Version 1.0.0

User's Guide

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1. Introduction to GreenH$_2$armony®

GreenH$_2$armomy® is a web-based application for the calculation of harmonised life-cycle indicators of hydrogen. In particular, the current version includes the calculation of the following life-cycle indicators: carbon footprint (global warming impact potential), energy footprint (cumulative non-renewable energy demand), and acidification footprint.

The usefulness of the application lies in the quick, robust and guided calculation of life-cycle indicators suitable for a consistent comparison of indicators for a wide range of hydrogen production options. The application facilitates such a calculation on the basis of harmonisation protocols that mitigate the methodological inconsistencies typically affecting life-cycle comparative studies in this field (for further information, please consult the references provided in Section 5). For the use of this application, the user must know certain information on the existing life-cycle study that he/she wants to harmonise (requirements detailed in Section 3).

2. System requirements

GreenH$_2$armomy®, as a web-based application, requires connection to the Internet and the use of a web browser. It is an application optimised for Google Chrome, Internet Explorer, Microsoft Edge and Mozilla Firefox, with screen resolution higher than 1024 x 768 pixels. For an optimal display of pictures and fonts, the user should check that the use of external libraries such as Google Web Fonts is not disabled within the browser.

3. Scope and information required

From the information available in a current life cycle assessment of a hydrogen energy system, GreenH$_2$armony® calculates the indicators corresponding to the harmonised system (Fig. 1). Regarding technological classification, the hydrogen system under study is classified as thermochemical, electrochemical or biological based on the hydrogen production technology involved.

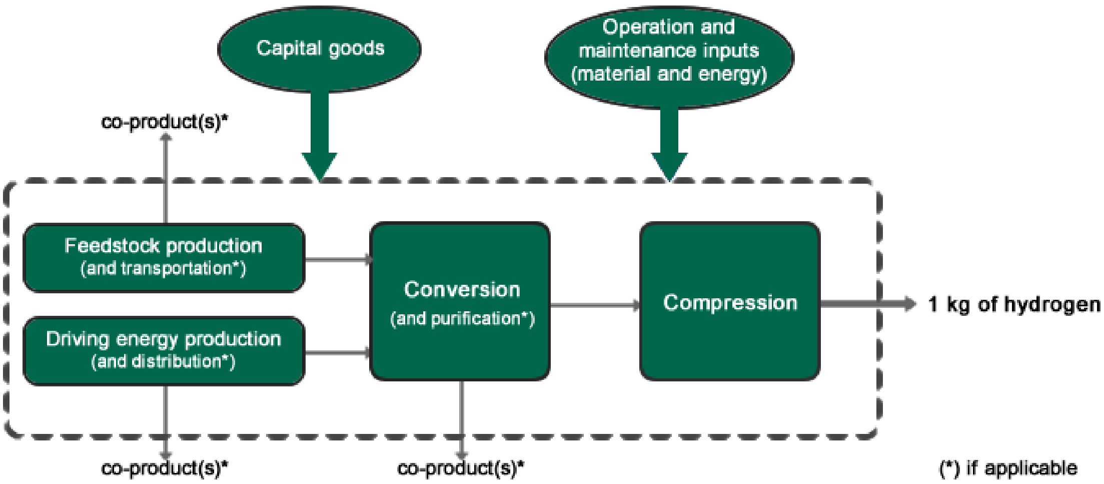

Fig. 1. Harmonised hydrogen production system.

3.1. Common information required

- The user must have a life cycle assessment of a hydrogen energy system whose carbon, energy and/or acidification footprint he/she would like to harmonise.
- The study to be harmonised must be attributional and include a hydrogen production phase.

- The user must be able to identify and classify the hydrogen production technology involved, as well as the hydrogen carrier and the driving energy.
- The user must know the functional unit used in the original study and the stages involved in the system's life cycle besides production (e.g., purification, compression, storage, distribution, and use). The functional unit of the current study must allow transformation into 1 kg of hydrogen (i.e., the amount of hydrogen produced per original functional unit should be known).
- The user must know the original results for the indicators to be harmonised. When the system includes stages beyond hydrogen purification, the user also must know the impacts specific to these stages (compression/liquefaction, storage, distribution, use).
- The user must be able to identify multifunctional subsystems and quantitatively define the approach followed to address multifunctionality (avoided burdens, amounts of co-products, allocation factors, etc.).

3.2. Specific information required for carbon footprinting

- The impact assessment method used in the original study must be IPCC-based (100-year horizon; at least CO_2, N_2O, and CH_4) and expressed in kg CO_2 eq.

3.3. Specific information required for energy footprinting

- The impact assessment method must be based on the quantification (in MJ) of the fossil + nuclear energy demand from a life-cycle perspective.

3.4. Specific information required for acidification footprinting

- The impact assessment method used in the original study must be CML-based and expressed in kg SO_2 eq.

4. Using GreenH$_2$armony®

In order to use GreenH$_2$armony®, the users with a valid account will log in online by introducing his/her user name (email address used for registration) and password. After logging in, user's preferences for account management can be changed within the application.

The use of the application is self-explanatory. English is the language of the application. For each case study to be harmonised, the user must create a new project that can be saved (stored in the server). The information required for the calculation of harmonised life-cycle indicators is gradually requested to the user in a series of steps. A virtual assistant guides the user during the implementation of the information requested. Some of the help boxes can be disabled by the user (only recommended in case of frequent use by the same person).

As shown in Fig. 2, information request is structured through seven consecutive blocks that can be saved and revisited through the harmonisation process. These blocks are:

- "System information" block. At this point, information is requested on the system's definition in terms of technological category, hydrogen production process, reference year, geographical location, etc.
- "Original scope" block. Further information on the original study is requested: functional unit used, impact assessment methods, system boundaries, impacts, etc.

- "Co-products" block.[†] At this point, information is requested on potential multifunctionality in the system. This is a critical stage when the system includes subsystems performing more than one function (typically, the generation of more than one product).
- "Intermediate scope" block.[†] In this block, quantitative information is requested in order to redefine the system's boundaries. This block affects only those stages after hydrogen purification.
- "Hydrogen conditioning" block.[†] Hydrogen compression is the conditioning technology selected according to the harmonisation protocols.
- "Final scope" block.[†] At this point, information is requested in order to include the impacts associated with capital goods (infrastructure).
- "Harmonised indicators" block. Finally, the resulting harmonised life-cycle indicators are displayed. Moreover, the application offers the possibility to automatically generate a summary report in PDF. This final report (Fig. 3) includes the specific harmonised results and compares them with the harmonised indicators of conventional hydrogen, as well as with those available in a database of harmonised life-cycle indicators of hydrogen. Furthermore, in the event that the user decides to harmonise the carbon footprint but not the energy footprint (or vice versa), the report includes its estimation by using a correlation equation between both life-cycle indicators.

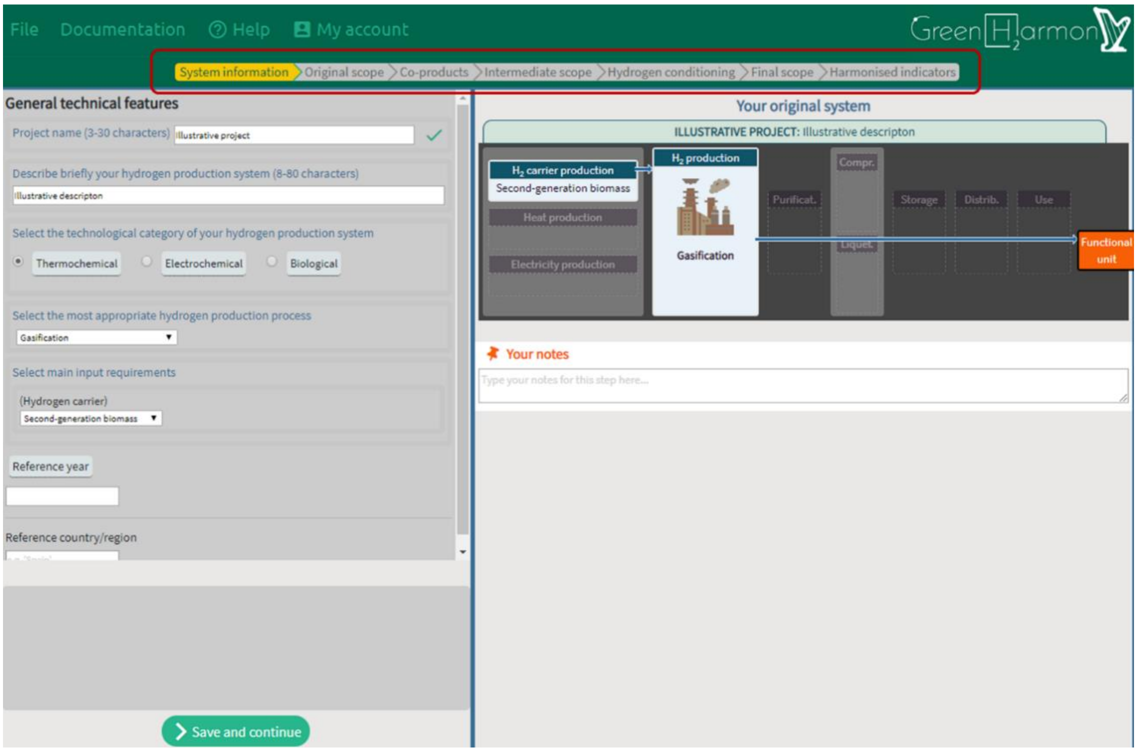

Fig. 2. Illustrative user interface of GreenH₂armony®. The red rectangle highlights the sequence of the harmonisation process.

[†] Under certain circumstances, the application offers the possibility to use default values in order to facilitate the calculation of harmonised indicators when specific information is not available. The use of default values should be avoided as far as possible.

User: GreenH2armony administrator

Project: Illustrative hydrogen

Original system

Name: Illustrative system

Technology: Gasification fed by second-generation biomass

Functional unit (FU): 1 kg of hydrogen

Impacts:

Carbon footprint:	0.385 kg CO2 eq/FU
Non-renewable energy footprint:	Not available
Acidification footprint:	0.0113 kg SO2 eq/FU

According to the information provided during the harmonisation procedure, your original system needs the harmonisation of the following aspects:
inclusion of capital goods, multifunctionality approach, final pressure.

Your harmonised results are:

Carbon footprint:	0.05 kg CO2 eq/kg H2
Non-renewable energy footprint:	57.6 MJ/kg H2 Estimated according to the GWP/CED correlation equation
Acidification footprint:	0.01 kg SO2 eq/kg H2

When compared to conventional hydrogen from SMR (harmonised):

Your carbon footprint is 99.5% lower.

Your energy footprint is 71.2% lower.

Your acidification footprint is 22.5% lower.

Taking into account our database of harmonised impacts of hydrogen:

In terms of carbon footprint, your harmonised system would rank 4 out of 73 hydrogen options.

In terms of energy footprint, your harmonised system would rank 16 out of 23 hydrogen options.

In terms of acidification footprint, your harmonised system would rank 14 out of 24 hydrogen options.

Fig. 3. Example of final report.

5. Relevant publications

Scientific studies published in the field of harmonisation of life-cycle indicators of hydrogen energy systems:

- ✓ Valente, A., Iribarren, D., Dufour, J., 2017. Harmonised life-cycle global warming impact of renewable hydrogen. J. Clean. Prod. 149, 762–772. https://doi.org/10.1016/j.jclepro.2017.02.163.
- ✓ Valente, A., Iribarren, D., Dufour, J., 2018. Harmonising the cumulative energy demand of renewable hydrogen for robust comparative life-cycle studies. J. Clean. Prod. 175, 384–393. https://doi.org/10.1016/j.jclepro.2017.12.069.
- ✓ Valente, A., Iribarren, D., Dufour, J., 2019. Harmonising methodological choices in life cycle assessment of hydrogen: a focus on acidification and renewable hydrogen. Int. J. Hydrogen Energy, in press. https://doi.org/10.1016/j.ijhydene.2018.03.101.

- ✓ Valente, A., Iribarren, D., Dufour, J., 2019. Cumulative energy demand of hydrogen energy systems. In: Muthu, S.S. (editor), Energy Footprints of the Energy Sector. Springer, Singapore. https://doi.org/10.1007/978-981-13-2457-4_2.
- ✓ Valente, A., Iribarren, D., Dufour, J., 2020. Harmonised carbon and energy footprints of fossil hydrogen. Int. J. Hydrogen Energy, in press. https://doi.org/10.1016/j.ijhydene.2020.03.074.
- ✓ Valente, A., Iribarren, D., Dufour, J., 2020. Validation of GreenH2armony® as a tool for the computation of harmonised life-cycle indicators of hydrogen. Energies, 1603; https://doi.org/10.3390/en13071603. (Open access article)

6. Developers and contact details

Web-based application conceived and developed by Antonio Valente (50%), Diego Iribarren (40%) and Javier Dufour (10%), from the Systems Analysis Unit of IMDEA Energy:

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