

# Social Life Cycle Assessment Case Study: Polymer electrolyte membrane fuel cell vehicles

Harmonized Life Cycle Sustainability Guidelines

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GreenDeLTa

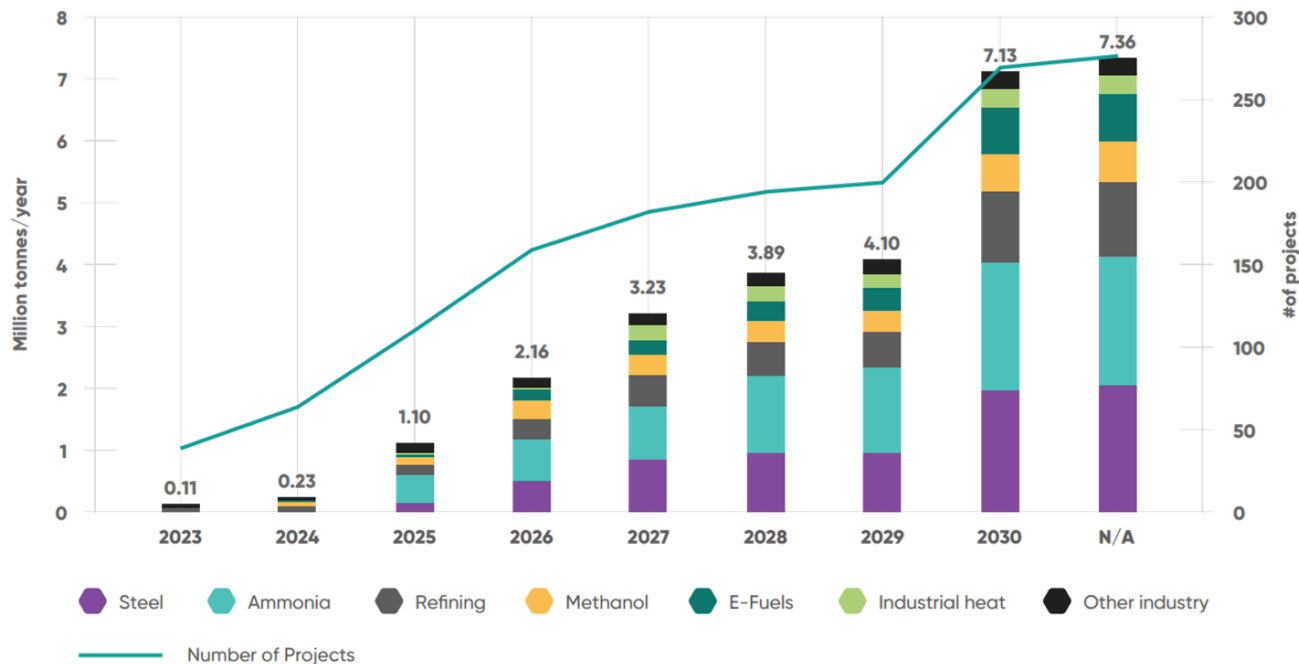


# Agenda

- Sustainability assessment of harmonized hydrogen energy systems
- About the SH2E project
- LCSA guidelines for fuel cell hydrogen
- Case study: polymer electrolyte membrane fuel cell vehicles
- Direct approach to SLCA calculation
- Conclusion

# Importance of LCSA guidelines for H<sub>2</sub> Systems

Cumulative announced consumption of clean hydrogen in industry by 2030 in Europe (Mt/year and # of projects)



Source: [https://hydrogeneurope.eu/wp-content/uploads/2023/10/Clean\\_Hydrogen\\_Monitor\\_11-2023\\_DIGITAL.pdf](https://hydrogeneurope.eu/wp-content/uploads/2023/10/Clean_Hydrogen_Monitor_11-2023_DIGITAL.pdf)

With the high growth in hydrogen demand and the need to meet climate policies and targets:

1. Assessing the life-cycle GHG emissions of hydrogen production is essential for various purposes such as certification and taxation.
2. There is a need for harmonization among LCA methodologies to allow for proper comparison.

# About SH2E Project

Call year: **2020**

Call topic: **FCH-04-5-2020 – Guidelines for Life Cycle Sustainability Assessment (LCSA)  
of fuel cell and hydrogen systems**

Project dates: **1st Jan 2021 – 30th Jun 2024**

Total project budget: **2,142,778.75 €**

Clean Hydrogen Partnership max. contribution: **1,997,616.25 €**

Other financial contribution: **145,162.50 €**

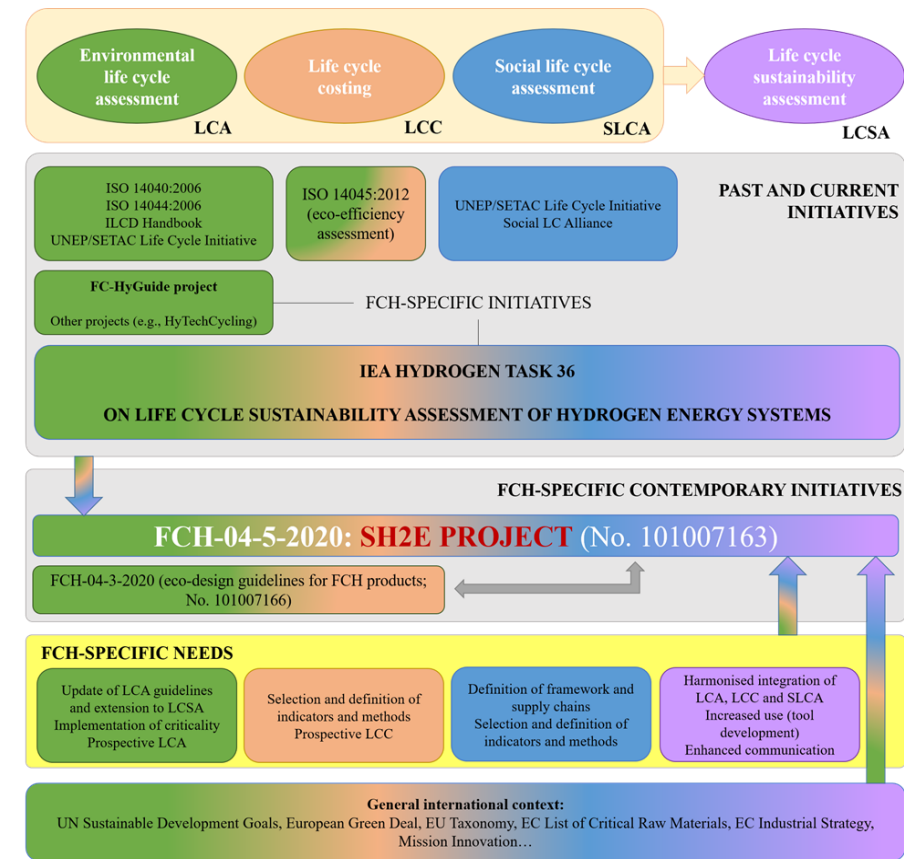
## Project Partners



# SH2E Guidelines

## Objectives

- To provide a well-defined, validated and practical framework for LCSA of FCH systems.
- To facilitate robust decision-making processes in the field of FCH by adding sustainability criteria to the characterization and benchmarking of FCH systems.
- Development and application of specific guidelines for the environmental, economic and social life cycle assessment of FCH systems, and their consistent integration into a sound LCSA framework.



# Project Outcomes

- 1 document of FCH-LCA guidelines
- 1 material criticality indicator
- 1 document of FCH-LCC guidelines
- 1 document of FCH-SLCA guidelines
- 1 document of FCH-LCSA guidelines
- 1 integrated FCH-LCA/LCC/SLCA/LCSA software tool

You can download the guidelines. Go to: <https://sh2e.eu/downloads/>

## D4.2 SH2E FCH-SLCA guidelines

This document provides methodological guidance on how to perform a Social Life Cycle Assessment (SLCA) of fuel cells and hydrogen (FCH) systems.

DOWNLOAD FILE

D4.2-SH2E-FCH-SLCA-GUIDELINES\_SUBMITTED.PDF – 2 MB

## D5.1 SH2E Guidebook for LCSA

This document provides methodological guidance on how to perform a Life Cycle Sustainability Assessment (LCSA)

DOWNLOAD FILE

D5.1-SH2E-GUIDEBOOK-FOR-LCSA\_SUBMITTED.PDF – 4 MB

## D4.1 SH2E Definition of FCH-LCC guidelines

This document provides methodological guidance on how to perform a Life Cycle Costing (LCC) of fuel cells and hydrogen (FCH) systems.

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D4.1-SH2E-DEFINITION-OF-FCH-LCC-GUIDELINES\_SUBMITTED.PDF – 2 MB

## D2.2 SH2E Definition of FCH-LCA guidelines

This document provides methodological guidance on how to perform a Life Cycle Assessment (LCA) of fuel cells and hydrogen (FCH) systems.

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D2.2-SH2E-DEFINITION-OF-FCH-LCA-GUIDELINES\_SUBMITTED.PDF – 3 MB

## 4th NEWSLETTER JULY 2023

Discover our latest newsletter.

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SH2E\_4NEWSLETTER\_JULY2023.PDF – 7 MB

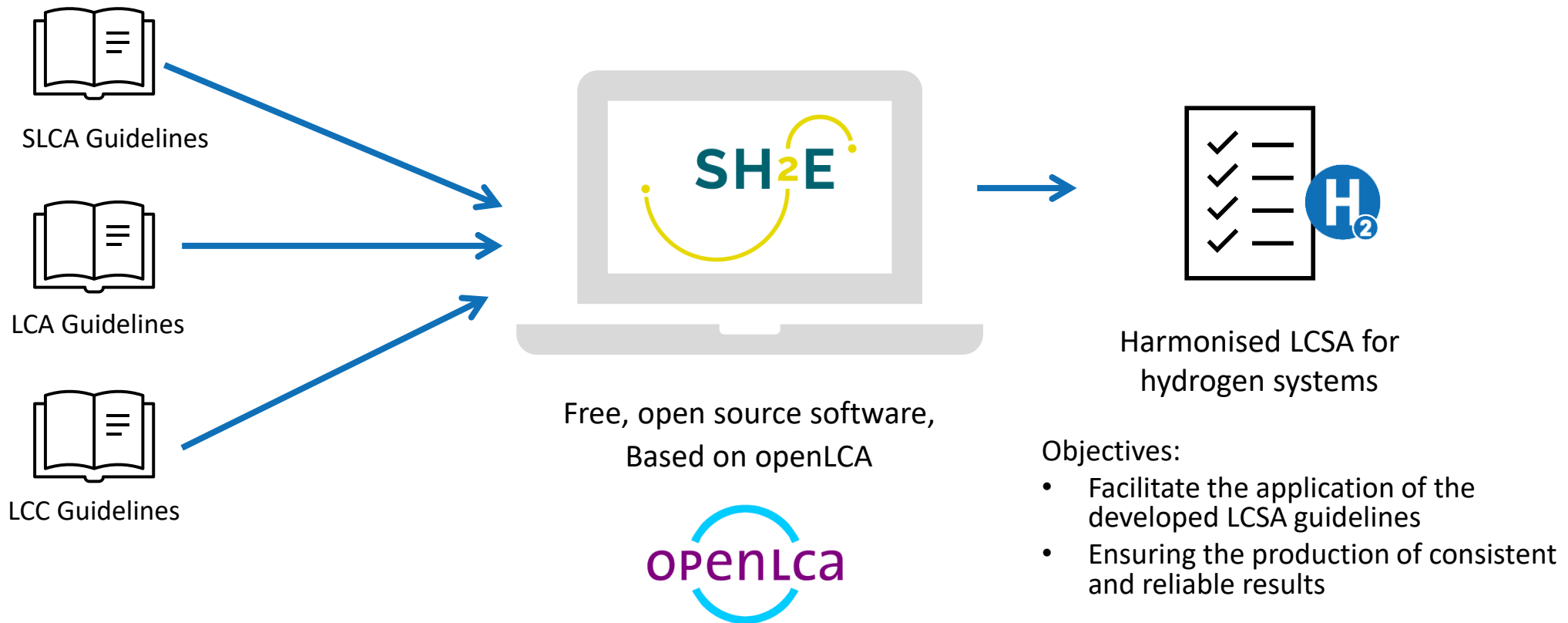
## D8.1 SH2E Communication Plan

This is to describe the means to guarantee maximum communication of the SH2E Project.

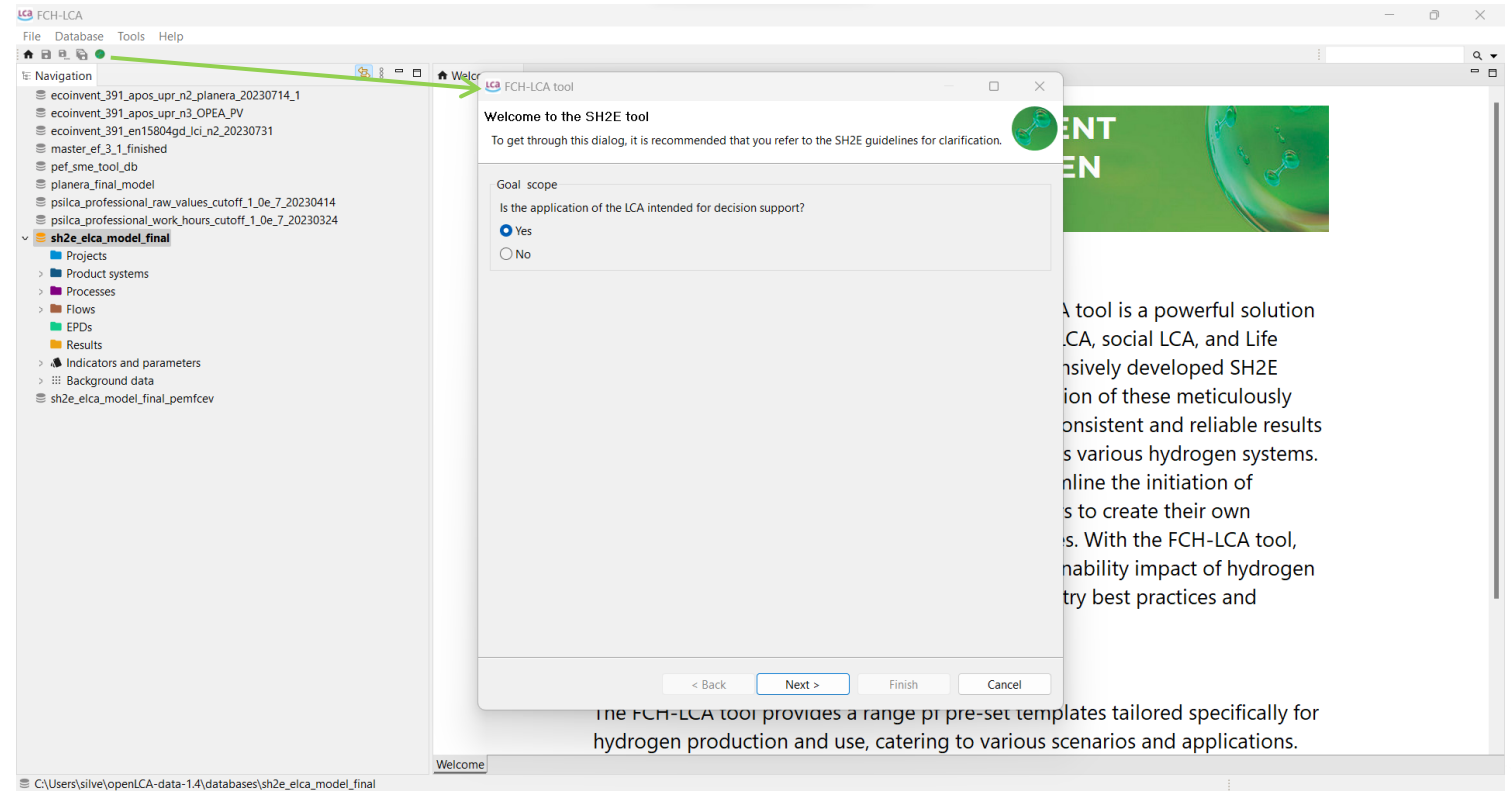
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D8.1-COMMUNICATION-PLAN-1.PDF – 1,000 KB

# SH2E FCH-LCA Tool



# SH2E FCH-LCA Tool



The FCH-LCA tool provides a range of pre-set templates tailored specifically for hydrogen production and use, catering to various scenarios and applications.



# SH2E FCH-LCA Tool

FCH-LCA tool

### Technology readiness level

Technology readiness level

Please state the Technology Readiness Level (TRL) of the involved technology:

- ☒ TRL 1 - basic principles observed
- ☐ TRL 2 - technology concept formulated
- ☐ TRL 3 - experimental proof of concept
- ☐ TRL 4 - technology validated in lab
- ☐ TRL 5 - technology validated in relevant environment
- ☐ TRL 6 - technology demonstrated in relevant environment
- ☐ TRL 7 - system prototype demonstration in operational environment
- ☐ TRL 8 - system complete and qualified
- ☐ TRL 9 - actual system proven in operational environment

< Back   Next >   Finish   Cancel

FCH-LCA tool

### Boundaries of hydrogen production

Boundaries of hydrogen production

Please state the system boundary of the hydrogen production:

- ☐ Cradle-to-gate 1 (hydrogen production)
- ☐ Cradle-to-gate 2 (hydrogen purification)
- ☐ Cradle-to-gate 3 (hydrogen compression)
- ☐ Cradle-to-gate 4 (hydrogen transportation)
- ☐ Cradle-to-gate 5 (hydrogen storage)
- ☐ Cradle-to-gate 6 (hydrogen distribution)

< Back   Next >   Finish   Cancel

FCH-LCA tool

### Hydrogen Production Parameters

Hydrogen production parameters

Hydrogen net calorific value (MJ/kg)

Hydrogen purity (%)

Hydrogen pressure (bar)

Hydrogen temperature (°C)

Operating production capacity (kg H<sub>2</sub>/year)

Carbon capture and storage

Has carbon capture and storage technology been installed in the hydrogen production plant?

- ☐ without CSS
- ☐ with CSS

Functional unit

Please select the functional unit:

- ☐ kg of H<sub>2</sub>
- ☐ MJ (LHV) of H<sub>2</sub>

< Back   Next >   Finish   Cancel

# SH2E FCH-LCA Tool

## Tool Wizard filters the templates

FCH-LCA tool

**Select a template**  
Please select a matching template and a top-category under which the template should be stored

Category:

Select a template:

Cradle-to-gate 1 (hydrogen production) (kg of H<sub>2</sub>)

< Back   Next >   Finish   Cancel



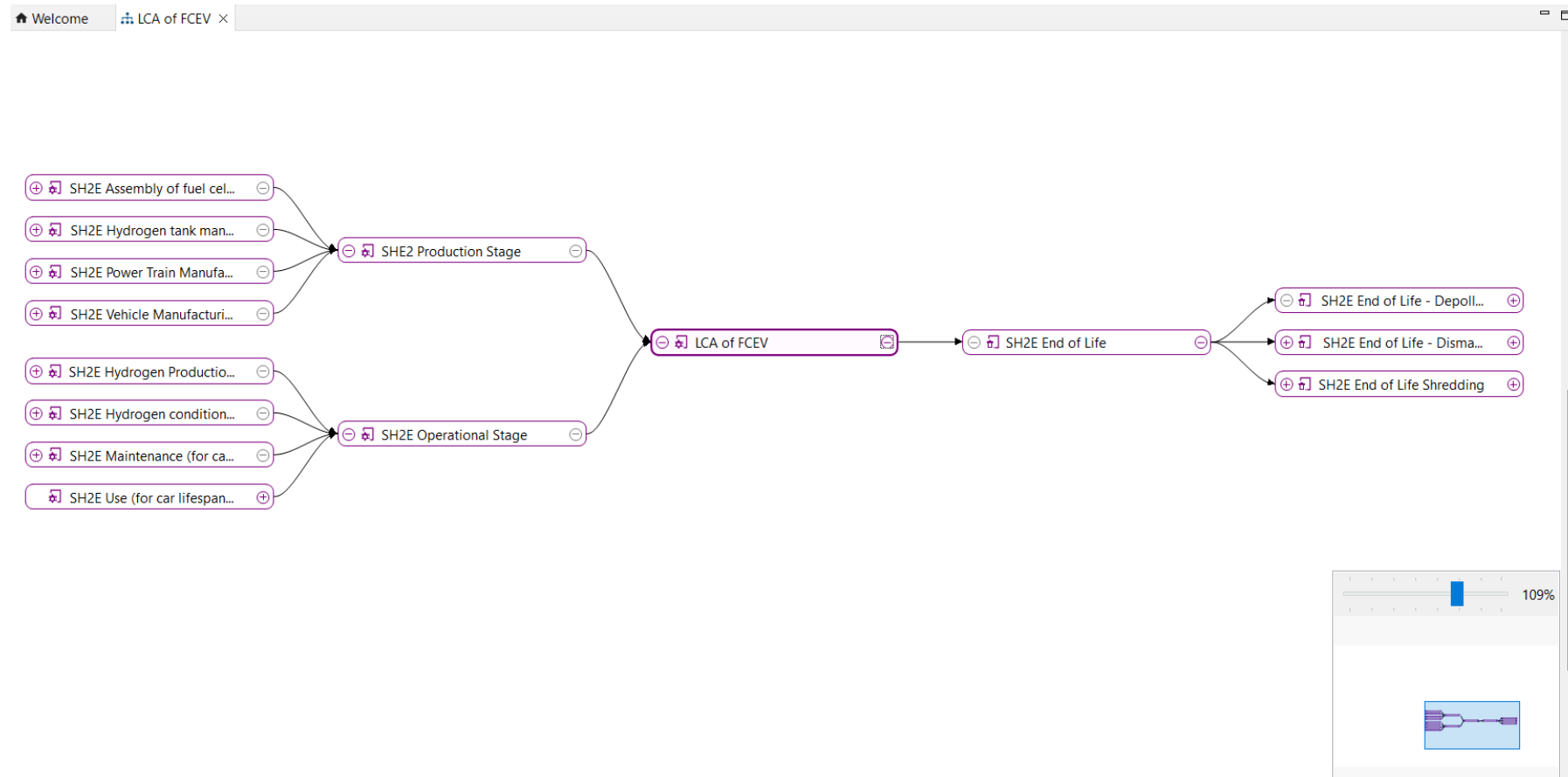
Welcome   Hydrogen Production & Use for transportation ×

**FCH-LCA Properties**

Intended application	Micro-level decision support
Modelling principles	Consequential
Prospectivity	Prospective study
End-of-life	Recycling approach
Capital goods	Included
Risk assessment	Simple LCA, without risk assessment
System boundaries	Hydrogen production and use
Technology readiness level	TRL 6 - technology demonstrated in relevant environment
LCI based on operating scale	Yes
Learning Curve Method	--
Hydrogen net calorific value (MJ/kg)	100.0
Hydrogen purity (%)	99.0
Hydrogen temperature (°C)	9.0
Hydrogen pressure (bar)	15.0
Operating production capacity (kg H <sub>2</sub> /year)	--
Functional unit	km travelled
Carbon capture and storage	with CSS
Boundaries of hydrogen production	Cradle-to-gate 1 (hydrogen production)
Comparative LCA	Absolute study
Use purpose	Transportation
Vehicle lifetime (years)	15.0
Vehicle consumption (kg H <sub>2</sub> /100km)	0.75

General information   Parameters   Model graph   Statistics

# SH2E FCH-LCA Tool – Pre-set Template



# FCH-LCA Tool: Time Parameter Analysis

## Inputs/Outputs: LCA of FCEV

### Inputs

Flow	Category	Amount	Unit	Costs/Revenu...	Uncertainty	Avoided waste	Provider	Data
SH2E Operational Stage		1.00000	Item(s)		none		SH2E Ope...	
SH2E Production Stage		1.00000	Item(s)		none		SHE2 Prod...	
price		- if(year > 2;1;0) * (Insurance * ((1 + inflation_rate)^year))	EUR 2000		none			
price		- if(year > 2;1;0) * (Maintenance_equipment * ((1 + inflation_rate)^year))	EUR 2000		none			
price		- if(year > 2;1;0) * (purchased_Materials * ((1 + inflation_rate)^year))	EUR 2000		none			
price		if(year > 2;1;0) * (hydrogen_revenue * ((1 + inflation_rate)^year))	EUR 2000		none			
price		- if(year < 3;1;0) * I_1	EUR 2000		none			
price		- if(year > 2;1;0) * (wages * ((1 + inflation_rate)^year))	EUR 2000		none			

Users can define conditional functions

### Outputs

Flow	Category	Amount	Unit	Costs/Revenu...	Uncertainty	Avoided pro...	Provider	Data quality ...	Location	Description
LCA of FCEV		1.00000	Item(s)		none					
SH2E End of Life Overall		1.00000	Item(s)		none		SH2E End ...			

Parameter analysis

Product system: SH2E Hydrogen Production Spain

Impact assessment method: Economic assessment

Allocation method: As defined in processes

Number of iterations: 15

Parameter	Context	Start value	End value
*year	global	1.0	15.0

OK Cancel

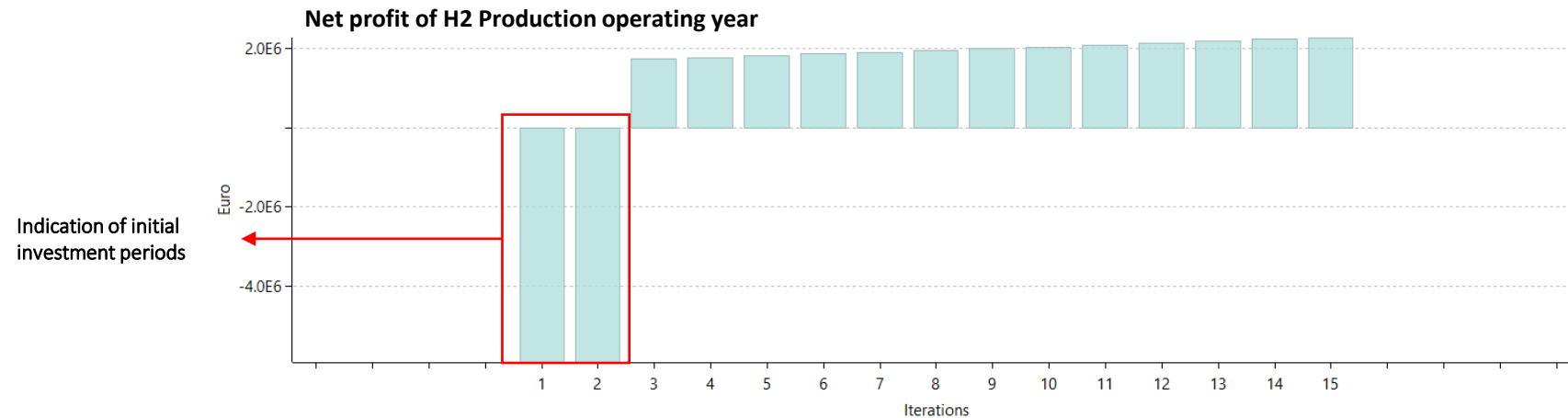
# FCH-LCA Tool: Parameter Analysis

## ▼ Impact assessment results

Impact category	1	2	3	4	5	6	7	8	9
economic assessment (Euro)	-5.92626E6	-5.92626E6	1.73581E6	1.77575E6	1.81662E6	1.85842E6	1.90119E6	1.94494E6	1.9897

## ▼ Impact assessment results per category

Impact category: economic assessment



results

# FCH-LCA Tool: Direct Approach SLCA

Manufacture of food products and beverages; Manufacture of tobacco products - RU

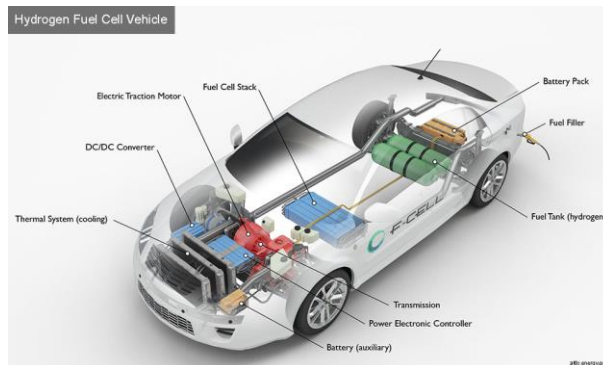
## Indicator results

	Activity value	Raw value	HO	MO	LO	NOP	NOR	VLR	LR	MR	HR	VHR	ND	NA
Local Community			0%	0%	0%	0%	5%	13%	20%	29%	12%	11%	9%	0%
Access to material resources			0%	0%	0%	0%	0%	56%	15%	14%	2%	12%	2%	0%
Certified environmental management	0.08630 work hours [h]	17.79860 [# of CEMS per 10000 em...]	0%	0%	0%	0%	0%	54%	17%	4%	9%	1%	15%	0%
Extraction of biomass (related to area)	0.08630 work hours [h]	67.03139 [annual t/km2]	0%	0%	0%	0%	0%	95%	2%	1%	1%	1%	0%	0%
Extraction of biomass (related to population)	0.08630 work hours [h]	4.48392 [annual t/cap]	0%	0%	0%	0%	0%	2%	95%	3%	1%	0%	0%	0%
Extraction of fossil fuels	0.08630 work hours [h]	8.77402 [annual t/cap]	0%	0%	0%	0%	0%	99%	1%	0%	0%	0%	0%	0%
Extraction of industrial and construction materials	0.08630 work hours [h]	5.67899 [annual t/cap]	0%	0%	0%	0%	0%	2%	2%	95%	0%	1%	0%	0%
Extraction of ores	0.08630 work hours [h]	1.75079 [annual t/cap]	0%	0%	0%	0%	0%	98%	0%	1%	0%	0%	0%	0%
Level of industrial water use (related to total water withdrawal)	0.08630 work hours [h]	1.17842 [% of total actual renewable water withdrawal]	0%	0%	0%	0%	0%	95%	0%	3%	1%	0%	0%	0%
Level of industrial water use (related to total water withdrawal)	0.08630 work hours [h]	47.68259 [% of total water withdrawal]	0%	0%	0%	0%	0%	3%	1%	2%	0%	94%	0%	0%
Environmental Footprints			0%	0%	0%	0%	31%	2%	32%	26%	8%	1%	0%	0%
GHG Footprints			0%	0%	0%	0%	2%	0%	0%	56%	42%	0%	0%	0%
Local employment			0%	0%	0%	0%	0%	0%	93%	0%	0%	0%	6%	0%
Migration			0%	0%	0%	0%	0%	33%	1%	16%	0%	0%	50%	0%
Respect of indigenous rights			0%	0%	0%	0%	2%	0%	1%	95%	1%	0%	2%	0%
Safe and healthy living conditions			0%	0%	0%	0%	0%	1%	1%	0%	32%	65%	0%	0%
Society			0%	4%	1%	0%	0%	42%	10%	20%	14%	8%	0%	0%
Value Chain Actors			0%	0%	0%	0%	0%	6%	23%	11%	5%	23%	32%	0%
Workers			0%	0%	0%	0%	9%	27%	8%	21%	16%	8%	11%	0%
Child labour			0%	0%	0%	0%	3%	78%	17%	1%	0%	0%	0%	0%
Discrimination			0%	0%	0%	0%	0%	65%	1%	1%	1%	0%	32%	0%
Fair Salary			0%	0%	0%	0%	0%	2%	2%	63%	1%	33%	0%	0%
Living wage, per month (AV)	0.08630 work hours [h]	359.59740 [USD]	0%	0%	0%	0%	0%	1%	2%	95%	1%	1%	0%	0%
Minimum wage, per month	0.08630 work hours [h]	178.13004 [USD]	0%	0%	0%	0%	0%	0%	1%	2%	0%	97%	0%	0%
Sector average wage, per month	0.08630 work hours [h]	701.60971 [USD]	0%	0%	0%	0%	0%	4%	3%	91%	2%	0%	0%	0%
Forced Labour			0%	0%	0%	0%	0%	1%	36%	2%	5%	31%	25%	0%
Frequency of forced labour	0.08630 work hours [h]	5.41101 [Cases per 1.000 inhabitants]	0%	0%	0%	0%	0%	3%	97%	0%	0%	0%	0%	0%
Goods produced by forced labour	0.08630 work hours [h]	0.26023 [#]	0%	0%	0%	0%	0%	1%	8%	3%	15%	0%	74%	0%
Trafficking in persons	0.08630 work hours [h]	2.91291 [Tier]	0%	0%	0%	0%	0%	0%	2%	4%	1%	93%	0%	0%

General information | Inventory results | Impact analysis | **Social assessment** | Process results | Contribution tree | Grouping | Locations | Sankey diagram | LCIA Checks

# Case study: PEM-FCeV

## Hydrogen produced from Polymer Electrolyte Membrane used in fuel cell electric vehicle

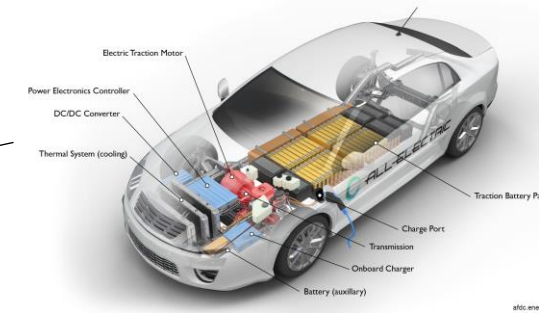


Source: <https://afdc.energy.gov/vehicles/how-do-fuel-cell-electric-cars-work>

- Type of vehicle : D-segment,
- Battery : 60kWh – NMC811 – 394 kg
- FCEV fueled by a 100kW PEMFC and a storage capacity of 5,2kgH<sub>2</sub> at 700bars

Vs

## All-Electric Vehicle



<https://afdc.energy.gov/vehicles/how-do-all-electric-cars-work>

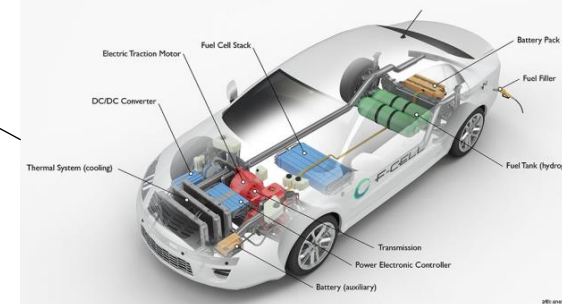
## Battery Electric Vehicle

Type of vehicle: D-segment vehicle

- Motor : 96kW
- Battery : 60kWh – NMC811 – 394 kg
- Driving range : 470 km
- Consumption: 15,5 kWh/100km

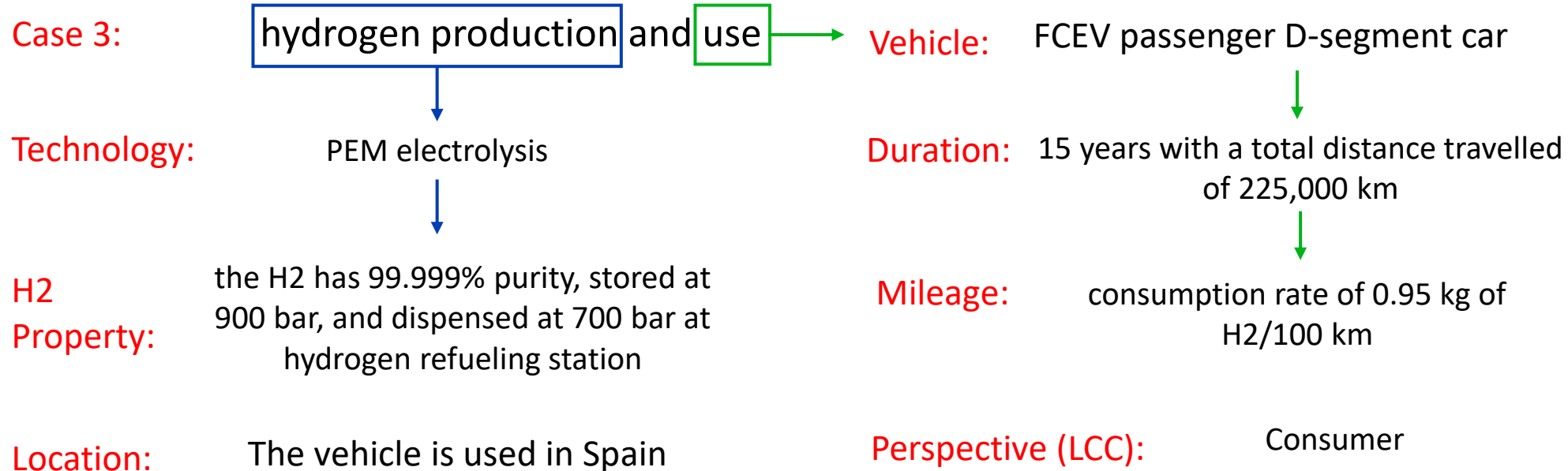
Vs

## Hydrogen Fuel Cell Vehicle



Hydrogen produced from Steam methane reformer used in fuel cell electric vehicle

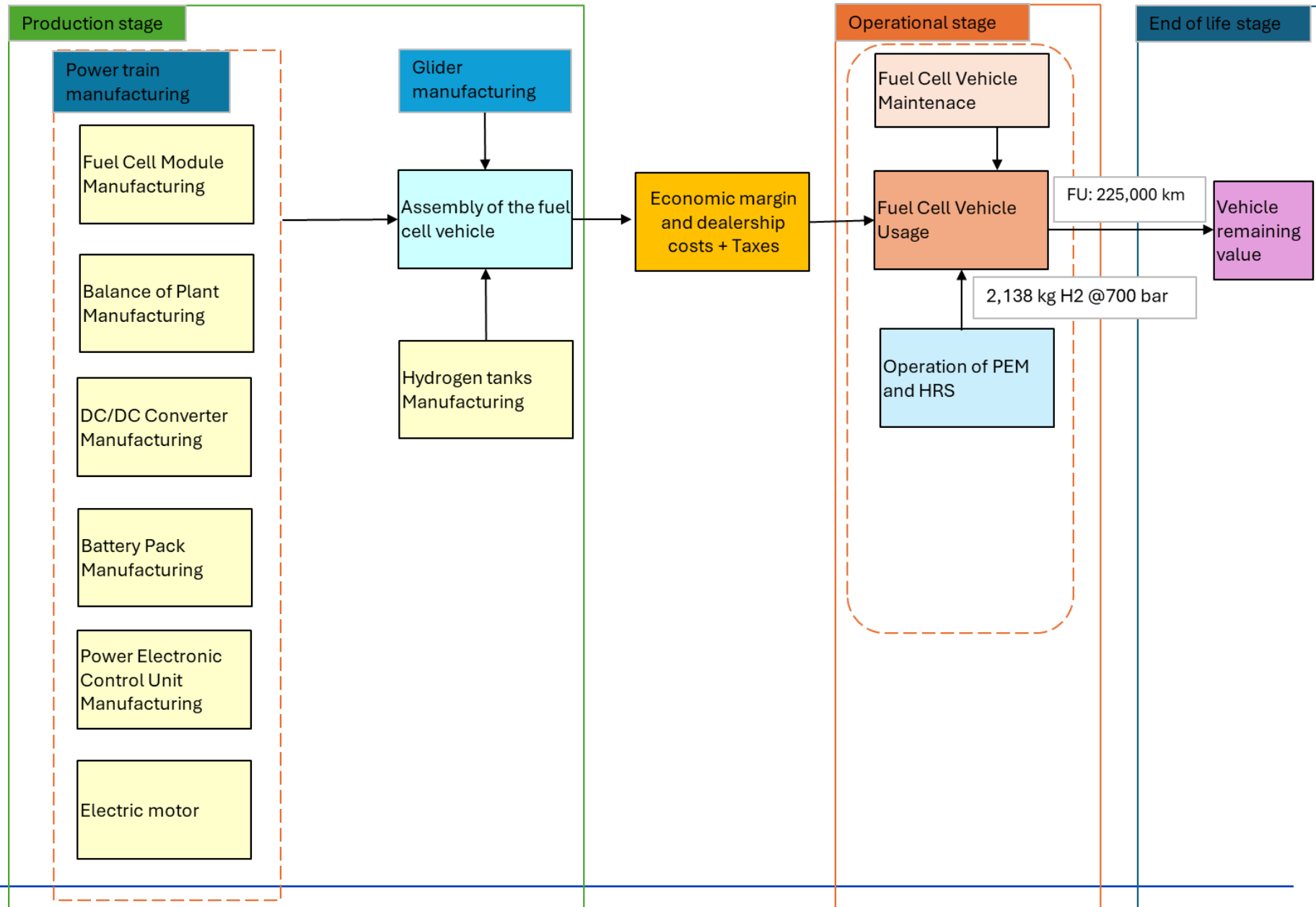
# Functional Unit



## Final Statement:

Hydrogen production from PEM electrolysis and its use in a FCEV passenger D-segment car for 15 years with a total distance travelled of 225,000 km (i.e. 15,000 km per year), at a hydrogen fuel consumption rate of 0.95 kg of H<sub>2</sub>/100 km (the H<sub>2</sub> has 99.999% purity, stored at 900 bar, and dispensed at 700 bar at hydrogen refueling station) which is based on the consumption of Nexso Hyundai. The vehicle is used in Spain.

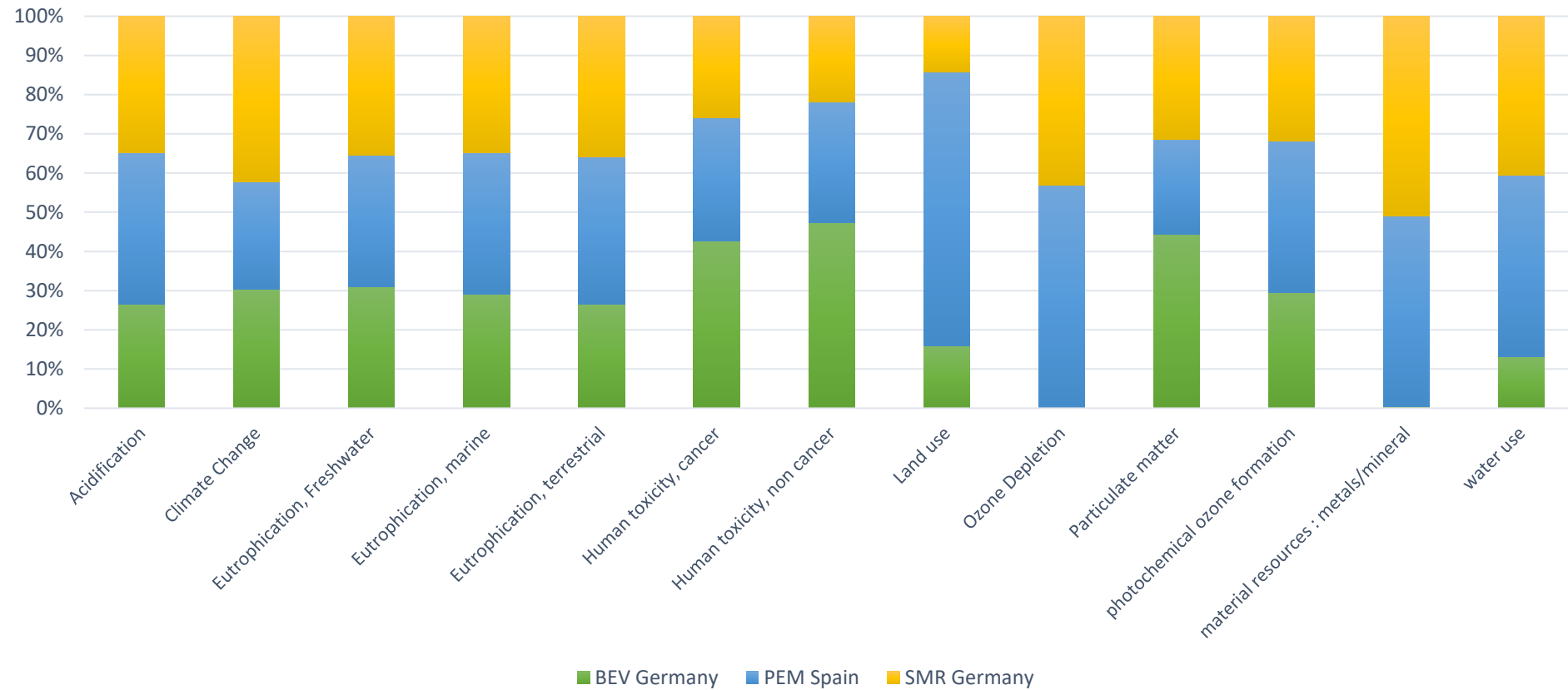




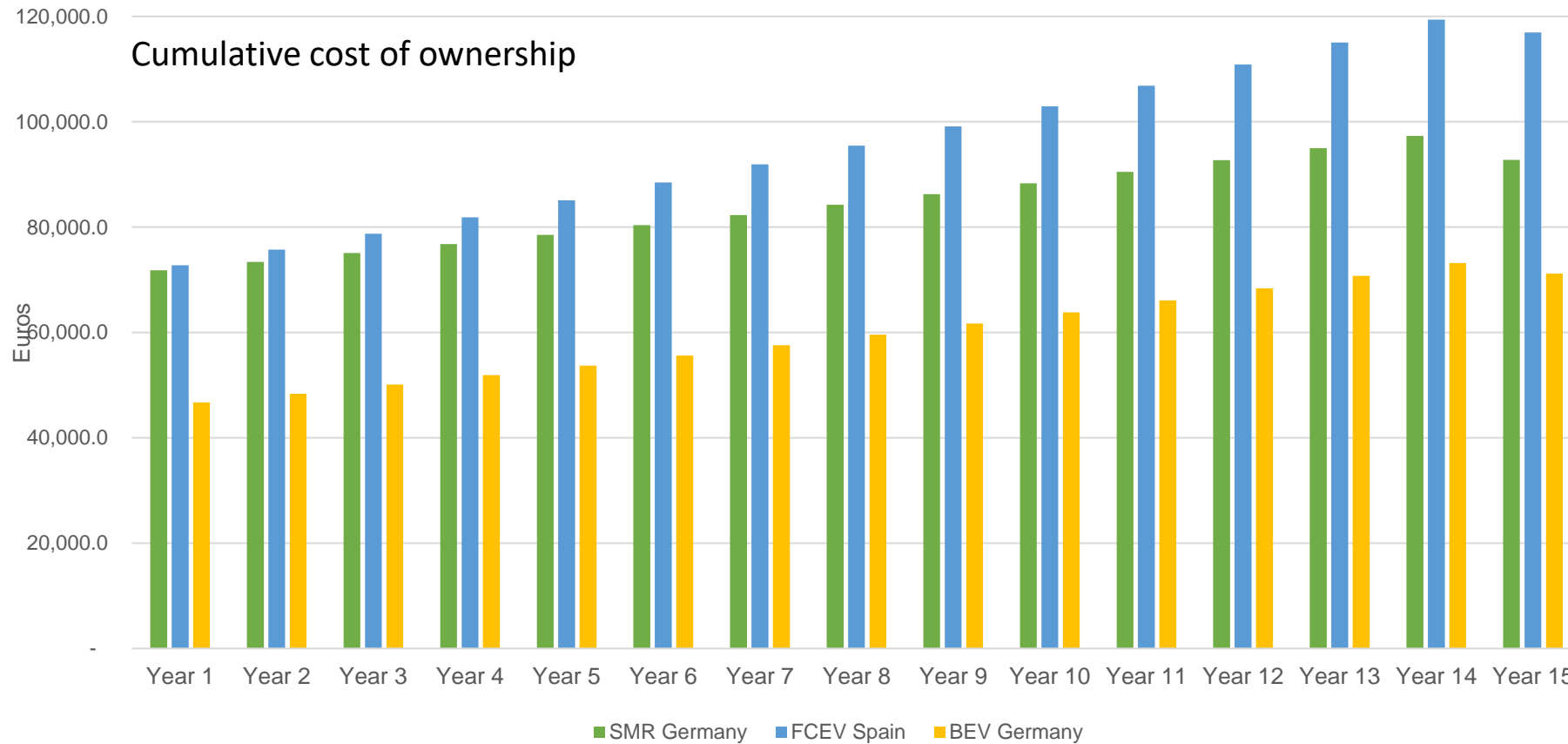
# Methodology

LCA		SLCA	LCC
<b>Data</b>	<ul style="list-style-type: none"><li>Literature sources</li><li>Industry partner SYMBIO provided on fuel cell manufacturing</li></ul>	<p>Literature sources</p> <ul style="list-style-type: none"><li>Industry partner SYMBIO provided on fuel cell manufacturing</li><li>Industry partner Fha provided data fuel cell operation</li></ul>	<p>Literature sources</p>
<b>Database</b>	Ecoinvent v3.9.1 APOS	Professional PSILCA V3.1.1	-
<b>LCIA</b>	EF 3.1	Social impact assessment + direct approach	<p>Total Cost of Ownership</p> $TCO = A + O + M - Salv.$ <p>A = acquisition cost, O = operational cost, M = maintenance cost, and Salv. = salvage or remaining value</p>

# Results LCA PEM-FCeV vs SMR vs BeV



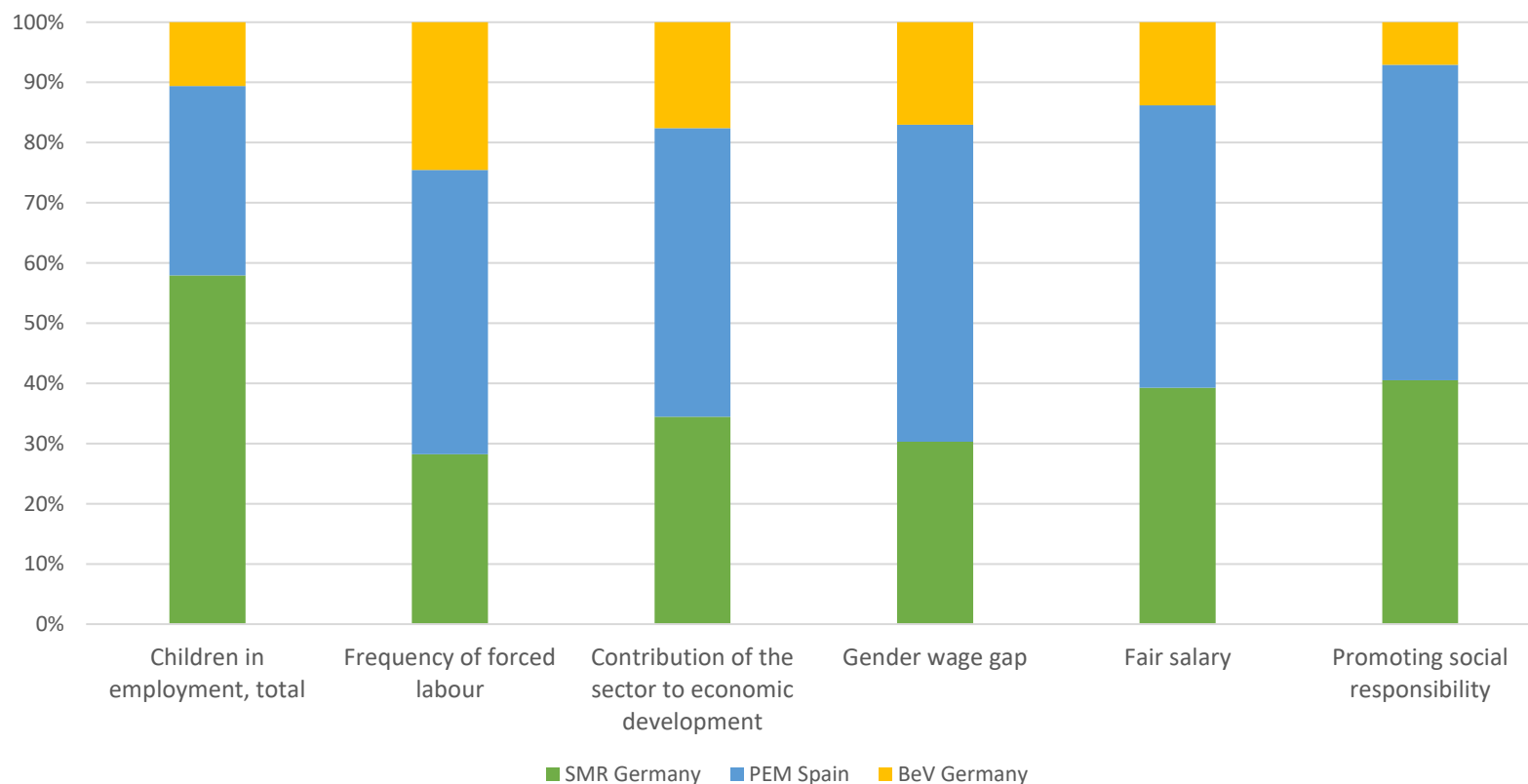
# Results LCC PEM-FCeV vs SMR vs BeV



The Total Cost of Ownership for:  
 PEM is 0.52 (€/km)  
 SMR is 0.39 (€/km)  
 BeV 0.30 (€/km)

# Results SLCA PEM-FCeV

Based on medium risk hours, PEM has the most contribution amongst selected social indicators



Does this necessarily mean PEM pose high risks across all social indicators?

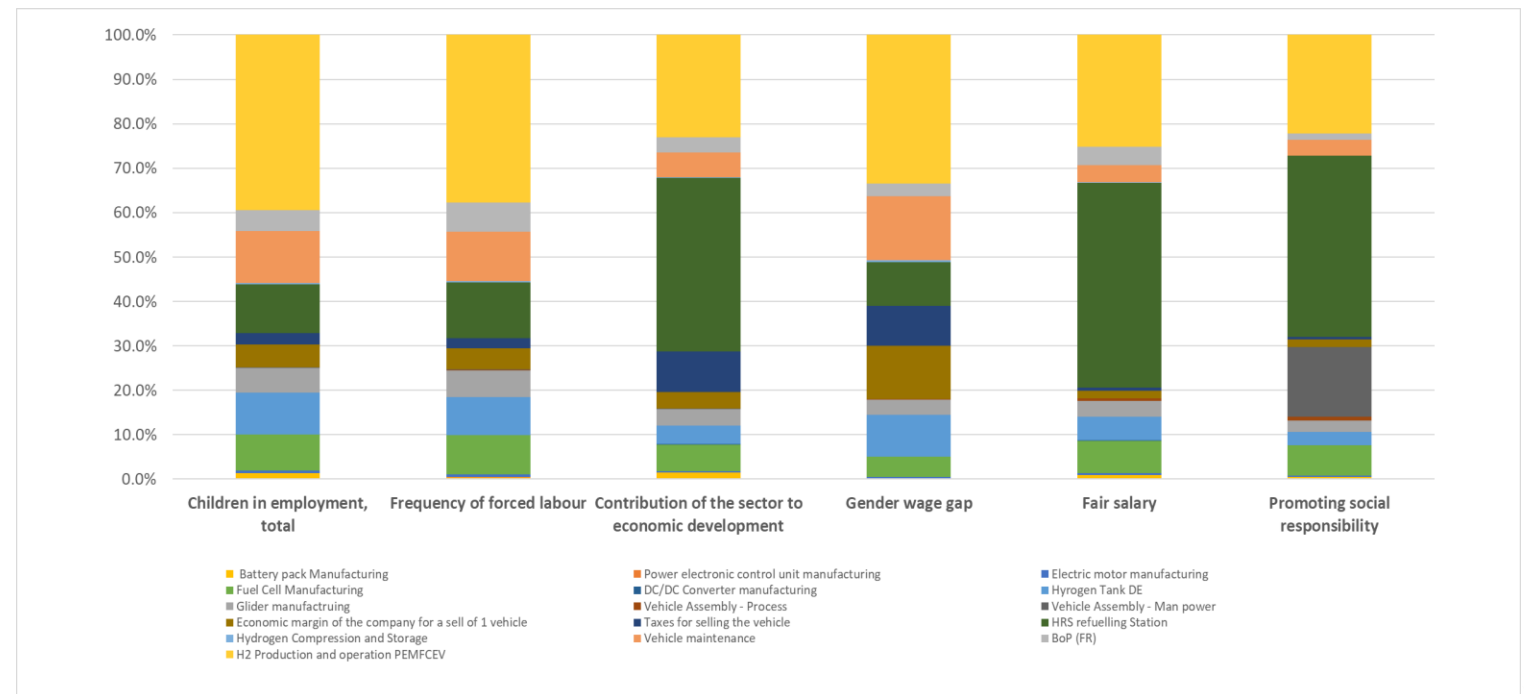
# Results SLCA PEM-FCeV

## A closer look:

Overall social impact assessment of FCEV per impact category

Impact Category	Unit	TOTAL
Children in employment, total	MRH	374
Frequency of forced labour	MRH	313
Contribution of the sector to economic development	MRH	39,879
Gender wage gap	MRH	44,389
Fair salary	MRH	849,231
Promoting social responsibility	MRH	454,019

Social impact (%) per each unit process in the FCEV product system



# A different look: direct approach SLCA

## Children in employment

Indicator results

	Activity value	Raw value	HO	MO	LO	NOP	NOR	VLR	LR	MR	HR	VHR	ND	NA
Society			1%	3%	1%	0%	5%	37%	21%	16%	10%	6%	0%	0%
Value Chain Actors			0%	0%	0%	0%	0%	11%	16%	23%	10%	18%	22%	0%
Workers			0%	0%	0%	0%	7%	28%	19%	21%	8%	7%	10%	0%
Child labour			0%	0%	0%	0%	7%	74%	18%	1%	0%	0%	0%	0%
Children in employment, female	4412.97118 work hours [h]	1.13563 [% of female children ages 5-17]	0%	0%	0%	0%	7%	63%	27%	2%	0%	0%	0%	0%
Children in employment, male	4412.97118 work hours [h]	1.55826 [% of male children ages 5-17]	0%	0%	0%	0%	7%	78%	15%	0%	0%	0%	0%	0%
Children in employment, total	4412.97118 work hours [h]	1.35190 [% of all children ages 5-17]	0%	0%	0%	0%	7%	82%	11%	0%	0%	0%	0%	0%
Manufacture of electrical machinery and apparatus n.e.c. - FR	256.44488	0.56000	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Manufacture of electrical machinery and apparatus n.e.c. - FR	256.00398	0.56000	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Manufacture of rubber products - ES	161.74905	0.56000	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Manufacture of rubber and plastic products - ES	145.46523	0.56000	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Other business services - FR	142.65681	2.36000	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Manufacture of rubber products - DE	130.88300	0.56000	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%

## Frequency of forced labour

Indicator results

	Activity value	Raw value	HO	MO	LO	NOP	NOR	VLR	LR	MR	HR	VHR	ND	NA
Workers			0%	0%	0%	0%	7%	28%	19%	21%	8%	7%	10%	0%
Child labour			0%	0%	0%	0%	7%	74%	18%	1%	0%	0%	0%	0%
Discrimination			0%	0%	0%	0%	1%	40%	16%	20%	11%	2%	10%	0%
Fair Salary			0%	0%	0%	0%	0%	20%	14%	32%	12%	22%	0%	0%
Forced Labour			0%	0%	0%	0%	1%	28%	27%	4%	3%	5%	33%	0%
Frequency of forced labour	4412.97118 work hours [h]	2.64932 [Case...]	0%	0%	0%	0%	0%	83%	13%	0%	0%	0%	3%	0%
Manufacture of electrical machinery and apparatus n.e.c. - FR	256.44488	2.00000	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Manufacture of electrical machinery and apparatus n.e.c. - FR	256.00398	2.00000	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Manufacture of rubber products - ES	161.74905	2.30000	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Manufacture of rubber and plastic products - ES	145.46523	2.30000	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%

# Direct Approach SLCA Results

## Fair Salary

### Indicator results

	Activity value	Raw value	HO	MO	LO	NOP	NOR	VLR	LR	MR	HR	VHR	ND	NA
> Local Community			0%	0%	0%	0%	13%	10%	16%	47%	7%	2%	5%	0%
> Society			2%	3%	0%	0%	8%	57%	18%	9%	1%	2%	0%	0%
> Value Chain Actors			0%	0%	0%	0%	0%	16%	20%	36%	3%	16%	10%	0%
▼ Workers			0%	0%	0%	0%	8%	34%	12%	30%	1%	7%	7%	0%
> Child labour			0%	0%	0%	0%	0%	86%	14%	0%	0%	0%	0%	0%
> Discrimination			0%	0%	0%	0%	0%	39%	26%	33%	1%	0%	1%	0%
▼ Fair Salary			0%	0%	0%	0%	0%	1%	1%	64%	1%	33%	0%	0%
> 🧑 Living wage, per month (AV)	3852.63443 work hours [h]	2061.74362 [USD]	0%	0%	0%	0%	0%	0%	0%	2%	1%	97%	0%	0%
> 🧑 Minimum wage, per month	3852.63443 work hours [h]	1754.24251 [USD]	0%	0%	0%	0%	0%	0%	1%	96%	1%	2%	0%	0%
> 🧑 Sector average wage, per month	3852.63443 work hours [h]	3517.89493 [USD]	0%	0%	0%	0%	0%	4%	2%	93%	1%	0%	0%	0%

## Promoting social responsibility

### Indicator results

	Activity value	Raw value	HO	MO	LO	NOP	NOR	VLR	LR	MR	HR	VHR	ND	NA
> Local Community			0%	0%	0%	0%	13%	10%	16%	47%	7%	2%	5%	0%
> Society			2%	3%	0%	0%	8%	57%	18%	9%	1%	2%	0%	0%
▼ Value Chain Actors			0%	0%	0%	0%	0%	16%	20%	36%	3%	16%	10%	0%
> Corruption			0%	0%	0%	0%	0%	11%	4%	81%	1%	1%	1%	0%
> Fair competition			0%	0%	0%	0%	0%	16%	55%	1%	0%	0%	28%	0%
▼ Promoting social responsibility			0%	0%	0%	0%	0%	19%	0%	25%	8%	47%	1%	0%
> 🧑 Membership in an initiative that promotes social responsibility along the supply chain	3852.63443 work hours [h]	41.98051 [numb...	0%	0%	0%	0%	0%	19%	0%	25%	8%	47%	1%	0%



# Conclusion

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- Hydrogen is expected to play a key role as an energy carrier on the path toward global sustainability.
- However, the right decisions are needed to make fuel cells and hydrogen (FCH) systems effective in this endeavor.
- Beyond technological advancements, methodological solutions are necessary to evaluate the suitability of FCH systems from a life-cycle perspective, thereby sensibly supporting decision-making.
- The FCH-LCA tool is one method of applying these guidelines properly, especially with its pre-set templates that promote further harmonization.
- Successful demonstration through case study application indicates that the guidelines are ready to be put into practice.