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

Matrix of impact indicators for LCA obtained for ammonia driven engine

30.10.2022

1 Life Cycle Impact Assessment - impact indicators

Having completed and updated the inventory analysis elaborated in the D4.1 by the experimental data of the engine with port injection technology, the life cycle impact assessment can be performed. The purpose of the LCIA is to translate how the inputs and outputs of the LCA model affect the environment, i.e.to estimate the environmental damage occurring due to resource exploitation and respective emissions using so-called charactesization factors.

The ReCiPe 2016 v1.1 method has been used for assessing the ACTIVATEngine which includes 18 midpoint indicators and 3 endpoint indicators. The way the midpoint categories affect the endpoint areas of protection is shown in figure 1.

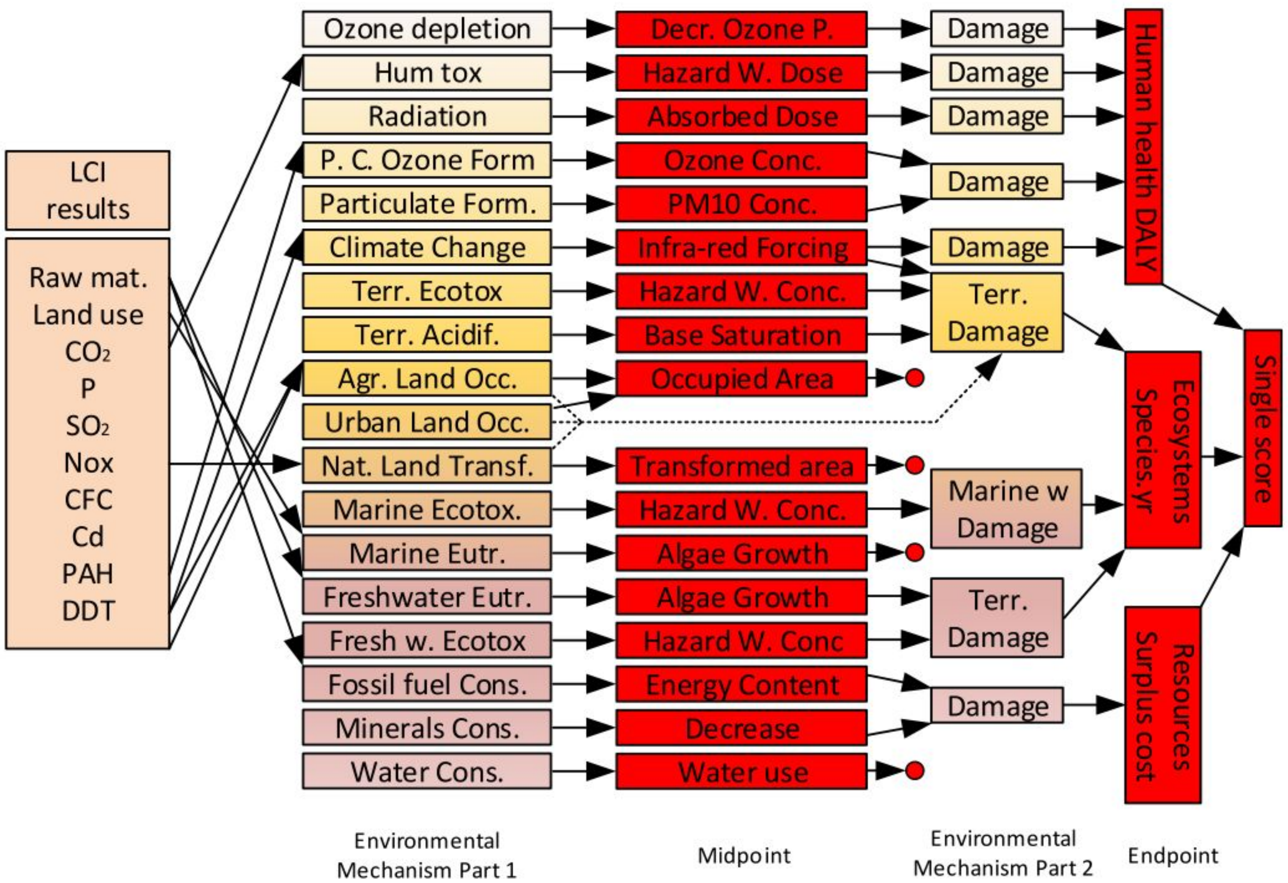

Figure 1: Overview of ReCiPe structure [1].

Short description of respective categories can be summarized as follows [2]:

1. Midpoint climate change – referred in kg CO2 eq. defining the measure of climate change caused by the emission of greenhouse gases that affect radiative forcing capacity of Earth causing an increase in global mean temperature.

2. Midpoint fossil depletion – referred in kg oil eq., measure of the reduction in future availability of fossil fuels caused by exploitation of these fuels in regard to the unit of product (production of 1 MJ of ammonia in this case).

3. Midpoint freshwater consumption – referred in m3, defining the measure of water exploitation referred to evaporation, incorporation into products and by-products or disposed to sea causing the loss in availability of freshwater for ecosystems.

4. Midpoint stratisogeric ozone depletion – referred in kg CFC-11 regards the Ozone Depletion Potential (ODP) quantifying the amount of ozone depleting by the substance.

5. Midpoint ionizing radiation – measure of collective exposure dose caused by the emission of radionuclide, referred in the kBq Co-60 eq. to air.

6. Midpoint fine particulate matter formation – expressed in PM2.5 eq. defining the health damage due to the exposure to fine dust.

7. Midpoint photochemical ozone formation – measure of intake of ozone by humans for human health category and by plants for ecosystem category, expressed in kg NOx eq.

8. Midpoint terrestrial acidification – measure of change in acidity in soil due to emission of inorganic substances (sulphates, nitrates and others), referred in kg SO2 eq.

9. Midpoint freshwater eutrophication – measure of eutrophication caused by the discharge of nutrients into soil and freshwater, expressed in kg P-eq. (phosphorus eq.) to fresh water.

10. Midpoint marine eutrophication – measure of runoff and leach of plant nutrients from soil and discharge into rivermarine and marine systems, referred in kg N eq. (nitrogen eq.).

11. Midpoint toxicity – human toxicity category accounts for the toxicity (measure of human intake of a chemical and accumulation in a human food chain) in regard to cancerogenic non-cancerogenic substances. Marine and terrestrial ecotoxicity accounts for the increase in concentration of the chemicals leading to disappeared fraction of species. It is expressed in kg 1.4-dichlorobenzene-equivalents (1.4 DB eq.).

12. Midpoint water use – accounts for freshwater consumption referred in m3 defining the quantity of water consumption resulting in water shortage and subsequent damage to human health and ecosystem quality, included in the endpoint categories.

13. Midpoint land use – measure of land transformation, occupation and relaxation expressed in annual crop eq.

14. Midpoint mineral resource scarcity – measure of resource extraction leading to ore grade decrease expressed in kg Cu eq.

15. Endpoint human health – referred in DALYs (disability adjusted life years) representing the years that are lost by a person due to the disease or accident.

16. Endpoint ecosystem quality – referred in species year as time-integrated species loss representing such loss at local scale.

ReCiPe 2016v1.1 method recognizes also the third endpoint category i.e. resource scarcity which represents the extra costs involved in future mineral and fossil resource extraction. It is calculated based on the average annual costs for cooper, crude oil, hard coal and natural gas, however since it could be seen rather as an economic and not environmental factor, it has been omitted from the results.

2 LCA scenarios

The LCA and LCIA have been calculated 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

3 LCIA results

The results for the midpoint categories are presented consecutively in figures 2, 3, 4, 5, 6. Production phase and end of life phase of tractor are the same for all of the cases and therefore fail to provide information required to compare between the fuelling systems. It is generally seen that the ammonia system achieves high values on many categories which is both due to energy intensity of its production phase as well as the emissions occurring during the co-combustion of ammonia and biodiesel (high emissions of NH3 and NO2, clearly seen for instance for fine particulate matter formation category).

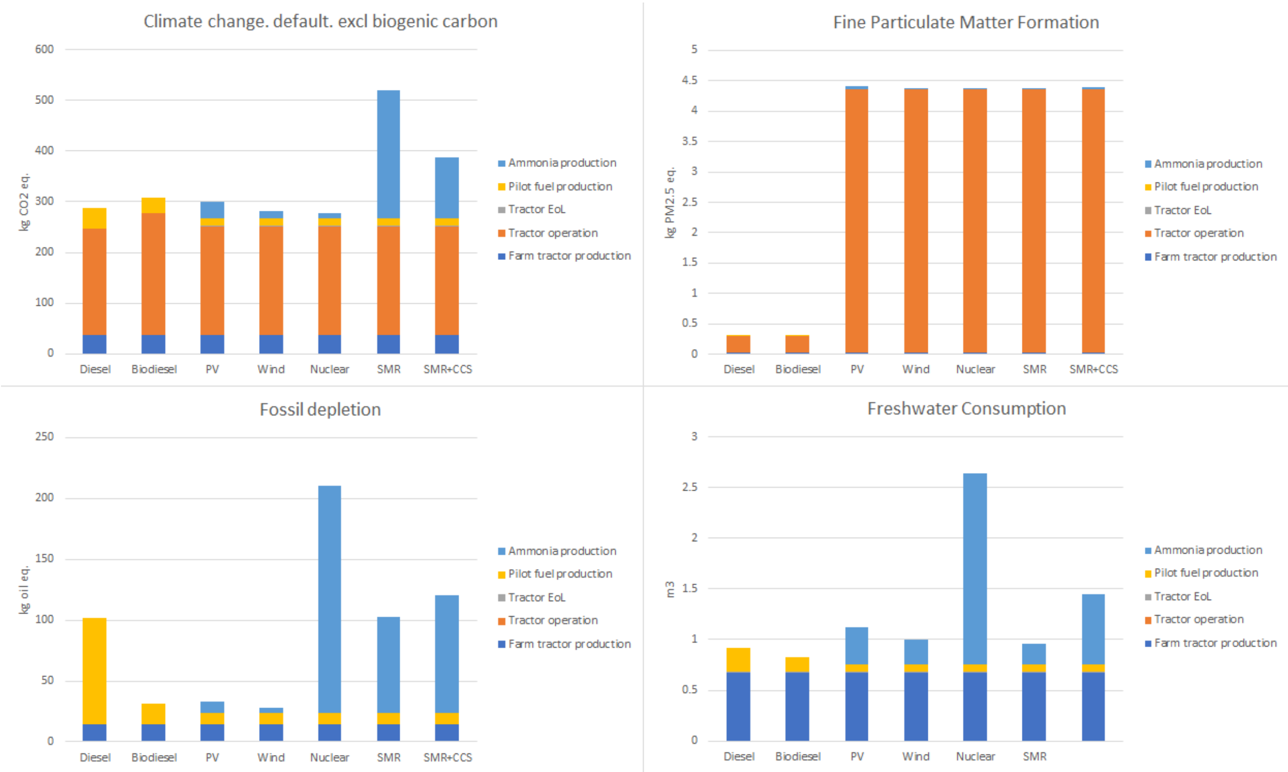

Figure 2: ReCiPe midpoint results per 1 ha over 1 year (1).

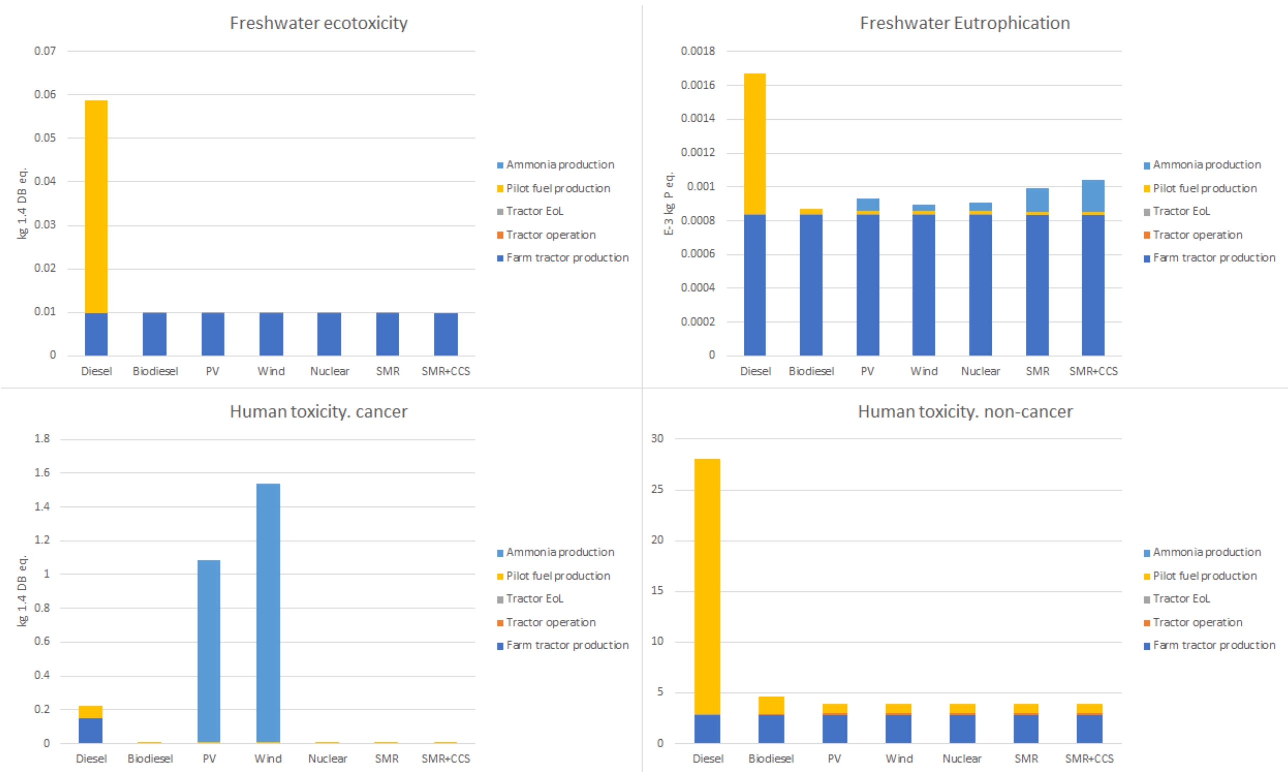

Figure 3: ReCiPe midpoint results per 1 ha over 1 year (2).

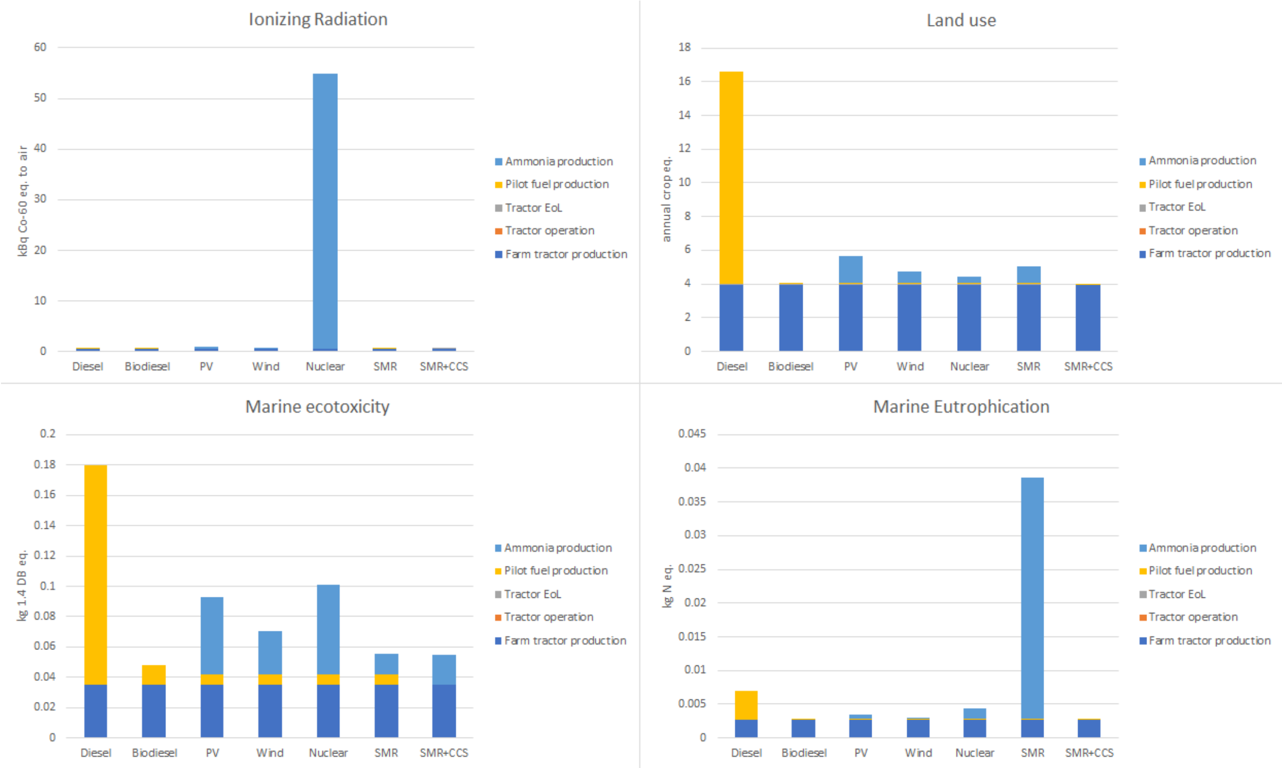

Figure 4: ReCiPe midpoint results per 1 ha over 1 year (3).

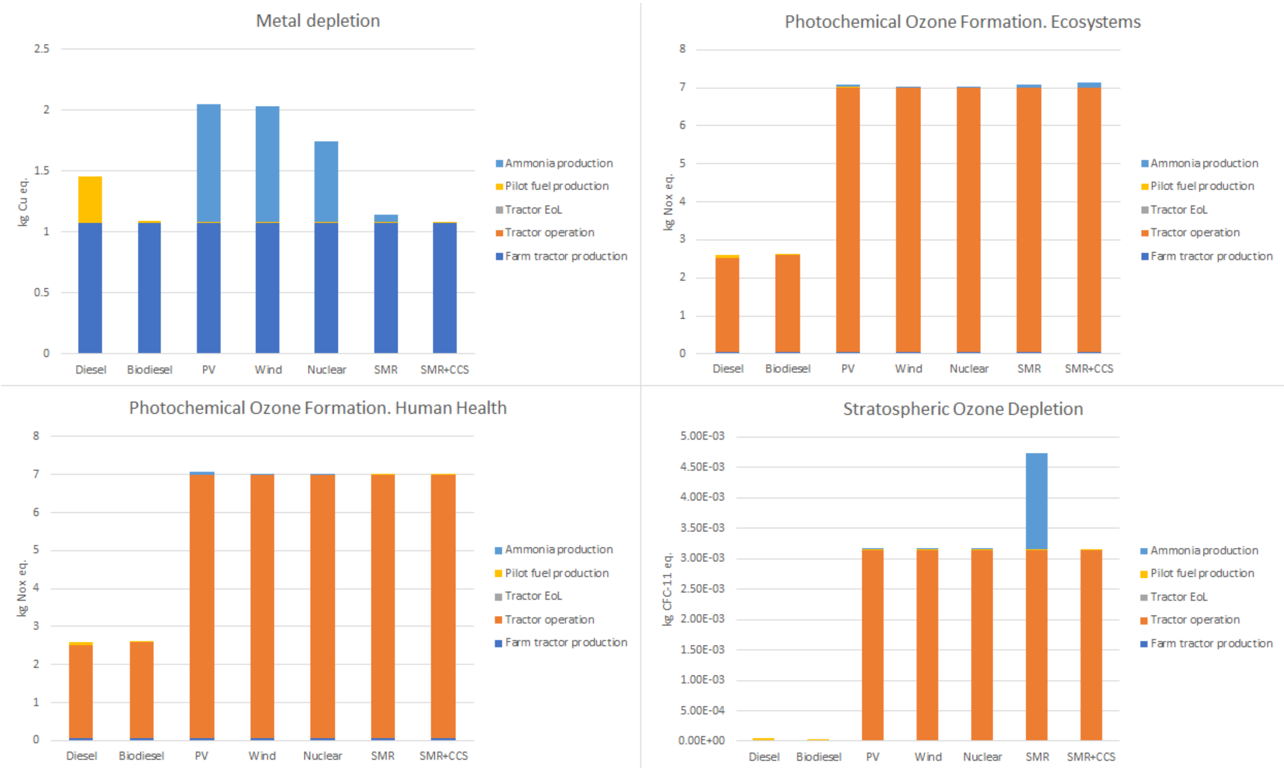

Figure 5: ReCiPe midpoint results per 1 ha over 1 year (4).

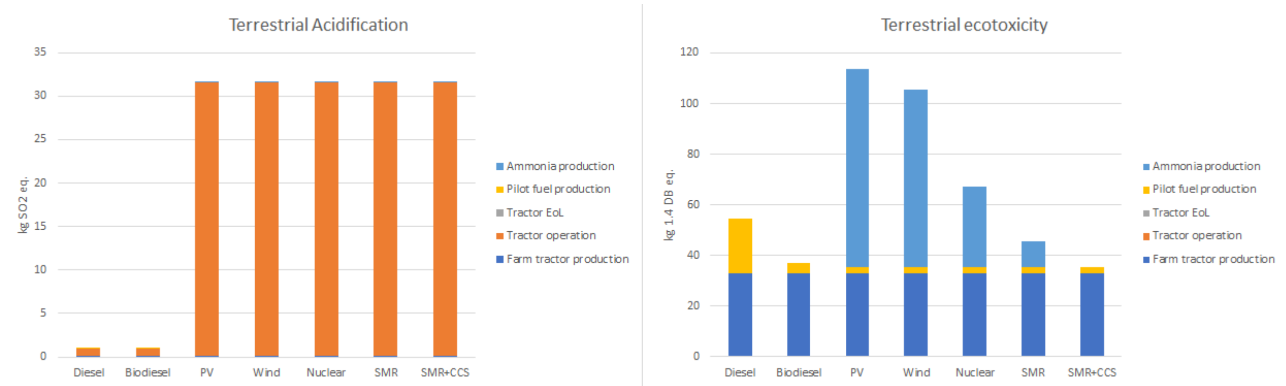

Figure 6: ReCiPe midpoint results per 1 ha over 1 year (5).

Since the general objective of the ACTIVATEngine is to achieve the low emission technology, considering the climate change as the main category (seen in figure 2), using the ammonia achieves little benefit which could be explained due to the difference in LHV of the fuels - whereas the diesel has the LHV of 43.1 MJ/kg [3], for biodiesel it is 37.4 MJ/kg (experimental data) and for ammonia it is 18.7 MJ/kg [3]. Therefore, in order to produce the same amount of energy, more than 2 times of ammonia per mass basis needs to be produced. Nevertheless, it has to be reminded that the results concern only the port injection technology (the experiments with direct injection are planned) and they will be verified in the WP5 using direct injection. Still, even the port injection could be beneficial if utilizing the electrical energy from the nuclear source.

Comparing the technologies through the endpoint categories, figure 7 is obtained. Utilizing ammonia via port injection does not provide environmental benefits as a whole using the ReCiPe 2016v1.1 characterisation factors.

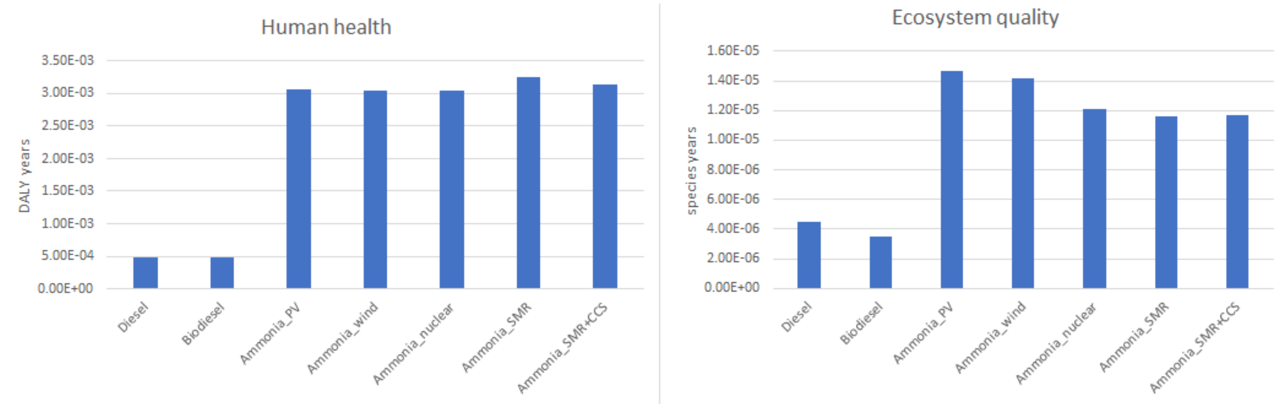

Figure 7: ReCiPe endpoint results per 1 ha over 1 year.

If we treat all of the midpoint categories equally, the technology that achieves the lowest environmental impact on most categories is the biodiesel, however the highest impact among the categories is attributed to diesel. Even though for such comparison the biodiesel would be the preffered option, its wide implementation is limited by the biomass supply. Therefore, even if the ammonia based fuelling systems achieve worse results in the endpoint categories, high value of diesel among the 5 midpoint categories indicates the need for further investigation of alternative sources, such as ammonia. Also, the values regarding the fuels production reflect the current industry data and so the diesel production process is more optimized than e.g. ammonia using hydrogen from electrical energy from PV energy. The comparison of such score is presented in figrue 8.

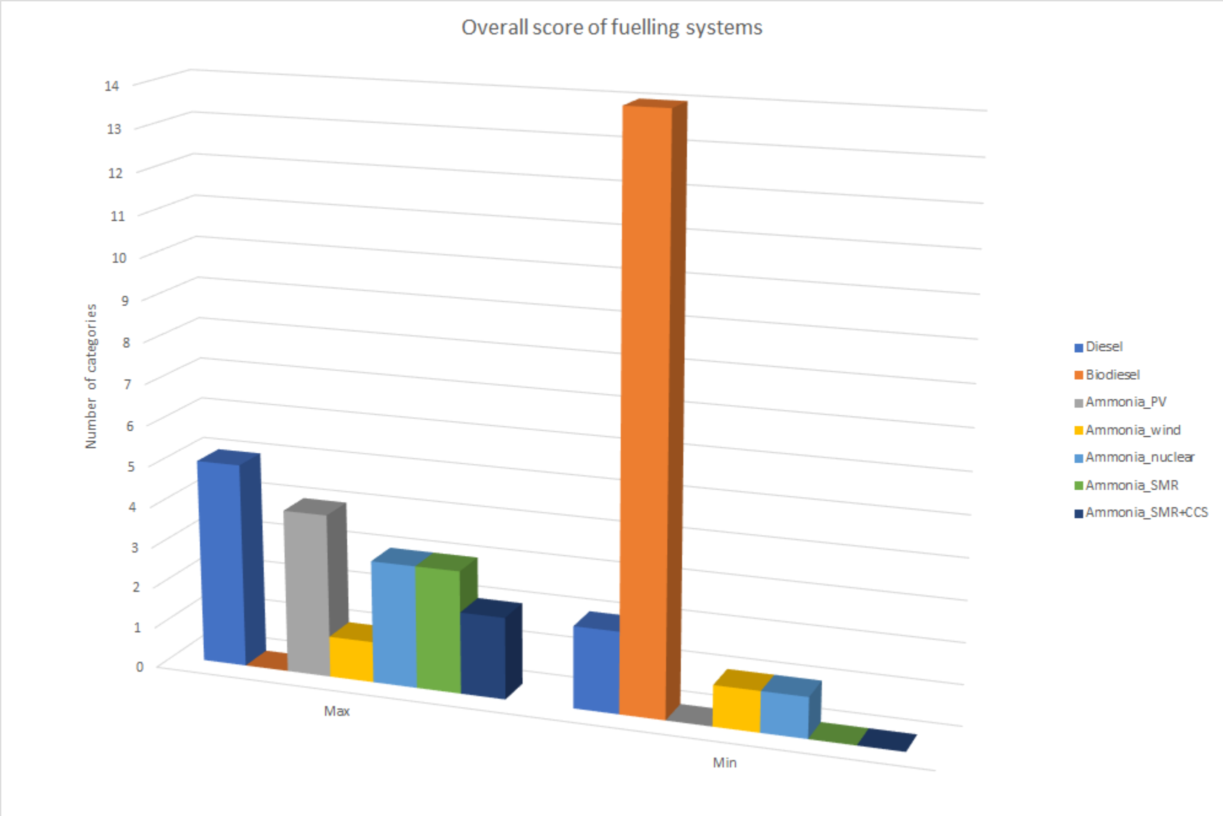

Figure 8: Overall score among the midpoint categories.

4 Conclusions

The LCIA shows 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. At this stage of TRL and maturity of ammonia production pathways, 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 (especially given the perspective that the renewable technologies are going to be further developed thus decreasing their environmental impact).

References

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

[2] Elshout P.M.F. Stam G. Verones F. Vieira M.D.M. Hollander A. Zijp M. Van Zelm R Huijbregts M.A.J., Steinmann Z.J.N. Recipe 2016 v1.1 a harmonized life cycle impact assessment method at midpoint and endpoint level report i: Characterization. *National Institute for Public Healthand the Environment*, 2016.

[3] GaBi® Software Documentation.