C2FUEL - This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 838014
The C2FUEL project results presented reflect only the author's view. The Commission is not responsible for any use that may be made of the information it contains.

C2FUEL

Carbon Captured Fuel and Energy Carriers for an Intensified Steel Off-Gases based Electricity Generation in a Smarter Industrial Ecosystem

Deliverable

D6.5 – Preliminary Environmental assessment through LCA

WP6 – Technical, economic, and environmental assessment

Project information

Grant Agreement n°	838014
Dates	1st June 2019 – 31st May 2023

Document Status

Document information

Deliverable name	C2FUEL_D6.5_01122021_Vx
Responsible beneficiary	R.BRIERE / ENGIE
Contributing beneficiaries	ALL
Contractual delivery date	M24 – 30/05/2021
Actual delivery date	M32 – 14/01/2022
Dissemination level	Public

Document approval

Name	Position in project	Organisation	Date	Visa
P. OLIVIER	Coordinator	ENGIE	14/01/2022	OK
L.NAIGLIN	Project Management Officer	BENKEI	07/01/2022	OK
A. MIQUELOT	Project Management Officer	ENGIE	14/01/2022	OK
A. MIQUELOT	WP6 LEADER	ENGIE	14/01/2022	OK

Document history

Version	Date	Modifications	Authors
V1	01/12/2021	1ST DRAFT	R.BRIERE / ENGIE
V2	02/12/2021	Minor modifications	A.MIQUELOT & P.OLIVIER / ENGIE
V3	08/12/2021	Minor modifications	R.BRIERE / ENGIE
V4	07/01/2022	Corrections	WP leaders
V5	07/01/2022	Final quality check	L. NAIGLIN / BENKEI
VF	14/01/2022	Final version	A. MIQUELOT / ENGIE, L. NAIGLIN / BENKEI

Table of Contents

List of Figures

List of Tables

Deliverable report

1 Executive Summary

1.1 Description of the deliverable content and purpose

Carbon capture and utilization (CCU) gathers all processes that use CO_2 as a feedstock to convert it into value-added products such as fuels, chemicals or materials. It involves different steps, from capturing the CO_2 from its source to its conversion into carbon-containing products, further including the use of such products up to their disposal as carbon-containing waste. C2FUEL project will develop and test two innovative routes for conversion of CO_2 into chemical energy carriers to be used for mobility applications:

- The first line relates to CO_2 hydrogenation in a membrane reactor with water removal to produce DME. The DME produced will be tested as a fuel for heavy mobility (buses, trucks, boats, etc.) in internal combustion engines.
- The second line relates to the conversion of CO_2 to formic acid through CO_2 hydrogenation or electrocatalytic conversion. Formic acid is one of the most promising hydrogen carriers for massive hydrogen storage and transportation and will be used within C2FUEL in a dedicated genset for electric boats charging at berth.

Besides technical feasibility, economic competitiveness and replication at industrial scale, environmental assessment is crucial as it is beneficial that the innovative CO_2 conversion routes of C2FUEL and the way the carbon-based products are used demonstrate reduced environmental impacts against current best available technologies. This demonstration can be realized with the Life Cycle Assessment (LCA). The first steps of the environmental study were described in the deliverable **D6.4 – Goal and scope of the environmental assessment applied to C2FUEL project**. The following deliverable aims at completing these first milestones and presenting the first results of a preliminary LCA. More specifically, it aims at identifying the most significant environmental impacts and sensitive parameters.

The goal definition is decisive for all the other phases of the life cycle assessment , so its clear initial definition was key for a correct interpretation of the results. It is important to identify what will be studied as well as the depth that will be considered for the modeling and the interpretation. It is a basis to ensure a common understanding from all partners and interactive dialogue along the project.

This report will follow the different steps of the LCA methodology: a reminder of the goal and scope of the study defined in **deliverable D6.4**, presentation of the inventories collected from the project partners, analysis of the results and first preliminary conclusions.

The task also includes the management of data collection, including data collection templates. This will ensure an efficient flow of information between partners, reducing the risk associated with the data collection process.

1.2 Brief description of the state of the art and the innovation breakthroughs

N/A

1.3 Corrective action (if relevant)

N/A

1.4 IPR issues (if relevant)

N/A

2 Life cycle assessment of the C2FUEL project

The LCA methodology is supported by two ISO standards: ISO 14040 (ISO, 2006) and ISO 14044 (ISO, 2006). The methodology is divided into 4 steps as shown in Figure 1:

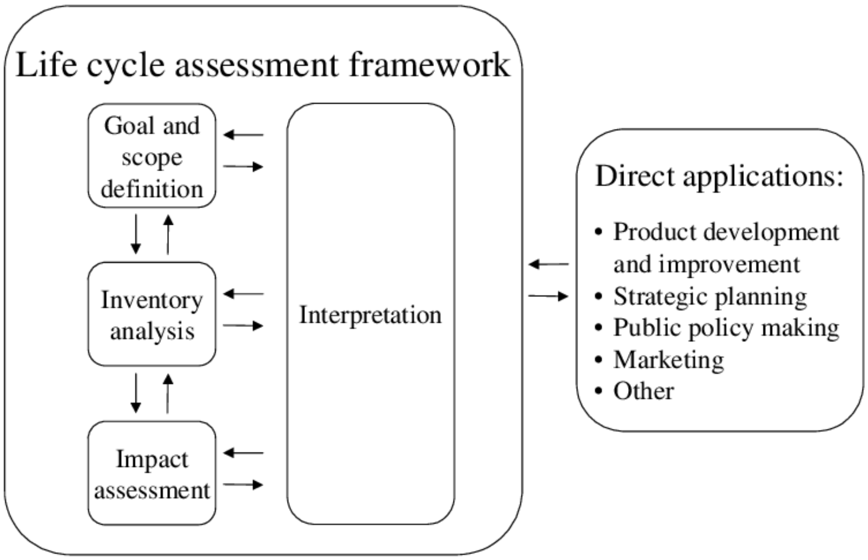

Figure 1: Description of the LCA methodology (ISO 14044, 2006)

The different steps will be detailed in the following sections.

2.1 Goal and scope definition

The first step of the methodology was to define the goal and scope of the study which encompasses:

- The context of the study
- The definition of the functional unit: quantitative description of the service provided by the system
- The description of the system boundaries: which steps/processes are included or excluded from the study
- The list of the selected indicators and the chosen impact evaluation method

The goal and scope step has been discussed in **deliverable D6.4**: the main outcomes of this last report are reminded in the next paragraphs (2.1.2, 2.1.3 and 2.1.4).

2.1.1 Context of the study

The objective of this task is to assess the environmental impacts of the use of two products (formic acid and DME) based on CO_2 capture for mobility purposes. The study will follow a cradle to grave approach that encompasses the extraction of the raw materials, the production step and the use phase. In the case of energy vectors, their use phase is also their end-of-life phase.

2.1.2 Definition of the functional units

As two products are studied, two functional units must be defined:

- For the formic acid, the results will be given for "The use of **formic acid** for the production of **1 kWh of electricity**". Two production pathways are considered for the formic acid: both processes have the same functional unit
- For the DME, the results will be provided for "The use of **1 kg of DME** for mobility purposes"

2.1.3 System boundaries

The main steps of the 2 systems are presented in Figure 2 and Figure 3 :

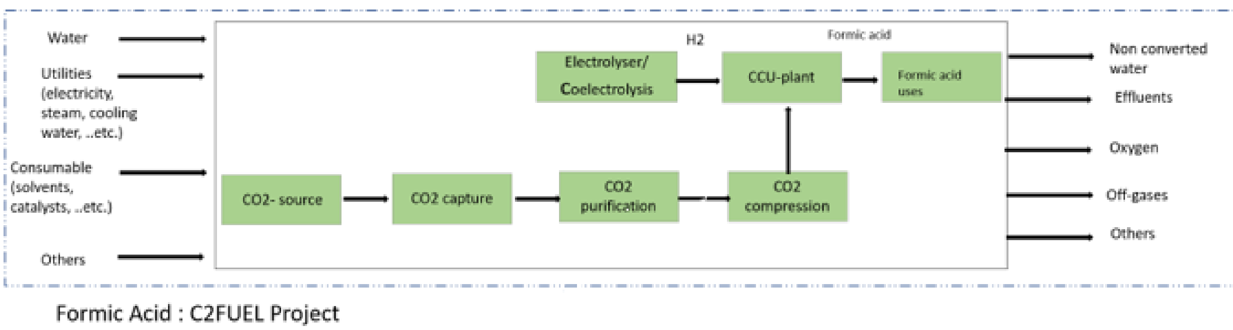

Figure 2: System boundaries of the acid formic system

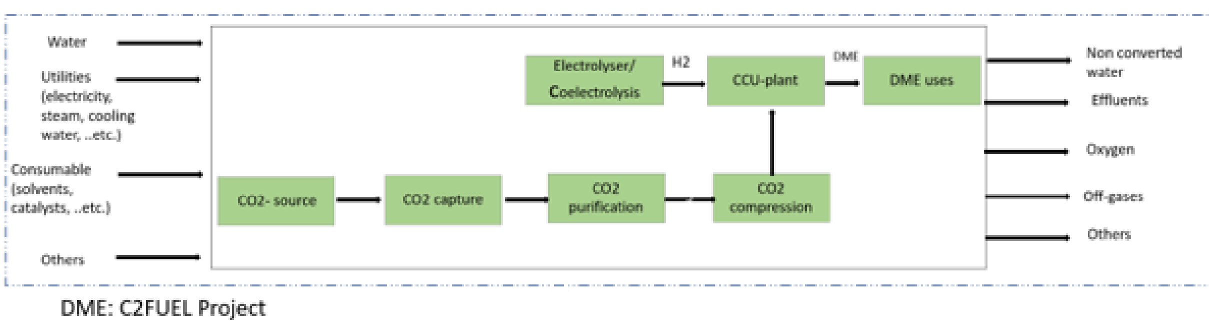

Figure 3: System boundaries of the DME system

The main steps that are accounted for in the study:

- The extraction of the raw materials and their transportation based on average global market data
- The material and energy inputs during the various production processes
- The specific equipment and infrastructures used during the production and the use phases.

2.1.4 Selected indicators and impact assessment method

An impact assessment method transforms the inventory (energy and material inputs, emissions…) into environmental impacts that are presented with indicators.

Contrary to what was stated in the goal and scope **deliverable D6.4**, another impact assessment method was chosen. The Environmental Footprint (EF) method (version 3.0) that replaces CML (Centrum voor Milieukunde Leiden) is the most recent and updated method and therefore used in this study (Fazio, 2018). The list of indicators available in the impact assessment method are listed below:

Table 1: List of the EF method indicators

Indicator	Unit
Climate change	kg CO2 eq
Ozone depletion	kg CFC11 eq
Ionising radiation	kBq U-235 eq
Photochemical ozone formation	kg NMVOC eq
Particulate matter	disease incidences
Human toxicity, non-cancer	CTUh
Human toxicity, cancer	CTUh
Acidification	mol H+ eq
Eutrophication, freshwater	kg P eq
Eutrophication, marine	kg N eq
Eutrophication, terrestrial	mol N eq
Ecotoxicity, freshwater	CTUe
Land use	Pt
Water use	m3 depriv
Resource use, fossils	MJ
Resource use, minerals and metals	kg Sb eq
Climate change – Fossil	kg CO2 eq
Climate Change – Biogenic	kg CO2 eq
Climate change – Land use	kg CO2 eq
Human toxicity, non cancer – organics	CTUh
Human toxicity, non cancer – inorganics	CTUh
Human toxicity, non cancer – metals	CTUh
Human toxicity, cancer – organics	CTUh
Human toxicity, cancer – inorganics	CTUh
Human toxicity, cancer – metals	CTUh
Ecotoxicity, freshwater – organics	CTUe
Ecotoxicity, freshwater – inorganics	CTUe
Ecotoxicity, freshwater – metals	CTUe

Given the large number of indicators available in the method, it is important to ease the interpretation to select a smaller set of indicators. For this preliminary study it was chosen to select four indicators based on [**ENGIE**]'s expertise. Indeed, these indicators are often used in intern studies as they encompass major environmental issues like global warming, air quality and resource use:

- Climate change: deals with the emissions of GreenHouse Gases (GHG) like carbon dioxide or methane
- Particulate matter: linked to air pollution (emissions of SOx, NOx and particulates)
- Resource use, fossil: consumption of fossil energies (coal, gas, uranium…)
- Resource use, minerals and metals: depletion of minerals and metals (magnesium, gold…)

The environmental results will be presented based on these four indicators. In the consolidated LCA, the selection of the indicators will be based on a more developed methodology that will look at the indicators that have the highest impacts on ecosystems, human health and resources.

2.2 Life cycle inventory

The inventories of each step of the model were gathered in the form of tables that list the inputs (energy and material flows) and outputs (air emissions, waste…). These flows were given by the partners of the projects based on Excel data collection files provided by the [**ENGIE**] team. These files are gathered on a TEAMS server. Some values can change through time by discussing with the partners: these changes are traced directly in the Excel sheet by indicating what is the source of the update.

The objective was to collect the data at an industrial scale as much as possible (sometimes only the demonstrator data level was available). The SOEC electrolysis and the DME production inventories are representative of the industrial whereas the carbon capture and both acid formic production pathways are still at the demonstrator level.

Two difficulties arose from this data collection step:

- The data was, sometimes, not directly available or hard to quantify: assumptions based on expertise or literature review were therefore necessary
- The flows that needed to be modelled could not be found in the LCA database. An LCA database proposes inventories which are already gathered, for various processes (materials, energy, waste…). However, for specific materials, no inventory is available and assumptions must be made: either by taking a similar product accessible in the database or by searching in scientific publications.

2.3 Impact assessment

The impacts of the hydrogen production, CO_2 capture and formic acid and DME use are presented in the following sections. It is important to keep in mind that the results are **not definitive results** for multiple reasons:

- The overall pilot demonstrator is still being developed and improvements in energy and material consumption will take place;
- Some hypothesis still need to be discussed between the partners and some important data are still lacking,
- From a modeling point of view, a deeper analysis is necessary as some flows were not modelled yet because no available processes exist or no proxies have been found

This deliverable shows a first glance at the results but above all present the potentialities of an LCA study: what kind of impacts can be obtained, what level of analysis can be expected…

2.3.1 Hydrogen production

The results are presented for the production of 1 kg of H_2 using a SOEC electrolysis process based on renewable energy (wind) in Figure 4:

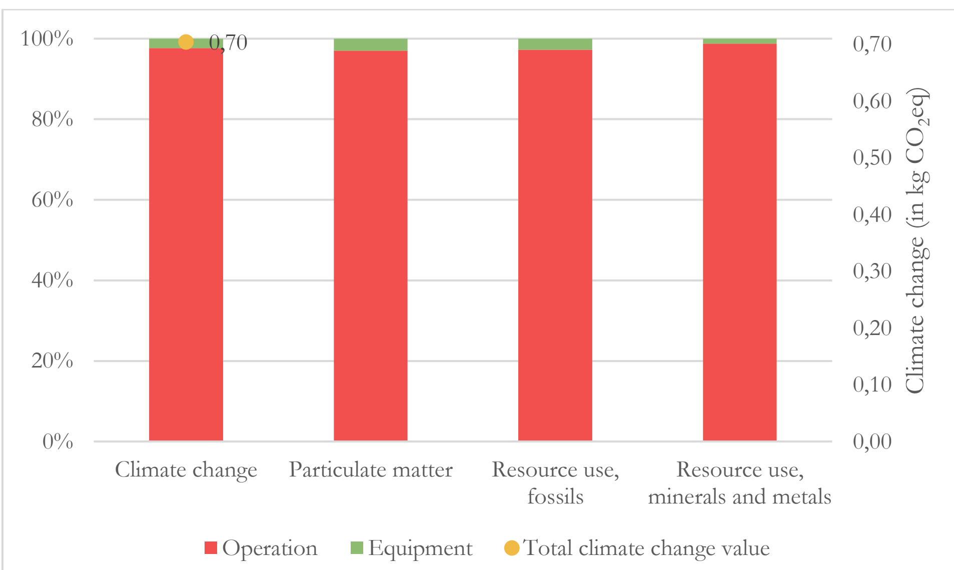

Figure 4: Environmental impacts for the production of 1 kg of H_2

The operation phase which corresponds to the electricity consumption is the main contributor in all the impacts. For the climate change indicator, an absolute value of 0,7 kg CO_2eq / kg H_2 produced is found. This result appears to be lower than other studies. For example, a recent report from the ADEME provided a value around 1,5 kg CO_2eq / kg H_2 for electrolysis based on renewable energy (ADEME, 2020). The main difference lies in the technology that were considered: the ADEME study focused on the PEM and alkaline electrolysis. Another reference value around 2,5 kg CO_2eq / kg H_2 can be found in an [**ENGIE**] internal study where the SOEC technology was also modelled. This value was also higher than the C2FUEL because of the heat from natural gas combustion during the process: in the C2FUELprocess, the heat needed was considered to be directly provided by the stacks.

2.3.2 Carbon capture

The results are presented for the production of 1 kg of CO2 captured in Figure 5:

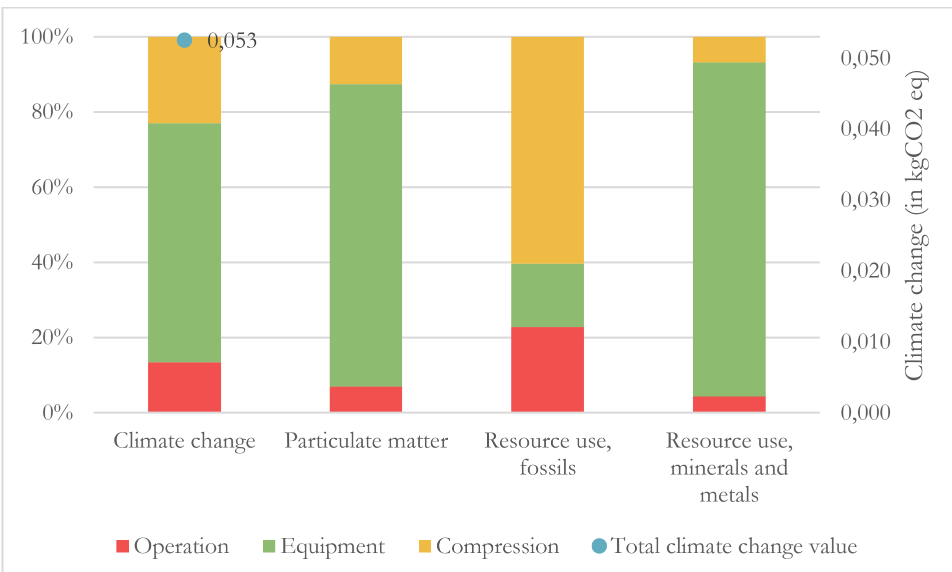

Figure 5: Environmental impacts of the 1 kg of CO2 captured

The equipment production has the highest contribution in three of the four impacts due to the energy used during the production of stainless steel. This conclusion could be different in the final version if the electricity mix is updated for example.

2.3.3 Acid formic results

The results are presented for both production pathways in the four indicators presented in section 2.1.4. All indicators are represented in the same figure to have an overall view of the environmental impacts.

The results are expressed in percent as the indicators have different units that cannot be represented on the same scale.

2.3.3.1 Formic acid by electrochemical reduction

The results for the use of 1 kWh from formic acid produced by electrochemical reduction are presented in Figure 6:

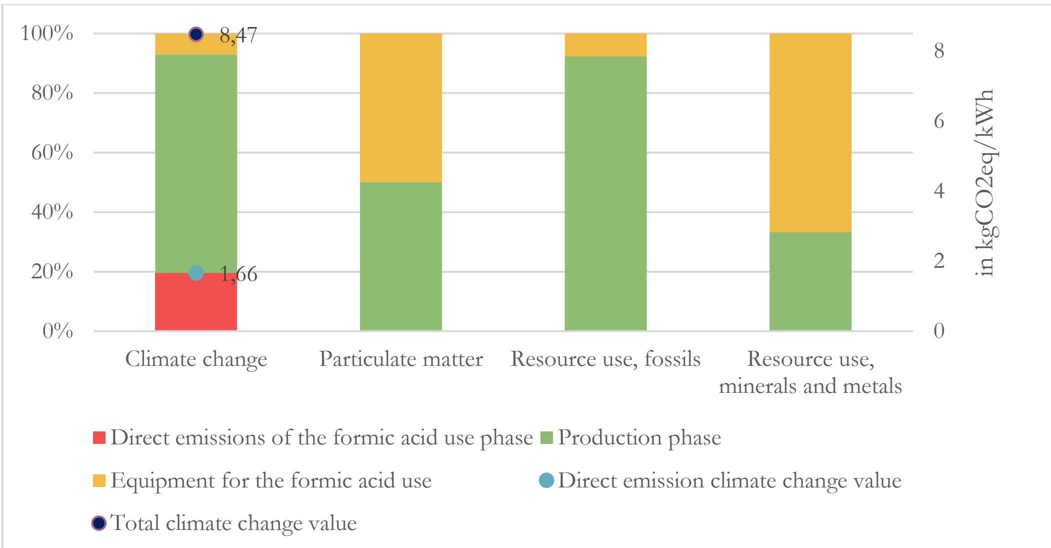

Figure 6: Environmental impacts of the formic acid by electrochemical reduction production

The direct emissions impacts appear only for the climate change indicator where the CO_2 emissions during the use phase are responsible of the impacts.

In the particulate matter and the resource use, minerals and metals indicators, the source of the impacts are the particulate emissions of the Chinese electricity used during the fuel cell production and the use of copper, also in the fuel cell.

The impacts of the production phase directly come from the use of Dutch electricity in the process and more particularly from the use of hard coal to produce electricity.

2.3.3.2 Formic acid by hydrogenation

The results for the use of 1 kWh from formic acid produced by hydrogenation are presented in Figure 7.

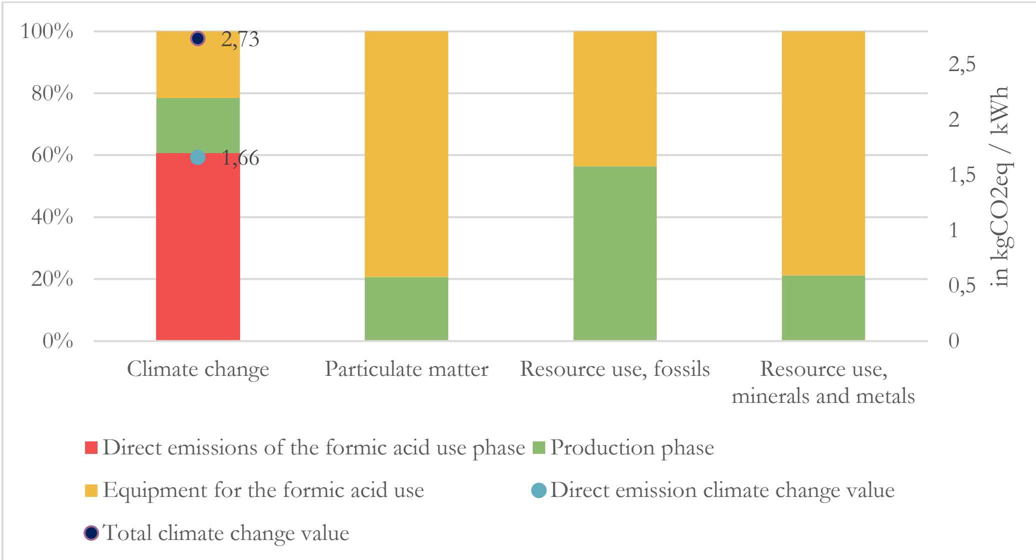

Figure 7: Environmental impacts of the formic acid by hydrogenation production

The contribution of the direct emissions, in the climate change indicator, is higher than in the previous case. Indeed, the absolute value is lower in the case of the hydrogenation pathway and the direct emissions are similar in both cases. Consequently, the share of the direct emissions is higher in the second case.

The impacts in the particulate matter and the resource use, minerals and metals are also due to the Chinese electricity used for the fuel cell production (for the same reasons than in the first pathway).

2.3.4 DME results

The results for the use of 1 kg of DME are presented in Figure 8.

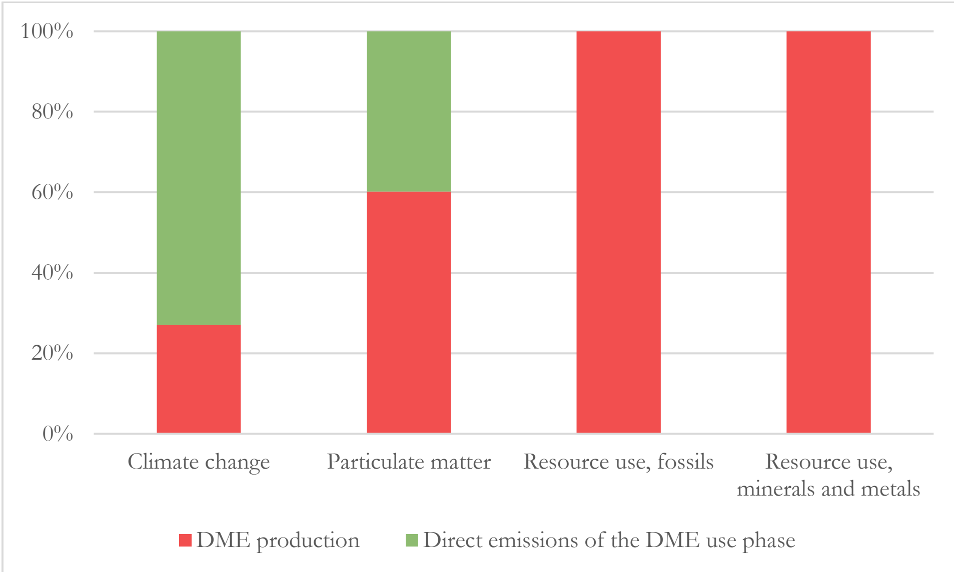

Figure 8: Environmental impacts of the DME

In the DME case, the same conclusion can be drawn for the climate change indicator: the direct CO_2 emissions from the combustion are the main contributor to the final impacts.
A deeper analysis of the particulate matter and the resource use, fossils indicators highlighted the contribution of the steam production used during the DME fabrication.

3 Conclusions

This deliverable presents the results of the preliminary LCA of the C2FUEL system. The interpretations that were established in the previous sections have to be taken with care. It gives some insights of inputs that could contribute the most to the environmental burdens of the system. For example, the CO_2 emissions during the use phase can be a key parameter in the climate change indicator. Also, the Dutch electricity used during the formic acid production have a non-negligible impact along with the Chinese electricity mix used during the fabrication of some equipment components like the fuel cell.

This study allowed the partners to have a better understanding of an LCA and of the data needed. The inputs and the modelling should be strengthened. The feedbacks obtained from the development of the processes and technologies and further extensive discussions with the partners will allow these improvements. Once these future reinforced results obtained, a comparison with conventional pathways for formic acid and DME production, ie. without the advantage of the CO2 capture technology, will be realized.

4 Bibliography

ADEME. (2020). Production d'hydrogène et usage en mobilité légère.

Duclos, L. L. (2017). Environmental assessment of proton exchange membrane fuel cell platinum catalyst recycling.

Fazio, S. C. (2018). *Supporting information to the characterisation factors of recommended EF Life Cycle Impact Assessment Methods.*

ISO. (2006). Environmental management - Life cycle assessment - Principles and framework.

ISO. (2006). Environmental management - Life cycle assessment - Requirements and guidelines .

Nuss, P. E. (2014). Life cycle assessment of metals : a scientific synthesis.