%]	0
Network electricity supply [%]	22
PV Solar electricity unit cost [€/MWh]	49.1
Onshore wind electricity unit cost [€/MWh]	58.3
Offshore wind electricity unit cost [€/MWh]	0
Network electricity unit cost [€/MWh]	66.6

The PPA prices for both solar PV and wind were assumed to be 20% higher than the LCOE computed for the dedicated solar PV and wind plants. The weighted averaged PPA price is then 66.6 €/MWh, considering the assumption of 30% of the electricity coming from solar PV and 70% from wind based on the *MIBGAS IBHYX*

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Table 4.24: Solar PV and wind plants data considered for the estimation of the LCOE. Capacity factor for the wind plant and the degradation rate for the solar PV facility were selected by LNEG, other values come from the *MIBGAS IBHYX Index's* website.

Variable Name [Unit]	Value
Solar PV plant capacity [MW]	75
Onshore wind plant capacity [MW]	25
Lifetime of both plants [years]	25
Annual discount rate [%/year]	8
Capacity factor solar PV plant [-]	0.2
Degradation rate for the solar PV plant [%]	0.5[1]
Capacity factor onshore wind plant [-]	0.3
CAPEX solar PV plant [€/kW]	500
CAPEX wind plant [€/kW]	1100
OPEX solar PV plant [€/kW-year]	5
OPEX wind plant [€/kW-year]	50
LCOE solar PV plant [€/MWh]	49.1
LCOE wind plant [€/MWh]	58.3

[1] https://www.nrel.gov/docs/fy12osti/51664.pdf

Index's website.

The result obtained from the LNEG-LCOH tool is presented in Figure 4.15. The value of 5.86 €/kgH$_2$ is very similar to the one published for the index on the 04/03/2025 (5.85 €/kgH$_2$). However, it is important to highlight that as the LCOE for the solar PV and wind plants were estimated, as well as the PPAs' electricity prices, the result may differ considerably under other assumptions.
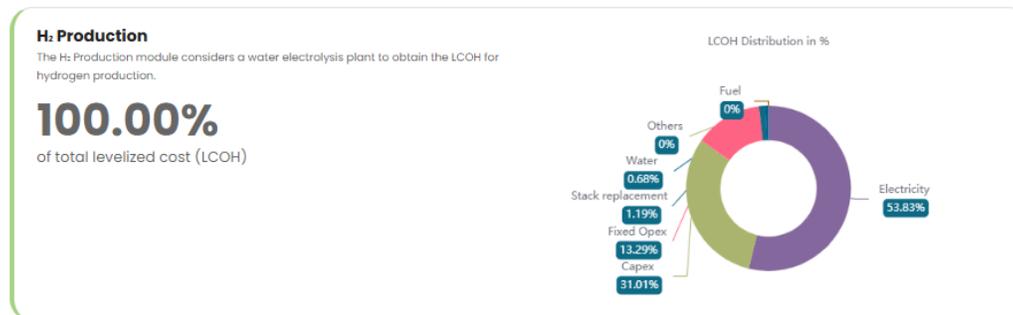

Figure 4.15: *MIBGAS IBHYX Index* retrieved on 03/10/2025.

5 How to Report Bugs, Suggestions, and Comments?

This section presents the procedure to follow by users to report bugs, make suggestions for improvement, and comments.

5.1 Procedure and Contacts

To report problems, bugs or errors associated with the LNEG-LCOH tool, make any suggestions related to possible improvements or changes, or leave any comments (e.g. about the user experience, the ease or difficulty of using the tool, general feedback, questions or any other matter), please write an email to lcoh.lneg@lneg.pt. Please include the words "Problem", "Suggestion", or "Comment" in the subject line, optionally followed by a brief description of the main topic or problem.

Title: LNEG-LCOH - Levelised Cost of Hydrogen Calculator: Description and Methodological Report
Authors: Juan C. C. Portillo and Sofia G. Simões
Edition: Juan C. C. Portillo
Date: 10/03/2025
URL: `http://repositorio.lneg.pt/handle/10400.9/4410`

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