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

Harmonized Life Cycle Sustainability Guidelines

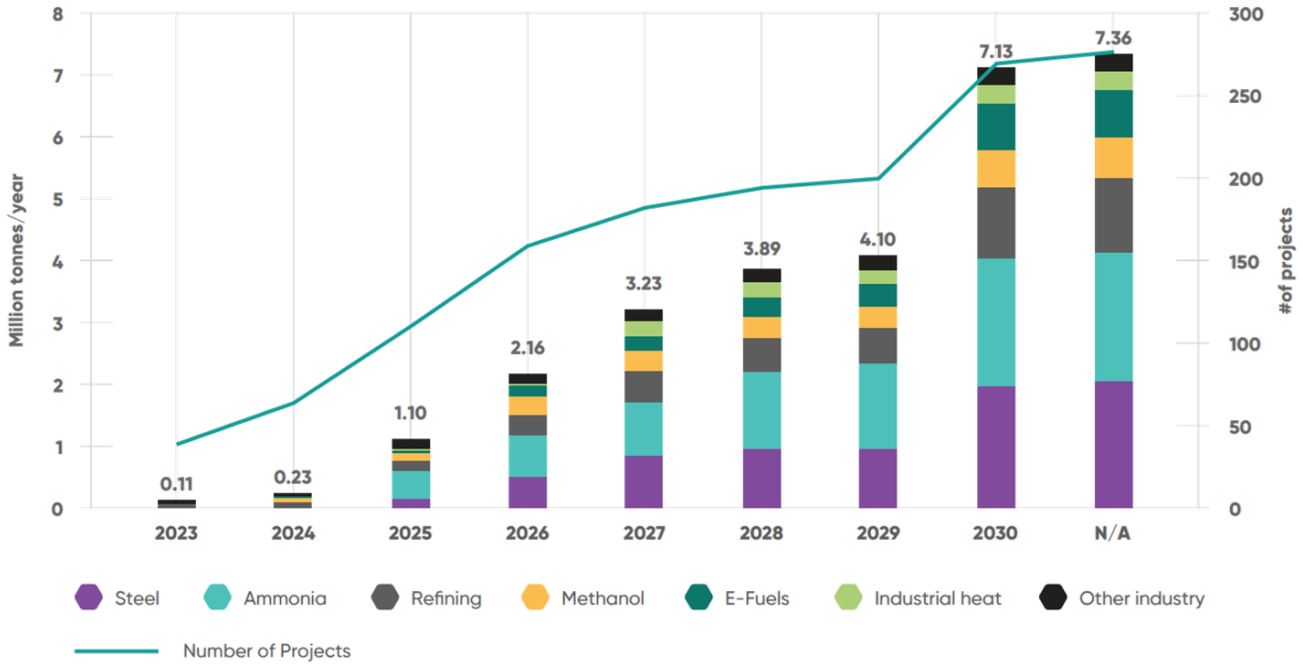
Ashrakat Hamed, Dr. Andreas Ciroth

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_2 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

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 €**

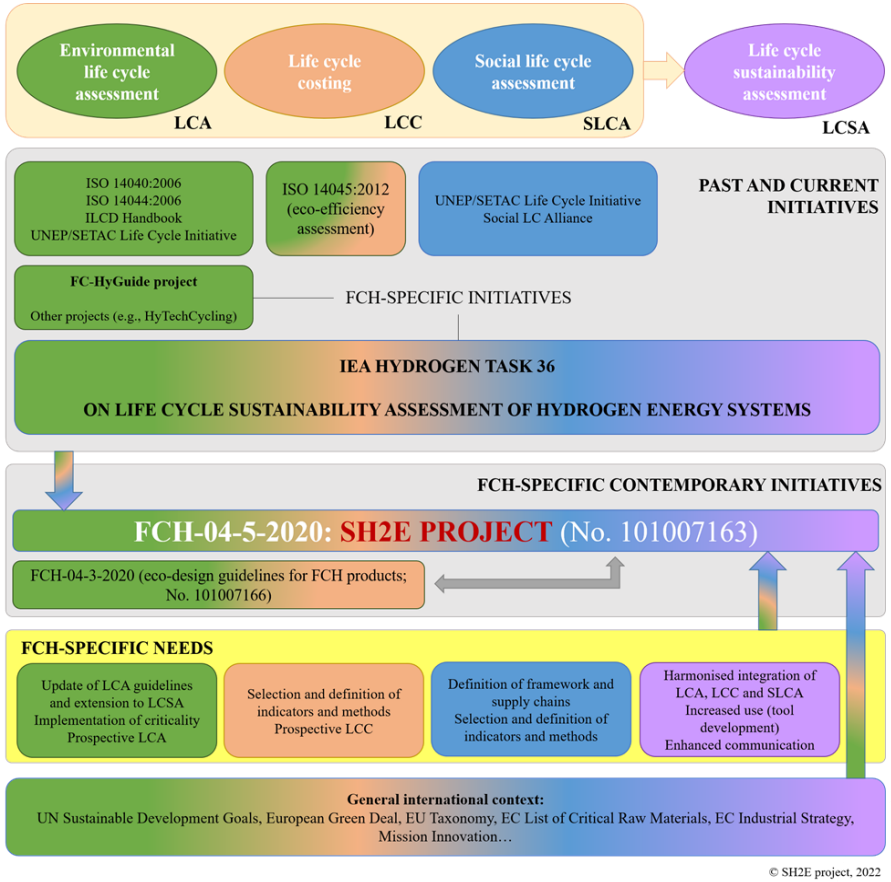
Other financial contribution: **145,162.50 €**

Project Partners

SH2E Guidelines

Objectives

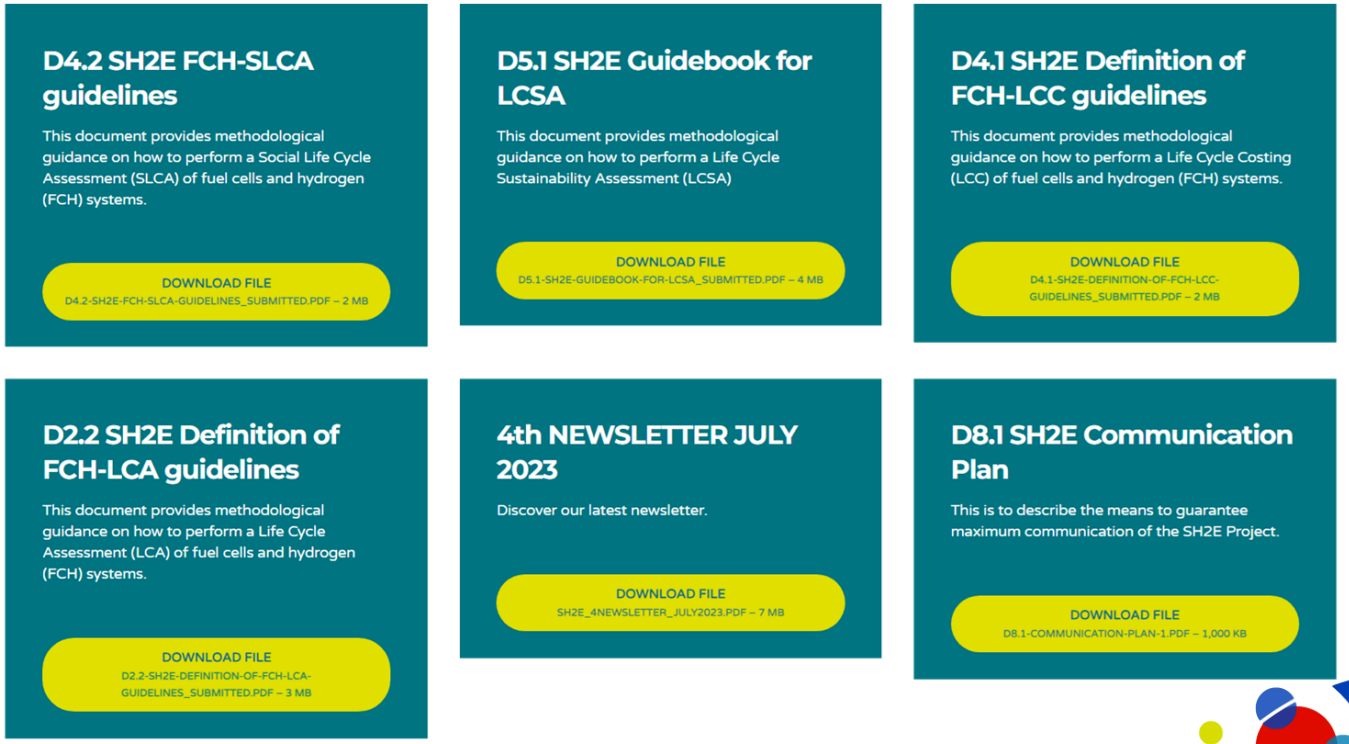
- To provide a well-defined, validated and practical framework for LCSA of FCH systems.
- To facilitate robust decision-making processes in the field of FCH by adding sustainability criteria to the characterization and benchmarking of FCH systems.
- Development and application of specific guidelines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



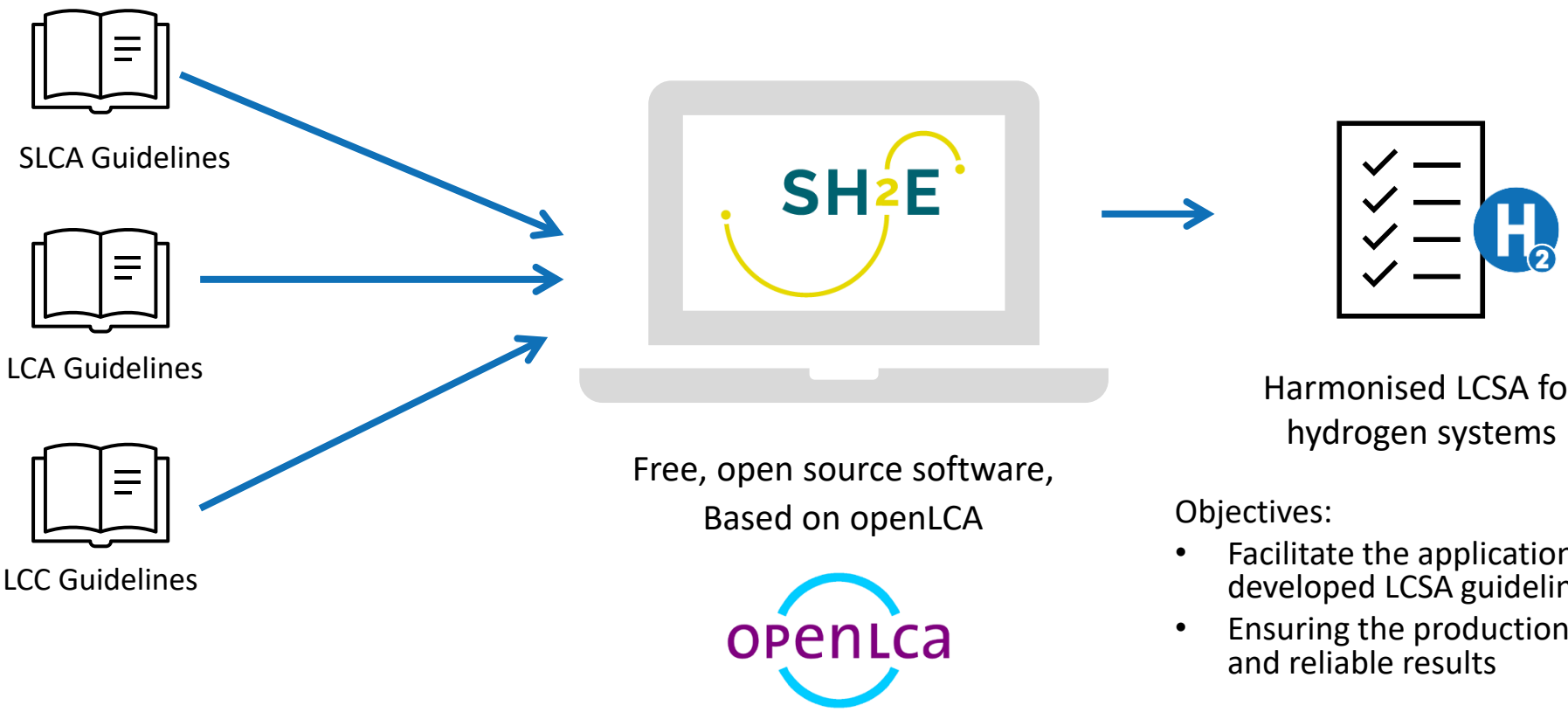
Project Outcomes

- 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/



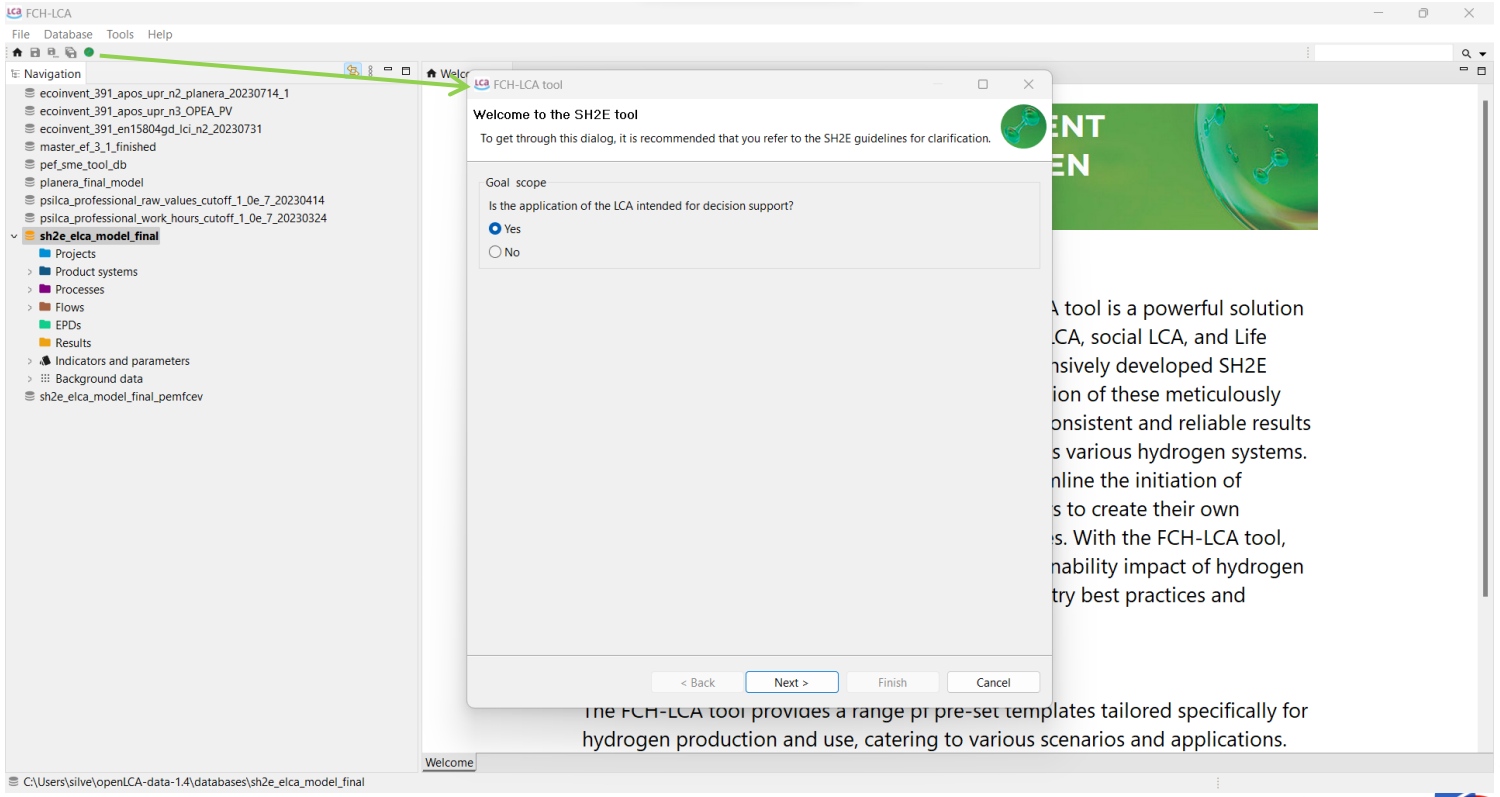
SH2E FCH-LCA Tool



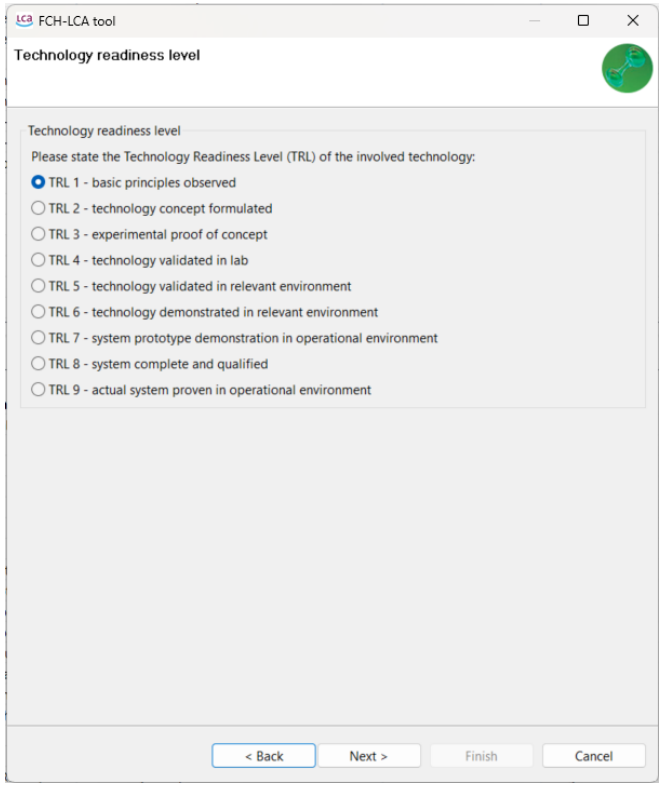
Objectives:

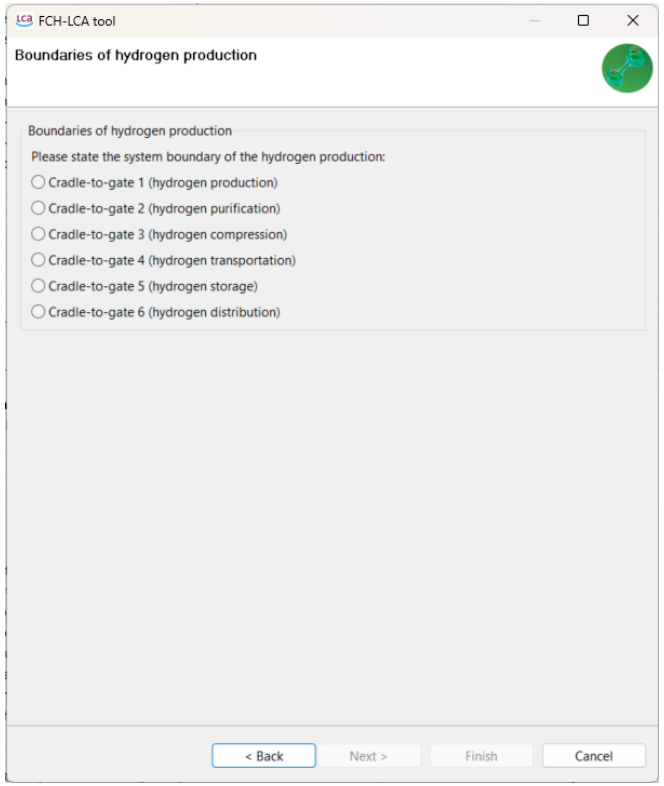
- Facilitate the application of the developed LCSA guidelines
- Ensuring the production of consistent and reliable results

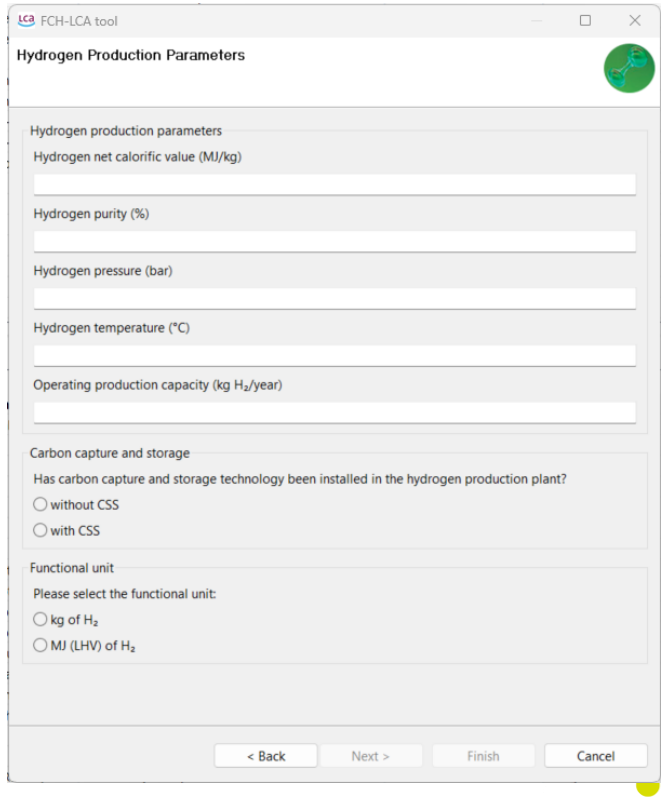
SH2E FCH-LCA Tool



SH2E FCH-LCA Tool

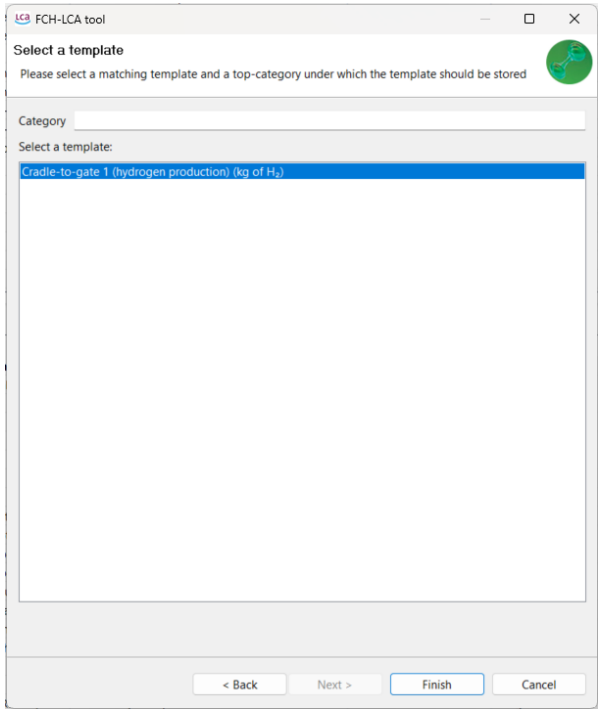


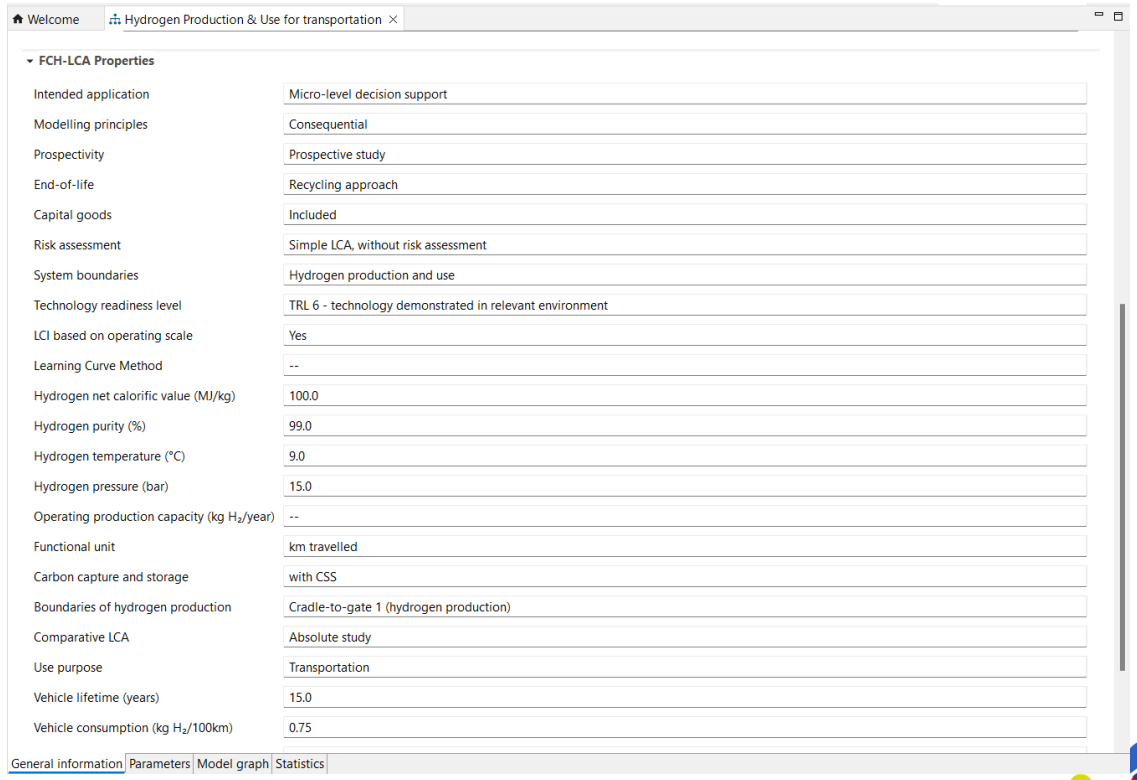




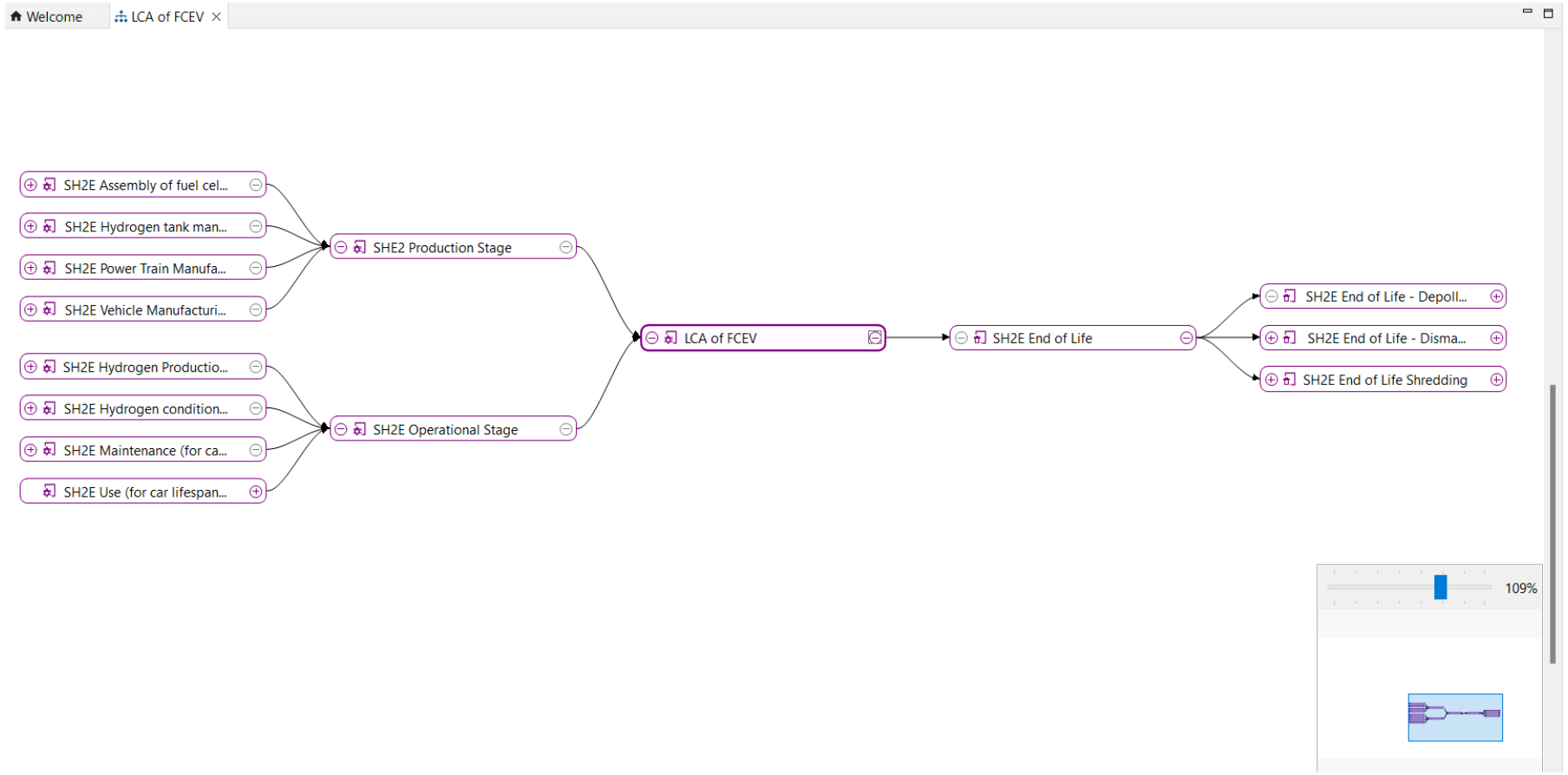
SH2E FCH-LCA Tool

Tool Wizard filters the templates

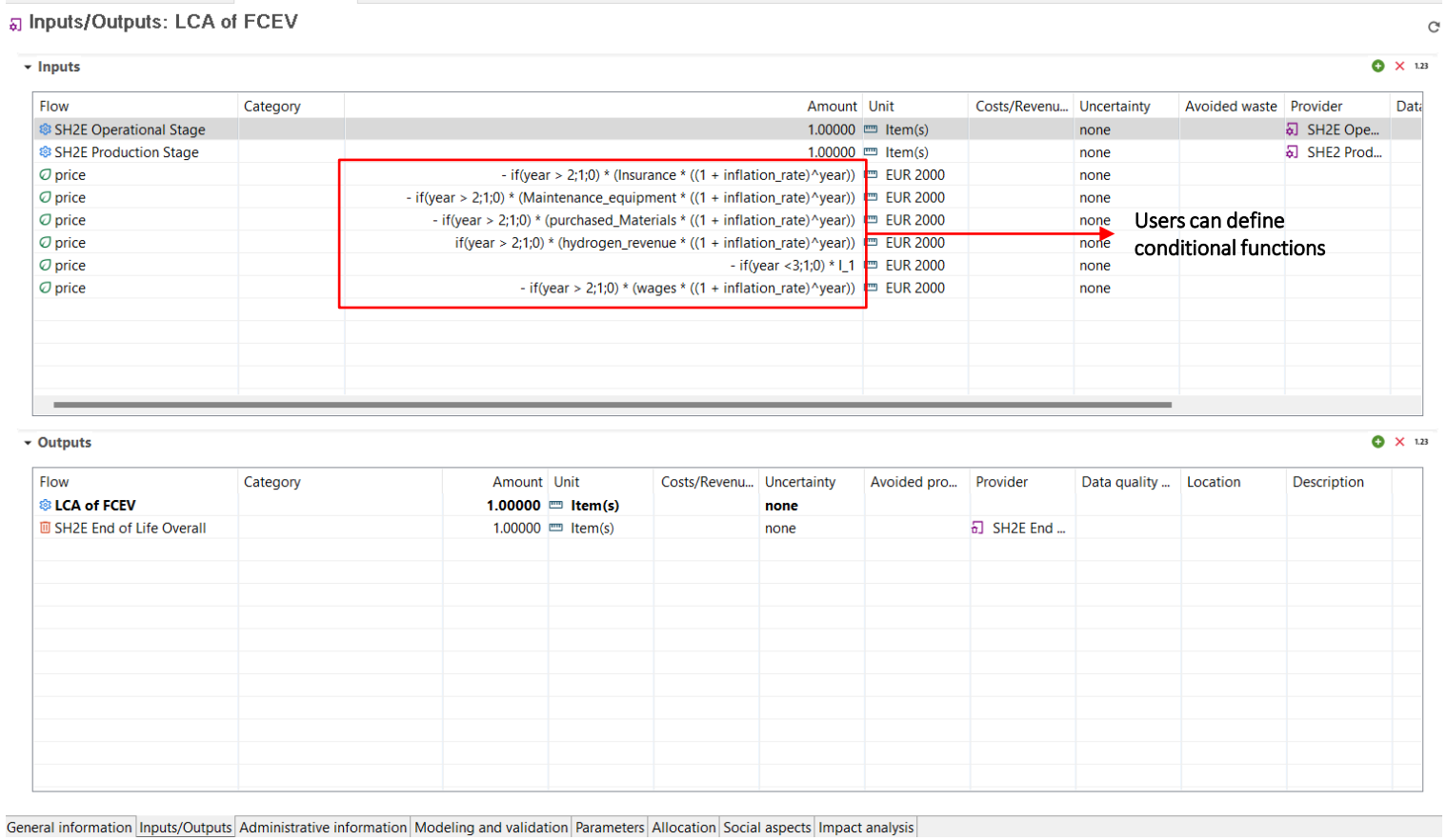


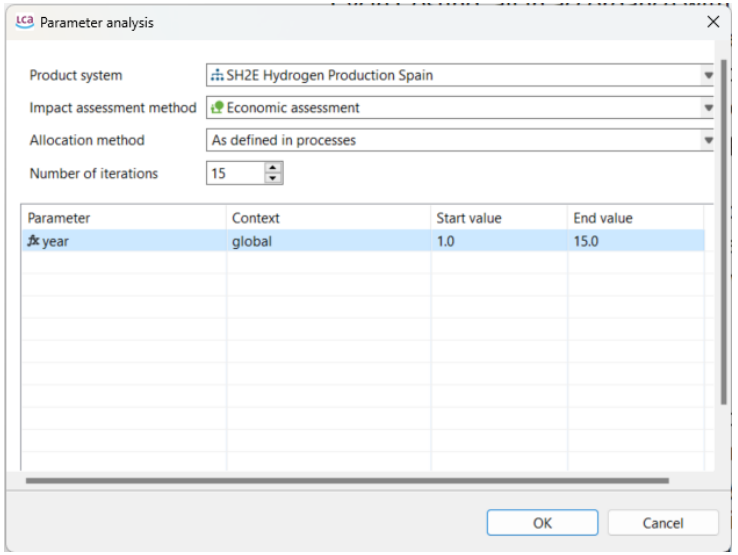


SH2E FCH-LCA Tool – Pre-set Template



FCH-LCA Tool: Time Parameter Analysis





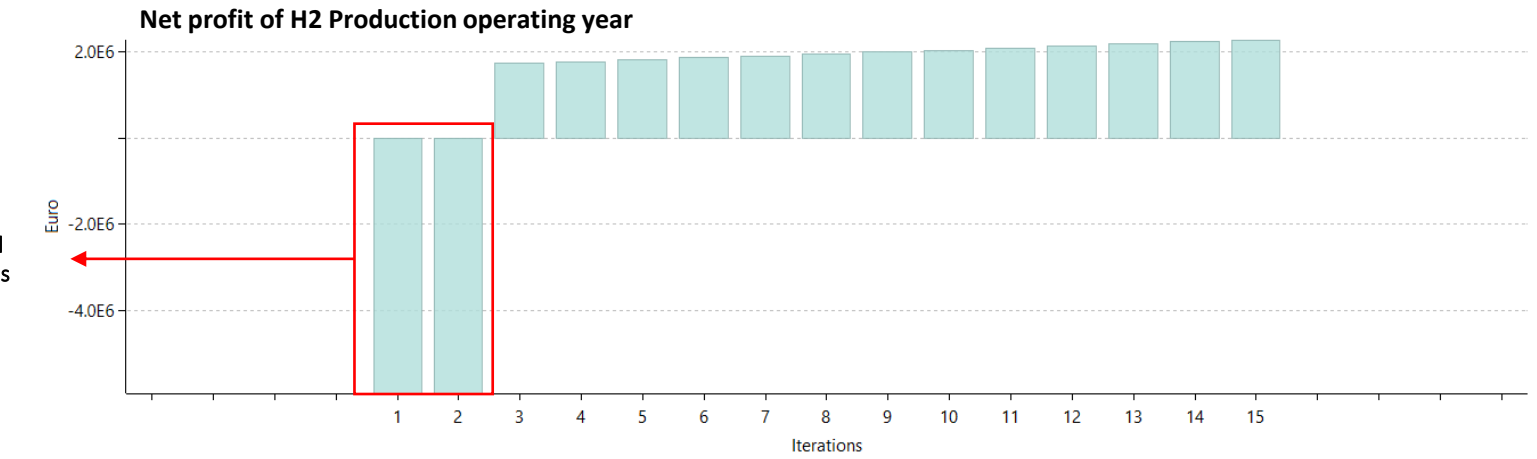
FCH-LCA Tool: Parameter Analysis

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



Indication of initial investment periods

FCH-LCA Tool: Direct Approach SLCA

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

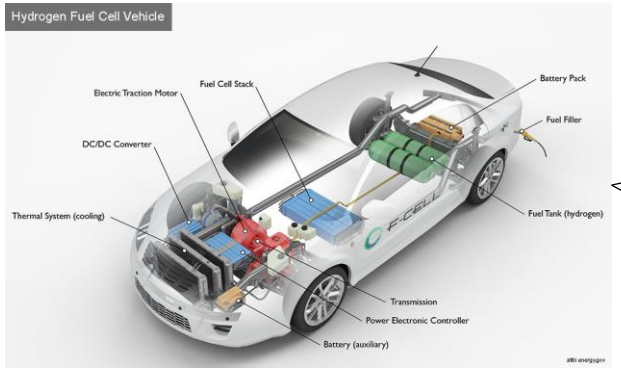
Indicator results

	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 managemen	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 pop	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 construct	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 t	0.08630 work hours [h]	1.17842 [% of total actual renewabl...	0%	0%	0%	0%	0%	95%	0%	3%	1%	0%	0%	0%
Level of industrial water use (related t	0.08630 work hours [h]	47.68259 [% of total water withdra...	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

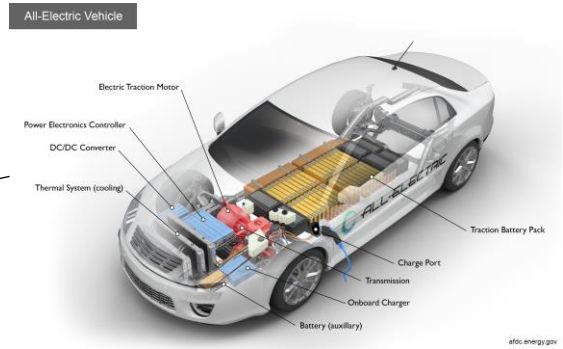
Hydrogen produced from Polymer Electrolyte Membrane used in fuel cell electric vehicle



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 5,2kgH2 at 700bars

Vs



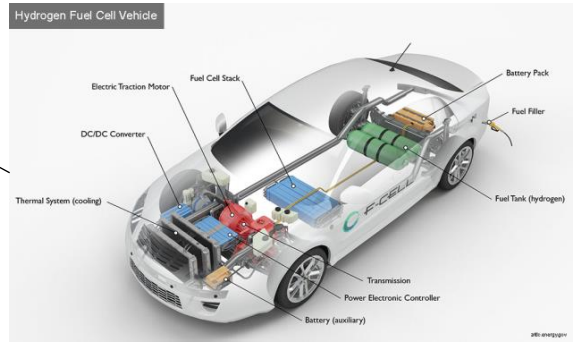
https://afdc.energy.gov/vehicles/how-do-all-electric-cars-work

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



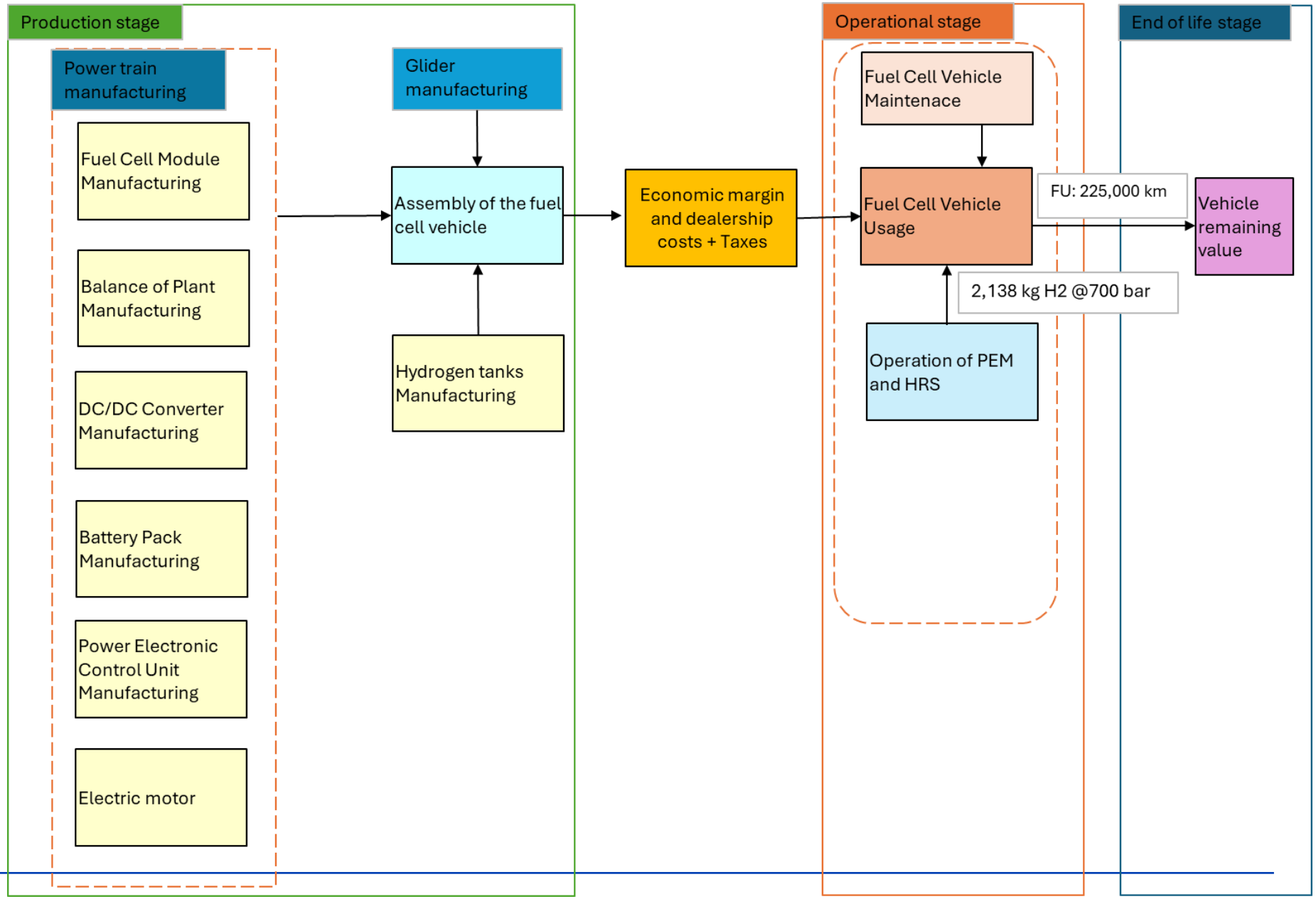
Hydrogen produced from Steam methane reformer used in fuel cell electric vehicle

Functional Unit

Case 3:	hydrogen production and use	Vehicle:	FCEV passenger D-segment car
Technology:	PEM electrolysis	Duration:	15 years with a total distance travelled of 225,000 km
H2 Property:	the H2 has 99.999% purity, stored at 900 bar, and dispensed at 700 bar at hydrogen refueling station	Mileage:	consumption rate of 0.95 kg of H2/100 km
Location:	The vehicle is used in Spain	Perspective (LCC):	Consumer

Final Statement:

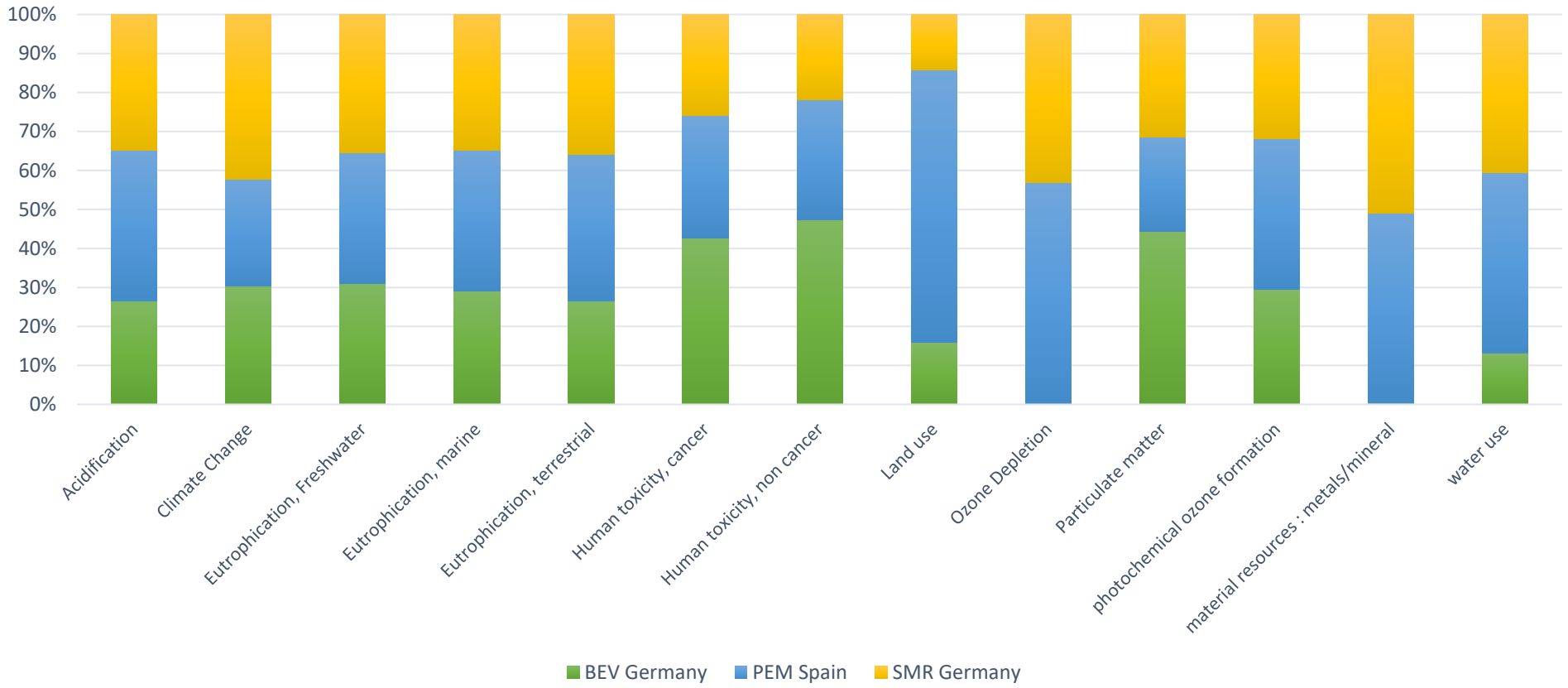
Hydrogen production from PEM electrolysis and its use in a FCEV passenger D-segment car for 15 years with a total distance travelled of 225,000 km (i.e. 15,000 km per year), at a hydrogen fuel consumption rate of 0.95 kg of H2/100 km (the H2 has 99.999% purity, stored at 900 bar, and dispensed at 700 bar at hydrogen refueling station) which is based on the consumption of Nexo Huyndai. The vehicle is used in Spain.


Production stage
Power train manufacturing
Fuel Cell Module Manufacturing
Balance of Plant Manufacturing
DC/DC Converter Manufacturing
Battery Pack Manufacturing
Power Electronic Control Unit Manufacturing
Electric motor
Glider manufacturing
Assembly of the fuel cell vehicle
Hydrogen tanks Manufacturing
Economic margin and dealership costs + Taxes
Operational stage
Fuel Cell Vehicle Maintenace
Fuel Cell Vehicle Usage
2,138 kg H2 @700 bar
Operation of PEM and HRS
FU: 225,000 km
End of life stage
Vehicle remaining value

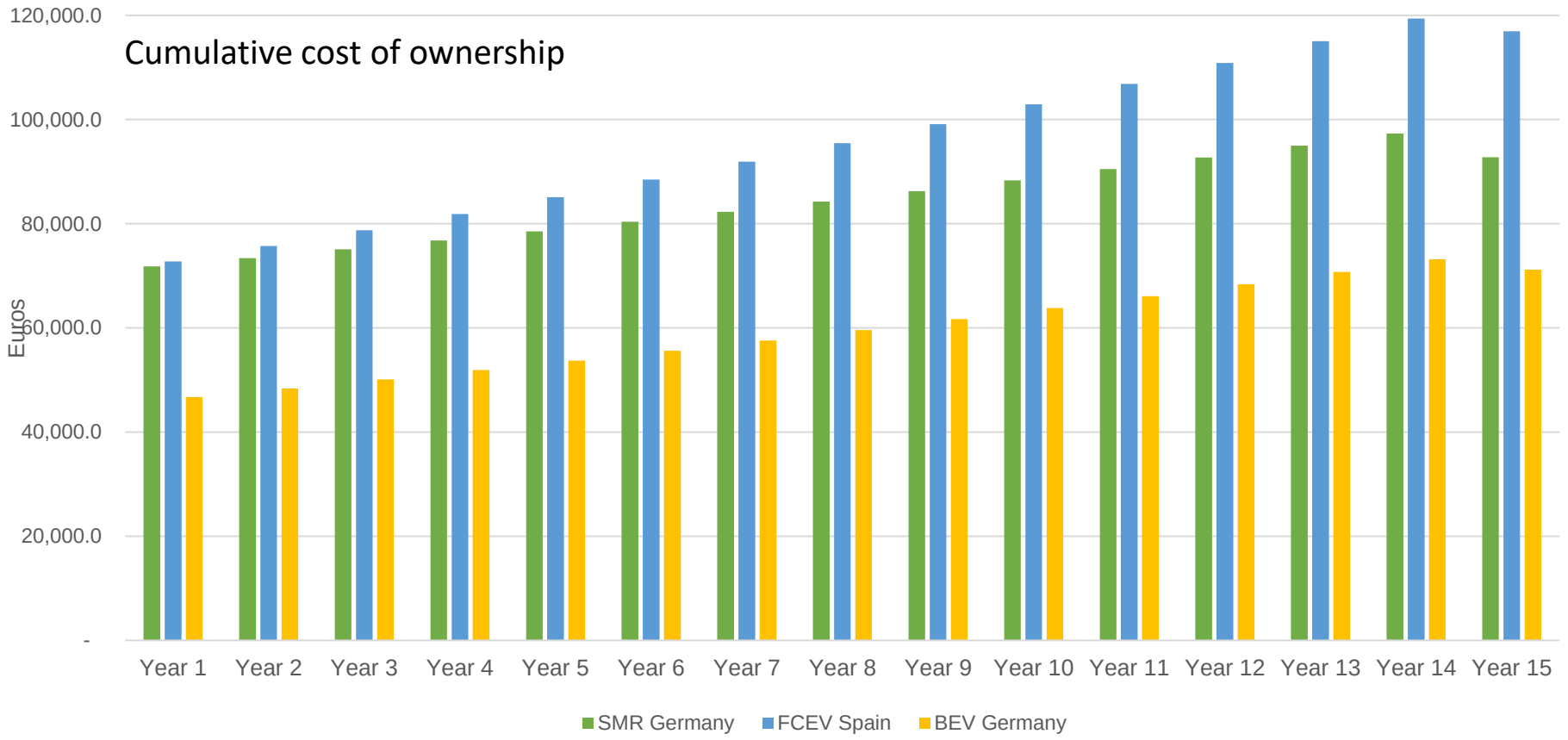
Methodology

	LCA	SLCA	LCC
Data	• Literature sources • Industry partner SYMBIO provided on fuel cell manufacturing	Literature sources • Industry partner SYMBIO provided on fuel cell manufacturing • Industry partner Fha provided data fuel cell operation	Literature sources
Database	Ecoinvent v3.9.1 APOS	Professional PSILCA V3.1.1	-
LCIA	EF 3.1	Social impact assessment + direct approach	Total Cost of Ownership $TCO = A + O + M - Salv.$ A = acquisition cost, O = operational cost, M = maintenance cost, and Salv. = salvage or remaining value

Results LCA PEM-FCeV vs SMR vs BeV



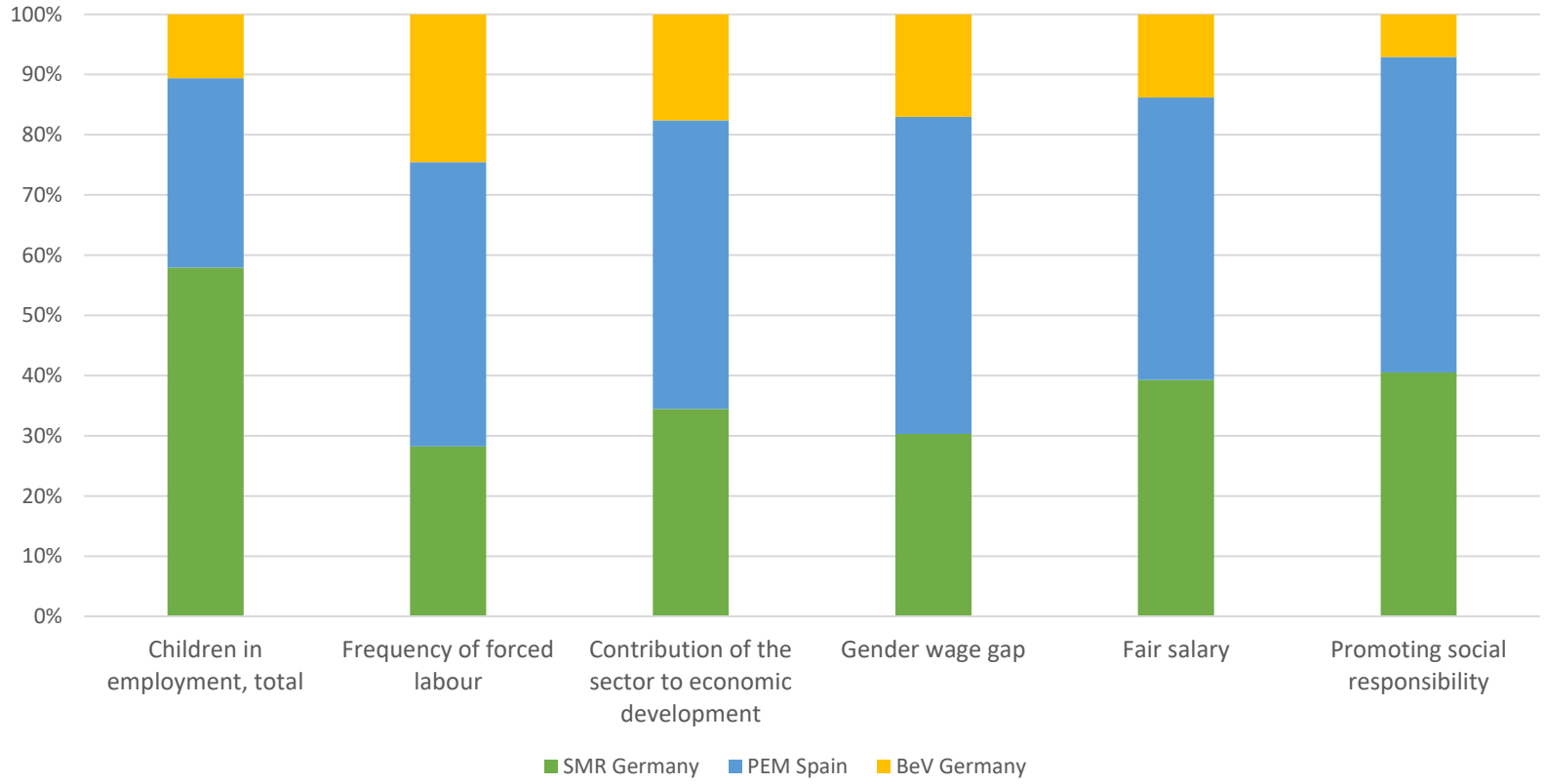
Results LCC PEM-FCeV vs SMR vs BeV



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?

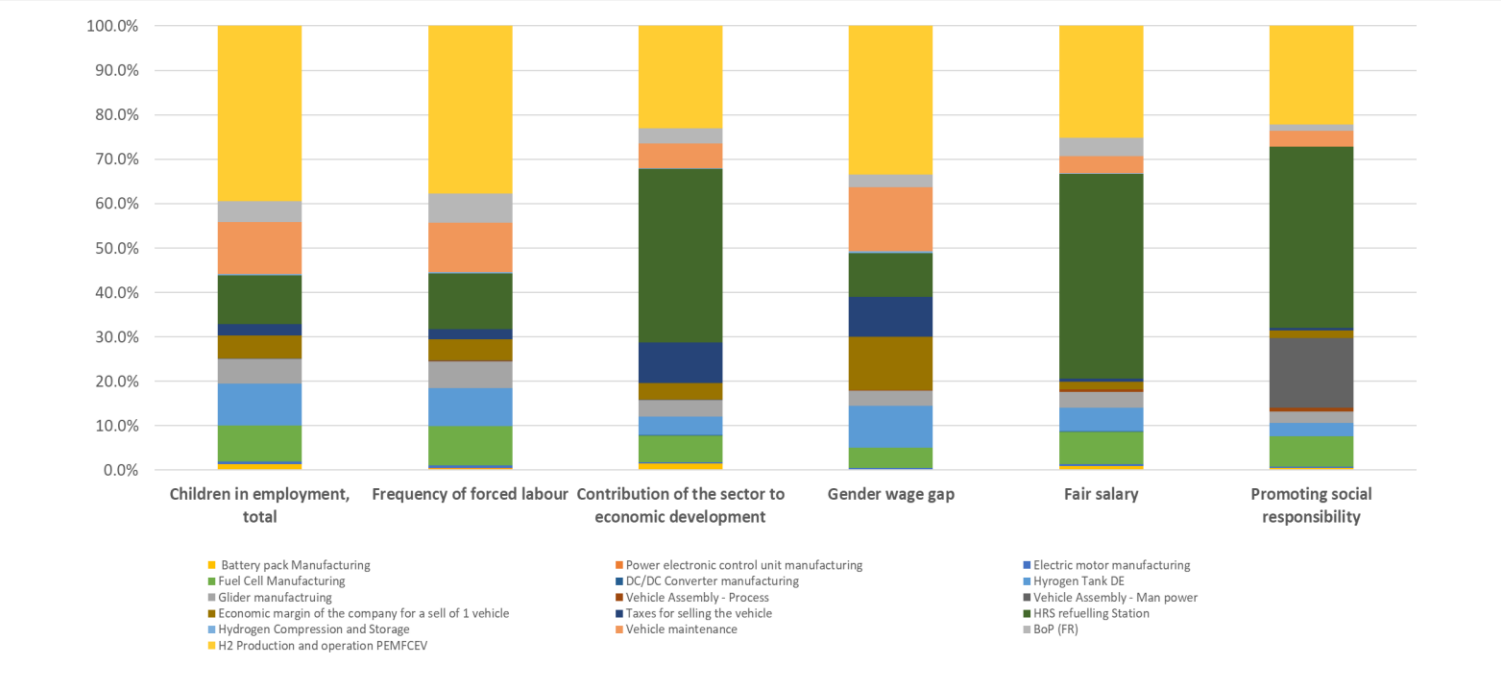
Results SLCA PEM-FCeV

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 responsibilty			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

- 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.