Advanced Sustainable Biofuels For Aviation

Summary of results of the BIO4A project

Title
BIO4A Advanced Sustainable Biofuels for Aviation.

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Publisher
ETA Florence Renewable Energies

Date of publishing
30 July 2023

Acknowledgements
The content of this document is based on original work published by BIO4A partners RE-CORD, ENI, SkyNRG, CENER, Camelina Company España, JRC and ETA-Florence in the respective project deliverables. The original documents and authors are cited in the references.

This work and the research leading to these results were undertaken as part of the project BIO4A – Advanced Sustainable Biofuels For Aviation. This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No. 789562.

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1 Executive Summary

David Chiaramonti (Politecnico di Torino), Tommaso Barsali (RE-CORD)

BIO4A – Biofuels for Aviation, is a Horizon 2020 project launched in 2018 to demonstrate the first large industrial-scale production and use of sustainable aviation fuel in Europe, and to investigate the potential to recover dry marginal land in Southern EU. The project was carried out by an international consortium of seven partners including industries, research organizations and SMEs, coordinated by RE-CORD - Renewable Energy Consortium for Research and Demonstration, and ended in May 2023.

BIO4A had a twofold nature, composed by ad-hoc designed industrial and research components.
The final aim of the research element was to investigate the production of sustainable lipids for HEFA production in marginal land recovered with biochar and compost, so to expand the feedstock base. Focused work on biochar and dry soil recovery in EU MED, sustainable agricultural management and selection of crop varieties was carried out in BIO4A. This work demonstrated the possibility to recover marginal land to both food/feed and energy production, in a reverse-ILUC win-win approach, enabling more sustainable agriculture while delivering sustainable lipids and coproducts.

The research component: Carbon-negative SAF are possible with biochar on marginal land
The main groundbreaking results of BIO4A research was the demonstration at pilot scale that Carbon-negative HEFA production is possible when Soil Organic Carbon (SOC) is permanently increased through the addition of biochar amendment from lignocellulosic residues. This brings the aviation biofuel value chain beyond the Net Zero target. In fact, biochar making from agroforestry residues brings biogenic Carbon back to soil in a long-term C storage approach. Biochar is a nature-based Negative Emission Technology, a very cost-competitive solution to sequester, store and utilise biogenic Carbon from the atmosphere, delivering C to soil and so improving soil health. Biomass that is grown on fields represents a kind of natural Direct Air Capture system, delivering C instead of CO2. To produce biochar for the project, innovative oxidative slow pyrolysis systems developed by RE-CORD were tested and used, together with a dedicated co-composting facility.

BIO4A explored for the first time the application of the new REDII Implementing Regulation 2022/996, which introduced the "Esca" factor in its Annex V: this factor considers the variation of Carbon stock in soil. The EU implementing regulation recognises the use of biochar as a sustainable agronomic practice, the one with the highest potential for Carbon sequestration (threshold set at 45 gCO2eq/MJ). Within BIO4A, pilot cultivations in Spain and Italy were performed by Camelina Company España and RE-CORD, and the potential benefits in terms of GHG reduction were calculated by CENER under experimental and optimised conditions, in a larger scale approach and using the REDII-IR formula. The GHG savings can be as high as 107%-128% under optimal conditions. This result also offers to farmers and stakeholders an opportunity to expand the feedstock base for Sustainable Aviation Fuel production.
Compost obtained from farm-scale biogas/biomethane plant digestate also complemented the research work on biochar for soil recovery. Compost is a non-permanent Carbon storage solution, alternative to the direct use of biochar, bringing volatile Carbon, Nitrogen and nutrients to soils. In BIO4A it has been tested in dry soils, alone or as COMBI, a very effective product for agriculture:

COMBI is obtained by blending digestate and biochar at different weight ratio before co-composting. The process benefits from biochar addition, even if in small amount, which reduces composting time and increase composting temperature, while retaining more Nitrogen in the final product.
New types of lysimeters were also designed, built, and operated in brand new climatic chambers, to replicate environmental conditions and assess mass, water and nutrient balances in very controlled conditions.
Different Camelina varieties were studied, to select the most performing ones for the given harsh conditions.
Finally, EC JRC assessed the potential application of the BIO4A solution to the EU MED region, where more than 8.5 Mha are under marginalization and desertification. JRC concluded that a significant production potential exists in Spain, Italy and Greece.

The industrial component: more capacity installed and demonstrated
ENI – the main industrial partner of the project, produced commercial-scale volumes of sustainable SAF from residual lipids (1,000 metric tons), fully compliant with ASTM standards and regulations on aviation fuels. ENI also managed to increase the production capacity of SAF, by building a supplementary process pathway through HVO-Naphta and by refurbishing a previously unused distillation column, that is now used for sustainable renewable fuels production. The SAF was then delivered to Schiphol airport and used for commercial flights with business-as-usual, conventional logistics, through the join collaboration of SKYNRG and KLM.
New industrial capacity, and a new HEFA production chain, has thus been implemented and demonstrated at full commercial scale.
This work was complemented by a dedicated market analysis of residual lipids in the EU and globally. The effect of disruptive market conditions due to pandemic and energy crisis indeed impacted in the analysis, which however identified a constant growth in UCO prices, slightly reducing in the latest months.

Future perspectives and research needs
BIO4A has opened a new pathway to SAF production, both in terms of industrial capacity and innovative approach to feedstock supply for HEFA. Most of research work lies on the agronomic side: the use of biochar and compost, the cultivation of Camelina varieties, the selection of crop rotation and, above all, the means to recover degraded land need further research and value chain optimization. By varying doses and characteristics of biochar, for instance, SOC will change, as well as crop yields: SAF GHG performance will then have to be re-assessed against the energy obtained per ha, applying the REDII-IR methodology. Also, longer-term performances of soil recovery and crop management will need further assessment (even if the experiments of BIO4A already covered the rather significant period of 5-years). Finally, demonstration at larger scale is recommended, to support with demo-scale results the green transition and the necessary evolutions of policies in the SAF and agricultural sectors.

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2 Introduction

BIO4A – Biofuels for Aviation, is a Horizon 2020 project launched in 2018 to demonstrate the first large industrial-scale production and use of sustainable aviation fuel in Europe, and to investigate the potential to recover dry marginal land in Southern EU. The project was carried out by an international consortium of seven partners including industries, research organizations and SMEs, coordinated by RE-CORD - Renewable Energy Consortium for Research and Demonstration, and ended in May 2023.

More in detail, the goal of BIO4A was to enable the large-scale pre-commercial production of ASTM Certified aviation biofuel from sustainable waste feedstock in the EU, with particular emphasis on developing production capacity, and investigating long-term opportunities to supply sustainable no-food lipids, through a long-term R&D work, for conversion in low-ILUC biofuels (as per REDII). In doing so, BIO4A adopted a two-pronged approach that was maintained throughout its duration. One prong was the industrial demonstration component, and the other was the research and development work.

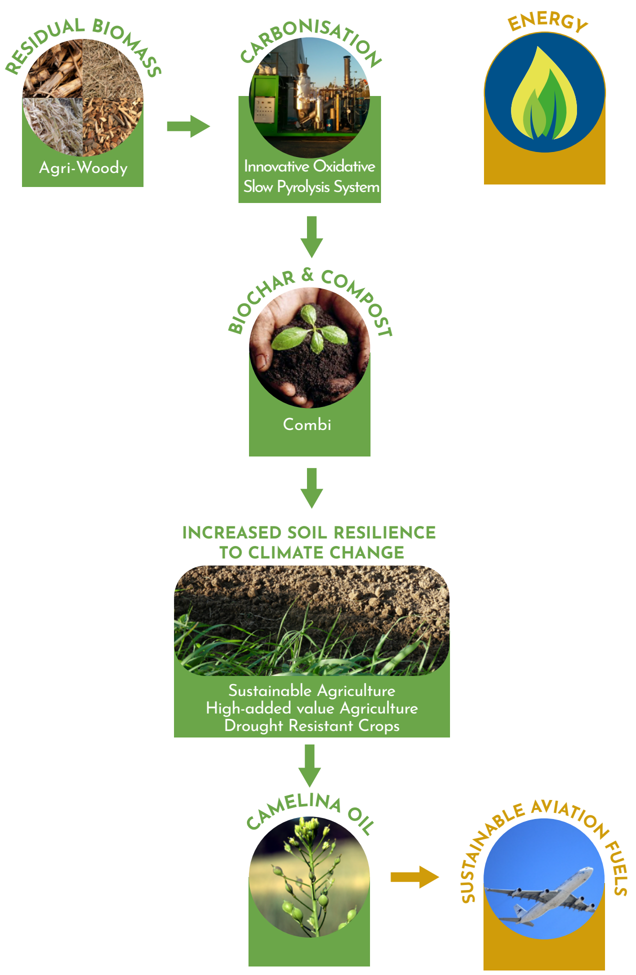
In the context of the industrial component, BIO4A aimed at demonstrating the full value chain by producing commercial-scale volumes of ASTM-certified biojet (HEFA) at competitive prices, as the main way to establish a production capacity. This work led to significant achievements, that can also be further exploited after the end of the project. As part of its BIO4A activities, ENI - the main industrial partner of the project, produced commercial-scale volumes of sustainable SAF from residual lipids (1,000 metric tons), fully compliant with ASTM standards and regulations on aviation fuels. ENI also managed to increase the production capacity of SAF, by building a supplementary process pathway through HVO-Naphta and by refurbishing a previously unused distillation column, that is now used for sustainable renewable fuels production. The SAF was then delivered to Schiphol airport and used for commercial flights with business-as-usual, conventional logistics, through the join collaboration of SKYNRG and KLM.

The research work was mainly dedicated to developing and evaluating feedstock alternatives to waste and residual lipids. The focus of the work was the sustainable production of sustainable lipids from *Camelina sativa*, a drought-resistant oleaginous crop, also grown in combination with biochar as soil amendment, as a strategy to increase soil health and climate resilience in EU dry Mediterranean land. This extensive R&D work also generated many tangible results at all the levels of the value chain. A new Camelina variety was selected for its traits of drought-resistance and filed for patent at European level. A new prototype technology for biochar production was filed for patenting and is now used for further research and demonstration activities. A 5-year agronomic experiment was set up in Spain, in a collaboration between Camelina Company España and RE-CORD Consortium, with various treatments of biochar and Combi (a co-composted mix of biochar and digestate), to determine the optimal quantity to be distributed to increase crop yields while contributing to soil health and increasing carbon stocks. Results were very encouraging, especially in low-rainfall years, thanks to the use of biochar as a soil amendment. Thanks also to the results of this experimental work, today biochar is recognized as a sustainable agricultural management practice which qualifies for Esca factor calculation on soil Carbon Stock, and is included in Annex V to the Commission Implementing Regulation (EU) 2022/996.

Such experiment was evaluated with a novel LCA approach by CENER, encompassing the whole RED-II compliance scheme. The assessment demonstrated that both traditional SAF value chains based on residual lipids, and value chains supplied by alternative feedstock such as sustainable oil from Camelina, can largely outperform the REDII of at least 70% requirement of GHG emission savings with respect to fossil Jet A1. In particular scenarios, the GHG savings can be as high as 107%-128%, for example when using biochar as a soil amendment combined with Camelina cultivation for sustainable oil production.
When including biochar as a sustainable land management practice, an increase in soil carbon stock and outperforming GHG savings can be attained, even without applying the degraded land bonus (Eb). Furthermore, considering the low doses of biochar applied for BIO4A R&D work (3 t/ha equivalent), an increase in the distributed dose of this amendment, can also contribute to the increase in yields, especially when Camelina is cultivated in low rainfall conditions.
In addition, biochar showed the ability to reduce the total amount of water and nitrogen exiting the soil cultivated horizon, thus contributing to optimize the efficiency of irrigation and inorganic fertilizers.
Finally, the environmental and socio-economic effectiveness of the BIO4A pathway was evaluated by JRC, producing datasets and maps on vast areas of marginal and underutilized agricultural land in Southern Europe, suitable for the cultivation of drought resistant oil crops to produce feedstock for Sustainable Aviation Fuels, in rotation with traditional cereal crops, without reducing food production while increasing the soil organic carbon content.

This publication presents a summary of the main results obtained by the different components of the project and their relevance for the current context of SAF deployment. However, more detailed information and data are available in the project deliverables, scientific papers, and presentations produced by the BIO4A partners. All this information is available on the project website and is cited in the references at the end of each chapter. Those documents provide more detail including the data and analysis that support the findings and constitute essential resources for anyone who wants to learn more about the research project and provide a comprehensive overview of BIO4A and its findings.

Long-term R&D strategy:
Ssustainable lipids for the SAF industry



3 Full scale industrial HVO-SAF production from waste feedstock

Fig. 1 – ENI refinery in Livorno. Source: ENI.

In November 2022 Eni achieved the target production of 1,000t of HEFA, for the BIO4A project.
The production of HEFA was obtained through a process configuration that involved two operational sites, namely the Eni's Gela biorefinery plant, where HVO was produced, and Eni's Livorno refinery, where the HVO was distilled to HEFA.
More in details, during the process HVO-naphtha long cut was produced at the Gela biorefinery from tallow cat. 1 and /or 2 and UCO (Annex IX, part b RED II), instead of HVO-Diesel, and the distillation in Livorno was obtained by using a dedicated distillation column that was refurbished for this purpose. The yields of HVO-naphtha long cut are significantly lower than the ones of HVO-Diesel -18, while the HEFA content in the above streams are comparable.

The Gela biorefinery produced the HVO using Eni's Ecofining™technology, developed in collaboration with Honeywell-UOP, which enables the production of high quality biofuels from a range of biogenic feedstock, including waste and residue raw materials (from vegetable oils residues to animal fats and used cooking oils).

Conventional biodiesel - technically referred to as FAME (Fatty Acid Methyl Esters) - production plants use the transesterification process whereby incoming triglycerides are treated with methanol to obtain a product whose characteristics depend heavily on the type of raw material used. The EcofiningTM technology replaces transesterification with a different chemical process consisting of two subsequent stages - hydrogenation and isomerisation - the former involving treating the initial feedstock with hydrogen to eliminate oxygen and saturate the double bonds, the latter "restructuring" the resulting paraffins to improve their cold properties.
The production of HEFA in Livorno allowed Eni to produce 1,000 t of HEFA without using third party's facilities, therefore with full control on the process and guarantee of quality of the product.
The quality of the resulting HEFA complies with

the required ASTM aviation fuel standards. The proposed configuration, integrating Gela bio-refinery and Livorno traditional refinery through the refurbishment of an idle naphtha fractionation column, has been an innovation by itself in Eni's operations and it facilitates the potential industrial scalability of the solution.
After the distillation in Livorno, Eni delivered the final product to the off-taker in the Netherlands, for the blending and final distribution of ASTM certified Jet A1 fuel.

The identified and realized solution represents an industrial choice in line with Eni's decarbonization strategy which transforms or integrates traditional sites into sites to produce new low-carbon footprint energy vectors/fuels such as HEFA Biojet.

In this regard, in October 2022 Eni officially announced a study for the possible realization of a new biorefinery at the existing industrial site of Livorno. The feasibility study foresees the construction of three new plants for the production of hydrogenated biofuels, including a 500 ktons/y Ecofining™ plant, a pre-treatment unit for biogenic feedstocks and a hydrogen production plant. The construction of the new biorefinery would enable the maximization of synergies with the existing infrastructures available on site and would and secure the site's future as an employment and production hub . This is in line with the company's announced roadmap to achieve the reach the production of 200 kt/y of SAF by 2025 and objectives of further production expansion within 2030 up to 1 Mt/y.

Fig. 2 - The vessel that delivered the HEFA produced in Livorno at Amsterdam Evos terminal in April 2023. Source: SkyNRG.

References and further resources

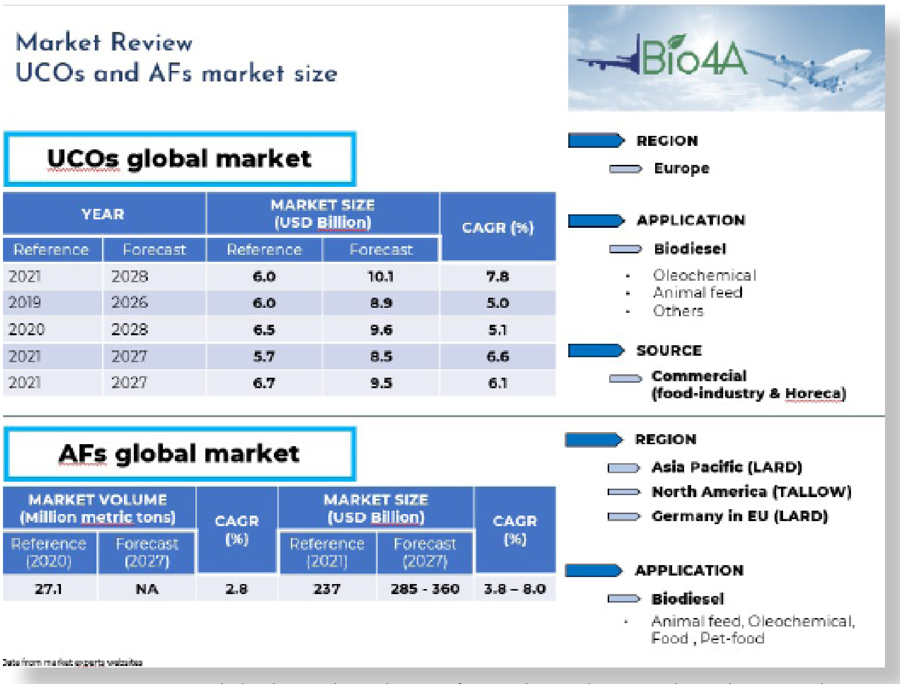
This chapter is an edited version of **Deliverable D1.3:** ASTM certified aviation biofuel production of at least 1,000 tons.

Sassi L., 2023 - ENI Full scale industrial HVO SAF production from waste feedstock (**slides**, **video**)

4 Market analysis of waste oil feedstock

As global emissions from the aviation sector are increasing, the demand of waste and by-products that can be used as a feedstock for Sustainable Aviation Fuels; such as animal fats (AFs) and used cooking oils (UCOs), is also on the rise.
The demand for these wastes is not pushed by the SAF sector only, as both animal fats and UCOs are already used in several other industrial sectors, so in the next 4-6 years, the UCO market is expected to increase by more than 41% over 2019-2021 values, with the European Union expected to be a major player. The market for animal fats is also on the rise and is expected to grow between 20.2 and 51.9% in 2026 compared to 2019. Germany, in particular, is expected to be the largest producer of animal fats.
In the commercial field (e.g. in the Hotel and Catering Industry sector - Horeca), the collection of AF and UCO has reached a good level, making much of this waste available to be converted in valuable products, while collection in the domestic field still presents obstacles that minimize the amount that can be re-used towards the amount of waste that are produced. Available data regarding the price of UCO and AF are scarce, however, data, regarding the price fluctuations of the materials from which these wastes originate, are available.
In general, the price of the major vegetable oils price is expected to increase by 65 to 164%, compared to 2019, considering the additional impacts of both Covid pandemic and conflict in Ukraine on the principal producing and importing countries. Such a price fluctuation inevitably affects the supply of sustainable oils in the market, thus affecting the demand. Consequently, the reduced amount of available sustainable oils will determine the maximum producible quantity of waste, which, in turn, will affect wastes price.
Also, the biodiesel and renewable diesel demand and supply could contribute to determine the value of such wastes: prices for these fuels have risen faster than the price of vegetable oils.

The pre-2020 identified trends in the availability of waste lipidic feedstock in Europe tend to forecast a situation where the availability of both animal- and vegetable-based residues is increasing.
This is mainly due to the increase in global overall well-being, leading to an improved lifestyle that is generally found, first and foremost, in a diet enriched in fats, especially animal fats.
This is also accompanied by a general increase in food productions, which must take into account the increase in global population as it reaches 8 billion and rising.



YEAR		MARKET SIZE (USD Billion)		CAGR (%)
Reference	Forecast	Reference	Forecast	
2021	2028	6.0	10.1	7.8
2019	2026	6.0	8.9	5.0
2020	2028	6.5	9.6	5.1
2021	2027	5.7	8.5	6.6
2021	2027	6.7	9.5	6.1

MARKET VOLUME (Million metric tons)		CAGR (%)	MARKET SIZE (USD Billion)		CAGR (%)
Reference (2020)	Forecast (2027)		Reference (2021)	Forecast (2027)	
27.1	NA	2.8	237	285 - 360	3.8 – 8.0

Fig. 3 – global market data of Used Cooking Oil and Animal Fats. Source: RE-CORD.

In addition, progress is being made in terms of waste collection, which tends to become more and more efficient, both in the professional sector, where it has already reached excellent levels, and in the household sector, where further efforts need to be made. On the other hand, worldwide, there has been a major upheaval in the agricultural and food market, in the 2020-2022 period, due to the Covid-19 pandemic and the geopolitical tensions.

According to FAOStat database, there was a general increase in import prices for both animal- and vegetable-based lipids in Europe in 2020 compared to the previous year. In particular, animal oils and fats and palm oil saw their entry price into Europe increase by about a third compared to 2019, and soybean oil by about a fifth. Sunflower and rapeseed, on the other hand, experienced slight increases compared to 2019 (+3.9% and +3.0%, respectively), likely due to robust domestic production of oils from these crops. However, the export price of sunflower and rapeseed oil also experienced slight changes equivalent to -1.5% and 0.6%, respectively, compared to 2019.

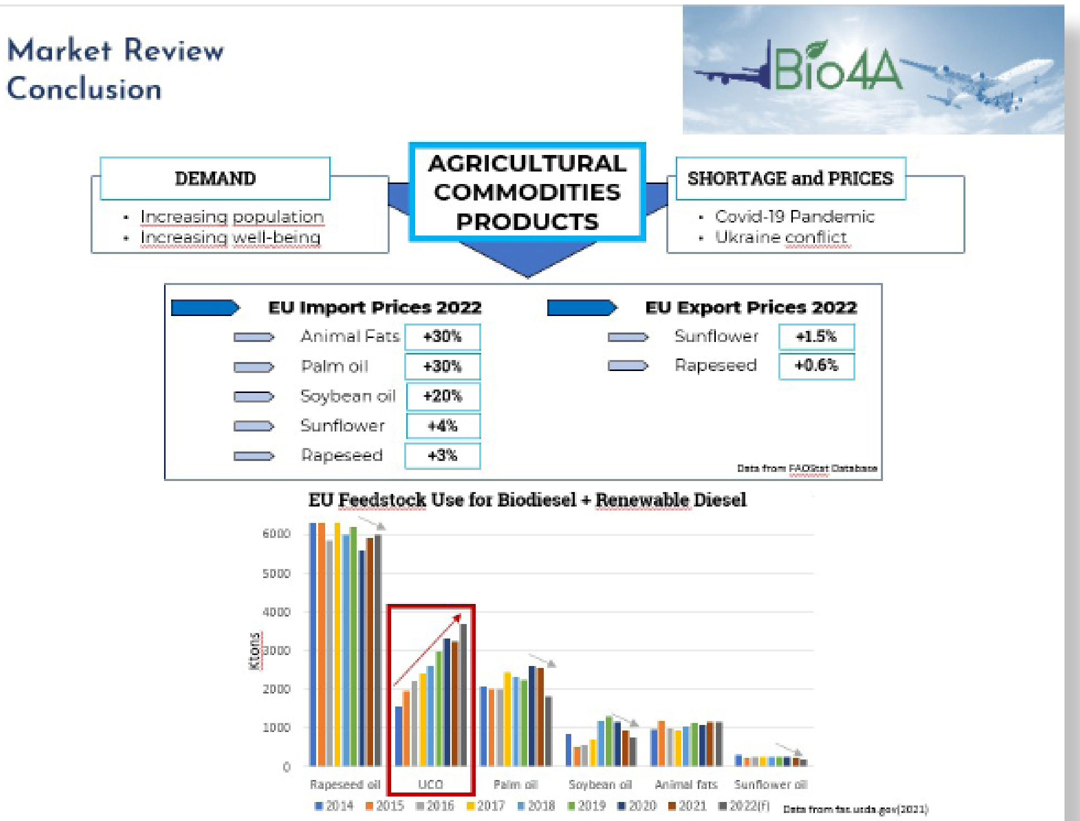


Fig. 4 – Demand, imports and use of waste oil feedstock in the EU. Source RE-CORD.

Nevertheless, the processed quantities of animal and vegetable fats are expected to increase in the coming years, leading to greater accumulation of related wastes. FAO, for example, estimates that about 50 million tons of waste from the use of vegetable oils as food will be generated in 2025.

This leads to the need for increased reuse of waste, from which the aviation sector can benefit greatly. In this regard, it is expected that in 2030, about 1.9 million tons of waste oils and fats and about 2.6 million tons of UCO will be used to produce advanced biodiesel. The share of UCO is expected to increase to 6.5 million tons in 2050 for the same purpose.

This growth can only be supported by a simultaneous enhancement in the collection efficiency of such waste. To date, in Europe, about 650 ktons of UCO are collected from the professional sector, and an increase of about 130 ktons is expected. On the other hand, in the household sector, there is a very large gap between the amount collected and the amount that could potentially be collected; it is estimated that only about 5.6% of UCO from the household sector is reused, compared to that could be collected. In Italy there is a parallel situation to that in Europe, with a high collection efficiency in the professional sector, and a gap of about 165 ktons between the collected and the collectable waste in the domestic sector.

The improvement of the collection system of UCO and animal fats can be also pivotal on addressing the trend of the current biofuel demand. This historical period is characterized by a great shortage of agricultural commodities, limiting their use to primarily food purposes, minimizing the possibility of their use in industrial fields. Many from the major vegetable oil-producing States, for example, have endorsed regulations limiting the production of renewable fuels so as not to run into the problem of food shortages for their population.

This recent issue has led to a general slowdown in the production of biofuel from vegetable oil, considering that most is obtained from sustainable oils, which are scarce in terms of availability and sold at high prices. However, this situation could encourage the acceleration in the development of technologies aimed at collecting and processing waste lipids of both plant and animal origin, with the goal of producing quality biofuel, particularly for the aviation sector, which, now, in the transportation field, is the most technologically advanced sector and able to accommodate such innovations most rapidly. This aspect is also highlighted by the RED II, where, this kind of waste (animal fats and UCOs) occupy a dedicated list of eligible sustainable feedstocks for the aviation sector, which can contribute to pursue the objective of carbon reduction, addressed in many documents and directives issued by the EU and, in general, by world-class institutional bodies.

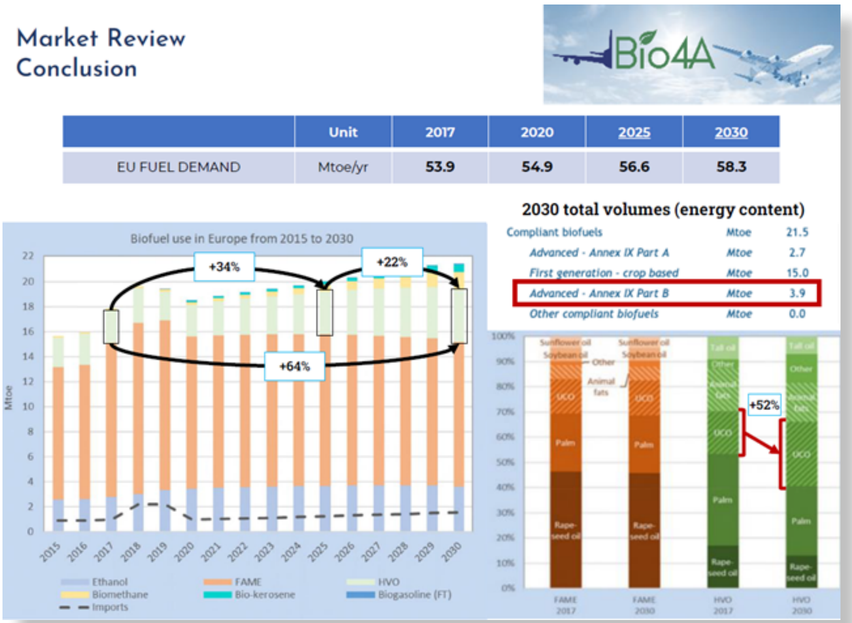


Fig. 5 – Demand, imports and use of waste oil feedstock in the EU. Source RE-CORD.

References and further resources

This chapter is an edited version of **Deliverable D5.3**: Waste Feedstock Market (Stefanucci D., Barsali T, 2023).

Stefanucci D., 2023 – Lipid waste feedstock market (slides, video)

5 Market outlook: vision, potentials, limitations, and strategy for upscaling SAF production in the EU

Hydrotreated Esters and Fatty Acids (HEFA) is the most advanced and commercialized pathway to make SAF today. BIO4A demonstrated the industrial production of SAF from HEFA pathway at kton scales.

Aviation accounts for a significant (>2%) contribution to global manmade emissions. Even though the sector has been hit hard over the past years by the COVID-19 pandemic, we have seen rapid recovery in the sector and prospects of growth as quick as 2023. This comes with significant pressure of increased emissions and challenges to decarbonize the aviation industry. SAF plays a very important and significant role in decarbonizing aviation and therefore a significant market will exist for HEFA production capacity. Over the course of BIO4A, many SAF projects have been announced to be in development, as well as significant production capacity has come online.

As part of the BIO4A project, SkyNRG developed a market outlook which provided insights in which technologies are expected to fulfil the mandates, the market outlook from 2021 and 2022 as well as other industry reports are used to reflect on the development since. This work also reviewed the feedstock availability.

Since the start of the project in 2018 the market of Sustainable Aviation Fuel has significantly developed and HEFA is (still) the only commercially ready and widely available technology today. The goal of BIO4A was to proof scale up of industrial production and demonstrate the market uptake of sustainable aviation fuel. While this has been successfully achieved, the market has since then also developed into a more mature and consistent market. With all this in mind, the market scaling strategy for HEFA-based SAF can be assessed on the following aspects:

Market potential

The demand for SAF is significant, aviation is here to stay and decarbonization options are very limited. Under conservative circumstances with the ReFuelEU targets in place, the total European market size in 2050 is expected approximately at 25 Mt, 15 Mt of which should be 'advanced bio-based'.

Including the UK market and more ambitious targets proposed by the European Parliament we can see the total European market potential for 2050 grow towards ~50 Mt.

On a worldwide level there is more uncertainty due to the lack of policy development, however significant movements are tangible in the US and Asia as well, creating market potential of >250 million tonnes towards 2050.

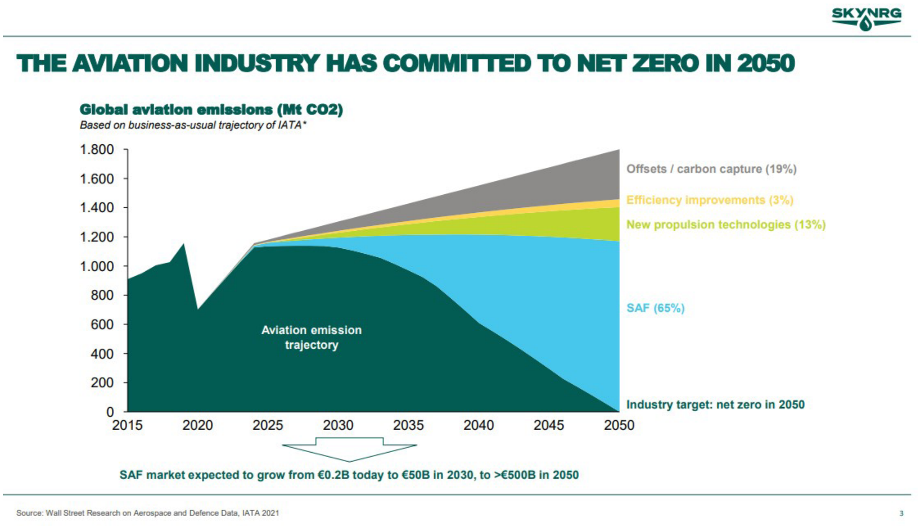


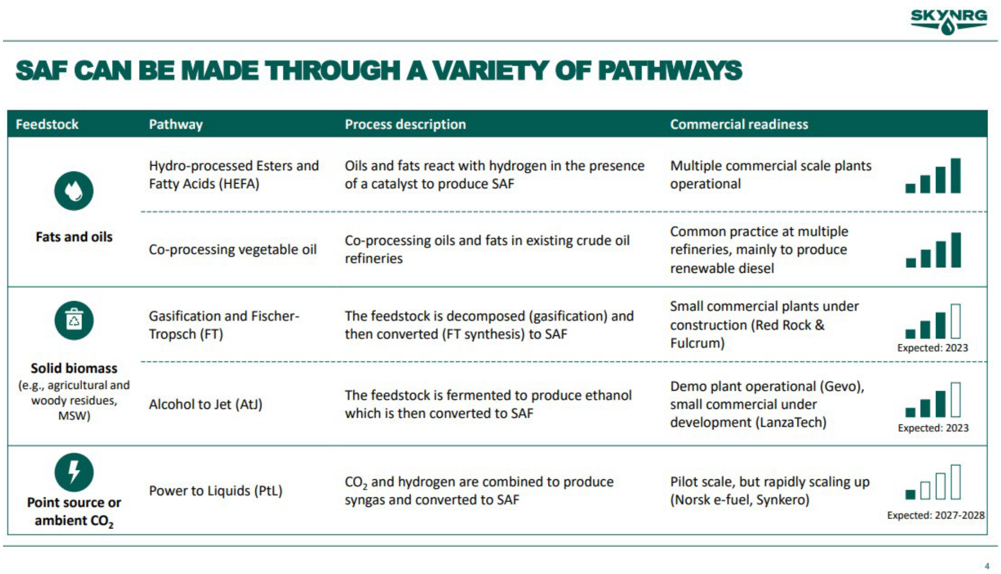
Fig. 6 - Global aviation emission scenarios. Source: SkyNRG

Technology readiness

There are various pathways to convert renewable feedstock into SAF, both bio-based as well as Power-to-Liquid pathways are currently pushed by policy in the EU. Even though there are 7 different pathways technically certified by ASTM D7566, the HEFA pathway is currently the only availably technology on a commercial scale. This is currently the only pathway for which licenses can be obtained at a fully proven (TRL 9) level. Other pathways such as Alcohol-to-Jet and Fischer-Tropsch (PtL-based) are in rapid development and could see commercial facilities as early as 2025. For widespread scaling we expect HEFA to be the dominant technology pathway up to 2030.

Feedstock potential

Regarding the feedstock availability for HEFA scaling, current focus of the EU RED and other policy frameworks is on the use of waste lipids, due to the risk of food/crop-based oils. Waste volumes are scarce reflected by the increasing price (partly due to the COVID pandemic reduced restaurant activities). There is room for better collection of Used Cooking Oil across Europe and the rest of the world especially on a household level. Animal fats are more uncertain especially due to the potential use of these feedstocks for animal feed or alternative products in the healthcare industry, this competing use impacts the ability to scale HEFA on these feedstocks. To successfully scale the HEFA pathway beyond 2030 and beyond existing waste material, it is therefore **essential to diversify the feedstock base**. Low-ILUC crops and cover crops on degraded lands are a promising path to further scale the availability of sustainable lipids. On a world-wide level the industry sees potential to scale towards 130 Mt of oils from degraded lands. It's to be noted that these feedstocks are not yet developed and need significant policy push, to educate, train and invest in farmers to diversify their portfolio towards these crops. Also, clear policy and certification schemes are needed to verify sustainability of these feedstocks to avoid any unwanted (land use change) effects.


SKYNRG
SAF CAN BE MADE THROUGH A VARIETY OF PATHWAYS

Feedstock	Pathway	Process description	Commercial readiness
Fats and oils	Hydro-processed Esters and Fatty Acids (HEFA)	Oils and fats react with hydrogen in the presence of a catalyst to produce SAF	Multiple commercial scale plants operational
Fats and oils	Co-processing vegetable oil	Co-processing oils and fats in existing crude oil refineries	Common practice at multiple refineries, mainly to produce renewable diesel
Solid biomass (e.g., agricultural and woody residues, MSW)	Gasification and Fischer-Tropsch (FT)	The feedstock is decomposed (gasification) and then converted (FT synthesis) to SAF	Small commercial plants under construction (Red Rock & Fulcrum) Expected: 2023
Solid biomass (e.g., agricultural and woody residues, MSW)	Alcohol to Jet (AtJ)	The feedstock is fermented to produce ethanol which is then converted to SAF	Demo plant operational (Gevo), small commercial under development (LanzaTech) Expected: 2023
Point source or ambient CO_2	Power to Liquids (PtL)	CO_2 and hydrogen are combined to produce syngas and converted to SAF	Pilot scale, but rapidly scaling up (Norsk e-fuel, Synkero) Expected: 2027-2028

Fig. 7 – Main pathways for SAF production and commercial readiness. Source: SkyNRG

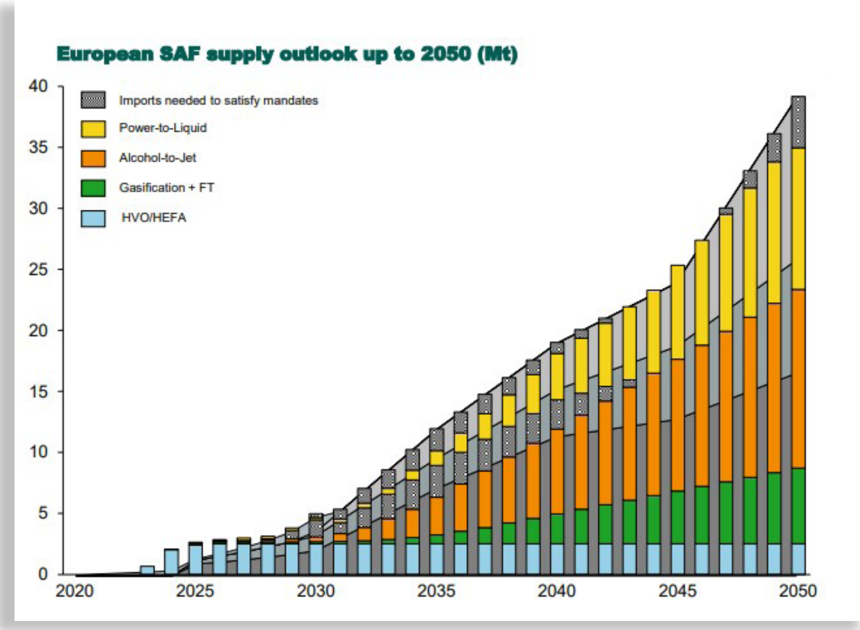


Fig. 8 – Outlook of EU SAF supply until 2050. Source: SkyNRG.

Concluding, the HEFA pathway is essential for SAF scaling. Especially until 2030, the HEFA pathway is the most scalable and commercially ready technology for widespread uptake of SAF. The scaling beyond 2030 towards the ambitious 2050 targets remains limited due to the limited availability of lipid-based feedstocks. Within Europe most of these waste-based feedstocks are already used for SAF production and alternative use cases such as Bio- and Renewable Diesel.

Further scaling on these feedstocks is dependent on the ability to import additionally collected waste material. With an increasing SAF industry in other places in the world, relying on the ability to import is a significant scaling risk.

To further scale the HEFA pathway towards the ambitious 2050 targets, we therefore recommend development on the following two points:

1. Policy makers, industry and the sustainability and NGO community should keep discussing the best use of certain feedstocks, such as sustainable lipids. The available sustainable lipids could potentially be prioritized towards the aviation industry without compromising other industries. With further electrification of road transport, waste oils might become available for use in the aviation sector. It is essential to avoid any unwanted effects in displacing renewable fuels in the road transport with fossil-based alternatives.

2. The agricultural sector can, with the initial proposed changes by the European Commission to allow for low-ILUC oils in aviation, focus on developing sustainable lipids from degraded (and low-ILUC) land. This will diversify the feedstock pool for HEFA SAF and create an ability to scale beyond waste materials currently available. With the recently suggested addition of these feedstocks in ReFuelEU and within the RED sustainability framework (pending approval), the ability to further scale HEFA is opened. This change could further contribute to a more sustainable use of land in Europe and worldwide.
r policy and certification schemes are needed to verify sustainability of these feedstocks to avoid any unwanted (land use change) effects.

References and further resources

This chapter is an edited version of Deliverable D5.5: Market Scaling Strategy (Meijerink O., 2022).

Meijerink O., 2023 – Market outlook, vision potentials, limitations and strategy for SAF production in the EU (slides, video)

6 Cultivation of Camelina in semi-arid land with a high risk of desertification and soil carbon sequestration

In the last few years Europe has witnessed its most severe droughts, climate change causes rising temperatures coupled with reduced rainfall and this increases the risk of degradation of agricultural drylands, particularly in some Mediterranean areas. Soil erosion, loss of soil organic matter, nutrient leaching, are some of the effects of degradation that lead to the reduction of fertility and ultimately to the desertification of those lands.

One of the aims of BIO4A was to develop and demonstrate methods and agronomic practices to recover and cultivate underutilized marginal lands in European dry Mediterranean areas at risk of desertification, while growing non-food and feed oil crops as feedstock to produce Sustainable Aviation Fuels.

The reduction of rainfall and soil fertility is causing a drastic decrement in agricultural productivity. Current agriculture is based mainly on cereal production, usually alternating with a fallow land year. This practice is directly linked with the erosion and desertification processes. The possibility to find some alternatives to replace the fallow year will allow farmers to stop the soil degradation process also increment the profitability of their activity.

Camelina sativa, is a resilient crop resistant to low temperatures and a very high drought tolerant plant characterized by its root development that allows high utilization of water and nutrients. The introduction of camelina in rotation schemes, a cruciferous crop with a deeper root, has a number of advantages related to soil fertilization and structure like a reduction of soil erosion and use the leftover nutrients potentially polluting by leaching among others. Camelina does not require high investment costs as it is cultivated with commercial equipment and requires medium fertilization. In addition, as camelina seed is not dormant, camelina can be easily controlled, not creating ecosystem issues nor threatening local biodiversity.

Fig. 9 – Camelina sativa. Source: ETA-Florence

For these reasons the interest in Camelina as an oil crop is growing, however this species has not reached its maximum potential yet; genetic improvement and variety selection can still play a crucial role in maximizing its agronomic potential, together with the adoption of specific cultivation protocols. For this reason, Camelina Company España has developed a breeding process in order to select high-yielding varieties which are adapted to different crop rotation models as well as different climatic conditions.

In the framework of this activity, partners RE-CORD and Camelina Company España carried out multi-annual field trials, in micro-plots and larger scale, in Spain and Italy respectively, to test and demonstrate the use of soil amendments such as biochar, compost and a mix of co-composted biochar and digestate named COMBI, to increase soil resilience and health in those lands.

In Spain, the trials have been running from 2018 to 2023, in two areas characterized by marginal land in Spain, with SOC < 2%, located in Finca la Canaleja, Alcalá de Henares (Madrid) and Finca Entresierras, Ciudad Real (Castilla La Mancha).

In these semi-arid areas of Spain, the usual farming practice is to alternate barley with a year of fallow, but this practice leads to a fast mineralization of organic matter and aggravates the effect of erosive processes in the soil. For this reason, the experimental fields were farmed with a simple two-years rotation scheme alternating Camelina with barley. *Camelina sativa* is a drought-tolerant and hardy crop whose deep root system allows for high utilization of both water and nutrients in the soil, while its oil-rich seeds can be used as a valuable feedstock, to supplement used cooking oil and fatty acids for the production of Sustainable Aviation Fuels in HEFA pathways. Replacing fallow with Camelina keeps the soil covered for a longer time of the year and this helps to reduce soil erosion. At the same time the deep root system of the crop has a beneficial effect on the soil physical structure and increases the uptake of minerals, reducing nutrient leaching into the groundwaters.

In the trials, different mixes of biochar from wood and organic material from the solid fraction of digestate from biogas plants were tested against the mineral fertilization treatments that are usually applied in conventional farming systems in those areas of Spain, as follows:
1) No fertilization
2) Mineral fertilization (250 kg/ha NPK)
3) COMBI with 10% - 15% - 20% Biochar
4) Biochar + mineral fertilization (250 kg/ha NPK)
5) 100% Compost

In Italy, RE-CORD performed a 1-year trial on larger scale, with similar conditions.

The objective of this trial was to corroborate the implementation of biochar addition with conventional machinery as well as to confirm the positive biochar effects observed during the microplot trials in a different location. More in details, the Italian trial was focused on the evaluation of the effect of biochar (alone or mixed with compost) on Camelina yield and biomass and on the chemical and physical fertility of the soil.

Two short cycle varieties of Camelina were selected, to account for any genotype effect.
RE-CORD carried out the experimentation in two different locations, in Tuscany (Italy), namely in Terontola (Arezzo) and in Montepaldi (Florence), to evaluate the different pedoclimatic characteristics of the two locations. Both locations showed a poor content in soil organic carbon (<2%), different texture and historical land use: in Terontola, the field had always been subject to intensive arable crops cultivation, while in Montepaldi, the test was conducted on an abandoned field (>10 years).

The experimental design involved the comparison of different amendments and fertilizers:

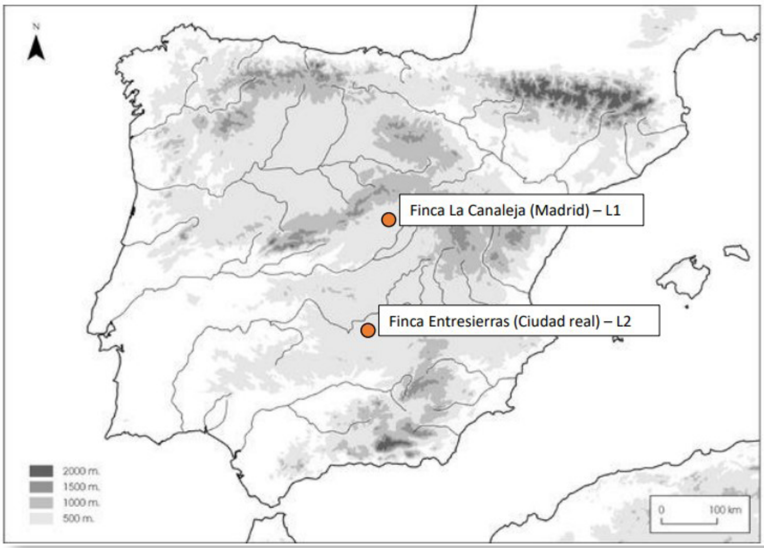


Fig. 10 – Locations of the BIO4A Camelina trials in Spain. Source: Camelina Company España

B) only biochar (3 ton/ha) + NPK (133 kg/ha);
CO) only compost (20 ton/ha) + NPK (133 kg/ha);
BCCO) compost (20 ton/ha) + biochar (3 ton/ha) + NPK (133 kg/ha);
NPK) only NPK fertilizer (133 kg/ha);
CK) control treatment (without fertilizer or amendment).

The soil was sampled for the determination of several physical and chemical properties (pH, electrical conductivity, cation exchange capacity, organic carbon content, total and available elements and water holding capacity). A further sampling at the end of the cultivation was realized to evaluate any significant variation of these properties.

The results from the field trials showed that Camelina grows well in conditions of low water availability, in some cases it even performed better than in conditions of large water availability. Results from the 5 years trials in micro-plot in Spain were also corroborated by the results from the 1-year trial in Italy.

The combined use of biochar and compost had a positive effect on crop development, leading to 25%-40% higher crop yields than conventional fertilization practices.
Biochar presented a clear incremental effect compared to the business-as-usual NPK fertilization, particularly in very low rainfall conditions (86 mm from seeding to harvest in 2019 in La Canaleja). Moreover, the use COMBI (a mix of biochar co-composted with digestate) showed a higher effect than the use of compost only, indicating a likely synergistic effect of the co-composting process of biochar with labile carbon organic material contained in the digestate.

The trials also showed large differences in the response of the different camelina varieties, owing to the wide genetic variability of this species. During the first year the test trials with different varieties were carried out in a growth chamber where light, temperature and relative humidity were controlled in order to simulate optimal conditions for camelina growth. In the second year five selected varieties were tested in marginal land with a high risk of desertification, exposing the treatments to ambient conditions with no irrigation in order to identify high yielding varieties with drought tolerance. In this trial one variety in particular seemed highly promising in terms of both seed and oil productivity and therefore it was selected for further trials in the third year of observation.

The treatments including 15% and 10% of biochar + compost (i.e. COMBI 10 and COMBI15) and 100 % biochar + mineral fertilization in the background fertilization have shown the fastest crop development when the 5 years of trials in Spain were analysed together.

Co-composted biochar (COMBI) at 15%, 10% and 20 % levels of biochar led to the highest seed yields, followed by 100% biochar + mineral fertilization and 100% compost treatments. Compost application has shown a positive correlation with seed weight and oil content. Biochar addition shown a positive effect on plant height, seed

weight and seed oil content.
All treatments including biochar generally tend to increase the organic carbon in soil after 3 years and all of them exhibited a buffering capacity for pH in soil. This is an important aspect, since acidification is one of the causes for soil degradation.

Biochar, alone or co-composted, is recommended as a sustainable agronomic protocol for sustainable lipids production in areas with low rainfall, coupled with Camelina/Barley rotation, compared to business-as-usual agronomic practices. In particular, these organic amendments showed the capability to increase yields and soil carbon stocks, at the same time, with low doses distributed only once in 5 years.

Fig. 11 – Biochar trials.
Source: Camelina Company España.

Fig. 11a – Screening of Camelina varieties in Spain.
Source: Camelina Company España.

References and further resources

This chapter is an edited version of:
Deliverable D2.3: Compost agronomic protocol utilization (Herreras, Y. 2023)
Deliverable D2.6: Selected Camelina variety at EU level, (Prieto J. 2023)

Leon P. - 2023 - Cultivation of Camelina in semi-arid land., 2023 (slides, video)

7 Biochar as a sustainable agricultural management practice

In the framework of the BIO4A project, RE-CORD conducted trials with biochar as a sustainable agricultural management practice also in lysimeters. For this scope, a prototype climatic chamber was designed, engineered and developed by RE-CORD.
The climatic chamber is a containerized prototype for agronomic experiments in controlled conditions. It is equipped with a PLC, controlled by remote, to regulate and automate daylight, temperature and humidity, simulating different photoperiods and field conditions. It also contains 9 lysimeters and precision scales, ambient sensors for temperature, CO2 and humidity.
The objective of the prototype was to allow simultaneous treatments, with sufficient replications (3 treatments with 3 replications) for statistical validity. Also, a logic control from remote of critical parameters (daylight duration and photoperiod simulation, temperature, humidity) was possible thanks to the prototype.
Using reduced irrigation techniques such as deficit irrigation along with biochar amendment is considered to have the potential to substantially reduce the amount of irrigation water required, and to enhance crop productivity. To date, there have been relatively few studies that investigated the effects of biochar under water deficit conditions for plant production.

Two trials were realized to corroborate the effect of biochar used as soil amendment on water retention under simulated semi-arid conditions. The trials were performed in lysimeters under controlled conditions, to simulate the real conditions of the field trials, were devised to produce quantitative results concerning the capacity of biochar to retain water, influence soil humidity, and the N content of water leaving the plant-soil system, compared to the business-as-usual conditions.
Two tests campaigns were realized in a climatic chamber using lysimeters for plant cultivation in order to control and minimize the effect of environmental factors.
In the first experiment, the use of lysimeters was useful to monitor the water loss trough the soil-plant system as well as to collect leachate samples for qualitative analysis, such as the measure of the concentration of soluble elements. In this contest, a

Fig. 12 – RE-CORD Climatic cell prototype and lysimeter

further goal of these experiments was to evaluate the ability of biochar to retain nutrients such as nitrates which are very soluble in water and thus susceptible to leakage as occurred under heavy precipitations. These nitrates losses might not only imply a great use of inorganic fertilizer to counter soil fertility and but also pose an environmental adverse effect as eutrophication.
In a second experiment, biochar was used at increasing rates in lysimeters (equivalent to 0, 10, 20 ton/ha), under severe water stress, simulating semi-arid conditions, and provide understanding over the effect on soil humidity and on plant biomass yield.

The two experimental campaigns in controlled conditions with lysimeters, provided some relevant indications regarding the effect of biochar on nitrogen leaching from soil, water stress and plant productivity.

The first indication is that biochar can be used to reduce the total amount of nitrogen forms which exit the soil depth explored by annual plant roots, thus providing an additional tool for the reduction of water pollution and eutrophication phenomena, potentially increasing barley development and productivity in terms of biomass (although no statistical significance was found).
Moreover, concerning water, biochar in lysimeters showed that it can play a role as a soil amendment, in conserving soil humidity.
In the framework of water stress conditions, the optimal dose of biochar should be investigated to maximise efficiency, probably under 20 t/ha d.b. equivalent, as there might be a competition between water available for plants and stored in biochar under severe conditions (in the experiment, available water was below 15% of field capacity).

Fig. 13 - RE-CORD Climatic cell prototype and lysimeters

References and further resources

This chapter is an edited version of Deliverable D2.10: Results on Lysimeters trials (Tozzi, F., Barsali T, 2023).

8 Mapping the potential Camelina yield and environmental sustainability in the EU Mediterranean region for advanced biofuel production

Vast areas of marginal and underutilized agricultural land in Southern Europe are suitable for the cultivation with sustainable soil management of drought resistant oil in rotation with traditional cereal to produce feedstock for SAF, without impacting food production while increasing the soil organic carbon stock. This is the result of a study carried out by EC JRC as part of its activities in BIO4A. In this study, JRC assessed the production potential of marginal and underutilized land that is available in Southern Europe and that could be dedicated to growing drought resistant oil crop for SAF production. This work used a range of soil and environmental spatial data and a process-based crop model (ARMOSA), with the support of RE-CORD and Camelina Company España, which provided detailed information obtained from field experiments that are currently underway in Spain. The analysis targeted the regions with a predominantly Mediterranean climate characterized by rainfed agricultural land cover (CORINE Land Cover 211), and marginal conditions (CORINE Land Cover 241-242-243) and considered the cultivation of Camelina in rotation with barley. There is an increasing interest in growing Camelina as an oil crop for SAF production in Mediterranean regions, however there is still a limited knowledge about the yields that these crops can deliver when grown at large scale on marginal land.

Defining marginal land and modelling crop yields

The term margin land is used in literature to indicate a wide range of unused abandoned, degraded, or fallow land. In this study the marginality was defined with an economic criterion, to identify the land where Camelina seed yield obtained from the 20 years modelling average was lower than Camelina average yields obtained in European countries based on a comprehensive literature assessment. The research first used a multi-criteria GIS for the definition of the suitable areas using topography, land cover and topsoil spatial data for the entire EU southern Mediterranean regions. The second step was to undertake a yield modelling exercise to assess the suitable areas based on the data from experimental field trials, weather patterns, soil properties, slope and aspect. The soil organic carbon pools and the Camelina yield potential in a two-years rotation with barley were modelled for the past 20 years and for the future using the crop growth ARMOSA model, calibrated for the Camelina yields in Mediterranean areas (the investigated area was around 500.000 km^2).

A viable economic potential and increase of Soil Organic Carbon in marginal lands

The analysis highlighted that an average yield of 2.468±0.64 t/ha^{-1} yr^{-1} of Camelina could be obtained in the investigated area (about 500,000 km2), which can be a viable and profitable economic potential for this crop, when grown in rotation with cereals in the marginal land of the study area.

The study also indicated an average increase in the Soil Organic Carbon stock in the investigated area with an average increase of Soil Organic Carbon of +43 kg ha^{-1} yr^{-1}. The extension of the area where the increase of the SOC stock is positive accounts for 60% of the total area investigated (over 310.000 km^2) and it is more than four times larger than the area where the model indicated a decline of SOC. In those cases, the application of biochar or compost could compensate the decline. A SOC increase of +43 kg C ha^{-1} yr^{-1} is in line with other results of many studies carried out either in the Mediterranean or continental climates within a crop rotation by adopting minimum tillage and straw retention. A higher SOC increase could also take place when Camelina is introduced in rotation with cereal in areas with high desertification risk.

In the Spanish regions where BIO4A field trials were conducted, namely Castilla La Mancha and Comunidad de Madrid which account for 40% of the total area of investigation in Spain, equivalent to 88.233 km^2, the SOC increase is much higher than the average value, reaching +188 and +236 kg ha^{-1} yr^{-1}, respectively. No competition with food crops or impacts on other ecosystem services is foreseen by the cultivation of Camelina with low input inorganic fertilizers and with organic fertilization from compost, or carbon enrichment using biochar to minimize negative impacts. In accordance with the available literature, there is also limited evidence on the impacts of bioenergy cultivation on soil biodiversity.

Significant production potential in Spain, Italy and Greece. In terms of potential production by country, Spain has the largest area of marginal land that could be cultivated with under the camelina/barley rotation scheme, 206,442 km2 equalling to a potential production of 348,918 t . In Italy the suitable land area is 140,136 km^2 with a potential production of 275,156 t of Camelina seeds and in Greece 47,949 km^2 and with a potential of 97,942 t.

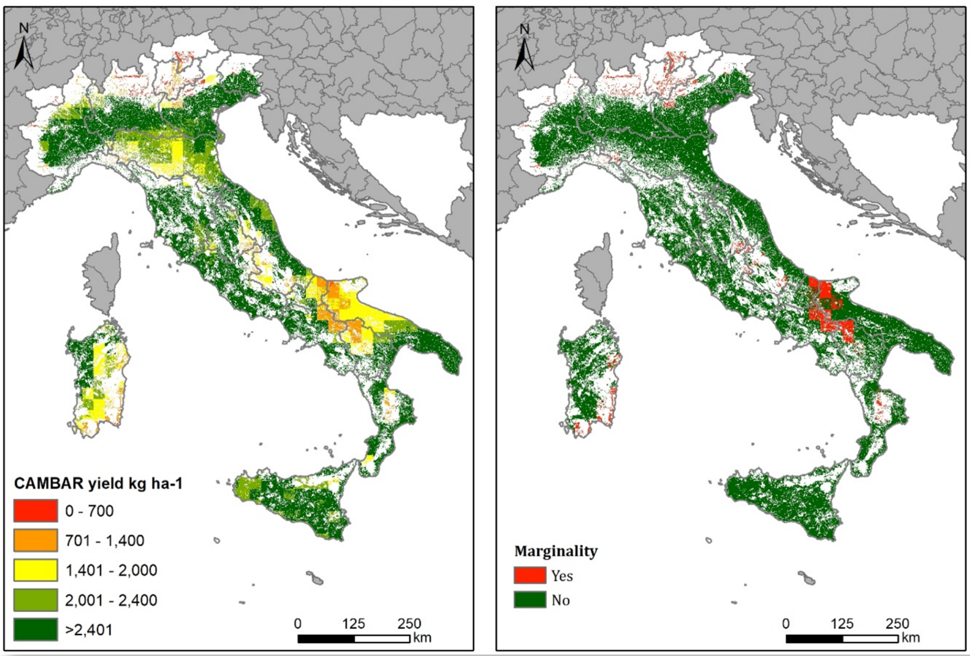


Fig. 14 - CAM-BAR model average yield 2000-2020 kg ha^{-1} Italy. Left panel modelled yield in t ha^{-1}, right panel marginality assessment using the 1.4 t ha^{-1} threshold. Source: JRC.

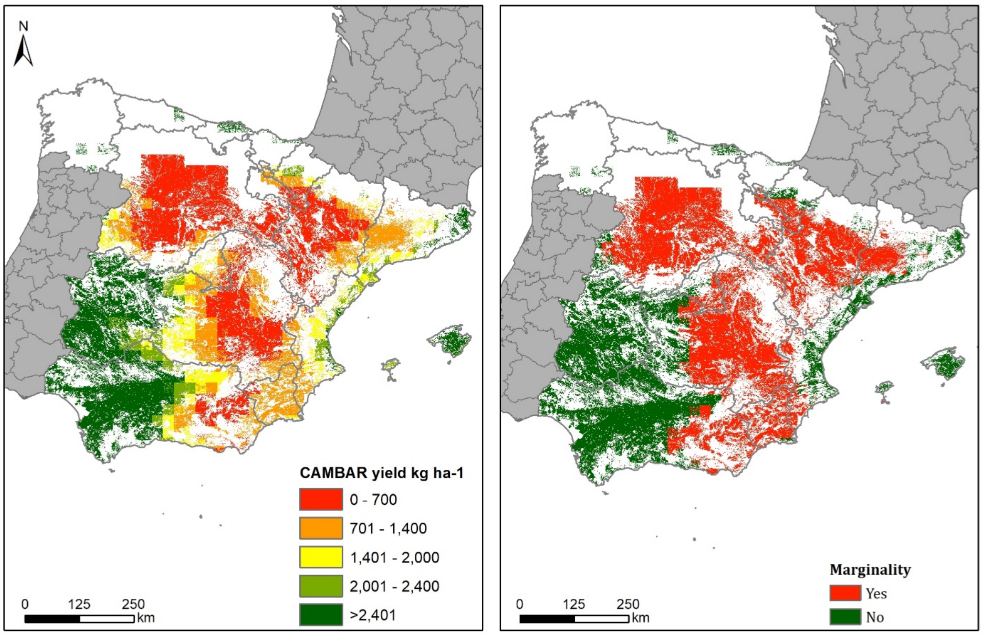


Fig. 15 - CAM-BAR model average yield 2000-2020 kg ha^{-1} Spain. Left panel modelled yield in t ha^{-1}, right panel marginality assessment using the 1.4 t ha^{-1} threshold. Source: JRC

By looking at the near future, considerable expansion of energy crop can be beneficial and become part of the south European agricultural systems, with rotations and consideration as a cover crop that can be harvested optionally. The suitability levels of the land are spread with a pattern that follows mainly SOC baseline stocks and the weather conditions. Areas which experience drought periods during the growing seasons have been subject to failure in single years therefore the average yield obtained on the 20-year timeframe can be lower than the average European yield as it was found in the literature. When the competition for land is highly intense in a given territory, a specific land use/cover might cause the displacement of another one, leading to land-use conversion and, potential negative environmental, economic and social impacts. The competition for land between food and biofuel production has become a well-known example. In the long term, this competition might increase the pressure and impacts on the land capacity to support ecosystems and productive systems which deserve to be in-depth investigated.

The territorial assessment carried out by the mechanistic model ARMOSA highlights the current climatic trends and suggests the need of soil amendments in areas where the profitability of the cultivation might be uncertain. In the other hand high yield targets might pose a threat to our land resources in the mid to long term. This might improve less suitable lands at a regional or local scale and increase their fertility and capacity to deliver ecosystem services. In general terms, growing Camelina on highly suitable land will result in higher yields and reasonable production costs (fertilizer use and tillage). However, as result of the increasing availability of biochar as by-product of energy power plans there is the possibility to sustain yields and offset SOC stock losses in several southern European areas.

Cultivating Camelina in rotation with cereals will, in turn, shift towards the use of marginal land for growing energy crops with environmental and economic benefits. However due to the lack of long-term specific studies at field scale in Mediterranean conditions the impact of biochar addition to energy crops has to be carefully evaluated.

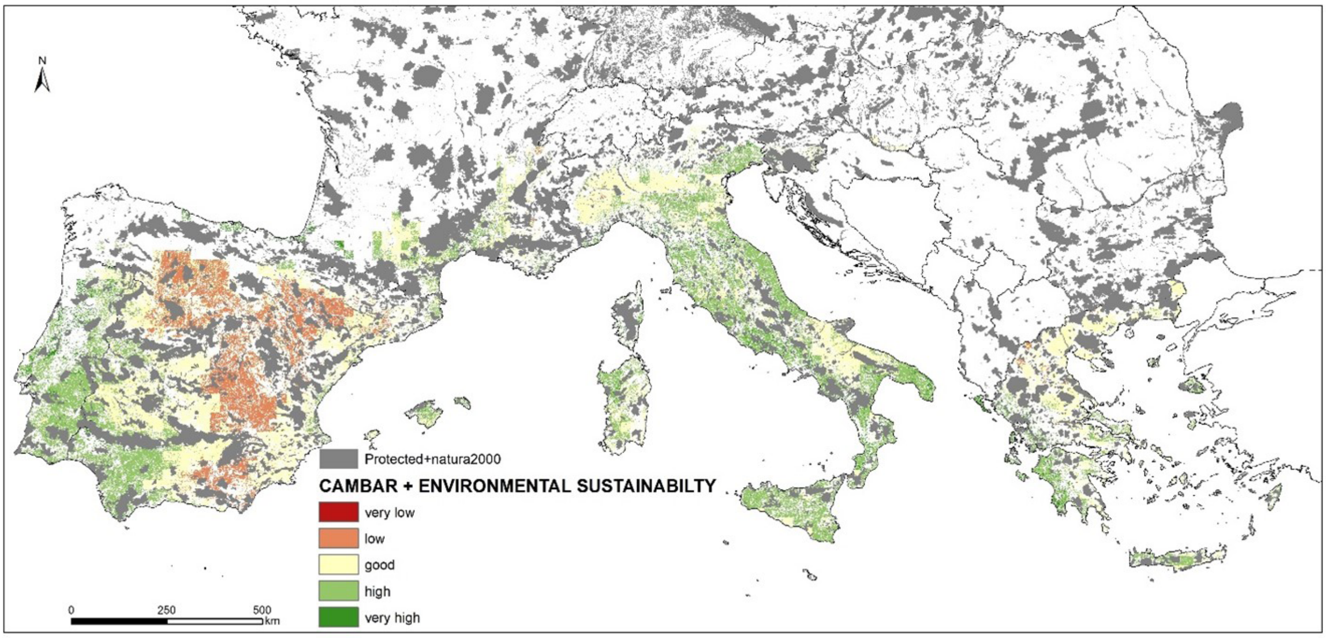


Fig. 16 - Overlay of CAMBAR average yield modeled (2000-2020) and environmental sustainability. Source: JRC

The results of this work constitute a key contribution to policy development at the subnational, national and EU level, through the investigation of low LUC risk biofuel from marginal areas before these are lost due to land degradation processes and other anthropogenic impacts.

References and further resources

This chapter is an edited version of **Deliverable D2.7**: Mapping the potential Camelina yield and environmental sustainability in the EU Mediterranean region for advanced biofuel production (Schillaci C., Jones A., 2023).

Schillaci C. 2023 - Mapping the potential Camelina yield and environmental sustainability in the EU Mediterranean region for advanced biofuel production, 2023 (slides, video).

Schillaci C. et al. 2023 - Assessing marginality of Camelina (C. sativa L. Crantz) in rotation with barley production in Southern Europe: A modelling approach. (link)

9 Sustainability assessment of low-ILUC feedstock SAF value chains at scale

Despite different technological pathways for the production of Sustainable Aviation Fuel (SAF) are already mature and relatively high blending percentages are allowed, the deployment of large supply chains is still scarce. The BIO4A project addressed this gap, by demonstrating a value chain not only including the industrial production of SAF, but also feedstock supply and logistics for fuel delivery.

As part of BIO4A activities, partner CENER carried out a study to analyse the GHG emissions of the proposed value chain, which considers the conversion of lipid feedstocks, namely Used Cooking Oil (UCO), animal Tallow and Camelina Oil (CO), by ENI's patented EcofiningTM process, based on the Hydroprocessed Esters and Fatty Acids (HEFA) technology. The study followed the methodological approach for Life Cycle Assessment of biofuels described in the recast of the Renewable Energy Directive (REDII).
An extensive set of cases was analysed by assuming different locations, logistic options and agricultural protocols (particularly the application of different soil amendments) for camelina cultivation, a crop which is being developed as an intermediate crop and as a potential alternative for restoring degraded lands, as the ones in the EU Mediterranean region here considered. As a meaningful contribution of the work, calculations introduced the Esca term (emissions savings from improved agricultural management), included in REDII methodology, whose application has been limited up to now.

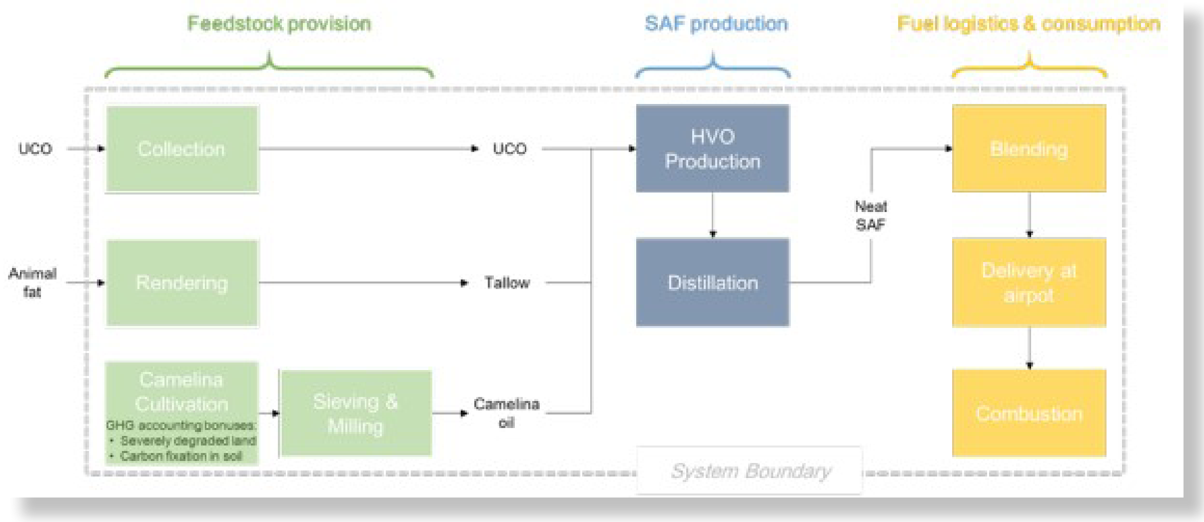


Fig. 17 – System boundaries of the BIO4A value chain. Source: CENER.

The formula recommended in Commission Implementing Regulation (EU) 2022/996 was used to calculate Esca as explained in the figure below:

$$e_{sca} = (CS_A - CS_R) \times 3.664 \times 10^6 \times \frac{1}{n} \times \frac{1}{p} - e_f$$

Where:

CS_R is the mass of soil carbon stock per unit area associated with the reference crop management practice in Mg of C per ha.

CS_A is the mass of soil estimated carbon stock per unit area associated with the actual crop management practices after at least 10 years of application in Mg of C per ha.

3.664 is the quotient obtained by dividing the molecular weight of CO_2 (44.010 g/mol) by the molecular weight of carbon (12.011 g/mol) in g CO_{2eq}/g C.

n is the period (in years) of the cultivation of the crop considered. 20 years assumed.

P is the productivity of the crop, measured as MJ biofuel or bioliquid energy per ha per year. Values are reported in Table A7.

e_f emissions from the increased fertilisers or herbicide use. Zero in this study.

Fig. 18 – Esca formula as per the EC Implementing Regulation (EU) 2022/996. Source: CENER

This term was applied by adopting two different approaches to the quantification of the change in soil carbon stock: i) one based on theoretical calculations, related to the content of fixed carbon in the soil amendments applied and ii) other based on experimental measurements from field trials carried out by BIO4A partners.
Encouraging results were observed for all the studied cases, for the calculated Greenhouse **Gas (GHG) emission savings were always >65%**, as required by REDII for biofuels to be quantified for national renewable energy objectives. In particular, the study **estimated 89% and 85% savings respectively for UCO and Tallow**.

Camelina cases performed even better, providing savings in the range of 107% - 128%. These were largely contributed by Esca and by the adoption of the degraded land bonus (eB), also indicated in REDII methodology. When the Esca and the eB contributions are not taken into consideration, the camelina cases -based on the experimental data obtained from BIO4A field trials in Spain and Italy- provide GHG emission savings ranging from 65% to 74%, depending on the country and cultivation scenario.

The relevance of the Esca term to the results was confirmed by a sensitivity analysis that considered different values for the change in Soil Organic Carbon (SOC) (in which the term is ultimately based). A positive outcome of the study is that the calculated theoretical Esca values for the different camelina cultivation scenarios and the esca values measured experimentally from soil sampling are aligned.

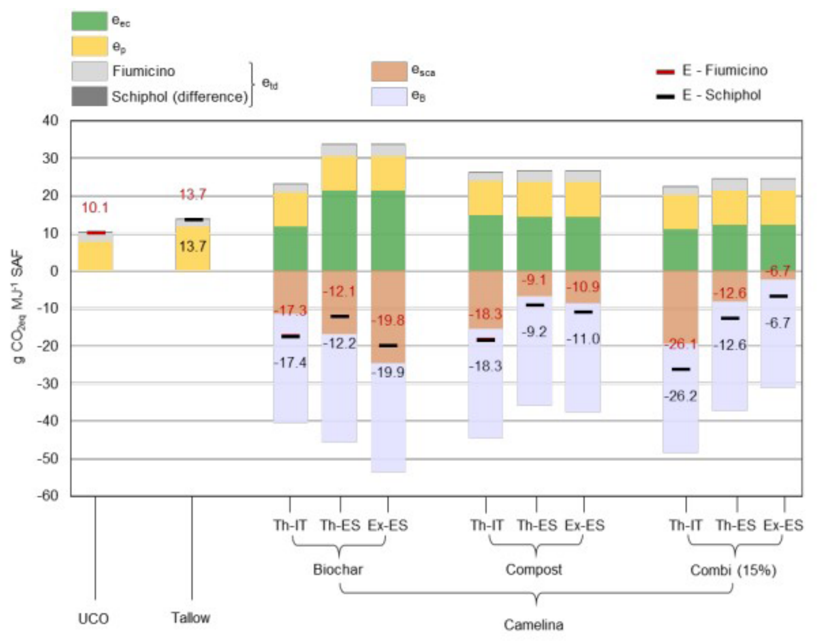


Fig. 19 - Greenhouse gas emissions of analysed SAF production value chains. Emissions from transport and distribution (etd) are jointly presented for SAF delivery at Fiumicino airport and Schiphol (etd Fiumicino + difference). Th: esca calculated from theoretical fixed carbon addition. Ex: esca calculated from experimental measures of change in soil carbon stock. IT: Italy. ES: Spain. Source: CENER

However, the consideration of Esca necessarily needs to be understood as a preliminary approach or pilot application of the term, once large uncertainty is involved in soil sampling and SOC measurements. Further experimental work in this sense should be performed to strengthen these results. Although a maximum limit for Esca of 45 g CO_2eq MJ^{-1}, as indicated in RED II, was taken into account, it was not reached in the study, given that the soil amendments (assumed as the major contributors to SOC change) were only applied at moderate amounts.

Additionally, the influence of crop productivity was also analysed, by varying this parameter ±10%, which yielded changes in overall emissions ranging -11% to +13%. Finally, an optimisation study was also carried out, which actually showed that there is room for even improving these results (minimising emissions) if larger amounts of amendment (biochar) are applied on land.

In summary, we can conclude that the BIO4A value chain and particularly, camelina as feedstock, can be an excellent option providing a synergic positive effect by contributing to decarbonising the aviation sector and reverting soil degradation.

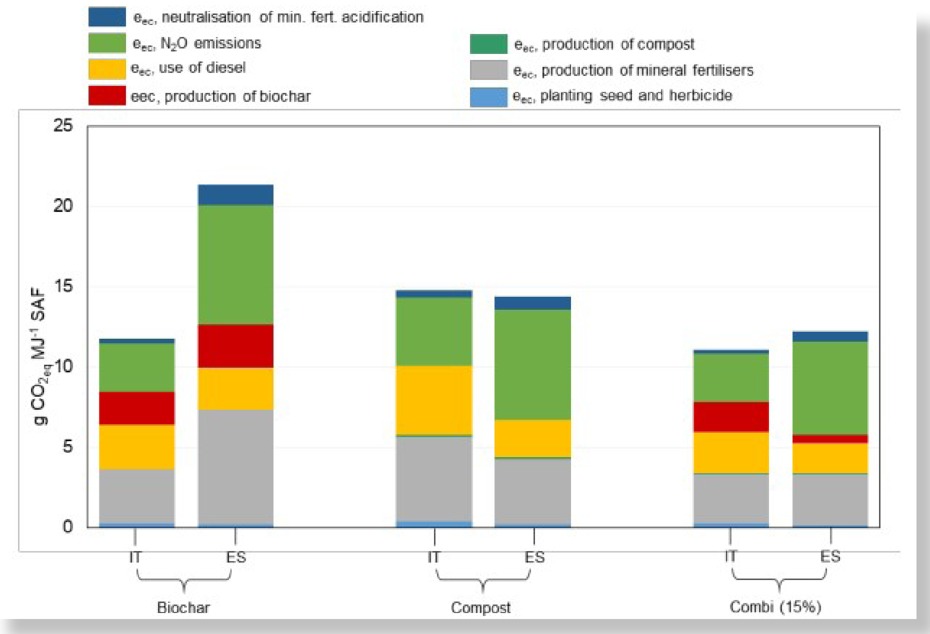


Fig. 20 - Breakdown of emissions derived from crop cultivation (eec) in camelina scenarios. IT: Italy. ES: Spain. Source. CENER

References and further resources

This chapter is an edited version of Deliverable D4.3: Final sustainability assessment (Medina Martos E., 2023).

Medina Martos E. 2023 - Sustainability assessment of low-ILUC feedstock SAF value chains at scale (slides, video).

10 Resources

DELIVERABLES

D 1.1 Technical Specification of Feedstock Quality
D 1.3 ASTM Certified aviation biofuel production
D 2.1 Biochar Units for Agroresidues
D 2.2 Results and product characterization for woody and agro-residue chars
D 2.3 Compost agronomic protocol optimization trial
D 2.6 Selected camelina variety protection at EU level
D 2.7 Mapping of sustainable potential for Mediterranean agricultural land
D 2.8 R&D on pretreatment report
D 2.9 R&D tests and product characterization
D 2.10 Results on Lysimeters trials
D 2.11 Results on optimal Biochar and Compost agronomic protocol
D 3.3 RED II status report 1st
D 3.4 RED II final status report
D 4.1 Process Technological performance
D 4.2 Preliminary Environmental Assessment
D 4.3 Final sustainability assessment
D 4.4 Final Report on the assessment of environmental sustainability indicators
D 4.5 Socio-economic sustainability assessment
D 4.6 KPIs monitoring report
D 4.7 Assessment of socio-economic sustainability indicators for advanced biojet fuel value chains
D 5.1 Business Case
D 5.2 Report on market dynamics
D 5.3 Waste Feedstock Market Analysis
D 5.4 Regulatory Framework Proposal
D 5.5 Market Scaling Strategy
D 6.3 Preliminary Plan for Exploitation and Dissemination of Results
D 6.6 Mid-Term Project Management Plan
D 6.7 Mid Term Plan for Exploitation and Dissemination of Results
D 6.9 Final Project Management Plan

PUBLICATIONS

Production and characterization of co-composted biochar and digestate from biomass anaerobic digestion
Casini D., Barsali T., Rizzo A.M., Chiaramonti D., 2019

Policy measures for sustainable sunflower cropping in EU-MED marginal lands amended by biochar: case study in Tuscany, Italy
Chiaramonti D., Panoutsou C., 2019

Assessing marginality of Camelina (C. sativa L. Crantz) in rotation with barley production in Southern Europe, a modelling approach.
Schillaci et al., 2023 – Accepted article in: Agriculture, Ecosystems and Environment ELSEVIER

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