Levelised Cost of Hydrogen (LCOH) Calculator Manual

June 2024

European Hydrogen Observatory

Disclaimer

The aim of this manual is to explain the **methodology** behind the **Levelized Cost of Hydrogen (LCOH) calculator**. Moreover, this **manual** also demonstrates how the calculator can be used for estimating the expenses associated with hydrogen production in Europe using low-temperature **electrolysis** considering **different sources of electricity**.

The default data in the LCOH calculator is based on values provided by Hydrogen Europe and will be continuously updated on an annual basis. Accordingly, the manual will also be annually updated to ensure accuracy and relevance over time. The authors believe that this data comes from reliable sources, but do not guarantee the accuracy or completeness of this information.

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TABLE OF CONTENTS

List of abbreviations 6

Overview 7

Use cases overview 8

01.
Introduction 10

1.1. LCOH concept 11

1.2. LCOH calculator 12

02.
Methodology 14

2.1. Overview 15

2.2. Default values 16

2.3. Calculations 19

03.
Use cases 24

3.1. Overview 25

3.2. Comparative cost analyses with default values 27

Use case 1 - Effect of country 28

Use case 2 - Effect of electricity source 31

Use case 3 - Combined effect of country and electricity source 34

Use case 4 - Effect of electrolysis technology 37

3.3. Comparative cost analyses with user specified values 40
Use case 5 - Effect of other electrolysis technology 41
Use case 6 - Effect of combining multiple electricity source 44
Use case 7 - Effect of subsidies and additional revenues 47
Appendix 50
A.1. Calculation of the average energy consumption over the economic lifetime of the project 50

List of abbreviations

Abbreviation	Definition
EHO	European Hydrogen Observatory
LCOH	Levelized Cost of Hydrogen
CAPEX	Capital Expenditures
OPEX	Operational Expenditures
EU27	The 27 countries of the European Union
EFTA	European Free Trade Association (Iceland, Liechtenstein, Norway and Switzerland)
NPV	Net Present Value
SMR	Steam Methane Reforming
CC	Carbon capture
PEM	Proton Exchange Membrane
RES	Renewable Energy Sources
PV	Photovoltaic
RFNBO	Renewable Fuels of Non-Biological Origin

Overview

In the transition towards a sustainable energy future, examining the Levelized Cost of Hydrogen (LCOH) is crucial for the successful integration of renewable hydrogen into the energy mix. The LCOH is a method used to evaluate the total expenses involved in producing hydrogen throughout its entire lifecycle, including both capital (CAPEX) and operational costs (OPEX). Considering these costs, LCOH allows to compare different methods of hydrogen production on a common basis. This enables stakeholders, policymakers, and investors to make informed decisions and evaluate the most cost-effective approaches for producing hydrogen.

This report aims to demonstrate the utilization of the LCOH calculator which allows the calculation of hydrogen production costs in Europe by electrolysis with various electricity sources. **The calculator is now set up only for low-temperature water electrolysis,** incl. alkaline and proton exchange membrane (PEM), which are currently the most mature technologies available. The data presented in this report is based on research conducted by Hydrogen Europe as of April 2024. The Interactive LCOH calculator can be accessed on the European Hydrogen Observatory website.

The first chapter provides an overview of the LCOH calculator's interface, outlines what the calculator covers and how it functions.

The second chapter offers insights in the calculation methodology that is behind the calculator. In addition, it explains the different default values utilized in the tool and references to the sources.

The final chapter of the manual showcases several use cases to demonstrate the functionality of the LCOH calculator, e.g. when user-specified values are utilized as input. Table 1 and Table 2 provide an overview of the use cases examined and their corresponding results.

Use cases overview

Table 1. Use cases overview of comparative cost analyses based on the default values.

Comparative cost analyses with default values				
Use case	**Description**	**Default values affected**	**LCOH components affected**	**Result in this situation**
1. Effect of country	Which country allows to produce hydrogen most cost effectively when using wholesale electricity and alkaline electrolysis technology? Germany or Norway?	1. Average electricity costs 2. Grid fees 3. Electricity taxes	1. Electricity costs 2. Grid fees 3. Taxes	Norway has lower LCOH
2. Effect of electricity source	Which electricity source is the most cost-effective solution for the production of hydrogen when using alkaline electrolysis in Spain? Wholesale or PV?	1. Operating hours 2. Average electricity costs 3. Grid fees 4. Electricity taxes	All LCOH components	PV has lower LCOH
3. Combined effect of electricity source and country	Which country and electricity source allows to produce hydrogen most cost effectively when using alkaline electrolysis technology? Malta with PV or Ireland with onshore wind?	1. Operating hours 2. Average electricity costs	All LCOH components	Ireland with onshore wind has lower LCOH
4. Effect of electrolysis technology	Which electrolysis technology is the most cost-effective when using wholesale electricity in Germany? Alkaline or PEM?	1. CAPEX 2. Energy consumption 3. Stack durability 4. Stack degradation	All LCOH components	Alkaline has lower LCOH

Table 2. Use case overview of comparative cost analyses based on user specified values.

Comparative cost analyses with user specified values				
Use case	**Description**	**Default values affected**	**LCOH components affected**	**Result in this situation**
5. Effect of other electrolysis technology	Does solid oxide electrolysis allow to produce hydrogen cost-effectively? Compared to alkaline technology and based on full year operation in Norway?	All values related to electrolysis unit and electricity source apart from installed power, grid fees and taxes	All LCOH components	Alkaline has lower LCOH
6. Effect of combining multiple electricity sources	Can a combination of PV and wholesale result in a lower LCOH? With alkaline electrolysis in Spain?	1. Operating hours 2. Average electricity costs 3. Grid fees 4. Electricity taxes	All LCOH components	PV + wholesale has a slightly higher LCOH than PV
7. Effect of subsidies and additional revenues	How does the inclusion of subsidies and additional revenues impact the hydrogen production cost? Effect on use case 6?	1. Electrolyser CAPEX subsidy 2. Hydrogen feed-in tariff or green premium 3. Reduction of grid fees or electricity taxes 4. Oxygen sale price	1. Subsidies 2. Oxygen	Strong potential impact of subsidies

01 Introduction

Introduction

This chapter emphasizes the significance of LCOH as a crucial parameter for hydrogen deployment, discusses the key factors influencing LCOH, and explains the components covered by the calculator and its functionalities.

1.1.

LCOH concept

In the constantly changing realm of clean energy, the pursuit of sustainable alternatives to traditional fossil fuels has become increasingly important. Hydrogen, often seen as the fuel of the future, has attracted considerable interest. Nevertheless, to establish hydrogen as a feasible energy or feedstock option, it is essential to understand its financial implications. This is where the LCOH becomes significant. The LCOH is a method used to evaluate the total expenses involved in producing hydrogen throughout its entire lifecycle, including both capital (CAPEX) and operational costs (OPEX).

The LCOH serves as a valuable tool for evaluating hydrogen against alternative energy options and determining its market competitiveness. This metric enables policymakers, investors, and industry players to make well-informed decisions regarding resource allocation and strategies for promoting cost-effective, sustainable hydrogen production.

Several key factors impact the LCOH. Of main importance is the production technology, in combination with the used energy source. Each production technology, such as steam methane reforming (SMR), potentially combined with carbon capture (SMR+CC), or electrolysis, either with grid connection or with direct connection to a renewable energy source, has its own varying associated costs. Electrolysis, with direct connection to renewable energy sources, is widely recognized as one of the most sustainable production processes, yet its cost competitiveness strongly varies in function of the electricity price.

For a broader view on the LCOH of the most used production techniques in Europe, including SMR, SMR+CC, grid-connected electrolysis and electrolysis with direct connection to renewable energy sources, please refer to the European Hydrogen Observatory (EHO) report "The European hydrogen market landscape", in addition to the corresponding interactive data dashboard on the website. This manual focuses on the functionalities of the LCOH calculator.

1.2.

LCOH calculator

The LCOH calculator provided in the EHO is a tool allowing the calculation of hydrogen production costs via low temperature water electrolysis in the different EU27 countries, Norway or the UK. A selection of four different electricity sources is provided in the calculator, including grid connection based on wholesale electricity prices, or direct connection to renewable electricity sources such as photovoltaics (PV) and onshore or offshore wind. The calculator allows to either use default values provided by Hydrogen Europe or user specified values. The default values can change depending on the selection of the country and the electricity source. The user specified values do not change automatically and have to be adapted by the user.

Figure 1 provides an overview of the LCOH calculator interface, outlining the input data utilized by the calculator to calculate the various components contributing to the total LCOH values. The first category of the input data refers to the operational characteristics of the electrolysis unit covering aspects such as the installed power, the investments and the operational costs, the energy consumption and stack durability. The second category encompasses data associated with the electricity source including operating hours of the electrolysis device, based on low-cost energy availability, the average electricity costs, grid fees and electricity taxes. Lastly, additional subsidies and revenues can be specified as user specified values.

Using these input data, the LCOH calculator computes the total LCOH in EUR/kg and provides a breakdown by CAPEX, electricity, other OPEX, grid fees, taxes, subsidies, and oxygen revenues, visualized in a waterfall plot.

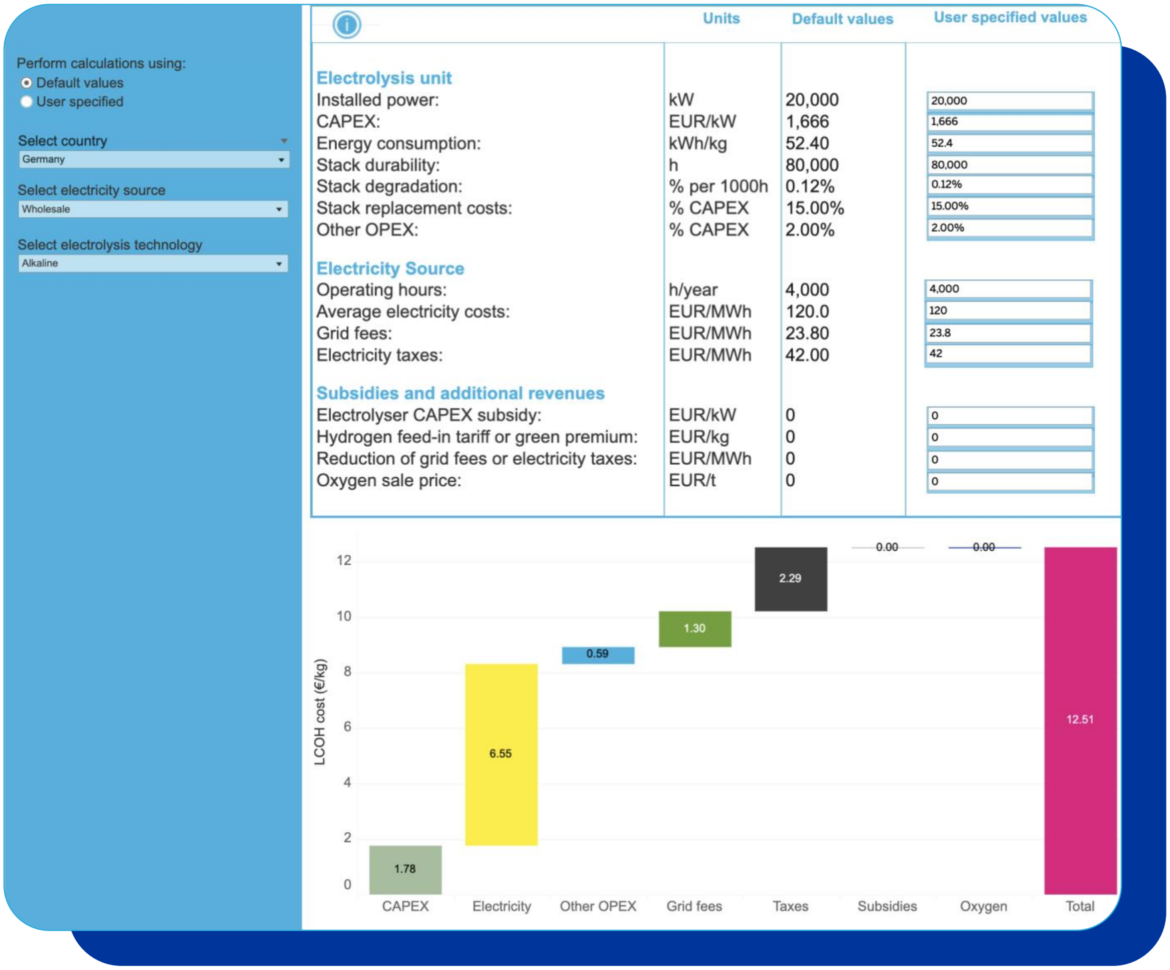


Figure 1. LCOH calculator interface.

02

Methodology

Introduction

This chapter provides a comprehensive understanding of the methodology behind the LCOH calculator's functionalities.

More specifically, it gives an explanation of the components involved in the calculation of the LCOH, and the data sources utilized by Hydrogen Europe to provide the default values.

2.1.

Overview

As introduced in section 1.2., the LCOH is dependent on different cost components such as CAPEX, electricity, other OPEX, grid fees, taxes, subsidies and oxygen revenues, which are explained in more detail in Table 3.

Table 3. Explanation of the components included in the LCOH calculation.

Component	Explanation
CAPEX	The CAPEX include all upfront investments required to establish the hydrogen production facility. This can encompass various components such as equipment and infrastructure costs, land acquisition, etc. CAPEX costs related to the energy source are not included and are part of the electricity costs. Moreover, CAPEX costs related to transport or processing of hydrogen for end-use applications are also not included, only costs related to the production facility are taken into account.
Electricity costs	Electricity costs include expenses related to the consumption of electricity during the electrolysis process. They are mainly dependent on the used energy source, in addition to the electrolysis efficiency.
Other OPEX	Other OPEX reflected in the LCOH cost include OPEX costs on top of electricity, grid fees and taxes. This includes stack replacements, maintenance, water consumption, etc.
Grid fees	These are charges imposed by utility companies for the use of their electricity transmission and distribution infrastructure. Grid fees may vary depending on factors such as location, time of use, and the amount of electricity consumed.

Taxes	Taxes imposed to the consumption of electricity, including renewable, capacity, environmental, nuclear and other electricity taxes. Tax rates may vary depending on local regulations and policies.
Subsidies	Financial incentives provided by governments or other entities to promote hydrogen production or support the use of renewable energy sources. Subsidies can include grants, tax credits, or other forms of financial assistance aimed at reducing the cost of hydrogen production.
Oxygen sales	In electrolysis-based hydrogen production, oxygen and heat are produced as by-products. The calculator allows to include potential revenues from selling oxygen to nearby consumers. This is not the case for excess heat and should be considered separately by the user, if applicable.

2.2. Default values

The LCOH calculator provides the option to make calculations based on default values or user specified values. These default values are provided by Hydrogen Europe, either sourced from literature or from insights of their members.

Table 4 presents the various assumptions and sources that were used for deriving the default values that are displayed in the LCOH calculator.

Table 4. Assumptions and sources for default values estimation in the LCOH calculator.

	Units	Assumptions and sources
Electrolysis unit		
Installed power	kW	A total size of 20 MWel is considered for deriving the other default values. Changing this value does not automatically change other default values, such as CAPEX or OPEX.
CAPEX	EUR/kW	Research from Hydrogen Europe for electrolyser CAPEX prices of projects located in EU27, EFTA or UK, based on interviews with developers and other industry sources.

Energy consumption	kWh/kg	Data was sourced from the Clean Hydrogen JU Strategic Research and Innovation Agenda in addition to the Danish Energy Agency Technology Data for Renewable Fuels.
Stack durability	h	Data was sourced from the Clean Hydrogen JU Strategic Research and Innovation Agenda in addition to the Danish Energy Agency Technology Data for Renewable Fuels.
Stack degradation	% per 1000h	Data was sourced from the Clean Hydrogen JU Strategic Research and Innovation Agenda.
Stack replacement costs	% CAPEX	Research from Hydrogen Europe for electrolyser OPEX prices of projects located in EU27, EFTA or UK, based on interviews with developers and other industry sources.
Other OPEX	% CAPEX	Research from Hydrogen Europe for electrolyser OPEX prices of projects located in EU27, EFTA or UK, based on interviews with developers and other industry sources.
Electricity source		
Operating hours	h/year	• For wholesale electricity, it is assumed that the 4,000 cheapest operating hours are used. • For solar PV, onshore and offshore wind the operating hours were estimated based on capacity factors in EU Member States obtained by the ENSPRESO model from the Joint Research Centre. • For directly connected off-grid electrolysis (PV or wind), the assumption is made that the electrolyser is scaled down vs. RES power, allowing for a higher electrolysis capacity factor. The following electrolyser capacity factor adjustments were made: ○ For PV the capacity factor of electrolysis is assumed to be 25% higher than RES ○ For onshore wind the capacity factor of the electrolyser is 11% higher than RES ○ For offshore wind the capacity factor of the electrolyser is the same as RES

Average electricity costs	EUR/MWh	• Wholesale electricity costs were sourced from the European network of transmission system operators for electricity (ENTSO-E), by calculating the 4,000 cheapest hours per country (2022 data was used for the LCOH calculator released in May 2024). • Solar PV, onshore and offshore wind electricity costs in Europe are sourced from IRENA's renewable power generation costs (2022 data was used for the LCOH calculator released in May 2024).
Grid fees	EUR/MWh	• The grid fees and electricity taxes are sources from Eurostat based on the 'electricity prices components for non-household consumers' dataset. The price components are extracted for a consumption range of 20,000 MWh - 69,999 MWh. (2022 data was used for the LCOH calculator released in May 2024). • By using the Eurostat dataset, the grid fees refer to network costs and the electricity taxes include renewable, capacity, environmental, nuclear and other taxes. • For PV and onshore wind, it is assumed that a direct connection to the electrolysis unit is used, excluding grid fees and electricity taxes. For wholesale electricity and offshore wind, it is assumed that grid connection is used, thus including grid fees and electricity taxes.
Electricity taxes	EUR/MWh	
Subsidies and additional revenues		
Electrolyser CAPEX Subsidy	EUR/kW	The subsidies and additional revenues are always zero under the default values. Any subsidies or additional revenues you might receive for a project, can be captured in the user specified values.
Hydrogen feed-in tariff or green premium	EUR/kg	
Reduction of grid fees or electricity	EUR/MWh	
Oxygen sale price	EUR/t	

It should be noted that the default data does not show actual hydrogen production costs from operational water electrolysis plants in Europe, but is a best estimate of what production costs could be expected to be achieved given current costs of multi-MW state-of-the art electrolysis system and latest available annual electricity costs.

2.3. Calculations

In order to understand the relationship among the various components comprising the LCOH and their impact on the overall cost of operating the electrolysis unit, several key calculations are involved. The formula for determining the total LCOH (Equation 1) encompasses the consideration of capital expenditures (CAPEX) and various operating expenses (OPEX). These expenses include electricity costs for operating the electrolysis unit, grid fees, electricity taxes, and other operating expenses as well as revenues from subsidies and oxygen sales.

$$\boldsymbol{Total\ LCOH}\left(\frac{\boldsymbol{EUR}}{\boldsymbol{kg}}\right) = CAPEX\ (Eq. 7) + Electricity\ Cost\ (Eq. 9) + Other\ OPEX\ (Eq. 13)$$
$$+ Grid\ fees\ (Eq. 15) + Taxes\ (Eq. 17) + Subsidies\ (Eq. 22) + Oxygen\ Sales\ (Eq. 25)$$

Equation 1. Calculation of the total Levelized Cost of Hydrogen (LCOH) in EUR/kg.

In order to calculate these different cost components starting from the default values or user specified values, first the hydrogen output and energy consumption of the installation should be known.

Hydrogen output and energy consumption

As the electrolysis unit operates, the stack it contains degrades over time, requiring periodic replacement. The frequency of these replacements depends on factors such as the durability of the stack, the operating hours and the economic lifetime of the installation (Equation 2). In the current version of the calculator (May 2024), the economic lifetime is chosen to be 25 years. Due to degradation of the stack over time, the energy consumption is not constant but progressively increases in time.

Therefore, Equation 3 is used to calculate the average energy consumption over the economic lifetime of the project. This energy consumption is also used to derive the total energy consumption of the project (Equation 6). See Appendix A1 for more clarifications on how Equation 3 was derived.

The total hydrogen output is then dependent on the operating hours, capacity and economic lifetime of the installation (Equation 5). The capacity can be derived from the project size, i.e. electrolysis installed power, and average energy consumption of the installation (Equation 4).

$$\textbf{Stack replacements} = Rounddown\left(\frac{Economic\ lifetime\ (years)\ \times\ Operating\ hours\ \left(\frac{h}{year}\right)}{Stack\ durability\ (h)}\right)$$

Equation 2. Calculation of stack replacement during the economic lifetime of the electrolysis unit.

$$\begin{aligned}\textbf{Energy consumption per kg} \\ &= (Energy\ Consumption * (1 + (Stack\ degradation * Stack\ durability/1000)) \\ &+ Energy\ Consumption)/2 * (Stack\ replacements * Stack\ durability)/(Operating\ hours \\ &* Economic\ lifetime)\ +\ (Energy\ Consumption * (1 + (Stack\ degradation \\ &* ((Operating\ hours * Economic\ lifetime) - (Stack\ replacements \\ &* Stack\ durability))/1000)) + Energy\ Consumption)/2 * ((Operating\ hours \\ &* Economic\ lifetime) - (Stack\ replacements * Stack\ durability))/(Operating\ hours \\ &* Economic\ lifetime)\end{aligned}$$

Equation 3. Calculation of the average energy consumption per kg hydrogen over the total economic lifetime of the electrolysis unit (kWh/kg).

$$\textbf{Capacity}\left(\frac{\textbf{kg}}{\textbf{h}}\right) = \frac{Electrolysis\ installed\ power\ (kW)}{Energy\ consumption\ per\ kg\ \left(\frac{kWh}{kg}\right)}$$

Equation 4. Calculation of the electrolysis unit capacity (kg/h).

$$\textbf{Hydrogen output (kg)} = Operating\ hours\ \left(\frac{h}{year}\right) \times Capacity\left(\frac{kg}{h}\right) \times Economic\ lifetime\ (years)$$

Equation 5. Calculation of electrolysis hydrogen output (kg).

$$\textbf{Energy consumption (MWh)} = \frac{Hydrogen\ output\ \left(\frac{kg}{h}\right) \times Energy\ consumption\ per\ kg\ \left(\frac{kWh}{kg}\right)}{1000}$$

Equation 6. Calculation of the energy consumption (MWh) of the electrolysis unit.

CAPEX

The electrolyser CAPEX is determined by considering the CAPEX in function of the installed power of the electrolysis unit, as outlined in Table 4 and computed using Equation 7.

This electrolyser CAPEX subsequently serves as an input parameter for Equation 8, facilitating the calculation of the CAPEX cost associated with producing each kilogram of hydrogen.

Here, a NPV calculation is used to take into account the cost of capital, which is set at an annual rate of 6%. This function considers that money spent today holds greater value compared to the future, as it could potentially be invested elsewhere at a certain rate.

$$\textbf{Electrolyser CAPEX (EUR)} = Electrolysis\ installed\ power\ (kW) \times CAPEX\ \left(\frac{EUR}{kW}\right)$$

Equation 7. Calculation of the electrolyser CAPEX (EUR) for the establishment of the electrolysis unit.

$$\boldsymbol{CAPEX}\left(\frac{\boldsymbol{EUR}}{\boldsymbol{kg}}\right) = \frac{Electrolyser\ CAPEX\ (EUR)}{NPV(cost\ of\ capital\ (\%), hydrogen\ output)}$$

Equation 8. Calculation of the electrolyser CAPEX costs per kilogram of hydrogen produced (EUR/kg).

Electricity

The cost of energy is determined by the energy consumption as defined in Equation 6 and the average electricity costs, which can either be default values or values specified by the user. No change in electricity costs is considered over the years. This cost of energy is subsequently utilized in Equation 10 to calculate the electricity costs per kilogram of hydrogen produced.

$$\boldsymbol{Cost\ of\ energy}\ (\boldsymbol{EUR}) = Energy\ consumption\ (MWh) \times Average\ electricity\ costs\left(\frac{EUR}{MWh}\right)$$

Equation 9. Calculation of cost of energy consumed (EUR) by the electrolysis unit.

$$\boldsymbol{Electricity\ Cost}\left(\frac{\boldsymbol{EUR}}{\boldsymbol{kg}}\right) = \frac{Cost\ of\ energy\ (EUR)}{Hydrogen\ output\ (kg)}$$

Equation 10. Calculation of electricity costs per kilogram of hydrogen produced (EUR/kg).

Other OPEX

Other OPEX reflected in the LCOH cost include both the stack replacement costs and other OPEX as expressed as a function of CAPEX.

The stack replacement costs are dependent on the number of stack replacements and the cost for a stack replacement, which is expressed by the default or user specified values as a percentage of the CAPEX costs (Equation 11). Similarly, the total other OPEX costs are also derived as an annual percentage of the CAPEX costs over the economic lifetime of the project (Equation 12). No changes in the costs for stack replacements or other OPEX are considered over the years. Finally, the output from Equations 11 and 12 is used to calculate the total other OPEX costs for each kg of hydrogen produced in Equation 13.

$$\begin{aligned}\boldsymbol{Stack\ replacement\ costs}\ (\boldsymbol{EUR}) &= Stack\ replacement\ costs\ (\%CAPEX) \times Electrolyser\ CAPEX\ (EUR)\\ &\times Stack\ replacements\end{aligned}$$

Equation 11. Calculation of stack replacement costs (EUR) during the economic lifetime of the electrolysis unit.

$$\begin{aligned}&\boldsymbol{Other\ OPEX}\ (\boldsymbol{EUR})\\ &= Electrolyser\ CAPEX\ (EUR) \times\ Other\ OPEX\ \left(\%\frac{CAPEX}{year}\right) \times Economic\ lifetime\ (years)\end{aligned}$$

Equation 12. Calculation of other OPEX costs (EUR) for the operation of the electrolysis unit.

$$\boldsymbol{Other\ OPEX\ Costs}\left(\frac{\boldsymbol{EUR}}{\boldsymbol{kg}}\right) = \frac{\left(Other\ OPEX\ (EUR) + Stack\ replacements\ costs\ (EUR)\right)}{Hydrogen\ output\ (kg)}$$

Equation 13. Calculation of other OPEX costs per kilogram of hydrogen produced (EUR/kg).

Grid fees

The costs associated with grid fees is dependent on the energy consumption as defined in Equation 6 and the grid fees, which can either be the default values or values specified by the user. No annual grow rate in grid fees is considered in the calculations. This grid fee cost is then applied in Equation 15, along with the hydrogen output, to determine the grid fee costs per kilogram of hydrogen produced

For the default values, as expressed in Table 4, for PV or onshore wind as the electricity source, no grid fees are considered.

$$\boldsymbol{Grid\ fees\ (EUR)} = Energy\ consumption\ (MWh) \times Grid\ fees\ \left(\frac{EUR}{MWh}\right)$$

Equation 14. Calculation of grid fees (EUR) for the operation of the electrolysis unit.

$$\boldsymbol{Grid\ fees\ \left(\frac{EUR}{kg}\right)} = \frac{Grid\ fees\ (EUR)}{Hydrogen\ output\ (kg)}$$

Equation 15. Calculation of grid fees costs per kilogram of hydrogen produced (EUR/kg).

Electricity taxes

As in the case of grid fees, the electricity taxes costs are influenced by the energy consumption as defined in Equation 6 and the electricity taxes. Again, no annual grow rate in electricity taxes is considered in the calculations. This electricity taxes cost is then applied in Equation 17, along with the hydrogen output, to determine the electricity taxes costs per kilogram of hydrogen produced.

Also no electricity taxes are considered when using PV or onshore wind as the electricity source, as expressed in Table 4.

$$\boldsymbol{Electricity\ taxes\ (EUR)} = Energy\ consumption\ (MWh) \times Electricity\ taxes\ \left(\frac{EUR}{MWh}\right)$$

Equation 16. Calculation of taxes (EUR) for the operation of the electrolysis unit.

$$\boldsymbol{Electricity\ taxes\ \left(\frac{EUR}{kg}\right)} = \frac{Electricity\ taxes\ (EUR)}{Hydrogen\ output\ (kg)}$$

Equation 17. Calculation of electricity taxes costs per kilogram of hydrogen produced (EUR/kg).

Subsidies

Hydrogen subsidies can be offered in various ways, either as a grant in function of the installed electrolyser plant (EUR/kW) (Equation 19), in function of the hydrogen that is produced (EUR/kg) (Equation 20), or by lowering the grid fees or electricity taxes (in EUR/MWh) (Equation 21).

Equation 18 sums up these different kind of subsidies, which is then applied in Equation 22, along with the hydrogen output, to determine the subsidies revenues per kilogram of hydrogen produced. For the CAPEX subsidies, also an NPV calculation is used to take into account the cost of capital.

$$\textbf{Subsidies}\ (\textbf{EUR}) = (1) + (2) + (3)$$

Equation 18. Calculation of subsidies revenues (EUR) for the operation of the electrolysis unit.

$$(\mathbf{1}) = Electrolyser\ CAPEX\ subsidy\ \times Electrolyser\ installed\ power$$

Equation 19. Calculation of CAPEX grants in function of the installed electrolyser plant (EUR).

$$(\mathbf{2}) = Hydrogen\ feed\ in\ tariff\ or\ green\ premium\ \times Hydrogen\ output$$

Equation 20. Calculation of the subsidies in function of the hydrogen that is produced (EUR).

$$(\mathbf{3}) = Reduction\ of\ grid\ fees\ or\ electricity\ taxes \times Energy\ consumption$$

Equation 21. Calculation of the subsidies related to the reduction of grid fees or electricity taxes (EUR).

$$\textbf{Subsidies}\ \left(\frac{\textbf{EUR}}{\textbf{kg}}\right) = -1 \times \left(\frac{(1)}{NPV(cost\ of\ capital\ (\%), hydrogen\ output)} + \frac{(2) + (3)}{Hydrogen\ output\ (kg)}\right)$$

Equation 22. Calculation of subsidies revenues per kilogram of hydrogen produced (EUR/kg).

Oxygen

Equation 23 is employed to quantify the oxygen output, a parameter linked to the hydrogen output based on the difference in molar mass. Subsequently, Equation 24 is used to determine the oxygen revenues (in EUR), taking into account both the selling price of oxygen and the quantity produced.

These oxygen revenues are then applied in Equation 25, along with the hydrogen output, to determine the oxygen revenues per kilogram of hydrogen produced.

$$\textbf{Oxygen output} = Hydrogen\ output\ (kg) \times 8$$

Equation 23. Calculation of the oxygen output during the economic lifetime of the electrolysis unit (kg).

$$\textbf{Oxygen revenues}\ (\textbf{EUR}) = Oxygen\ output\ (kg) \times \frac{Oxygen\ sale\ price\ \left(\frac{EUR}{t}\right)}{10^3}$$

Equation 24. Calculation of the oxygen revenues (EUR) during the economic lifetime of the electrolysis unit.

$$\textbf{Oxygen Revenues}\ \left(\frac{\textbf{EUR}}{\textbf{kg}}\right) = -1 \times \frac{Oxygen\ renenues\ (EUR)}{Hydrogen\ output\ (kg)}$$

Equation 25. Calculation of the oxygen revenues per kilogram of hydrogen produced (EUR/kg).

03

Use cases

Introduction

This chapter presents various use case scenarios to demonstrate how the LCOH calculator can be used and which illustrate the potential impact of input data on the total LCOH.

The goal of the different use cases is to explain all the different functionalities of the calculator, including the selection of the country, electricity source and electrolysis technology for changing the default values, but also the option to make calculations based on user defined values.

3.1.

Overview

The LCOH calculator automatically calculates the different cost components determining the total hydrogen production costs. When calculating with the default values, the output is directly influenced by parameter selections made from the dropdown menu within the calculator, which include:

- Country: 29 options available, namely EU27 countries, Norway and UK.
- Electricity source: 4 options available, namely wholesale, PV, onshore, and offshore wind.
- Electrolysis technology: 2 options available, namely Alkaline or PEM.

Users also have the option to input their own values. Note that these user-specified values do not update automatically when changing the parameters in the dropdown menu and must thus always be adjusted manually.

Figure 2 illustrates the process for selecting these parameters within the LCOH calculator to determine the total LCOH.

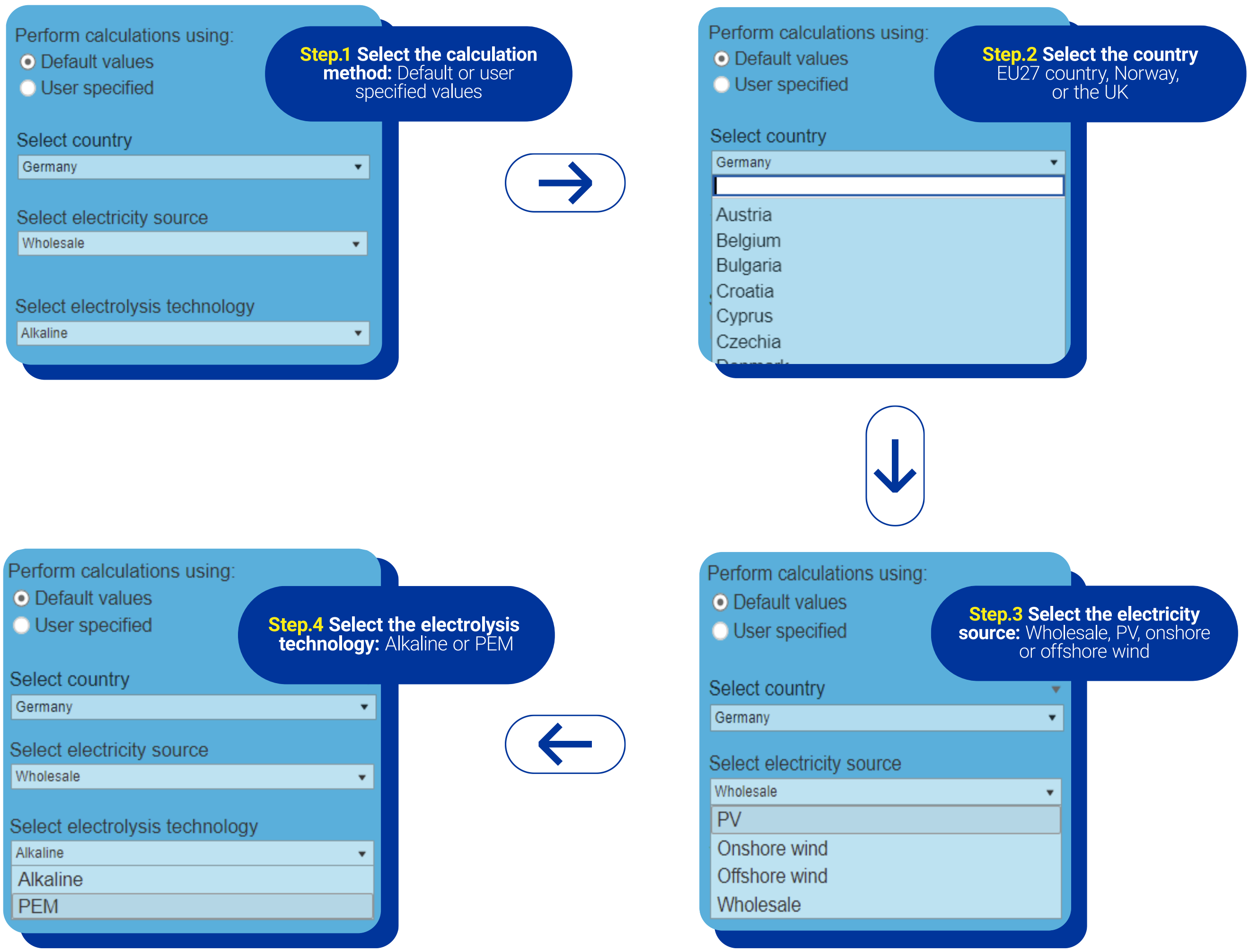


Figure 2. Step-by-step process for selecting parameters within the LCOH calculator.

3.2. Comparative cost analyses with default values

To explore all the different functionalities of the calculator when using default values, four distinct use cases are examined. These cases involve selecting the country, electricity source, and electrolysis technology, as well as a combination of them.

Use case 1 concentrates on the effects of selecting different countries for the same electrolysis technology and electricity source. In use case 2, the evaluation focuses on changing the electricity source with identical electrolysis technology and country. Use case 3 combines the methodologies of case 1 and case 2, enabling alterations in both the electricity source and the country while holding the electrolysis technology constant. Use case 4 compares the influence of the electrolysis technology selection while keeping the electricity source and country constant.

Table 5 provides an overview of the different use cases examined.

Table 5. Overview of the different use cases based on default data.

Use case	Calculation method	Electrolysis technology	Electricity source	Country
Use case 1	Default values	Alkaline electrolysis	Wholesale	Germany vs. Norway
Use case 2	Default values	Alkaline electrolysis	Wholesale vs. PV	Spain
Use case 3	Default values	Alkaline electrolysis	PV vs. onshore wind	Malta vs. Ireland
Use case 4	Default values	Alkaline vs. PEM electrolysis	Wholesale	Germany

Use case 1 - Effect of country

In use case 1, the LCOH of Germany is compared to Norway when using the same electricity source (wholesale) and electrolysis technology (alkaline). This comparison can be useful if the objective is to evaluate the most cost-effective location for producing hydrogen based on a fixed electrolysis technology and electricity source. Selecting Norway when using wholesale electricity also allows the production of RFNBO hydrogen1, since Norway's grid electricity is nearly 100% renewable.

Use case 1: Which country allows to produce hydrogen most cost effectively when using wholesale electricity and alkaline electrolysis technology? Germany or Norway?

As observed in Figure 3, the choice of the country within the LCOH calculator only impacts the default data related to the electricity source. In this example, the selection of Norway as the country for installing an electrolysis plant demonstrated several advantages over Germany. Norway had 1.2 EUR/MWh lower average electricity costs in 2022, in addition to 18 and 33 EUR/MWh lower grid fees and electricity taxes, respectively.

As a result, in Figure 4, the LCOH calculator output indicates that, for a company intending to establish an electrolysis plant utilizing alkaline technology and operating on wholesale electricity, Norway emerged as the most economically advantageous setting at 9.7 EUR/kg (2.81 EUR/kg cheaper compared to Germany).

In this use case, the country selection had an impact on the electricity and mainly on the grid fees and taxes costs components, being 0.07, 0.97 and 1.78 EUR/kg lower, respectively.

[1] Based on the assumption that the share of renewable electricity in the electricity mix is above 90% in the chosen bidding zone.

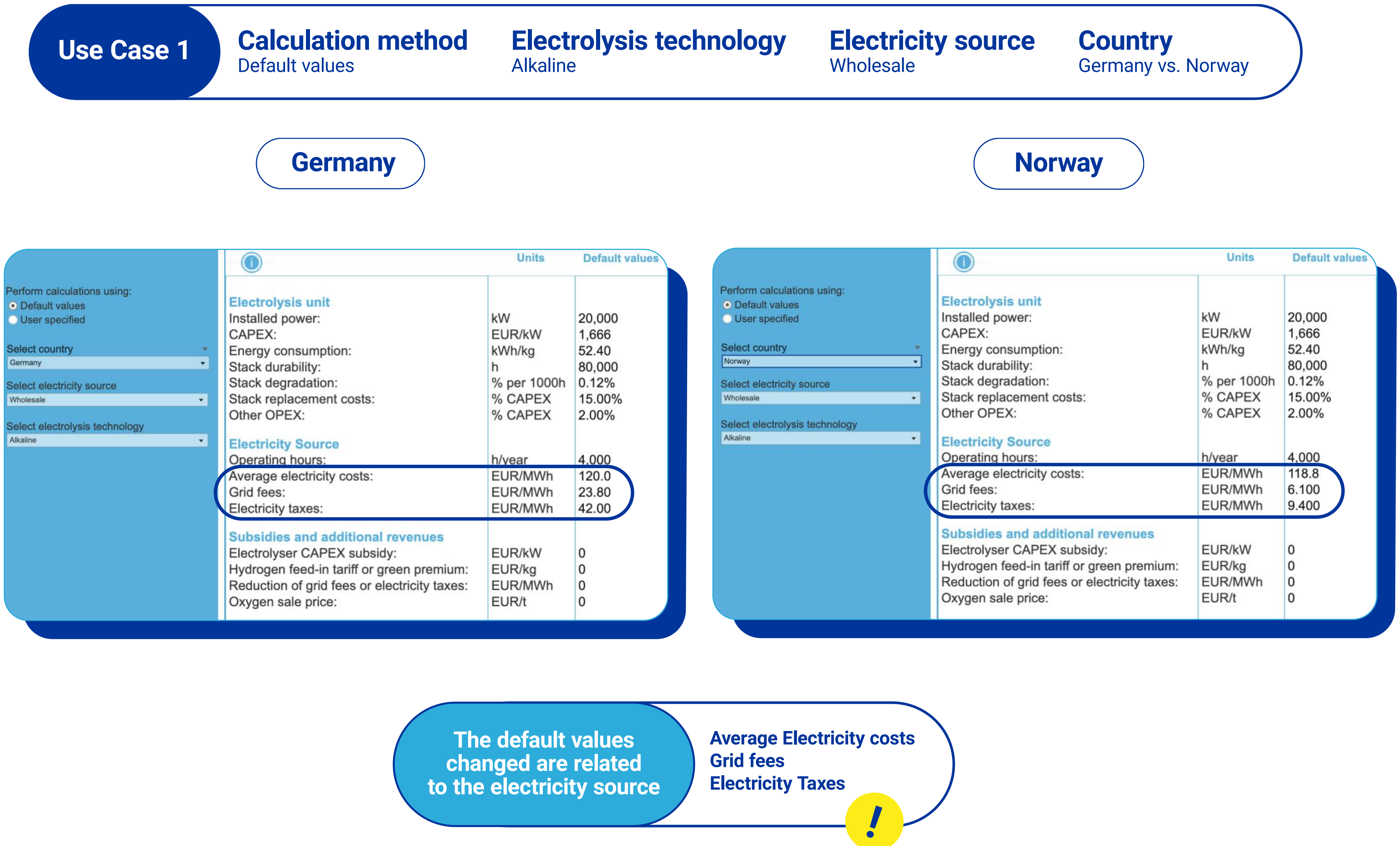


Figure 3. Use case 1 - effect of changing the country on the default values.

Use Case 1

Calculation method
Default values

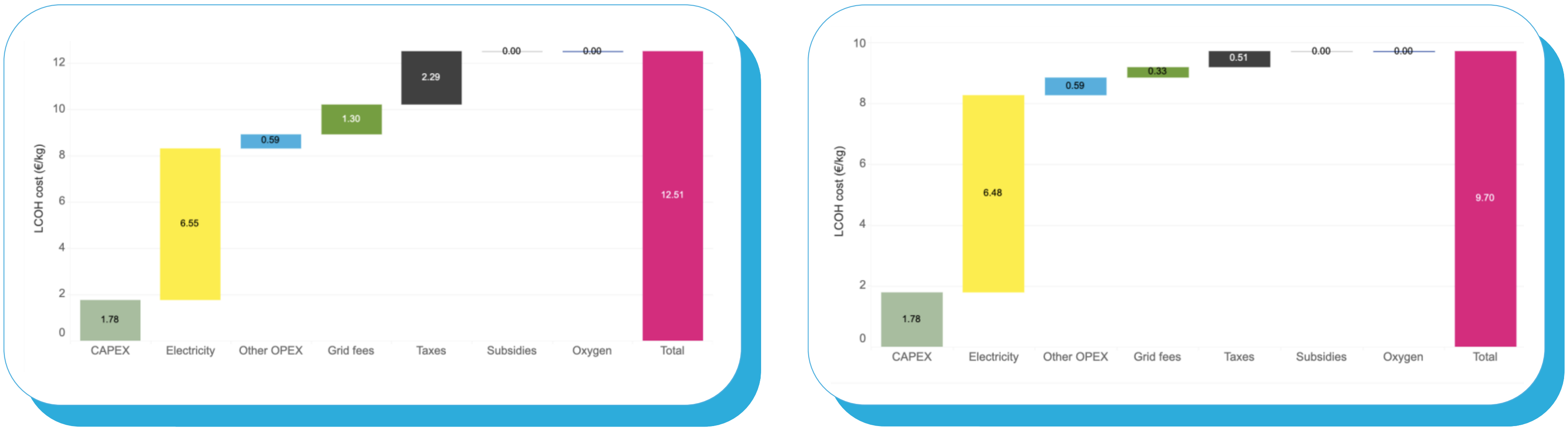
Electrolysis technology
Alkaline

Electricity source
Wholesale

Country
Germany vs. Norway

Germany
Total LCOH: 12.51 EUR/kg

Norway
Total LCOH: 9.70 EUR/kg



LCOH components changed

Electricity costs
Grid fees
Taxes

Figure 4. Use case 1 - effect of changing the country on the LCOH output.

Use case 2 - Effect of electricity source

In use case 2 the electricity sources wholesale and PV are compared when using the same electrolysis technology (alkaline) and country (Spain). This comparison can be useful if the objective is to evaluate the most cost-effective electricity source for producing hydrogen in the same country and with identical electrolysis technology.

Spain serves as a compelling case study for examining hydrogen production utilizing PV technology as it is an EU country with abundant solar irradiation. Hydrogen production based on a direct connection between the PV technology and the electrolysis unit, could also be considered as RFNBO hydrogen[2].

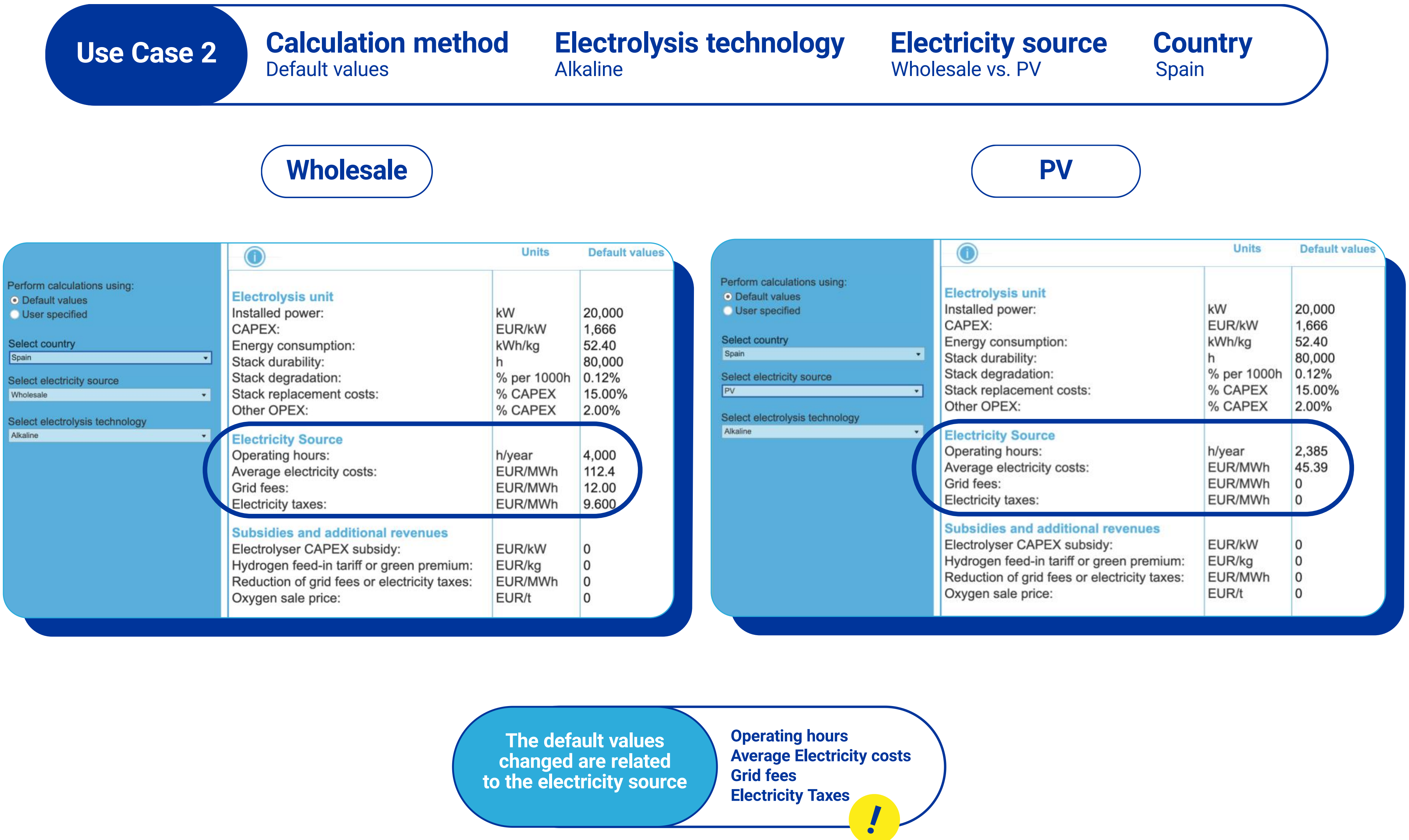
Use case 2: Which electricity source is the most cost-effective solution for the production of hydrogen when using alkaline electrolysis in Spain? Wholesale or PV?

As observed in Figure 5, the choice of the electricity source within the LCOH calculator only impacts the default data related to the electricity source. Utilizing PV technology as the electricity source in Spain offers distinct advantages compared to wholesale electricity. Specifically, PV exhibited 67 EUR/MWh lower average electricity costs in 2022, and unlike wholesale, incurs no grid fees or taxes as the calculator considers a direct connection between the PV technology and electrolysis device. However, the operating hours of the electrolysis device are significantly lower when PV is used as electricity source compared to wholesale.

Despite the lower operating hours, the LCOH calculator output (Figure 6) indicates that the LCOH of the alkaline electrolysis plant utilizing PV technology in Spain is more cost-effective at 6.19 EUR/kg (3.49 EUR/kg lower than wholesale).

Notably, all individual LCOH components are lower with PV as the electricity source, except for CAPEX, which was estimated to be around 1.2 EUR/kg more expensive. This difference in CAPEX can be attributed to the lower operating hours when using PV compared to wholesale. The most significant disparity was observed in electricity costs, with PV being more than 3.5 EUR/kg lower. Note that wholesale electricity costs were historically high in 2022, and the observed differences will thus be lower when using data of 2023.

2 If the criteria on additionality and temporal and geographic correlation are met.



Wholesale

	Units	Default values
Electrolysis unit		
Installed power:	kW	20,000
CAPEX:	EUR/kW	1,666
Energy consumption:	kWh/kg	52.40
Stack durability:	h	80,000
Stack degradation:	% per 1000h	0.12%
Stack replacement costs:	% CAPEX	15.00%
Other OPEX:	% CAPEX	2.00%
Electricity Source		
Operating hours:	h/year	4,000
Average electricity costs:	EUR/MWh	112.4
Grid fees:	EUR/MWh	12.00
Electricity taxes:	EUR/MWh	9.600
Subsidies and additional revenues		
Electrolyser CAPEX subsidy:	EUR/kW	0
Hydrogen feed-in tariff or green premium:	EUR/kg	0
Reduction of grid fees or electricity taxes:	EUR/MWh	0
Oxygen sale price:	EUR/t	0

PV

	Units	Default values
Electrolysis unit		
Installed power:	kW	20,000
CAPEX:	EUR/kW	1,666
Energy consumption:	kWh/kg	52.40
Stack durability:	h	80,000
Stack degradation:	% per 1000h	0.12%
Stack replacement costs:	% CAPEX	15.00%
Other OPEX:	% CAPEX	2.00%
Electricity Source		
Operating hours:	h/year	2,385
Average electricity costs:	EUR/MWh	45.39
Grid fees:	EUR/MWh	0
Electricity taxes:	EUR/MWh	0
Subsidies and additional revenues		
Electrolyser CAPEX subsidy:	EUR/kW	0
Hydrogen feed-in tariff or green premium:	EUR/kg	0
Reduction of grid fees or electricity taxes:	EUR/MWh	0
Oxygen sale price:	EUR/t	0

Figure 5. Use case 2 - effect of changing the electricity source on the default values.

Use Case 2

Calculation method
Default values

Electrolysis technology
Alkaline

Electricity source
Wholesale vs. PV

Country
Spain

Wholesale
Total LCOH: 9.68 EUR/kg

PV
Total LCOH: 6.19 EUR/kg

All LCOH components changed

Figure 6. Use case 2 - effect of changing the electricity source on the LCOH output.

Use case 3 – Combined effect of country and electricity source

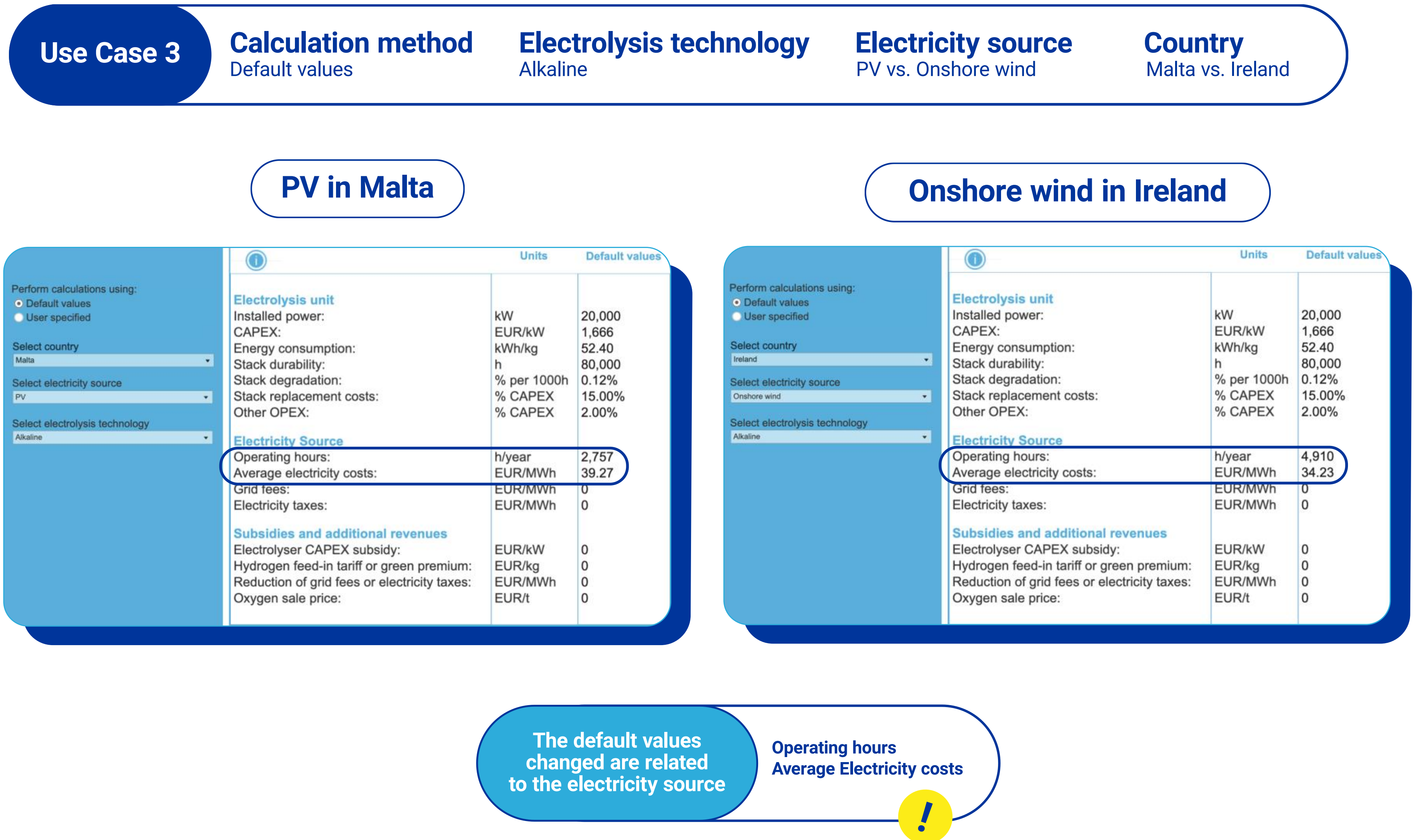
In use case 3, the LCOH of Malta is compared to Ireland when using PV and onshore wind as the electricity source, respectively. Both projects make use of the same electrolysis technology (alkaline). This comparison can be useful if the objective is to evaluate the most cost-effective combination of location and electricity source for producing hydrogen based on a fixed electrolysis technology.

Use case 3: Which country and electricity source allows to produce hydrogen most cost effectively when using alkaline electrolysis technology? Malta with PV or Ireland with onshore wind?

As observed in Figure 7, changing the country and the electricity source in the LCOH calculator only impacts the default data related to the electricity source. In this example, the selection of Ireland as the country for installing an electrolysis plant using onshore wind demonstrated several advantages over Malta using PV. Onshore wind in Ireland showcased 5.0 EUR/MWh lower average electricity costs in 2022, while the installation was able to operate for over 2,000 hours more. In both cases no grid fees and electricity taxes were imposed.

As a result, in Figure 8, the LCOH calculator output indicates that, for a company intending to establish an electrolysis plant utilizing alkaline technology, using onshore wind in Ireland emerged as the most economically advantageous setting at 3.8 EUR/kg (1.59 EUR/kg cheaper compared to PV in Malta).

In this use case, combining the country selection with the electricity source had an impact on the CAPEX, electricity and other OPEX costs components. The most substantial difference lied in CAPEX which was 1.14 EUR/kg lower for onshore wind in Ireland, as a result of the increased operating hours.



PV in Malta

Perform calculations using: Default values / User specified
Select country: Malta
Select electricity source: PV
Select electrolysis technology: Alkaline

	Units	Default values
Electrolysis unit		
Installed power:	kW	20,000
CAPEX:	EUR/kW	1,666
Energy consumption:	kWh/kg	52.40
Stack durability:	h	80,000
Stack degradation:	% per 1000h	0.12%
Stack replacement costs:	% CAPEX	15.00%
Other OPEX:	% CAPEX	2.00%
Electricity Source		
Operating hours:	h/year	2,757
Average electricity costs:	EUR/MWh	39.27
Grid fees:	EUR/MWh	0
Electricity taxes:	EUR/MWh	0
Subsidies and additional revenues		
Electrolyser CAPEX subsidy:	EUR/kW	0
Hydrogen feed-in tariff or green premium:	EUR/kg	0
Reduction of grid fees or electricity taxes:	EUR/MWh	0
Oxygen sale price:	EUR/t	0

Onshore wind in Ireland

Perform calculations using: Default values / User specified
Select country: Ireland
Select electricity source: Onshore wind
Select electrolysis technology: Alkaline

	Units	Default values
Electrolysis unit		
Installed power:	kW	20,000
CAPEX:	EUR/kW	1,666
Energy consumption:	kWh/kg	52.40
Stack durability:	h	80,000
Stack degradation:	% per 1000h	0.12%
Stack replacement costs:	% CAPEX	15.00%
Other OPEX:	% CAPEX	2.00%
Electricity Source		
Operating hours:	h/year	4,910
Average electricity costs:	EUR/MWh	34.23
Grid fees:	EUR/MWh	0
Electricity taxes:	EUR/MWh	0
Subsidies and additional revenues		
Electrolyser CAPEX subsidy:	EUR/kW	0
Hydrogen feed-in tariff or green premium:	EUR/kg	0
Reduction of grid fees or electricity taxes:	EUR/MWh	0
Oxygen sale price:	EUR/t	0

Figure 7. Use case 3 - effect of changing the country and the electricity source on the default values.

Use Case 3

Calculation method
Default values

Electrolysis technology
Alkaline

Electricity source
PV vs. Onshore wind

Country
Malta vs. Ireland

PV in Malta
Total LCOH: 5.39 EUR/kg

Onshore wind in Ireland
Total LCOH: 3.80 EUR/kg

LCOH components changed

!
CAPEX
Electricity costs
Other OPEX

Figure 8. Use case 3 - effect of changing the country and the electricity source on the LCOH output.

Use case 4 - Effect of electrolysis technology

In Use case 4 alkaline electrolysis is directly compared to PEM electrolysis when using the same electricity source and country. In this example, wholesale electricity is selected as the electricity source and Germany as the country of examination. This comparison can be useful if the objective is to evaluate the most cost-effective electrolysis technology when the country and electricity source have already been selected.

Use case 4: Which electrolysis technology is the most cost-effective when using wholesale electricity in Germany? Alkaline or PEM?

As observed in Figure 9, the choice of electrolysis technology within the LCOH calculator only impacts the default data concerning the characteristics of the electrolysis unit. Specifically, the implementation of alkaline technology demonstrated several advantages over PEM technology. Alkaline technology showcased approximately 300 EUR/kW lower CAPEX costs, 1 kWh/kg lower energy consumption, 0.07%/1000h lower stack degradation rate, and 20,000 h higher stack durability compared to PEM.

As a result, in Figure 10, the LCOH calculator output indicates that, for a company intending to establish an electrolysis plant utilizing wholesale electricity in Germany, alkaline technology emerged as the most cost-effective option at 12.51 EUR/kg (0.76 EUR/kg cheaper compared to PEM).

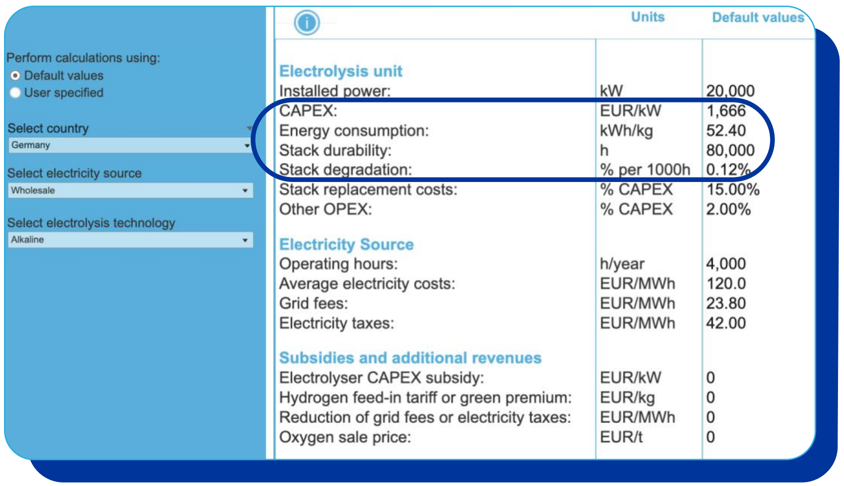
Please note that the PEM technology has a faster response time compared to alkaline electrolysis, which should also be taken into account when comparing technologies, in addition to other parameters that are not in scope of this calculator.

Notably, all individual cost components contributing to the total LCOH were lower when utilizing alkaline technology. The most substantial difference lied in CAPEX, where it was 0.38 EUR/kg lower, while the variance in grid fees and taxes was less than 0.1 EUR/kg.

Use Case 4

Calculation method	Electrolysis technology	Electricity source	Country
Default values	Alkaline vs. PEM	Wholesale	Germany

Alkaline



Perform calculations using:
- Default values
- User specified

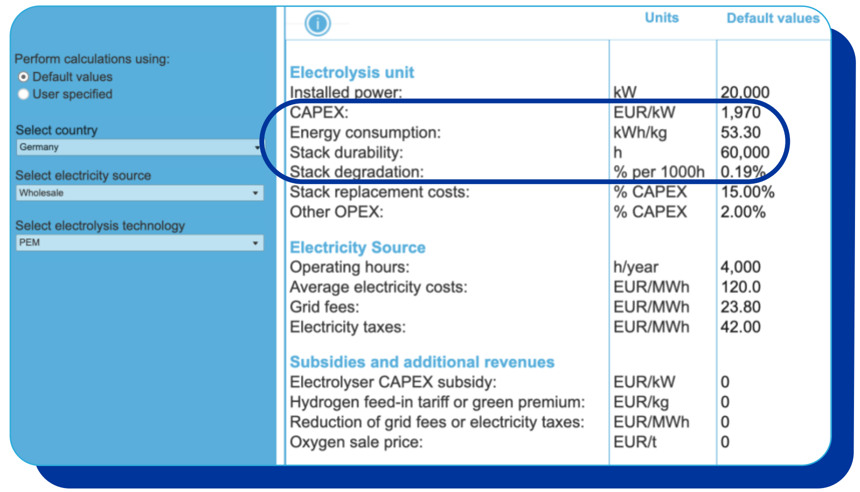
Select country: Germany

Select electricity source: Wholesale

Select electrolysis technology: Alkaline

	Units	Default values
Electrolysis unit		
Installed power:	kW	20,000
CAPEX:	EUR/kW	1,666
Energy consumption:	kWh/kg	52.40
Stack durability:	h	80,000
Stack degradation:	% per 1000h	0.12%
Stack replacement costs:	% CAPEX	15.00%
Other OPEX:	% CAPEX	2.00%
Electricity Source		
Operating hours:	h/year	4,000
Average electricity costs:	EUR/MWh	120.0
Grid fees:	EUR/MWh	23.80
Electricity taxes:	EUR/MWh	42.00
Subsidies and additional revenues		
Electrolyser CAPEX subsidy:	EUR/kW	0
Hydrogen feed-in tariff or green premium:	EUR/kg	0
Reduction of grid fees or electricity taxes:	EUR/MWh	0
Oxygen sale price:	EUR/t	0

PEM



Perform calculations using:
- Default values
- User specified

Select country: Germany

Select electricity source: Wholesale

Select electrolysis technology: PEM

	Units	Default values
Electrolysis unit		
Installed power:	kW	20,000
CAPEX:	EUR/kW	1,970
Energy consumption:	kWh/kg	53.30
Stack durability:	h	60,000
Stack degradation:	% per 1000h	0.19%
Stack replacement costs:	% CAPEX	15.00%
Other OPEX:	% CAPEX	2.00%
Electricity Source		
Operating hours:	h/year	4,000
Average electricity costs:	EUR/MWh	120.0
Grid fees:	EUR/MWh	23.80
Electricity taxes:	EUR/MWh	42.00
Subsidies and additional revenues		
Electrolyser CAPEX subsidy:	EUR/kW	0
Hydrogen feed-in tariff or green premium:	EUR/kg	0
Reduction of grid fees or electricity taxes:	EUR/MWh	0
Oxygen sale price:	EUR/t	0

The default values changed are related to the characteristics of the electrolysis unit

!

- **CAPEX**
- **Energy consumption**
- **Stack durability**
- **Stack degradation**

Figure 9: Use case 4 - effect of changing the electrolysis technology on the default values.

Use Case 4

Calculation method
Default values

Electrolysis technology
Alkaline vs. PEM

Electricity source
Wholesale

Country
Germany

Alkaline
Total LCOH: 12.51 EUR/kg

PEM
Total LCOH: 13.27 EUR/kg

All LCOH components changed

Figure 10. Use case 4 - effect of changing the electrolysis technology on the LCOH output.

3.3.

Comparative cost analysis of user specified values

Users can utilize this function to extend the capabilities of the LCOH calculator by manually adjusting input data with their own values to calculate the cost of producing hydrogen in Europe. To explore the capability of user-specified values, three distinct use cases are examined.

These cases involve using different parameters for the electrolysis unit and the electricity source.

As examples in use case 5, a case study is made for the use of solid oxide electrolysis, and in use case 6, PV is combined with wholesale electricity to increase the operating hours. Finally in use case 7, the use of subsidies and additional revenues is showcased. The details of each use case are summarized in

Table 6.

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Table 6. Overview of the different use cases.

Use case	Calculation method	Production method	Electricity source	Country
Use case 5	User specified values	Solid oxide vs. alkaline electrolysis	Wholesale	Norway
Use case 6	User specified values	Alkaline electrolysis	Combination of PV + wholesale	Spain
Use case 7	User specified values	Alkaline electrolysis + subsidies and additional revenues	Combination of PV + wholesale	Spain

Use case 5 - Effect of production method

In use case 5; as an example of an alternative electrolysis device, input values of solid oxide electrolysis technology are used. This kind of assessment can be useful to evaluate the impact of an electrolysis unit with performance parameters that deviate from the default values. In this example, wholesale electricity is selected as the electricity source and Norway as the country of examination. Again Norway is chosen as it has almost a 100% green grid, allowing RFNBO hydrogen to be produced over the entire year with grid electricity.

Use case 5: Does solid oxide electrolysis allow to produce hydrogen cost-effectively? Compared to alkaline technology and based on full year operation in Norway?

As depicted in Figure 11, the data related to the characteristics of the electrolysis unit are adapted and reflect the KPIs for solid oxide electrolysis expressed in the Strategic Research and Innovation Agenda 2021 – 2027 (SRIA) by the Clean Hydrogen Joint Undertaking, in addition to the Danish Energy Agency Technology Data for Renewable Fuels. This includes a CAPEX of 4000 EUR/kW, stack durability of 20,000 hours (and stack degradation of 0.6% each 1000 hours), electricity consumption of 40 kWh/kg (assuming access to nearby waste heat for free) and other OPEX amounting to 12% of CAPEX per year.

Furthermore, the electricity source data were also adapted. Specifically, adjustments were made to the operating hours and the average electricity costs. For alkaline electrolysis, the analysis relied on the 4,000 cheapest hours, whereas for solid oxide electrolysis, it is assumed that the unit operates on a 24-hour basis throughout the entire year with a minimal delay due to maintenance (8,500 hours per year). This adjustment is made to accommodate for the lower dynamic response time and to avoid losing temperature during hours of no operation. The average electricity costs were therefore computed by averaging the electricity costs over the entire year, as opposed to considering only the 4000 cheapest hours, which results in an average electricity cost of 211.3 EUR/MWh for Norway in 2022.

As a result, in Figure 12, the LCOH calculator output indicates that solid oxide electrolysis, based on the parameters used, is still 5.05 EUR/kg more expensive compared to alkaline electrolysis.

All individual cost components contributing to the total LCOH changed. Despite lower CAPEX, due to higher operating hours, and lower grid fees and taxes, due to lower energy consumption, the electricity costs and other OPEX are significantly higher for solid oxide electrolysis in this example. Particularly noteworthy is the increase in other OPEX, where. solid oxide incurs a cost that is 3.0 EUR/kg higher compared to alkaline, mainly due to the lower durability and high maintenance costs. As for the electricity cost component, note that this can be further optimized by using less operating hours at a lower average electricity price.

Use Case 5

Calculation method
User specified values

Electrolysis technology
Solid oxide electrolysis

Electricity source
Wholesale

Country
Norway

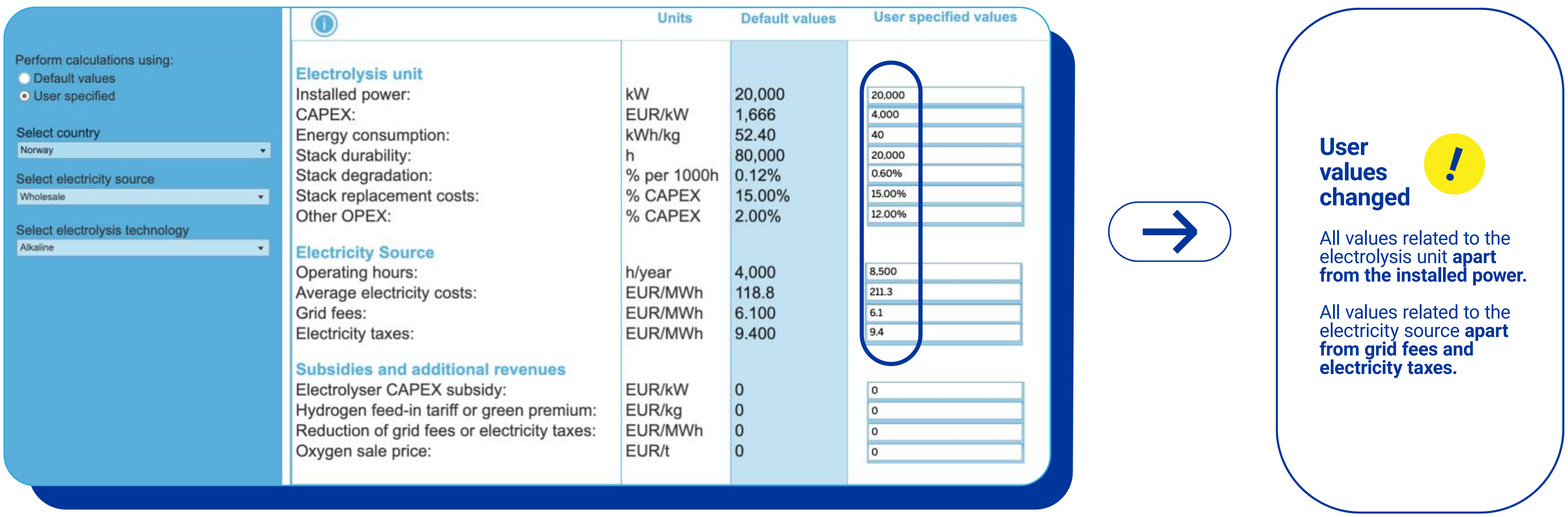


Figure 11. Use case 5 - User-specified data input for changing the electrolysis technology compared to default values.

Use Case 5

Calculation method User specified values

Electrolysis technology Solid oxide electrolysis

Electricity source Wholesale

Country Norway

Alkaline electrolysis
Total LCOH: 9.70 EUR/kg

Solid oxide electrolysis
Total LCOH: 14.75 EUR/kg

All LCOH components changed !

Figure 12. Use case 5 - effect of changing the electrolysis technology on the LCOH output.

Use case 6 – Effect of combining multiple electricity sources

In use case 2, which evaluates the cost-effectiveness of utilizing wholesale or PV as the electricity source for hydrogen production in Spain via alkaline electrolysis, it is found that while PV has a lower LCOH, the CAPEX component is still significantly higher due to limited operating hours. Therefore this use case showcases the effect of increasing the operating hours by using grid electricity on top of PV electricity.

Use case 6: Can a combination of PV and wholesale result in a lower LCOH? With alkaline electrolysis in Spain?

In this use case, the electricity source data are manually configured, as shown in Figure 13. These values are derived from calculations using the default data for wholesale and PV sources, as outlined in Table 7 using the Equation 26. The equation was used for the computation of each individual cost, including average electricity cost, grid fees, and taxes. This calculation reflects the extra added grid operating hours with the assumption that the same default prices can be used for electricity cost, grid fees and taxes.

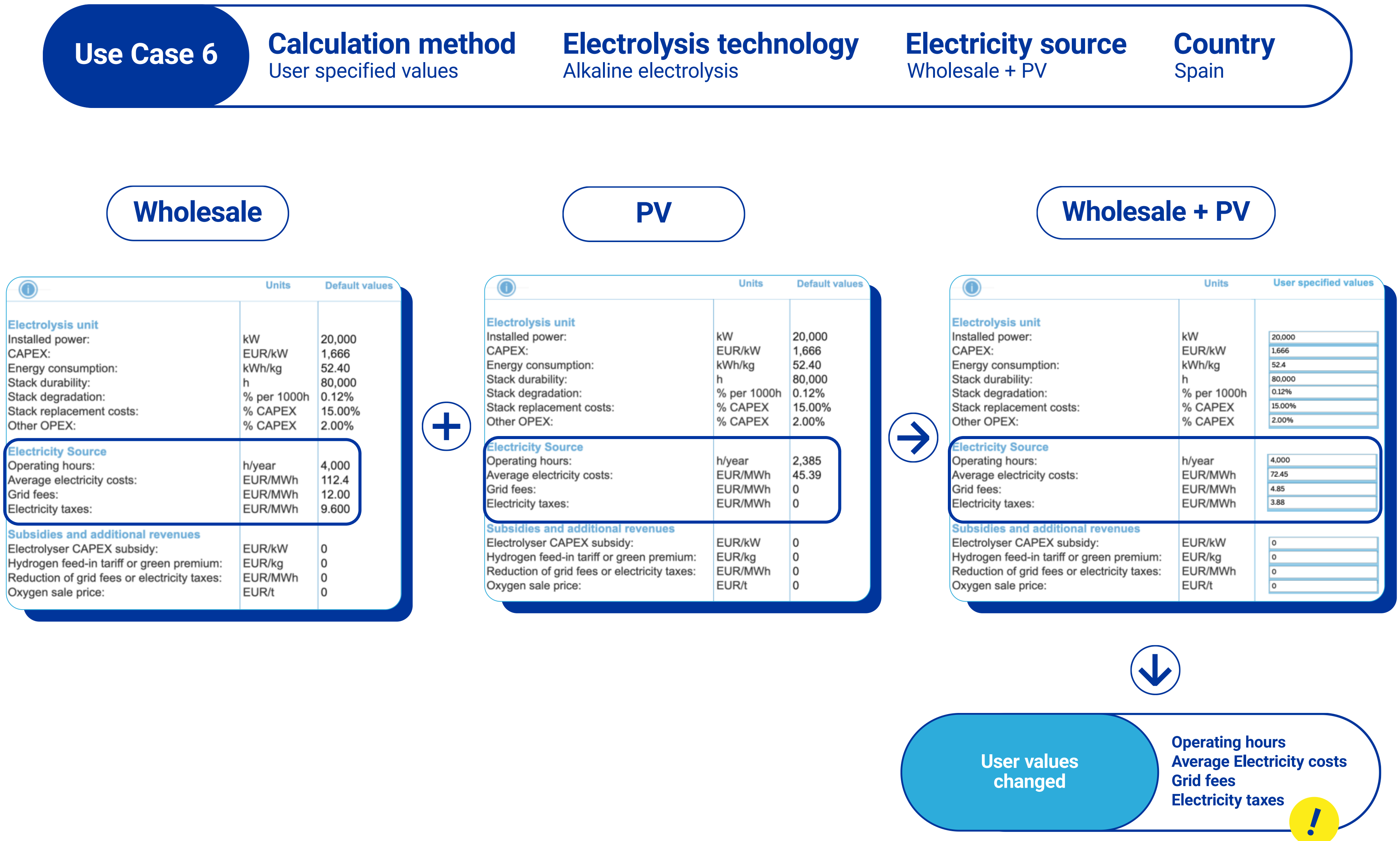
Table 7. Input data for LCOH calculation with different electricity sources.

Electricity source	Wholesale	PV	Wholesale + PV
Operating hours (h)	1615	2385	4000
Average electricity cost (EUR/MWh)	112.4	45.39	72.45
Grid fees (EUR/MWh)	12	0	4.85
Taxes (EUR/MWh)	9.6	0	3.88

$$Combined\ cost = \frac{(operating\ hous\ PV \times cost\ PV +\ operating\ hous\ wholesale \times cost\ wholesale)}{Total\ operating\ hours}$$

Equation 26. Calculation of the input data for the combined energy source (wholesale + PV) with default data from individual energy sources.

As a result, in Figure 14, the LCOH calculator output indicates that, for a company intending to establish an electrolysis plant utilizing alkaline technology in Spain incorporating grid electricity alongside PV energy, results in a lower LCOH compared to using wholesale electricity alone, albeit slightly higher than relying solely on PV. However, this combined approach presents a notable advantage in reducing the CAPEX component compared to relying solely on PV energy, and yielding a higher hydrogen output.



Wholesale

	Units	Default values
Electrolysis unit		
Installed power:	kW	20,000
CAPEX:	EUR/kW	1,666
Energy consumption:	kWh/kg	52.40
Stack durability:	h	80,000
Stack degradation:	% per 1000h	0.12%
Stack replacement costs:	% CAPEX	15.00%
Other OPEX:	% CAPEX	2.00%
Electricity Source		
Operating hours:	h/year	4,000
Average electricity costs:	EUR/MWh	112.4
Grid fees:	EUR/MWh	12.00
Electricity taxes:	EUR/MWh	9.600
Subsidies and additional revenues		
Electrolyser CAPEX subsidy:	EUR/kW	0
Hydrogen feed-in tariff or green premium:	EUR/kg	0
Reduction of grid fees or electricity taxes:	EUR/MWh	0
Oxygen sale price:	EUR/t	0

PV

	Units	Default values
Electrolysis unit		
Installed power:	kW	20,000
CAPEX:	EUR/kW	1,666
Energy consumption:	kWh/kg	52.40
Stack durability:	h	80,000
Stack degradation:	% per 1000h	0.12%
Stack replacement costs:	% CAPEX	15.00%
Other OPEX:	% CAPEX	2.00%
Electricity Source		
Operating hours:	h/year	2,385
Average electricity costs:	EUR/MWh	45.39
Grid fees:	EUR/MWh	0
Electricity taxes:	EUR/MWh	0
Subsidies and additional revenues		
Electrolyser CAPEX subsidy:	EUR/kW	0
Hydrogen feed-in tariff or green premium:	EUR/kg	0
Reduction of grid fees or electricity taxes:	EUR/MWh	0
Oxygen sale price:	EUR/t	0

Wholesale + PV

	Units	User specified values
Electrolysis unit		
Installed power:	kW	20,000
CAPEX:	EUR/kW	1,666
Energy consumption:	kWh/kg	52.4
Stack durability:	h	80,000
Stack degradation:	% per 1000h	0.12%
Stack replacement costs:	% CAPEX	15.00%
Other OPEX:	% CAPEX	2.00%
Electricity Source		
Operating hours:	h/year	4,000
Average electricity costs:	EUR/MWh	72.45
Grid fees:	EUR/MWh	4.85
Electricity taxes:	EUR/MWh	3.88
Subsidies and additional revenues		
Electrolyser CAPEX subsidy:	EUR/kW	0
Hydrogen feed-in tariff or green premium:	EUR/kg	0
Reduction of grid fees or electricity taxes:	EUR/MWh	0
Oxygen sale price:	EUR/t	0

Figure 13. Use case 6 - User-specified data input for a combined electricity source compared to default values.

Use Case 6

Calculation method
User specified values

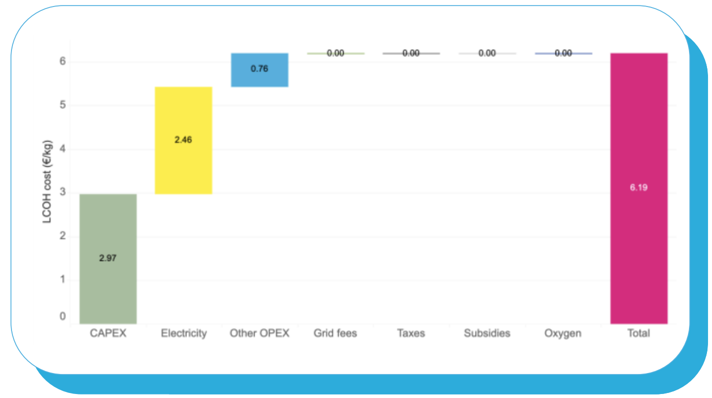
Electrolysis technology
Alkaline electrolysis

Electricity source
Wholesale + PV

Country
Spain

Wholesale
Total LCOH: 9.68 EUR/kg

PV
Total LCOH: 6.19 EUR/kg



Combined (Wholesale + PV)
Total LCOH: 6.80 EUR/kg

Figure 14. Use case 6 - effect of a combined electricity source on the LCOH output.

Use case 7 - Effect of subsidies and additional revenues

Use case 7 examines the impact on the LCOH as estimated in use case 6, considering the incorporation of financial incentives provided by governmental or other entities to promote hydrogen production, along with additional revenues from the sale of oxygen generated during the hydrogen production process.

Use case 7: How does the inclusion of subsidies and additional revenues impact the hydrogen production cost? Showcased for an electrolysis plant utilizing alkaline technology, while incorporating grid electricity alongside PV electricity in Spain.

As depicted in Figure 15, in this use case, it is assumed that the fictive project illustrated in use case 6, receives a subsidy for reducing hydrogen production costs by 2 EUR/kg, a grant of 400 EUR/kW and a reduction of grid fees and electricity taxes by 5 EUR/MWh. Moreover, they are able to sell the produced oxygen at 50 EUR/ton (extra process costs included).

As a result, in Figure 16, the LCOH calculator output reveals a significant impact when integrating these subsidies and additional revenues, almost reducing the LCOH with a factor of 2.

Use Case 7	Calculation method	Electrolysis technology	Electricity source	Country
	User specified values	Alkaline electrolysis	Wholesale + PV	Spain

Combined (Wholesale + PV)

	Units	User specified values
Electrolysis unit		
Installed power:	kW	20,000
CAPEX:	EUR/kW	1,666
Energy consumption:	kWh/kg	52.4
Stack durability:	h	80,000
Stack degradation:	% per 1000h	0.12%
Stack replacement costs:	% CAPEX	15.00%
Other OPEX:	% CAPEX	2.00%
Electricity Source		
Operating hours:	h/year	4,000
Average electricity costs:	EUR/MWh	72.45
Grid fees:	EUR/MWh	4.85
Electricity taxes:	EUR/MWh	3.88
Subsidies and additional revenues		
Electrolyser CAPEX subsidy:	EUR/kW	0
Hydrogen feed-in tariff or green premium:	EUR/kg	0
Reduction of grid fees or electricity taxes:	EUR/MWh	0
Oxygen sale price:	EUR/t	0

→

Combined (Wholesale + PV) with subsidies and additional revenues

	Units	User specified values
Electrolysis unit		
Installed power:	kW	20,000
CAPEX:	EUR/kW	1,666
Energy consumption:	kWh/kg	52.4
Stack durability:	h	80,000
Stack degradation:	% per 1000h	0.12%
Stack replacement costs:	% CAPEX	15.00%
Other OPEX:	% CAPEX	2.00%
Electricity Source		
Operating hours:	h/year	4,000
Average electricity costs:	EUR/MWh	72.45
Grid fees:	EUR/MWh	4.85
Electricity taxes:	EUR/MWh	3.88
Subsidies and additional revenues		
Electrolyser CAPEX subsidy:	EUR/kW	400
Hydrogen feed-in tariff or green premium:	EUR/kg	2
Reduction of grid fees or electricity taxes:	EUR/MWh	5
Oxygen sale price:	EUR/t	50

User values changed

Electrolyser CAPEX subsidy
Hydrogen feed-in tariff or green premium
Reduction of grid fees or electricity taxes
Oxygen sale price

Figure 15. Use case 7 - User-specified data input to include subsidies and additional revenues.

Use Case 7

Calculation method
User specified values

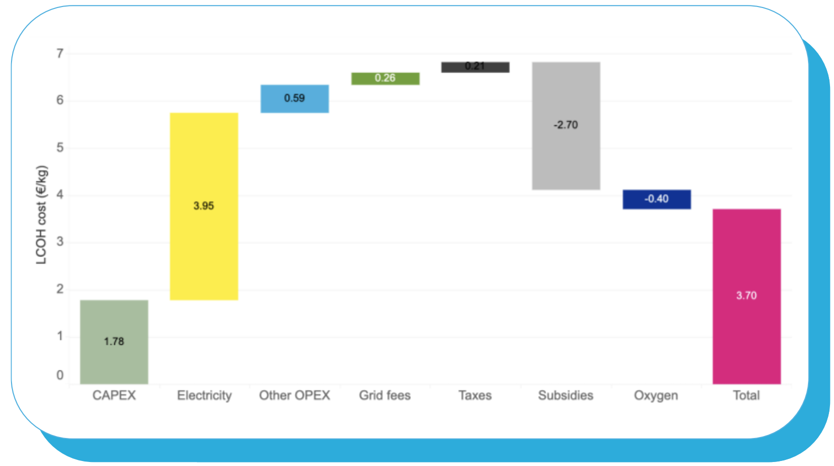
Electrolysis technology
Alkaline electrolysis

Electricity source
Wholesale + PV

Country
Spain

Combined (Wholesale + PV)
Total LCOH: 6.80 EUR/kg

Combined (Wholesale + PV) with subsidies and additional revenues
Total LCOH: 3.70 EUR/kg



LCOH components changed

Subsidies
Oxygen

Figure 16. Use case 7 - effect of subsidies and additional revenues on the LCOH output.

Appendix

A.1.

Calculation of the average energy consumption over the economic lifetime of the project

This appendix presents the evolution of the energy consumption over the economic lifetime of an electrolysis unit. Identical to the default values, a 25 year economic lifetime is adopted for the analysis, operating 4000 hours annually. The initial energy consumption is set at 52.4 kWh per kg of hydrogen produced, with a stack durability of 80,000 hours and a degradation rate of 0.12% per 1000 hours.

As shown in Figure 17 the average energy consumption is gradually increasing over the years reaching its highest point of 57.1 kWh/kg after 19 years, corresponding to 76,000 operating hours. At the 20th year, the stack reaches the end of its 80,000-hour durability and is replaced. It is assumed that this replacement resets the energy consumption back to its initial value of 52.4 kWh/kg, initiating a new cycle of gradual increase until the next stack replacement. Table 8 provides a detailed overview of the average energy consumption across the 25-year economic lifespan of the installation.

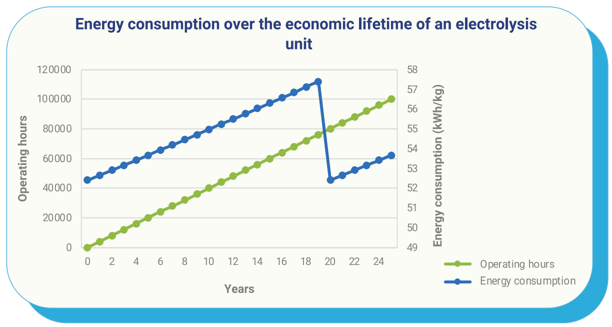


Figure 17. Energy consumption (kWh/kg) throughout the 25-year economic lifetime of an electrolysis unit operating 4000 hours annually at a degradation rate of 0.12% per 1000 hours.

Table 8. Evolution of the energy consumption (kWh/kg) throughout the 25-year economic lifetime of an electrolysis unit operating 4000 hours annually at a degradation rate of 0.12% per 1000 hours.

Operating hours	Years	Energy consumption (kWh/kg)
0	1	52.4
4,000	2	52.7
8,000	3	52.9
12,000	4	53.2
16,000	5	53.4
20,000	6	53.7
24,000	7	53.9
32,000	8	54.2
36,000	9	54.4
40,000	10	54.7
44,000	11	55.0
48,000	12	55.2
52,000	13	55.5
56,000	14	55.8
60,000	15	56.0
64,000	16	56.3
68,000	17	56.6
72,000	18	56.8
76,000	19	57.1
80,000 (stack replacement)	**20**	**52.4**
84,000	21	52.7
88,000	22	52.9
92,000	23	53.2
96,000	24	53.4
100,000	25	53.7
	Average energy consumption	**54.3**