Ammonia as carbon free fuel for internal CombusTion engIne driVen AgriculTural vEhicle (ACTIVATE)

Work Package 4
Deliverable Report

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Topic: D4.2

Report on activities performed in the WP4

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1 Work Package 4 - the Scope

According to the ACTIVATE project proposal and consequential grant agreement, Work Package 4 had the aim to calculate the effect indicators indispensable to asses the technology in terms of its environmental sustainability and economic profitability. The main goal of this WP was to calculate environmental impact indicators and to perform the economic analysis. The environmental impact analysis is realized using a well known methodology of Life Cycle Assessment. Activities in WP4 were planned in such a way that all of the standardized steps of LCA are covered. The obligatory steps are presented in in figure 1 inspired by the International Reference Life Cycle Data System (ILCD) Handbook [1].

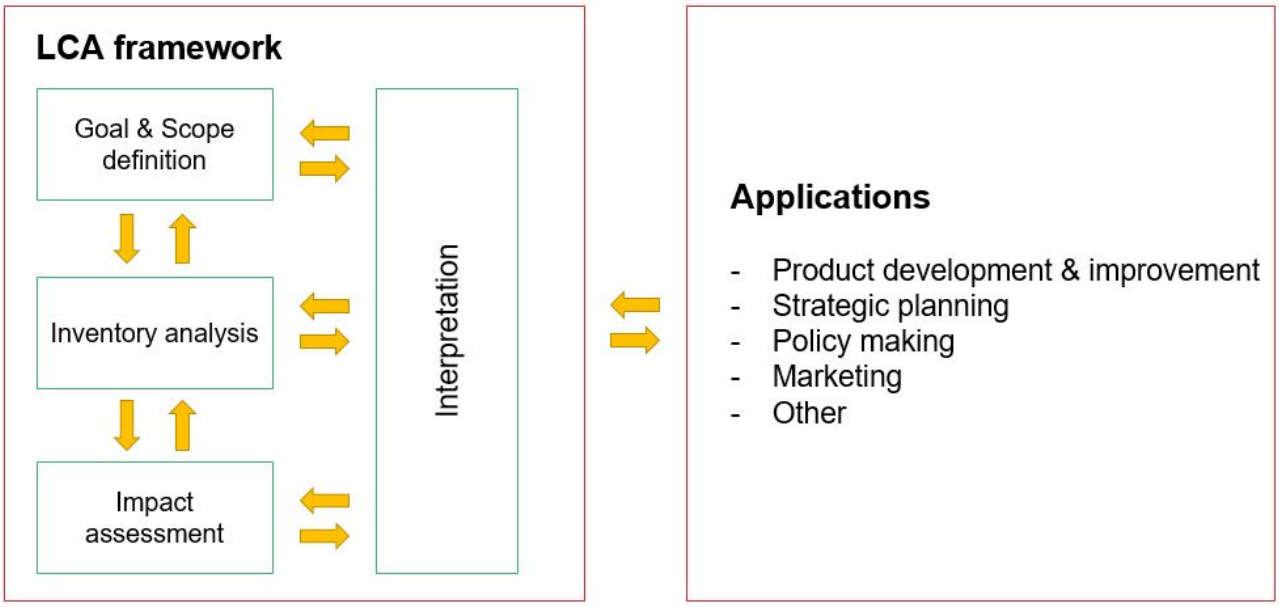

Figure 1: ISO standard based framework for LCA

The environmental and economic analysis were performed always in a comparative manner, referring the results to a conventional agricultural vehicle equipped with a CI engine. The analyses were indeed done for variable case scenarios, however the indication on the engine-operation-case with lower cumulative environmental impact will only be possible during subsequent actions in WP5 where model validation is also planned.

WP4 was divided into three tasks. The schedule of actions is provided below, while the details of activities in each tasks are described in the following sections.

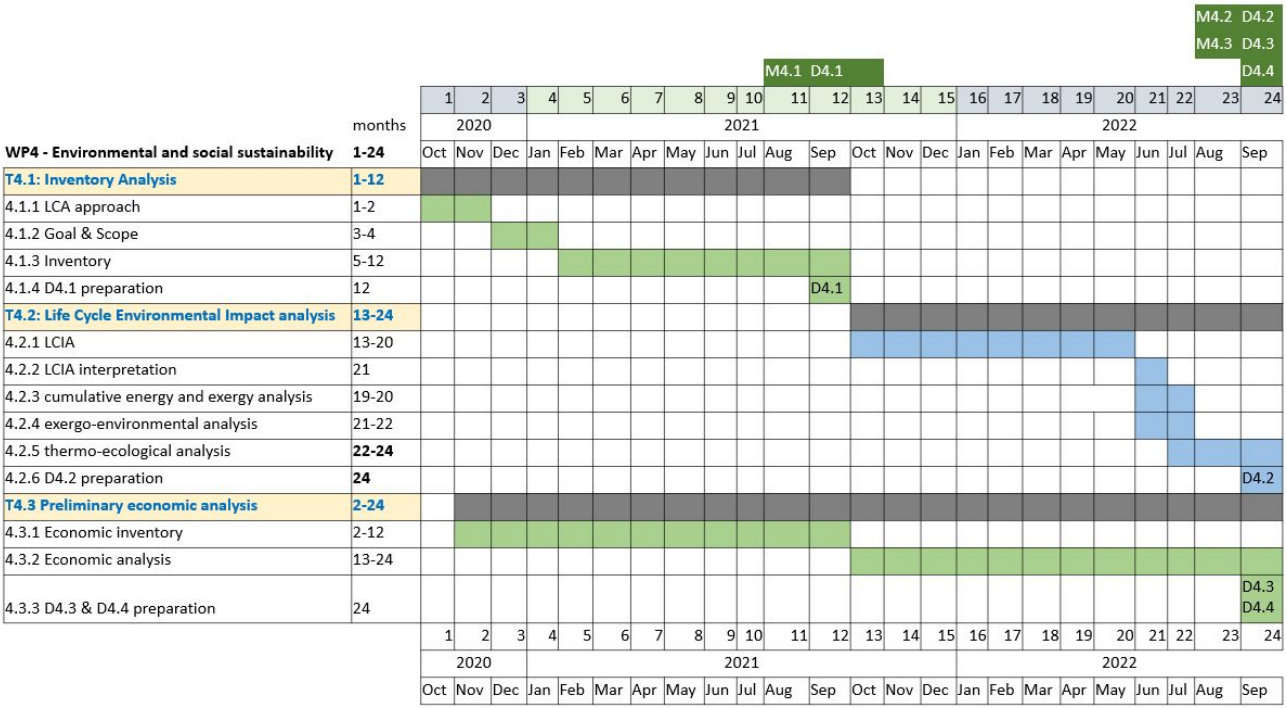

Figure 2: WP4 - Gantt chart

2 Task 4.1 Inventory analysis

Task 4.1 started together with the beginning of the whole project implementation and lasted 12 months

It included the preparation phase needed for LCA approach definition. This phase required a complex literature review. It supported the process of formulating problems and choosing the approach along with the specific assumptions. The reviewed papers were divided according to their main topic: focus and scope, functional unit, performance method (software and databases used), conclusions. The findings from the literature review allowed for the aware choice of functional unit, as well as were a background for the first step of LCA: Goal and Scope definition. Defining Goal and Scope is consistent with defining the parameters list given by ISO 14040 and 14044:2006 standards, as well as described in the International Reference Life Cycle Data System (ILCD) Handbook [1]. The detailed summary of assumptions for Goal and Scope is given in Deliverable D4.1 Map and quantification of all material and energy inputs and outputs submitted in October 2021.

This stage was then followed by the first iteration of Inventory Analysis, that is by detailed quantification of energy and material input/output streams during each life cycle phase. All inventory and subsequent models were prepared using GaBi® Academy software and the GaBi Professional database. Three general phases regarding life of the vehicle can be derived:

1. production phase – production of the vehicle and parallel production of fuel (or fuels) supplying the vehicle,

2. operation phase – exploitation of vehicle,

3. end of life phase – utilization of vehicle.

Each of the phase can be further divided into smaller phases consisting of particular processes

that allow to understand the complete usage of material and energy requirements occurring along the life of the technology.

The construction and end-of-life phases inventory data are relying on assumed and modelled values, while the operational phase data are strictly experimental data reliable. The collection mode of these type of data must have been compatible with activities performed on the engine test stand. Taking it into account, the inventory analysis in D4.1 (1st iteration) had to be treated as theoretical since it did not use experimental data for tractor's operation phase but used process representative for passenger's car with engine of similar size. 2nd iteration of the Inventory Analysis appeared in 2022 once the experimental campaign for port-injection of fuel was completed.

The list of activities that shall be mirrored by the lab campaing is explained in table 1.

Table 1: Apple orchard management

Activity	Frequency during a year	Purpose	Activity execution
Dormant pruning	2	Remove dead wood, improve light penetration.	Single pass through the orchard, manual pruning.
Tree fertilizing	3	Tree nurturing (nutrient supply).	Single pass through the orchard with sprayer.
Branch and leaves sweeping and raking	12	Preventing snow mold and grass smothering.	Branch and leaves sweeping by two-rotor sweeper.
Mechanical weed removal	1	Weed control (quackgrass etc.).	Single pass through the orchard with lateral weeder.
Grass mowing	6	Grass and weed control.	Single pass through the orchard with flail mower.
Insecticide and fungicide application	20	Insects control (codling moth, caterpillars etc.) and fungi control (apple scab etc.).	Single pass through the orchard with sprayer.
Fruit harvest	1	Collecting apple harvest.	Single pass through the orchard with trailer.

2.1 Collecting the inventory data - support in the SUT laboratory

3 Task 4.2 Life cycle environmental impact analyses

Second year of the project execution and WP4 implementation was devoted to constant update of the Inventory Analysis (following the still emerging new lab results from port injection test campaign) and the same to support the lab efforts of the SUT team. The inventory analysis in updated form was

then translated into environmental impact indicators applying ReCiPe impact assessment method. It allows for showing the environmental impact on three aggregation levels (three endpoint indicators): effect on human health, biodiversity and damage to resource availability. The ReCiPe 2016 v1.1 method has been used for assessing the ACTIVATEngine which includes 18 midpoint indicators and 3 endpoint indicators. ReCiPe structure is presented in figure 3.

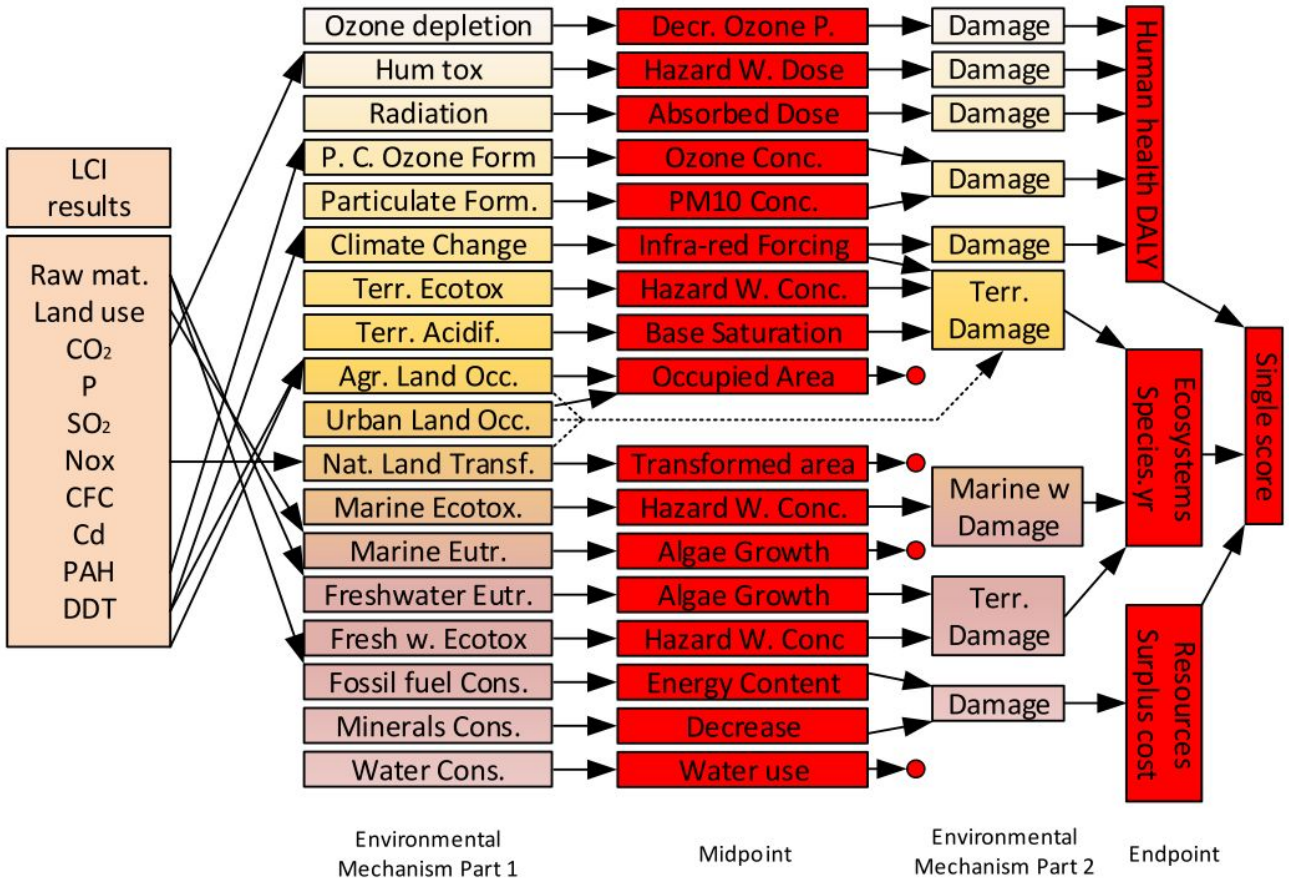

Figure 3: Overview of ReCiPe structure [2].

The standardized LCIA was also enriched by thermo-ecological (TEC) analysis allowing for evaluation of environmental impact of the process if exergy is accepted as the only rational measurer of the quality of the resources. TEC analysis combines cumulative exergy analysis with the environmental impact analysis providing knowledge on the non-renewable resources exergy consumption. Additionally, it takes into account how much exergy has to be additionally extracted from nature to compensate the negative effects of wastes and harmful substances emission. The task ended on 30.09.2022 together with the finish of WP4.

The LCA, LCIA and TEC analyses have been performed for the following cases of fuelling the tractor:

1. Diesel tractor - reference case which utilizes only diesel as a fuel, the values are based on the GaBi professional database and dedicated experiment for the pure diesel fuelling.

2. Biodiesel tractor - case which utilizes only diesel as a fuel, the values are based on the GaBi professional database, literature for the biodiesel production phase and dedicated experiment for the pure biodiesel fuelling.

3. Ammonia fuelled tractor - case which utilizes biodiesel as pilot fuel and the ammonia, the values are based on the GaBi professional database, literature for the biodiesel production phase and dedicated experiment for the co-combustion of biodiesel and ammonia.

The last case is further divided between the source of hydrogen that is used to produce the ammonia:

1. Steam methane reforming - based on the GaBi professional database.

2. Steam methane reforming with carbon capture and storage - based on GaBi professional database.

3. Electrolysis - based on the GaBi professional database.

The following sources of electricity for electrolysis are considered:

1. PV

2. Wind

3. Nuclear

The results for the 2nd iteration of Inventory Analysis are summarized in deliverable D4.2 report (Matrix of impact indicators for LCA obtained for ammonia driven engine).

4 Task 4.3 Preliminary economic analysis

This task lasted 24 months and was divided into 2 stages: Economic Inventory and Economic Impact indicators assessment.Economic assessment aims at comparing the costs for diesel tractor as a reference case (which is the same approach as in case of the LCA) and compare it to ammonia fuelled tractor. The Total Cost of Ownership (TCO) is defined as the sum of the costs for: acquisiton of the vehicle, exploitation and end of life. Just like the Life Cycle Inventory, the Economic Inventory had to be performed iteration-wise. First the data were assumed theoretically basing on literature data and public reports, being updated together with information appearing from the partners. Citing from D4.3: "The cost of acquisition of the tractor based on the market data, other parameters have been selected arbitrarily. Modernization cost is a cumulative term including the costs for: ammonia tank, fuel line, controllers, assembly and the SCR. The price for the ammonia tank has been taken from the market data, SCR from the literature [3] (extrapolating the data for 1l engine), the rest takes value of the LPG adaption system to the passenger vehicle (the approach consulted with the WP2). The detailed value for port injection system has not been obtained based on the WP2 due to lack of the data as the engine has been installed on a test rig, installing the real case on a demonstrator vehicle will allow for estimation of realistic value."

5 Deliverable and milestones

Formally, the work package was linked with preparation of 4 Deliverable reports and achievement of 3 milestones. Hereby, all of the reports are prepared and milestones achieved.

5.1 Milestones

- M4.1 Inventory analysis performed
- M4.2 Impact indicators and TEC calculated
- M4.3 Economic indicators obtained

5.2 Deliverable

- D4.1 Map and quantification of all material and energy inputs and outputs
- D4.2 Matrix of impact indicators for LCA obtained for ammonia driven engine
- D4.3 Report on economic impact indicators of the technology
- D4.4 Report on activities performed in the WP4

6 WP4 dissemination

6.1 Conference papers and presentations

Partial results were presented during 3 international conferences

1. ECOS2022 35th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, 3-7 July 2022, Copenhagen, Denmark
    - Proniewicz Mateusz, Petela Karolina, Szlek Andrzej, LCA and LCC framework for special purpose vehicles based on a case study of a mini-tractor fo orchard operations, Proceedings of ECOS 2022, 35th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, July 4-7, 2022, Copenhagen Denmark, DTU Construct, Nils Koppels Allé Bld. 404, DK-2800 Kgs. Lyngby Denmark.
2. 1st Symposium on Ammonia Energy, 1-2 September 2022, Cardiff, United Kingdom
    - Proniewicz Mateusz, Petela Karolina, Szlek Andrzej, Adamczyk, Wojciech, EVALUATING THE SUSTAINABILITY OF AMMONIA FUELLED MINI-TRACTOR FOR ORCHARD OPERATIONS, OPEN COMPILATION Techno-Economics and LCA 1st Symposium on Ammonia Energy
3. CPOTE2022 7th International Conference on Contemporary Problems of Thermal Engineering, 20-23 September 2022, Warsaw, Poland
    - Proniewicz Mateusz, Petela Karolina, Szlek Andrzej, Life cycle assessment of selected ammonia production technologies from the perspective of ammonia as a fuel for heavy-duty vehicle, Conference Proceedings, 7th International Conference on Contemporary Problems of Thermal Engineering Warsaw, Poland, 20-23 September 2022, TOWARDS SUSTAINABLE & DECARBONIZED ENERGY SYSTEM, Politechnika Ślaska, Katedra Techniki Cieplnej, ISBN: 978-83-61506-55-3.
    - Petela Karolina, Proniewicz Mateusz, Szlek Andrzej, ACTIVATE: Sustainability and profitability of ammonia-driven engine, Oral Presentation, Book of Abstracts, 7th International Conference on Contemporary Problems of Thermal Engineering Warsaw, Poland, 20-23 September 2022,

6.2 Journal papers under preparation

1. "Fuel cycle comparison for ammonia fuelled tractor" - LCA paper with special focus on fuel production phase, to be submitted by the end of 2022

2. "Energy transition in agriculture machinery from diesel to ammonia" - article prepared in close cooperation with WP2 team, to be submitted at the turn of 2022 and 2023

7 Conclusions

All of the WP4 activities planned in the project proposal were successfully implemented. The team with full awareness acknowledge the deviations expected in the inventory data collection phase. It is however, as a matter of ISO standard principle, allowed because the whole Life Cycle Assessment, including environmental and economic analyses, is an iterative process, constantly updated for the purpose of getting closer to reality.

It is important to highlight that the LCA and economic analysis results presented in deliverable reports D4.2 and D4.3, respectively, are reflecting the settings of an ammonia engine equipped with port injection. In summer 2022 first direct injection experiments were successful and according to this type of engine exploitation both analyses will be updated in WP5. In this period also a demonstration vehicle should be constructed - the inventories and impact analyses will be updated according to the field tests results. However, already at this stage it is possible to formulate valuable conclusions. For instance there related to Life Cycle Impact Assessment interpretation after 2nd Inventory Analysis iteration (port-injection related): Current LCIA the need for further investigation of ammonia injection technologies, i.e. port injection could achieve the decarbonisation goal, if utilizing the electrical energy from nuclear source, however the direct injection is predicted to achieve even more promising results. As expected, even the ammonia production from renewable sources is not environmentally neutral (e.g. due to resources exploitation), so the optimization of the operation phase of the tractor could increase its attractiveness.

References

[1] JRC. *ILCD Handbook: Framework and requirements for LCIA models and indicators First edition.* 2010. URL: http://lct.jrc.ec.europa.eu/%0Ahttp://www.jrc.europa.eu/%0A, https://doi.org/10.2788/38719 doi:10.2788/38719.

[2] María González-Campo, Jorgelina Pasqualino, Claudia Díaz-Mendoza, and Alfonso Rodriguez-Dono. Environmental life cycle assessment for a large-scale gold mining. 2020.

[3] Sarah Chambliss Francisco Posada and Kate Blumberg. Cost of emission reduction technologies for heavy-duty diesel vehicles. *The Internation Council of Clean Transportation*, page 7, 2016.