CEMA
European Agricultural
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The role of agricultural machinery in decarbonising agriculture

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Within agriculture multiple potential CO_2 reduction options exist for farmers to become more sustainable while improving the farm productivity. As there is no such thing as one size fits all in agriculture, farmers should have a strong voice in the assessment on which solutions work on their farm. One suitable solution in agriculture, for the coming decade, remains the internal combustion engine with the use of alternative fuels.

Additionally, for success to be guaranteed, there must be a commitment to support the adoption and optimal use of innovative technologies, the digital transformation, technical training, and necessary investments in production and storage infrastructure. This must be enshrined within a long-term strategy.

Proof should be delivered by either implementation of well-defined and harmonised practices or data-driven monitoring tools.

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Executive summary

The ambitious political will to engage and address our changing climate will affect us all.

Every sector must commit to an absolute reduction of its CO_2 footprint. The agriculture sector accounts for **10%** of the total EU27 greenhouse gas (GHG) emissions (from crops, livestock and soils), and an additional **~1%** of total EU27 GHG emissions can be attributed to agriculture from the combustion of fossil fuels during the normal course of operating agricultural machinery.

Approaches to reduce the CO_2 footprint are multiple. But farming is a holistic process, which includes many operations and variables which differ from crop to crop, farm to farm, and even year to year. Accounting for these variables when deciding how to reach an optimal technology mix for mitigating climate change within farming practices is an economic and industrial challenge.

The agricultural machinery industry produces a large range of advanced machinery and solutions that already support sustainable farming and help EU farmers of all sizes and types in getting the most out of their land while protecting the environment and generating economic and social value. This document highlights **potential CO_2 reduction solutions related to fuel combustion in agricultural production when using agricultural machinery and considering the whole agricultural mechanization processes**. In particular it assesses the possibilities of the use of alternative drives and fuels, best practice model predictions in overall efficiency, and touches upon technical solutions for CO_2 sequestration.

A first basic qualitative assessment shows that there are different ways to look at the issue of CO_2 reduction from the use of agricultural machinery.

There are multiple options depending on the focus of the CO_2 reduction exercise but there are no one size fits all solutions.

The digital transformation of farming and the use of smart technologies/solutions will be key to support farmers in becoming more sustainable while remaining competitive. Connected farming will enable traceability, for a better functioning of the EU internal market, and reduced administration.

Within a long-term vision and planning, well-targeted national strategies are needed to financially support farmers and contractors to invest in infrastructure, to ensure use of their fleet is optimised, to access the best available CO2 friendly technologies, or adjust to harmonised practices for energy optimised crop production. Therefore, this is not about a single solution, but about an overall strategy which fits in the advancing developments of other sectors, the availability of energy carriers and technologies, and the specific needs of agricultural work and machinery to maximise full potential benefit for every use case and end market.

In order to reach the final aim of carbon neutrality or even carbon negative balance, there are many options for the agricultural sector, including fleet use. In any assessment farmers should have a strong voice and retain the freedom of choice on which options to use in the most suitable and cost-effective way.

Due to the characteristics of agricultural machinery and the work they have to perform, the agricultural machinery industry believes that internal combustion engines remain a viable and suitable solution for the coming decade to deliver on the CO_2 reduction targets. This requires the promotion, production, and use of alternative fuels whilst other technologies (e.g. electrification) come to maturity.

Introduction

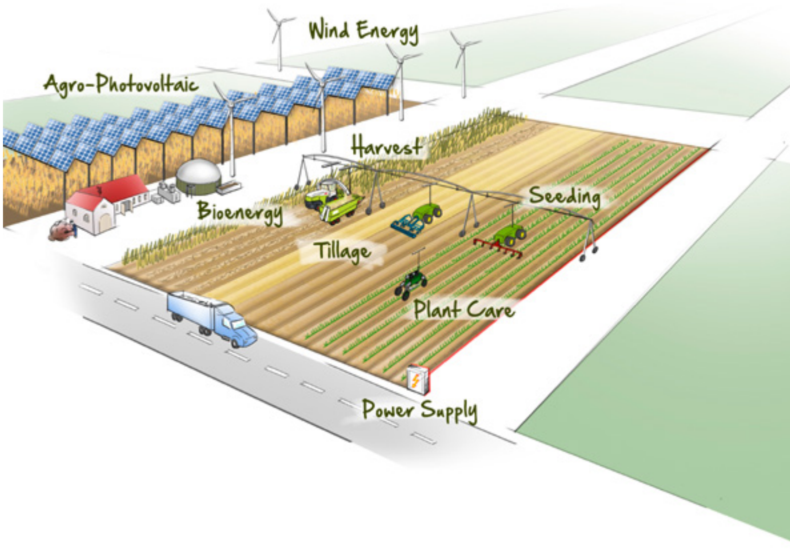
The climate is changing. Its effects are becoming tangible and there is broad scientific consensus it is caused by human activities producing more greenhouse gasses than oceans and biomass can sequestrate. With a proposed 55%[1] reduction of CO_2 emissions by 2030, Europe set the ambitious first target of reaching carbon neutrality by 2050. Member States will have to deliver, and every sector will have to contribute.

Agriculture[2] is, and will be even more affected by climate change with increased events of drought, floods, new pests. European agriculture is not uniform; it diverges from region to region and from year to year due to the varying conditions of weather, soil, topography, and organization of operations. This results in different farming practices depending on the weather conditions and crops year by year. Additionally, there are differences between subsectors. Crop production typically consumes fossil fuel and mineral and organic fertilisers. Dairy production consumes more electricity and emits methane. As agriculture depends more on the weather, the climate, on nature and its resources than many other sectors, the application of the sustainability principle is a common and crucial element of European agriculture.

The 'Paris Agreement'[3] established a global approach for tackling climate change. It enhances the implementation of the United Nations Framework Convention on Climate Change, adopted in New York on 9th May, 1992. This entails holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels.

For the EU this is translated in binding annual emission reductions by Member States[4] and is also overall embedded in the 'Green Deal'[5] which aims at making the transition to a carbon-neutral EU economy.

Every sector must commit to an overall reduction of its CO_2 footprint. Looking at the overall Eurostat figures[6] the agricultural output from crops, soils and livestock accounts for 10 % of the total EU27 greenhouse gasses in CO_2 equivalent (see Figure 1). The main contributors are N_2O and CH_4 emissions from fertilizers, slurry, and ruminant animals. For agriculture the aim is at least carbon neutral farming, which is supported by many actors in the chain including farmers and the supplier industry. The options range from improvements for waste and slurry management, use of precision and other advanced technologies to increase efficiency, increase of permanent pasture acreage, reestablishment of wetlands, production and use of bio-fuels, bio-plastics, and installation of additional capacity for solar and wind energy production.



1 55 % reduction of the CO2 production in 2030 compared to reference year 1990 (Green Deal proposal) - COM(2020) 562 final.

2 The meaning of agriculture in this document: arable crops, horticulture, speciality crops, livestock and further areas.

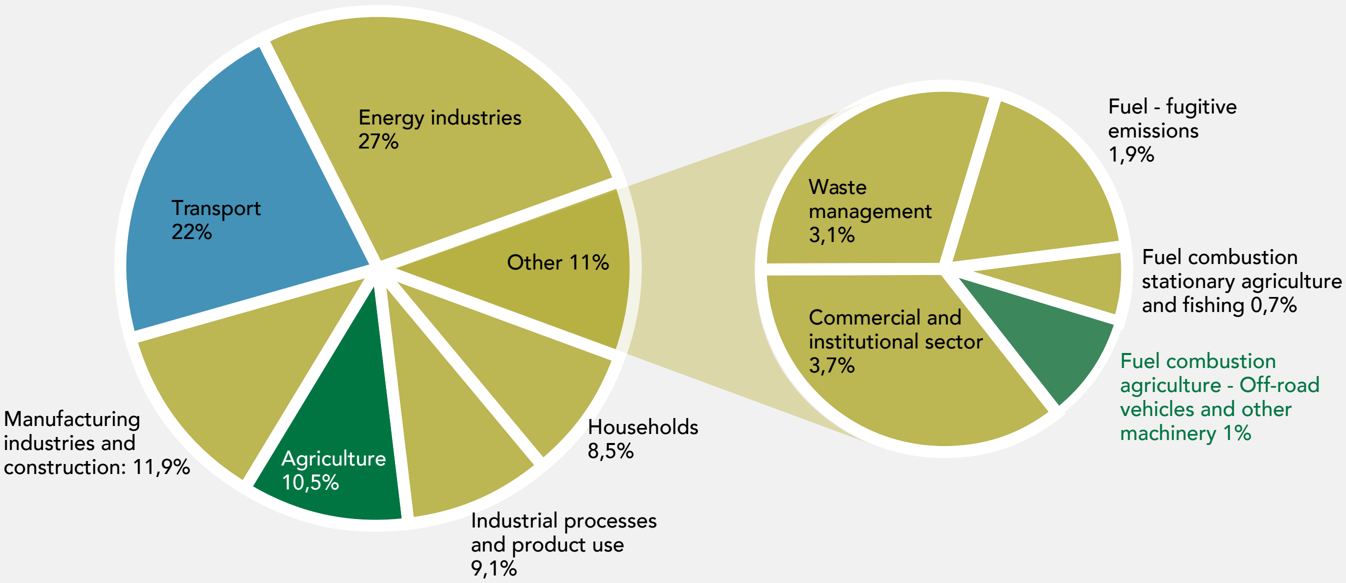
3 https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

4 Regulation (EU) 2018/842 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013

5 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en#documents

6 EUROSTAT online data code: ENV_AIR_GGE ; Source of data: European Environment Agency (EEA) ; Last data update: 09/06/2020 – this excludes for agriculture

Figure 1.
Share of total GHG emissions [CO_2eq] of the different sectors



Farmers should maintain freedom on which options to use in order to minimise their CO_2 footprint in the most suitable and cost-effective way. A systemic approach can help farmers in their selection[7,8].

The agricultural machinery industry, shaped by its end customers, European agriculture, and global trade, is committed to the cause of reducing GHG emissions. For many years, our industry has offered a wide range of innovative products and machines meeting European and worldwide environmental regulations and allowing efficient agricultural production processes. The sustainability principle is part of our companies´ industrial practices (as shown in their sustainability and CO_2 footprint reports) but also in the development of the machines (in relation to performance, reliability, durability, disposal). The agricultural machinery industry was the first one to introduce the international sustainability standard ISO 17989 (Tractors and machinery for agriculture and forestry - Sustainability - Part 1: Principles).

Based on this self-commitment concept, the industry initiated various developments with the intention to increase the eco-friendliness of machines and production. Examples are machine connectivity with ISOBUS, precision farming, alternative fuel technology, automated machinery operation, and International and European standards for the protection of the environment during the use of sprayers and fertilizer application equipment. The latter has been promoted in the joint CEMA-ECPA Step-Water Webtool[9].

The CO_2 emissions of agricultural and forestry machinery[10] from fossil fuel combustion accounts for approximately 1% of the total GHG emissions in the EU27. It must be clarified these are the CO_2 emissions from energy used as an input to agricultural production and is not part of the 10% as an output from agricultural production.

7 https://www.tu-braunschweig.de/energy-4-agri
8 https://www.agrofossilfree.eu/

9 https://step-water.org/
10 https://di.unfccc.int/detailed_data_by_party: CO2 from fuel combustion of off-road vehicles and other machinery (from agricultural/forestry excluding stationary machines and fishery)

This limited impact on overall GHG emissions did not stop the industry from investigating further CO_2 reductions from using agricultural machinery. It started in 2011 when CEMA and CECE (the construction machinery industry) developed an approach using 4 pillars looking at:

- **Machine efficiency** - looking at the optimisation of all elements related to the machine itself (engine, transmission, hydraulics, tyres, etc.)
- **Process efficiency** - considering the setup of the process to fulfil the desired job (e.g. selecting the most efficient combination of machines for the application, the best machine for each task etc.) and the use of latest technologies (e.g. coordination of multiple machines' operations via satellite navigation).
- **Operation efficiency** includes the training of machine operators or technologies - to simplify machine use (e.g. providing enhanced process information to the operator, fully/partly automate machine operation)
- **The use of alternative energy sources** that deliver the same amount of energy but emitting less CO_2 such as biofuels, electric drives, hybrid drives, etc.

The main outcome of this approach at that time was that best results can only be obtained by measuring fuel efficiency over the entire crop or livestock production process, also from a cost-effective point of view. This insight was elaborated in a brochure[11] with many practical examples within the 4-pillars and was shared with EU policy makers.

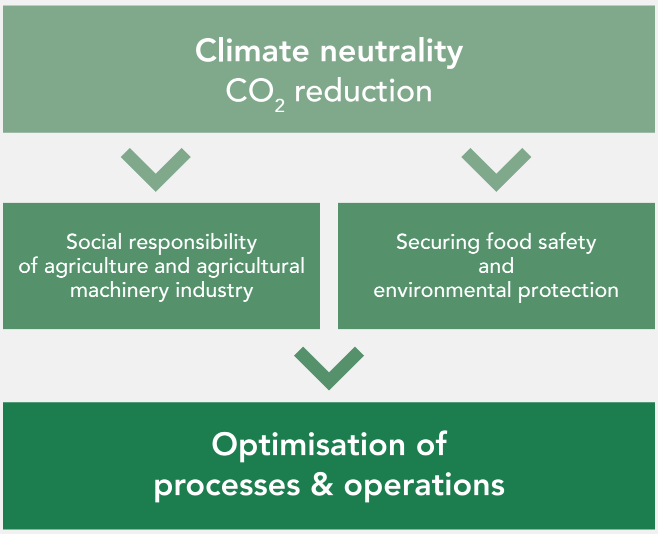
In this paper we will provide a state of play on the different approaches to reduce CO_2 emissions from fossil fuel combustion during the use of machinery in agriculture.

Three key questions have been identified:

1. How can the optimized use of the most suitable machinery within the crop production process help reduce CO_2 from fuel combustion?
2. What alternatives are available for traditional fossil fuels? What are the benefits and what are the challenges?
3. How can advanced technologies provide further help to turn agricultural land into more efficient carbon sinks?

For reaching the target of CO_2 neutrality, these questions must be dealt with comprehensively (see Figure 2). The outcome should be the optimisation of agricultural processes, which will preserve the balance between the necessary environment protection and agricultural production notwithstanding our social responsibility.

Figure 2. Reaching CO_2 neutrality while keeping a proper balance results in an industry vision oriented toward optimisation of process and operations, possibly combined with usage of alternative energy sources



11 https://www.cema-agri.org/images/publications/brochures/CECE_CEMA_brochure_Reduction_CO2_emissions.pdf

How can the optimized use of the most suitable machinery within the crop production process help reduce CO_2 from fuel combustion?

The target is to reduce the CO_2 footprint of fossil fuel combustion from agricultural and forestry vehicles and other machinery.

From the automotive sector we know the Well-to-Wheels concept[12] which takes into account the chain of CO_2 emitting operations when comparing cars, energy sources, and related emissions (Figure 3).

Figure 3. Different operations based on the sources in scope of the JEC Well To Wheel analysis (JEC Well-To-Wheels report V5[13])

WELL

- Production primary fuel
- Production "road" fuel
- Fuel to vehicle
- Transport primary fuel
- Distribution "road" fuel

TANK

- Charging losses
- Fuel combusted in the vehicle within the process chain

WHEELS

CO_2 emissions / kms travelled

STANDARD STEPS

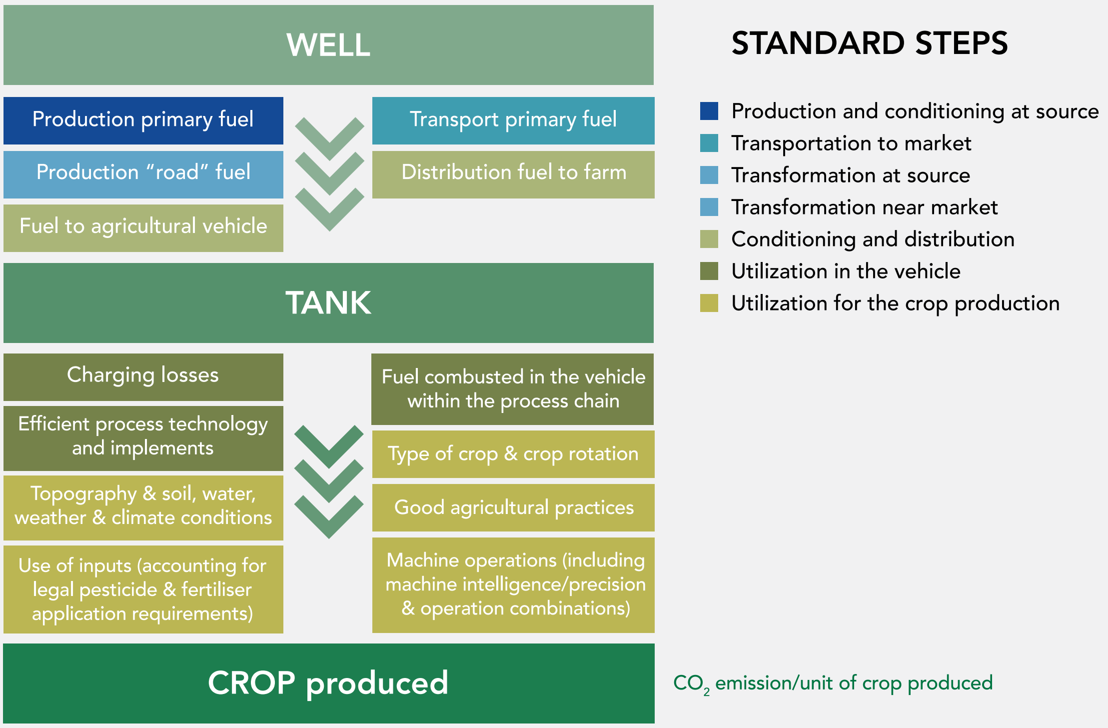
- Production and conditioning at source
- Transportation to market
- Transformation at source
- Transformation near market
- Conditioning and distribution
- Utilization in the vehicle

12 https://ec.europa.eu/jrc/en/jec/activities/wtw
13 https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/jec-well-wheels-report-v5

A corresponding exercise for agriculture would imply to refer not to the distance travelled, but to the tonnes of crop produced and harvested. It could be calculated as CO_2 emission per unit of crop produced.

Within this exercise a multitude of factors needs to be considered as displayed in Figure 4.

Figure 4. Additional factors in agriculture influencing the output (in unit of produced and harvested crop) versus input (in CO_2 emission)



Reduced fuel consumption improves the ecological balance and has a positive effect on production costs. There is a clear economical interest from farmers to lowering the CO_2 footprint (fuel use) from producing crops, and for decades efficiency gains have been a significant market demand in agriculture. To realise further efficiency gains, the sector has expanded its perspective to focus on process components. It is well known that agriculture is characterised by a high degree of complexity and variability. Farming differentiates from other industrial processes because it takes place in a natural environment. Many parameters like soil, water, sun, slope, pests, effects of previous crops, are highly variable, but they also impact efficiency and working quality. That is why they are difficult to predict and can scarcely be quantified with single standardised values.

Other examples are the yield effects of annually variable precipitation, and the required diversity of procedures and tools used in soil tillage or simply the working depth when using these tools. Therefore, a generic and standardized methodology for agricultural machinery and practices for reducing CO_2 emissions, would be an enormous effort on a continuous basis.

However, reviewing the different process steps makes considerable savings potentials possible along the entire production chain and gaining such insights will be of great support for farmers.

That was the chief goal of the EKoTech project, where a highly qualified group of industrial, academic, and association experts qualitatively and quantitatively evaluated a large number of technology innovations from multiple manufacturer brands. 27 different individual innovations were identified, with the potential individual innovation savings going up to 42%.

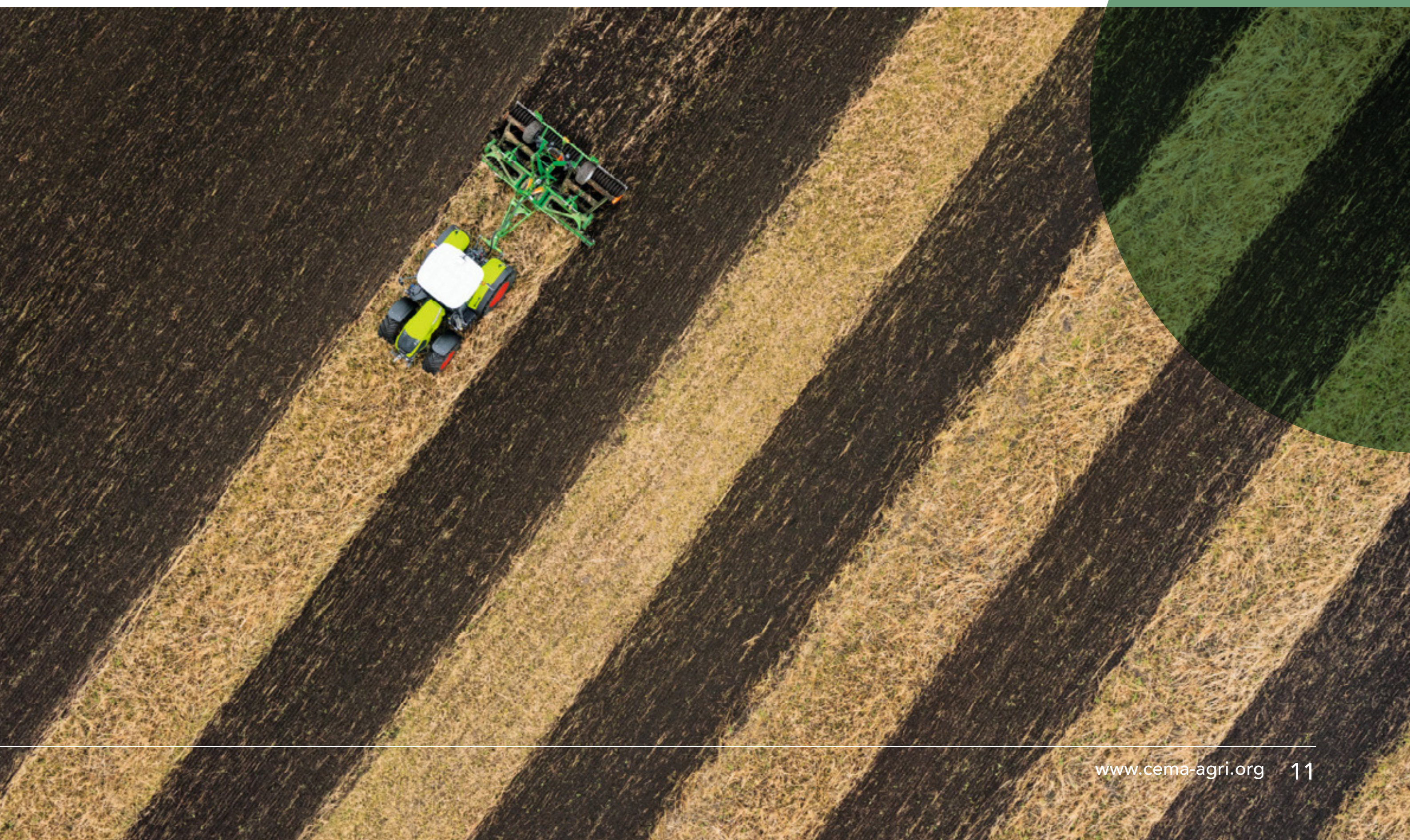
Up to now the following major findings were released:

- For the period from 1990 to 2030, using the best practices, combining a selection of innovations as described by the EKoTech project, the forecast is a fuel consumption savings potential on average between **35 and 40%** per ton of crop produced and harvested.
- The greatest fuel consumption, looking at the individual process steps, takes place during soil tillage and harvesting of agricultural crops.
- 19 of the 27 savings potentials relate to process steps with the greatest fuel consumption in the farm production chain. The greatest savings for the overall crop production process can be achieved by optimizing the process steps for soil tillage and sowing.

The EkoTech study, though example-based and not a detailed simulation of agriculture, demonstrates that agricultural practices play an important role in reducing the total fuel consumption and thus CO_2 emissions from the use of the current fleet of machinery with combustion engines for the production of crops.

To be successful in implementation, the practices revealed should be part of the solutions offered to farmers to comply with the Green Deal/Farm2Fork strategy and to deliver on the Paris Agreement.

Monitoring of the implementation will be important to ensure a proper functioning of the EU internal market. This proof of compliance by data within the digital transformation of farming and within a European common data space will also serve to gain further insights in agricultural processes in support of farmers to become more sustainable.



What alternatives are there for fossil fuels? What are the benefits and what are the challenges?

For the transport sector it was already identified that alternative options to decarbonise exist, but will require infrastructure development at local and EU scale (e.g. electric charging stations, hydrogen/ alternative fuel stations, etc.). For some hard to abate sub-sectors, notably aviation, this will also require the development of advanced biofuels and synthetic fuels. **The main bottlenecks** observed are **infrastructure** (for electrification of the fleet or the use of hydrogen and alternative fuels) and a **non-maturity of technology** (mainly batteries) for certain sub-sectors. Though not comparable with the transport sector, similar bottlenecks can be identified in the agricultural sector. Particularly on the development of the necessary infrastructure on-farm and even in-field for daily refuelling (almost every farm has a diesel tank for fast refuelling in high season) there is a need for a **long-term vision**. For battery-electric and fuel-cell electric solutions such vision should consider the evolution in CO_2 neutral energy production and battery technology, but also the diversity in the fleet from very small to very large, and the many different operations from short low-energy to constant high energy demanding operations.

Electrification

Looking into the practical aspects related to electrification the following can be observed:

Electrification - full battery electric: besides the issues of cost and life cycle, the main challenge related to batteries remains energy density and weight. Taking the example of an average tractor[14,15] the traditional system with diesel engine requires a 400l energy reserve of fuel (9.8 kWh/l resulting in a total of 3920 kWh or 1670 kWh due to the 40-45% engine efficiency).

For the full electric variant this energy reserve in the form of Li-Ion batteries (best values of the battery pack expected in 2025: midterm 0.2 to 0.25 kWh/ kg), resulting in a total of 2000 kWh due to the high battery efficiency, weighs **9-10 ton and takes 5000 l in volume** and this to do the same 8 hours of work.

An exercise on the potential of the different **electrification options** by 2030 for the different subsectors the highest potential for smaller machines when looking at tractors/agricultural mobile machines[16] with batteries as primary energy source. Larger tractors would exceed acceptable weight limits and subsequently create highly negative, non-sustainable soil compaction. The assumption is also that the buyer in the future will not benefit anymore from reduced prices for fuel and will therefore accept a higher price for an electric powered vehicle. The main driver for smaller electric machines is the possibility/allowance to do operations close to the farm for charging or indoor applications. Products such as electric low power tractors or loaders are already on the market due to available technical solutions and customers' demand for such products, noticeably hobby farmers.

14 https://www.fendt.com/de/geneva-assets/article/94968/592540-fendt700vario-2002-td-de.pdf

15 https://www.volkswagenag.com/de/news/stories/2018/10/powerful-and-scalable-the-new-id-battery-system.html

16 VDMA doc 'Antrieb in Wandel' - https://elektromobilitaet.vdma.org/documents/266699/25083160/Antrieb+im+Wandel+-+Broschuere/1bdef884-8c1c-4681-8ac1-ef51bd12fff0

The challenges observed are the sufficient energy supply of farms, the charging infrastructure, but also the issue of increased weight and reduced operation time.

Electrification – fuel-cell electric: An alternative to battery-electric solutions are fuel cell-electric solutions based on **hydrogen**. Depending on the kind of fuel cell, they require pure hydrogen made from non-efficient electrolysis. In terms of sustainability green hydrogen (made from (excess) renewable energy) or blue hydrogen (made from fossil fuel with carbon capture) should be targeted.

The weight and volume of hydrogen storage systems are lower/more compact than full battery electric but still too high at present, resulting in inadequate vehicle range compared to conventional diesel fuelled vehicles. Fuel cell-hydrogen tractor prototypes have been developed but are currently commercially not viable. For tractor applications, besides installation issues, there are the challenging, high-demanding issues of tank and fuelling infrastructure, and logistics which implies the need for significant investments. While this technology has an advantage over battery electric solutions for high power applications in terms of size and weight, efficiency decreases due to high cooling demand. Such a development and its viability are dependent on how ICE (Internal Combustion Engine) will remain accepted long-term and how successful fuel cell technology will become in other sectors of industry, as a reference for the agricultural machinery sector.

Electrification - hybrid: this fits within the followed path of manufacturers to electrify functions and towed/mounted implements (e-implement enabler) to optimise energy use by decoupling energy use from the engine power. Direct energy for these functions/implements simplifies and minimises losses while increasing the flexibility of the whole platform. Overall, it results in efficiency gains for the tractor itself but also for the implements used that is reflected in reduced fuel use.

Alternative fuels

A 2020 JEC study[17] concluded that overall for the alternative fuels they investigated, almost all offer a better Well-To-Wheel performance than conventional diesel when used in Internal Combustion Engines.

CNG/LNG (compressed or liquified natural gas with the gas being mainly methane):
It considers natural gas from fossil sources and accessed from the national gas grid and provides a 10-20% reduction in CO_2 compared with diesel, while offering equivalent power and torque. As for CNG there is a vehicle storage constraint as 4 times more storage space is needed for the same working hours, even if there are many applications where this more limited capacity is not an issue (e.g. livestock related activities, wheel loader, etc.) For open field work extended autonomy can be achieved if additional storage is placed on the implement side, or in the front of the tractor instead of the ballast weights.

LNG is enabling a 2,5x better volumetric energy storage vs. CNG, but requires storage at low temperature to keep methane at liquid state. Heat slowly affects the tanks, which can cause the LNG inside to evaporate and produce a substance known as boil-off gas (BOG), which needs to be vented. This is a storage problem considering the seasonal use of agricultural machinery.

The more complex refuelling infrastructure is also a constraint, but in countries where road fuelling infrastructure is available it may become suitable also for farm machinery.

17 JEC Well-To-Wheels report v5 - Well-to-Wheels analysis of future automotive fuels and powertrains in the European context

Biomethane: gaseous fuel produced from agricultural biomass (crop residues and manure from husbandry), or from the organic fraction of the municipal solid waste, as biogas which is then further upgraded to biomethane. However, it may also be produced from dual use plants, double cropping areas, intercropping sources, or biomass from biodiversity reserved areas, which do not negatively affect food production capacity.

Benefits are the restoration of organic matter in the soil using the digested material as an excellent natural fertilizer. There is also an immediate reduction of greenhouse gas emissions from animal waste being processed in a biogas plant, as methane gas that would have been emitted naturally is now captured in the process.

Biomethane generated from city waste, manure or agricultural waste, which can be used within the farm or distributed through the national gas grid, **has the best CO_2-balance of Well-to-Wheel of any currently known energy source, and is even considered CO_2-negative in the case of manure**.

Biofuels: important liquid fuels to be mentioned are Hydrotreated Vegetable Oil (HVO) and biodiesel (FAME - biofuel produced by transesterification of vegetable oils). There are also 'advanced biofuels', a term used for biofuels that can be manufactured from various types of non-food biomass. Within the European Regulation EU 2018/2001 the biomass that can be used for advanced biofuels is currently strongly limited to straw and manure to ensure a low risk for indirect land use change (ILUC).

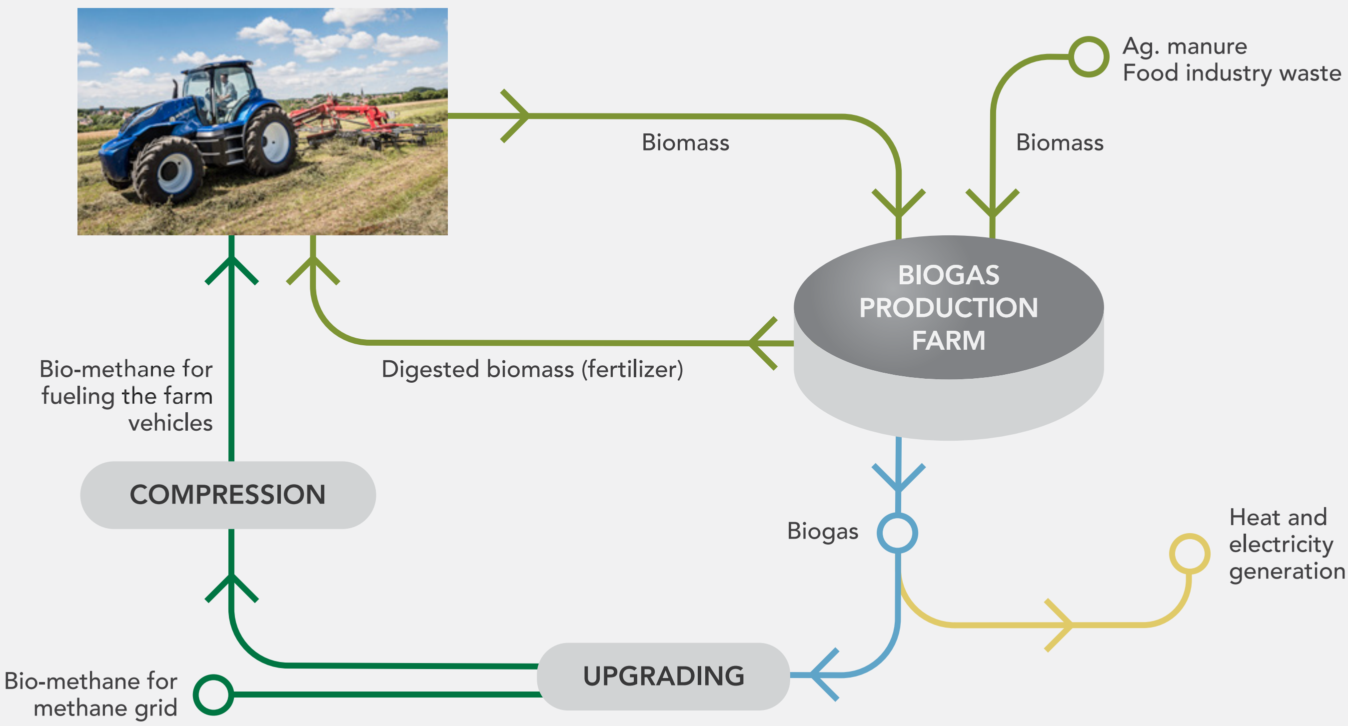
Pure Plant oil: could be produced directly on the farm whenever needed. With adaptations traditional engines could run on plant oil according to predetermined quality criteria. It is for direct use as it is difficult to store over long periods of time. Though the technology has proven that it works, take off in the past has been low due to technical limitations for use and missing standardised quality parameters.

On-farm produced alternative fuels (i.e. bio-methane, plant oil): production can generate several business opportunities for farmers (Figure 5) from the use as fertiliser of the digested biomass (rest product), direct heat and electricity production, to use in agricultural vehicles and for feeding of the gas grid with biomethane for other applications.

Another benefit of on-farm production of alternative fuels is that the parameters fuel transport and distribution outlined as CO2 sources from the JEC Well-To-Wheels analysis are not relevant anymore.

Synthetic fuels (also called Power-to-X fuels or e-fuels): Green electricity can be converted into liquid fuels, starting from hydrogen, in an environment-friendly way with the aid of chemical synthesis processes. In addition to electrical energy, primarily water (to make hydrogen) and CO_2 are required as source materials – the latter can either be gained from biomass, industrial processes or separated directly from the air. The production of liquid fuels has the advantage of the best energy storage, especially for transportation.

Figure 5.
Business model related to the on-farm biogas production cycle.



Energy in form of electricity or hydrogen is difficult to transport, e.g. when produced in other countries around the world which often have much better preconditions to produce renewable energy. One method called 'direct air capture' is currently in the testing phase. Ideally, it could make CO_2-neutral diesel fuels possible. The technology offers many advantages, as synthetic fuels may be used in current infrastructure as well as in existing combustion engines.

Future use of ICE in agricultural machinery: Internal combustion engine technology itself is not affecting climate. The burning of fossil fuel does. Where battery electric drives have limitations for use in larger farm machinery, combustion engines fuelled by gaseous biofuels like biomethane, liquid biofuels like HVO, FAME (Bio-Diesel) or synthetic fuels combine several advantages.

To start, case dependent, these fuels do not require huge investments in new fuelling infrastructure. Agricultural machinery are characterized by very long life cycles of 25 to 30 years. Still, agricultural mechanization can already contribute in the short term to the EU climate targets as alternative fuels burned in combustion engines may be used as well in the existing fleet, depending on the fuel, the engine type/stage and engine conformity requirements. In case of limited availability, they can even be mixed in various portions with conventional diesel.

It must be noted that hydrogen could also be used directly in combustion engines (30 % efficiency well-to-wheel compared to 35 % H2-fuel cell[18]) providing a zero-emissions option for specific use cases while supporting the growth of hydrogen infrastructure.

To conclude, some alternatives are already available but dependent on availability of fuelling infrastructure in rural areas and type of farm management. There is also a difference in strategy between Member States on the promotion of certain alternative fuels for mobility. Alternative fuels can play a key role in decarbonizing the agricultural sector, also on the short term by greening the existing fleet. But there is a need for a strong and clear political commitment from European and national authorities. Examples are the promotion of alternative fuel production directly on the farm derived from agricultural or animal waste (to avoid the competition with food production), or the recognition of the agricultural sector as a key sector for the use of synthetic fuels. This can be achieved by supporting the installation of appropriate technical solutions or the needed infrastructure and by keeping engines affordable. **As there is not one particular solution that is predominant, promotion of alternatives within a long-term strategy should encourage the exploration of the potential of multiple technologies to guarantee 'farmers' freedom of choice.**

18 https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/how-hydrogen-combustion-engines-can-contribute-to-zero-emissions

How can smart technology provide further help in carbon farming to turn agricultural land back into carbon sinks?

Both farmers and the EU Commission see agriculture and forestry becoming "the first sector to deliver net zero greenhouse gas emissions" and balancing out greenhouse gas emissions from other more polluting sectors. They see the potential to become rapidly climate-neutral by around 2035 in a cost-effective manner by enhanced soil management. Globally, soils store more carbon than all the vegetation and the atmosphere combined[19]. The total storage of organic carbon for the EU27+UK topsoil (0-30 cm) is estimated to be 73 billion tons of carbon. About 50% is in peatlands and under forests and 22% in agricultural soils[20]. Mineral soils store considerably less carbon than organic soils. In Europe, organic soils store four to five times more carbon than forests[21]. Under cultivation, organic soils are usually drained, which causes high CO_2 emissions. Total CO_2 emissions from organic soils in the EU reached 107 million tons CO_2eq in 2019 which represents about 37% of total EU net removals from LULUCF.

Soil quality is increasingly under pressure around the world. The increased production without proper soil monitoring and management leads to poor soil fertility, poor soil structure and thus soil degradation. The result is that often more CO_2 is released than stored by these soils.

There are some practices that are indisputably positive like the restoration of wetlands as they are carbon sinks which in case of drainage turn into a carbon source.

19 Friedlingstein, P., Jones, M. W. et al., 2019, Global Carbon Budget 2019. In: Earth Syst. Sci. Data 11 (4), pp. 1783–1838. DOI: 10.5194/essd-11-1783-2019
20 Camia, A., Giuntoli, J. et al., 2021, The use of woody biomass for energy production in the EU (JRC122719). Publications Office of the European Union (ed.). Luxembourg, 2021. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC122719.
21 Swindles, G.T., Morris, P.J. et al., 2019, Widespread drying of European peatlands in recent centuries. In: Nat. Geosci. 12 (11), pp. 922–928. DOI: 10.1038/s41561-019-0462-z.

But in other cases and in particular for creating healthy, agricultural soils, there will need to be trade-offs. There is a dependency on many factors like soil type, climate, or weather conditions. Taking the example of no-till, promoted as an important solution for soil preservation/regeneration, and already prevalent in South America, it does not provide the same yields in most European highly intensive agricultural areas.

The European Commission has taken a big step forward with the carbon farming initiative, launched at the end of 2021, which also focuses on peatland restoration and rewetting, agroforestry, and maintaining and enhancing soil organic carbon (SOC) on mineral soils. The overall potential of these practices must be assessed in function of the crop production. And farmers, in order to deliver, should be given the choice of technology/practices as wide as possible. Environmental observation, described as the main focus of a potential partnership 'Agriculture of Data' to help farmers reach the sustainability targets and improve compliance by data, could be a valuable asset to ensure the freedom of innovation.

Additionally, farmers going beyond the basic environment and climate requirements would get a percentage of financial support from the direct payments within the Common Agricultural Policy through the introduction of "eco-schemes", most probably binding as of 2025. One of the flagship eco-schemes proposed by the Commission is 'Precision Farming' – plant or spot specific applications for optimal nutrient management.

The use of connected precision farming technologies to reduce application of soil work, seed, fertilizer, or pesticides to individual needs of any specific area and crop variety is a key solution for sustainability and climate action in terms of:

- less soil compaction, less traffic marks in the field,
- use of improved, adapted practices in soil tillage leading to increased soil fertility, and soil resilience to erosion,
- use of more plant and soil specific and precise monitoring and treatment in terms of sowing, planting, fertilising, spraying pesticides, and harvesting,
- use of intercropping, cover- and deep-rooting crops, multi-cropping, rotation extension or a combination of these practices,
- use of dedicated operations for organic farming like mechanical or electrical weeding.
- adaptation of mechanization for new practices like agroforestry or crop diversification practices.

In support of this exercise, studies like EkoTech could be extended to more relevant sources of CO2 emissions from inputs like fertiliser and from crops and the soil itself. This could be done by adding the relevant emission models. Such systemic approach could serve as an example to gain insights in the right practices, their interaction and land-use overall to achieve 'regenerative' agriculture[22].

Assessment of the different potential options with estimates on reduction potential, efficiency gains, costs, investment needs and return on investment

There are many ways in which adapted agricultural mechanisation processes can contribute to a significant CO_2 emission reduction in agricultural production. We did not include in this assessment the use of agricultural machinery to obtain improved soil CO_2 sequestration, as the focus of the document is the CO_2 reduction potential when using agricultural machinery and this within the whole agricultural mechanization processes. It must however be clear that agricultural machinery and smart technologies overall will play a role in carbon farming. In this respect it is important to stress again the necessary flexibility, in terms of legal requirements and fair administrative framework, of agricultural machinery producers to adapt existing technologies, develop new technologies, and place them on the market swiftly to support the new needs of farmers.

In table 1 the different options for CO_2 reduction in agriculture using machinery are outlined versus some key parameters as CO_2 reduction potential, costs and return on investment. The assessment is done within the concept well-to-crop produced.

For clarity reasons the different terms are explained for a correct interpretation of the table, looking at the different alternatives for traditional diesel fuel and energy efficiency optimisation methodologies.

22 A conservation and rehabilitation approach to food and farming systems. It focuses on topsoil regeneration, increasing biodiversity, improving the water cycle, enhancing ecosystem services, supporting biosequestration, increasing resilience to climate change, and strengthening the health and vitality of farm soil. Practices include recycling as much farm waste as possible and adding composted material from sources outside the farm.

As alternatives for diesel fuel for this assessment we only make distinction between two types of fuels:

- **Sustainable biomass fuels** - current alternative fuels, being liquid or gaseous, made from biomass that meet the sustainability criteria (with low risk for ILUC- indirect land use change /does not impede the food production) like biodiesel, biomethane, pure plant oil, hydrotreated vegetable oils (HVO[23]). In this context we do not restrict to the biomass as accepted within EU 2018/2001.

- **Synthetic fuels** - hydrogen based Power-to-X fuels like Power-to-Liquids (PtL) and Power-to-gas (PtG)

Alternative drives can be distinguished between:

- **Full electric powertrain with battery** (source: renewable energy only/carbon capture): by using as energy source a battery, with full electric drive train - compared to traditional combustion engines, electric motors are up to 3 times as efficient. If the electricity is produced from renewable sources, the CO_2 reduction potential is near 100 %.

- **Full electric powertrain with H2 - fuel cell** (source: renewable energy only): by using as energy source a fuel cell, with full electric drive train – the main issues are the efficient production of hydrogen and storage.

- **Hybrid electrification in combination with internal combustion engines (ICE)**: can range from mild hybrid electrification of certain functionalities, full hybrid solutions where some/all work functionalities, including those on the towed /mounted implements and even part of the drive train can be powered by a battery, to full electric drive train where the combustion engines is the only energy source.

23 For explanation of fuel names we refer to EN 15940

In terms of energy efficiency optimisation methodologies, for this assessment we make a differentiation between:

- **Towing machine optimisation (drivetrain)**: it concerns the optimisation of a single towing vehicle in terms of the transfer of energy from the energy source (e.g. combustion engine) to the drive train and the auxiliaries.

- **Towing machine + implement use optimisation within the process and the process chain**: with 'process' is meant following activities among others: ploughing, seeding, weeding, harvesting. With 'process chain' is meant the full crop production process including field practices, farm management, precision farming… With 'optimisation' is meant here the optimisation, in terms of energy use, of the application of a tractor-implement combination or self-propelled machinery, within the execution of an individual process and within the different processes of a crop production process chain. This entails the understanding on how different operations are impacting each other to find an optimal mix of processes and technologies to minimise the energy use within the process chain.

Looking at the different key parameters the following meaning is provided to understand the context:

- **Energy efficiency gains in crop production**: the efficiency gains of only the use of machinery in the crop production process chain, not considering efficiency gains on any other input or of the energy source used.

- **CO_2 reduction potential**: looking from well-to-crop produced what is the overall CO_2 reduction potential only of the use of machinery.

- **Investment in vehicle adaptation and/or infrastructure on farm/ in-field**
  - *Investment in vehicle adaptation:* the amount of investments by manufacturers, necessary to make changes to the vehicle design, in order to make it suitable for the use of specific alternatives to diesel or for use within an energy efficiency optimisation methodology.

  - *Investment in infrastructure on farm/ in-field:* the additional investments farmers/public authorities would have to make to install special charging/ fuelling infrastructure (e.g. underground storage facility for biofuels, high voltage cables)

- **Return on investment for farmers (farmer's cost vs CO_2 reduction - mid-term 2030**: return on investment for vehicles, infrastructure or implementation of energy efficiency optimisation methodologies in relation to the resulting reduction in CO_2 production for the coming years until 2030.

- **Applicable fleet**:
  - *Existing fleet*: though the energy efficiency potential and CO2 reduction is generally higher with new machinery, under certain conditions adaptations to/retrofitting of engines can make the existing fleet suitable for the use of specific alternatives to diesel or for use within an energy efficiency optimisation methodology. It could have an immediate effect on the CO_2 production of the existing fleet.

  - *New fleet*: some adaptations can only be done by full redesign and therefore be applied to new types of vehicles.

  - *Future fleet*: due to high cost or immature technology the implementation is only feasible for future types of vehicles after 2030.

Table 1.
Assessment table for different options in function of key parameters and this within the concept well to crop produced.

- Clearly negative potential
- Somewhat negative potential
- Neutral/ difficult to assess/Not applicable
- Somewhat positive potential
- Clearly positive potential

	Potential options for CO_2 reduction in agriculture using machinery	Energy efficiency gains in crop production	CO_2 reduction potential	Low need for investment in vehicle adaptation and/or infrastructure on farm/in-field	Return on investment for farmers (cost vs CO_2 reduction - mid-term 2030)	Applicable fleet
ALTERNATIVE FUELS	Sustainable biomass fuels	Not applicable		Low cost for vehicle design and infrastruc-ture (case dependent)		Existing fleet (case dependent) & New fleet
	Synthetic fuels (not available yet)	Not applicable		Current engines can be used		Existing fleet & new fleet depending on fuel availability
ALTERNATIVE DRIVES	Full electric powertrain with **battery** (source: renewable energy only/carbon capture)	High efficiency of the powertrain		High cost for vehicle design, less for infrastructure		New fleet (limited power range) & Future fleet
	Full electric powertrain with H_2 - **fuel cell** (source: renewable energy only)	High efficiency of the powertrain		High cost for vehicle design and for infrastructure on farm		New fleet (limited power range) & Future fleet
	Hybrid electrification in combination with ICE		Due to e-implements	Current engines can be used		Existing fleet with add-ons & New fleet
ENERGY EFFICIENCY OPTIMISATION METHODOLOGIES	Towing machine optimisation (drivetrain)	Additional efficiency gains are low		High cost for vehicle design		New fleet
	Towing machine + implement use optimisa-tion within the process and the process chain			It is about ongoing process optimisation		Fleet independent

The table shows that, depending on the priority, e.g. return on investment, CO_2 reduction potential for the whole fleet or only new/future fleet, the preferred options will differ. There is a high potential for the improvement of the current situation without replacing diesel fuel as the main energy source, by focussing on the energy efficiency in the whole production process with the existing fleet. But a much bigger carbon reduction can be achieved with the integration of alternative fuels, in the short and long term. In case some alternative fuels can be produced on farm and require no additional investment in infrastructure, the return on investment will be positive.

This can be applied in some cases to the existing fleet with certain adaptations and under certain preconditions, and certainly on the new fleet. For existing, new and future fleet, synthetic fuels could enter the list of alternatives, with great potential due to the low investment needs in relation to infrastructure and adaptations to existing drive trains. This depends on the scale up of their production and /or availability on the market. In the long-term, after 2030 for the future fleet, full electrification with full electric drive train is expected to gain in importance but its application will vary due the diversity in the fleet from very small to very big, and the many different operations from short low low-energy to constant high energy demanding operations.

Conclusions and recommendations

To limit global average temperature increase to well below 2°C, no half-hearted measures can be taken, and stringent reduction targets are to be met by all sectors. This position paper is neither asking for softer measures for agriculture, nor does it pretend to provide a best pathway. Instead, it pleas to smartly use all available options within the production process and with consideration of the specific conditions and capabilities of each farmer and of the sector to achieve the highest possible reduction.

Agriculture is producing CO_2 from both input and output side. From the input side it is coming from, among others, fuel burning in engines (1 %), and from production of mineral fertiliser and pesticides; from the output side main sources are livestock, draining wetlands and imbalance of CO_2 capture/emission in soils (10,5%).

Reductions are possible for both input and output side. In addition, there are possibilities to compensate CO_2 emissions by producing green energy or storing CO_2 in soils by humus build-up. Any measure must be considered using a systemic approach within the full cycle of cultivating agricultural products, be it crops or livestock. A consideration of the individual farm concept, region, climatic regions suitable crop cultures, level of skills, organisation structure, general awareness, willingness, and financial capacity is essential.

Within this position paper three main options are analysed to reduce the CO_2 production from fuel combustion when using agricultural mobile equipment in the agricultural production.

These are:

- The optimisation of energy efficiency when using the agricultural mobile machinery fleet within the agricultural operations and the whole production process,
- The technological open use of alternative drives and fuels,
- And the use of smart mobile machinery in support of farmers to make the transformation toward neutral and negative carbon farming.

In terms of importance of the different options, a qualitative assessment is provided, which shows that there are different ways to look at the issue of CO_2 reduction from the agricultural machinery use. On the short- and long-term, alternative fuels are the most promising option for the old fleet, and certainly for the new fleet on the condition that combustion engines remain affordable and that the energy efficiency over the whole crop production process is enhanced. Only after 2030, battery or fuel cell-based electrification will gain importance, but at different speed depending on the vehicle type and the energy demand of the operations. Biomass produced within agriculture as basis for alternative fuels like biomethane, HVO, or Biodiesel as well as electricity from solar and wind can play a key role in the overall return on investment for farmers and their overall energy independency. This should be embedded in a systemic approach at farm level. This is not about single point decisions but about working out a long-term roadmap which might need adjustments according to the development in other industries, the developments on a global perspective especially in the energy sector and the further evolution of the agricultural methods. It is not about selecting the best drivetrain technology but to find a solution which fits in the whole context.

The agricultural machinery industry is fully committed on this path to continue its support by offering new innovations and best efficiency.

Recommendations for decision makers:

In the transformation towards a low-carbon industry, agriculture will need to be smart, connected, and flexible. It is about changing current practices, using more knowledge and new skills. It is about managing an increased complexity of digital inputs and outputs for making the right decisions.

The transformation to zero CO_2 emission must be seen and handled as an investment with proper assignment of value. This is certainly true for agriculture.

The farmers but also the industry need a clear perspective to plan accordingly, as the development processes for new products have a certain lead time.

Based on its assessment, the agricultural machinery industry recommends the following to decision makers:

- Governments must work within a long-term strategy, including on targets and incentives to encourage farmers to invest in farm infrastructure for refuelling, smart machinery and tools, and to ensure a relevant contribution against climatic change and a good return on investment. Such strategy must consider that farmers need long-term investment plans in relation to their fleet of machinery and compatible implements, as they cannot afford investing in all possible infrastructures and technologies. Additionally, the machinery industry, as facilitator, needs to plan their investments and the development of new products several years in advance. Agriculture should be recognised as a key sector for the use of alternative and synthetic fuels. A proper political framework is needed for investment in the scale up and uptake of these fuels. This must facilitate the applicability of alternative fuels for agricultural purposes and grant the necessary financial support.

- Combustion engines are a necessary key energy converter for agricultural machinery in the long-term due to its specific types of use.

- New business models must ensure a fair income to farmers that adopt carbon farming measures. They must be further studied, developed, and disseminated. Incentives for further adoption of carbon farming measures and rewarding early adopters are essential to support farmers in the transition period[24].

- Investment in the digital transformation can support in reaching the climate targets. Connectivity and data analytics tools are key for precision farming and carbon farming and are the main arguments for further promotion of the respective flagship eco-schemes. The establishment of a common agricultural data space is an important part of this transformation.

- 'Data driven monitoring tools' can help to prove achievements of good practices and support farmers making better decisions towards sustainable practices and to lower their administrative burden. This can be supported by the flagship eco-scheme carbon farming and by the Horizon Europe candidate partnership 'Agriculture of data'.

- Awareness raising of farmers, contractors, advisers towards the state-of-the-art technologies/practices must be promoted. This could be a combination of providing proof of concept of innovative tools/practices through demonstration farms and the promotion of the outcomes of projects like EKoTech. This can be supported by the flagship eco-scheme precision farming.

- Promotion of training and education to realise the transition towards low carbon farming by obtaining new digital skills. In this respect it is appropriate to mention the Commission initiative 'Pact of skills' as a joint effort on upskilling and reskilling the EU workforce.

24 https://ec.europa.eu/eip/agriculture/sites/default/files/eip-agri_ws_carbon_neutral_agriculture_final_report_2021_en_lr.pdf

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