Advanced Sustainable BIOfuels for Aviation

Deliverable D5.3:

Waste feedstock market analysis

Consortium:

Acronym	Legal entity	Role
RE-CORD	CONSORZIO PER LA RICERCA E LA DIMOSTRAZIONE SULLE ENERGIE RINNOVABILI	CO
ENI	ENI S.p.A.	BEN
SKYNRG	SKYENERGY BV	BEN
CENER	FUNDACION CENER-CIEMAT	BEN
ETA	ETA – Energia, Trasporti, Agricoltura Srl	BEN
CCE	CAMELINA COMPANY ESPANA S.L.	BEN
JRC	JOINT RESEARCH CENTRE – EUROPEAN COMMISSION	BEN

CO…Coordinator, BEN…Beneficiary

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 789562.

General Information

Call identifier:	H2020-LCE-2017-RES-IA
GA Number:	789562
Topic:	LCE-20-2016-2017
Start date of project:	01/05/2018
Duration:	5 years (30/06/2023)
Work Package:	WP5
Type:	Deliverable
Number:	D5.3
Title:	Waste feedstock market
Due Date:	31/12/2022
Submission date:	28/12/2022
Reference Period:	01/05/2018 – 31/12/2022

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Dissemination Level:	Public

INTERNAL MONITORING & REVISION TABLE					
REV.	DATE	DESCRIPTION	PAGES	CHECKED	APPROVED
1	28/10/2022	Original	28	DS	
1.1	10/11/2022	Revised draft	28	TB	
2	23/11/2022	Version 2	31	DS, TB, DC	
3	24/11/2022	Version 3	37	TB	DC

Document Type		
PRO	Technical/economic progress report (internal work package reports indicating work status)	

DEL	Technical reports identified as deliverables in the Description of Work	**X**
MoM	Minutes of Meeting	
MAN	Procedures and user manuals	
WOR	Working document, issued as preparatory documents to a Technical report	
INF	Information and Notes	

Dissemination Level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	
CON	Confidential, only for members of the Consortium	

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1 Summary

Global emissions from the aviation sector have tended to increase over the recent years, due to the growing phenomenon of globalization that has triggered an increase in the volume of air travel, concerning both cargo and passenger transport, especially on an international scale.

This has led to the establishment of institutional bodies dedicated to encouraging and developing strategies to lower the carbon footprint of the aviation sector, especially on the introduction of sustainable and environmentally friendly biofuels.

Bio-kerosene represents the alternative biofuel in aviation, which is produced mostly by means of dedicated crops, such as rapeseed, soybean, sunflower, and oil palm. Nevertheless, the use of land for crops unrelated to food as end use cannot be considered as a viable option, especially for the long term. Alternatively, the European Union has turned its attention to wastes and by-products that can be used as a feedstock for Sustainable Aviation Fuels; such wastes include animal fats (AFs) and used cooking oils (UCOs).

The market for these wastes is not occupied by aviation fuel alone, as both AFs and UCOs are already used in several industrial sectors; however, their use as feedstock for Sustainable Aviation Fuels recently turned out to be a very interesting application, as confirmed by the European RED II Directive, in which, in Annex IX, these feedstocks represent one of the two categories of sustainable feedstock suitable for the production of biofuel, as a substitute for fossil fuels.

Due to this rising environmental awareness, the market for both AFs and UCOs is expected to grow in the near future, despite the fact that the Covid pandemic and the conflict in Ukraine have seriously compromised the market during the 2020-2021 biennium. In the next 4-6 years, the UCO market is expected to increase by more than 41% over 2019-2021 values, with Europe looking set to take priority.

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.

Biodiesel represents the market sector that seems to be mainly influenced from the growth in AF and UCO markets, which may in turn lead to a desirable increase in demand for biodiesel as well.

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 virgin oils in the market, thus affecting the demand. Consequently, the reduced amount of available virgin 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.

2 Introduction

2.1 Contribution of the aviation sector to CO_2 emissions[1]

Lee et al.[2] (2020), in 2018, estimated that global aviation (including both passenger and freight) emitted 1.04 billion tons of CO_2. This represented 2.5% of total CO_2 emissions occurred in 2018, which is based on total CO_2 emissions estimated by Global Carbon Budget, referred to fossil fuels, cement production and land-use change, corresponding to 42.1 billion tons in 2018[3]. Global CO_2 emissions, referred to 2018, have increase by 400% since 1966, doubled since 1987 and underwent a 4-5% growth per year since 2010.

In figures 1 and 2 global and European CO_2 emissions from aviation sector are showed, expressed in million tons (Figure 1) and expressed as a percentage on the global share (Figure 2).

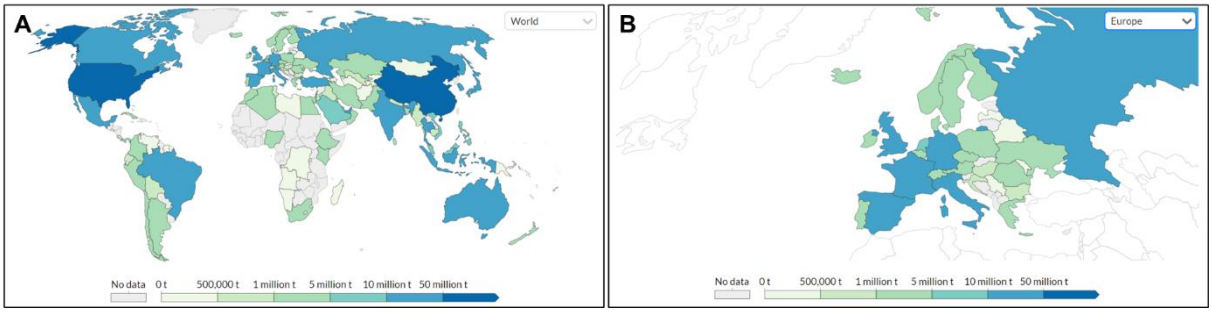

Figure 1 CO2 emissions from aviation sector in 2018. A: Global emissions on the left; B: European emissions on the right (Our World in Data).

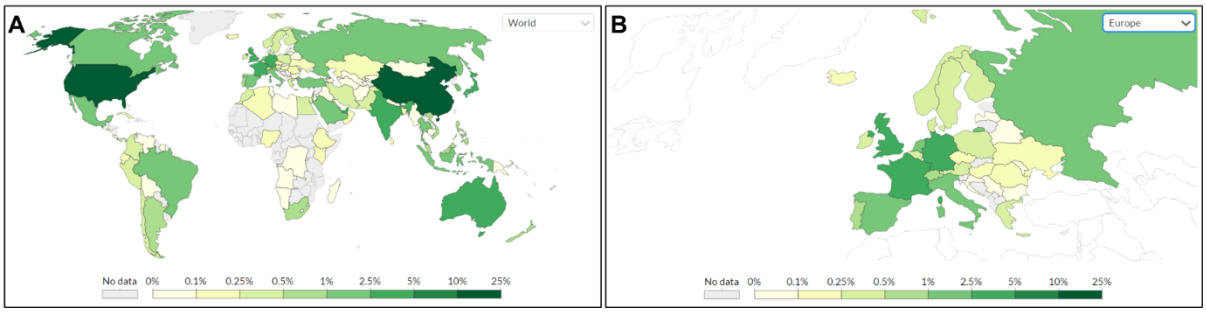

Figure 2 Share of global CO2 emissions from aviation sector in 2018. A: Global emissions on the left; B: European emissions on the right.

Aviation contribution on climate change also rely on affecting the concentration of other gases and pollutants on the atmosphere. They result in a short-term increase, but long-term decrease in ozone

[1] Data in this chapter is obtained from "Our World in Data" unless otherwise indicated. Our World in Data

[2] David S. Lee *et al.* The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. Atmospheric Environment (2021)

[3] GCP: Global Carbon Project https://www.globalcarbonproject.org/

(O_3), a decrease in methane (CH_4), and emissions of water vapour, soot, sulfur aerosols, and water contrails. While some of these impacts result in warming, others induce a cooling effect; overall, the warming effect is stronger. Lee et al. (2020) quantified the overall effect of aviation on global warming when all the impacts were included. To do this they calculated the so-called Radiative Forcing. When the radiative forcing of the different elements is combined, aviation accounts for approximately 3.5% of effective radiative forcing.

Global aviation, including domestic and international flights and passenger and freight transports, in summary, accounts for:

- 1.9% of greenhouse gas emissions (which includes all greenhouse gases, not only CO_2), referred to 2016
- 2.5% of CO_2 emissions, referred to 2018
- 3.5% of effective radiative forcing, referred to 2018.

Even though aviation's contribution to climate change occupies a small part on global emissions share, the key challenge is that it is particularly hard to decarbonize. Compared to other sectors, there is a shortage of innovative solutions in the aviation sector to reduce emissions. While in road transports, a variety of possible renewable fuels (mainly biofuels, but also electricity) can be considered, in aviation only high-quality paraffinic biofuels can be adopted.

Aviation impact on CO_2 emissions rely on both international aviation, which contribute for the major part, and domestic aviation. The former falls under the responsibility of the International Civil Agency Organization (ICAO), while the latter is reported under the United Nations Framework Convention on Climate Change (UNFCCC). To address the increasing global CO_2 emissions, ICAO in 2016 adopted a global carbon-offset scheme under the Carbon Offset and Reduction Scheme for International Aviation (CORSIA), where aviation biofuel could generate eligible emissions units used for carbon offsetting. The carbon offset can be obtained from either emissions trading scheme of the Clear Development Mechanism (CDM) as defined in the Kyoto Protocol[4].

Global emissions from aviation have increased steadily over the past fifty years, however, air travel volumes increased even more rapidly. According to the 2019 International Council on Clean Transportation (ICCT) report on global aviation[5], most emissions come from passenger flights (2018), accounting for 81% of aviation's emissions; the remaining 19% came from freight transport. A proportion of 60% of emissions from passenger flights come from international travel; the other 40% come from domestic (in-country) flights (Figure 3).

[4] Cheng Tung Chong and Jo-Han Ng, Chapter 1 - Global Aviation and Biojet Fuel Policies, Legislations, Initiatives, and Roadmaps, Biojet Fuel in Aviation Applications, Production, Usage and Impact of Biofuels (2021)

[5] CO_2 emissions from commercial aviation, 2018 (theicct.org)

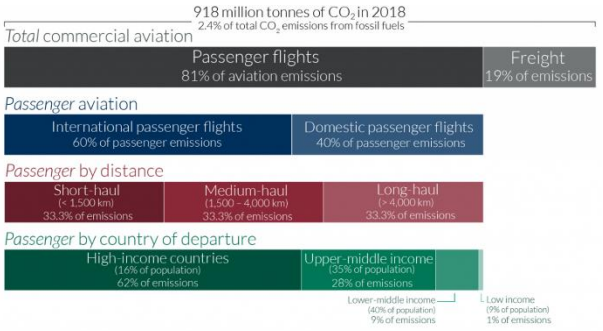

Figure 3 2019 ICCT report - Global CO_2 emissions from commercial aviation.

Combining per capita emissions from domestic and international travel, the global footprint from aviation is 103 kg of CO_2 per year, with strong inequity in emissions within world countries (Figure 4). For example the highest emission value per capita relies on the United Arab Emirates, where each person emits about 1,950 kg of CO_2 from flying each year; while in many countries, most people do not fly at all (the average Indian emits just 18 kg from aviation).

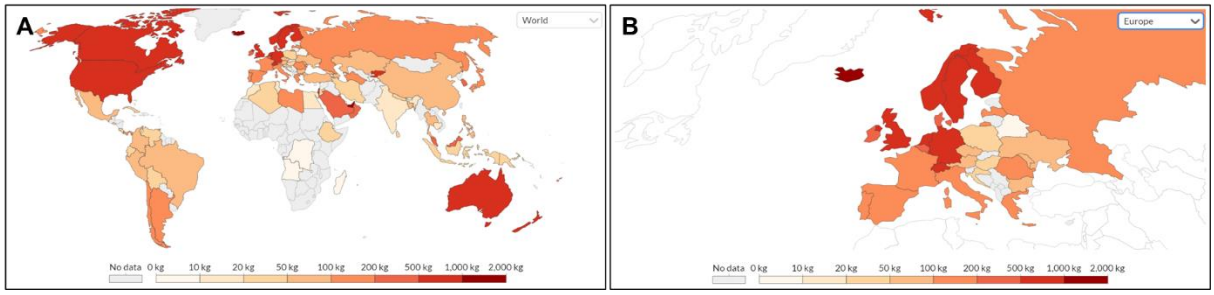

Figure 4 Per capita CO_2 emissions from aviation in 2018 (kg). A: Global emissions; B: European emissions.

2.2 Sustainable Aviation Fuel (SAF) and CORSIA Eligible Fuel (CEF)

ICAO recognizes Sustainable Aviation Fuels (SAFs) as an important element to reduce aviation emissions and also to eventually ensure the success of CORSIA. States are requested by ICAO to assess the sustainability of all alternative fuels for use in aviation, where they should achieve net greenhouse gas emissions reduction on a life cycle basis and work together through ICAO and other relevant international institution to share information and best practices on the sustainability of alternative fuels for aviation. ICAO also pursues three key programs with regard to SAF, namely the ICAO Global Framework for Aviation Alternative Fuels (GFAAF), the 2050 ICAO Vision, and the ICAO Stocktaking Process. The GFAAF is an online database containing information, projects, and news announcements of aviation fuels dating back to 2005. The 2050 ICAO Vision requires stakeholders within the international aviation sector to operate flights using a significant proportion of SAF by 2050. The ICAO Stocktaking Process has the objective of assessing the SAF development and deployment progress.

On July 14th, 2021, the European Commission (EC) proposed an EU-wide blending mandate on SAF, as well as improved obligations for airlines. As outlined in "A Market Outlook on SAF – Summary Report [6] (July 2021)", the ReFuelEU proposal consists of a 2% blending obligation for SAF in 2025, increasing to 5% in 2030, 32% by 2040, and 63% in 2050, with a specific sub-mandate for Power-to-Liquids fuels (0.7% in 2030, 8% by 2040, 28% by 2050). Several European countries already implemented or proposed a national blending mandate, overcoming the ReFuelEU targets. EU Parliament and Council are assessing the level of the proposed blending targets, addressing competitive distortion, proposing measures to incentivize SAF production through revolving funds and the need for a cap on the use of waste oil feedstock, in line with the RED II framework. To meet the total demand from EU and UK mandates and the additional demand expected from national mandates, a SAF supply of 4.7 Mt in 2030 and 39.1 Mt in 2050 is needed[7].

The CORSIA Eligible Fuels (CEFs) comprises both the "sustainable aviation fuel" and the so-called "Low-Carbon Aviation Fuel". The CORSIA sustainable aviation fuel refers to a renewable or waste-derived aviation fuel that meets the CORSIA Sustainability Criteria, while the CORSIA lower carbon aviation are for fossil-based aviation fuels[8] meeting the same sustainability requirements. The focus is on sustainability criteria and life cycle methodologies in order to assess the life cycle emissions value (LS_f): to ensure that the CEF meets the CORSIA Sustainability Criteria, Sustainability Certification Schemes (SCSs) are developed by ICAO to conduct the sustainability certification process.

The general guiding principle of CEF Certification is such that, for waste, residues, or by-products, only the core LCA values as the LS_f are to be considered. LS_f indicates the expected CO_2-equivalent reduction from the use of a CEF due to the sustainable fuel conversion pathway, production region, feedstock type, land size usage, and the type of land used. In case of virgin lipids, the additional indirect land usage change (ILUC) is to be accounted in the LS_f value.

2.2.1 Sustainability Certifications

Biofuel sustainability analysis is complex due to the stringent environmental measures and the lack of the majority of the law to audit for sustainability to any levels and throughout the entire production chain. This can lead fuel purchaser to find themselves acquiring unsustainable fuels, despite what the law requires about environment protection.

Sustainability certification systems verify environmental protections at the detailed field level, allowing customers to identify and reward biofuel producers that take certified measures to protect the environment.

Biofuel sustainability certification systems measure and verify environmental performance of fuels throughout all major stages of the product life cycle, including feedstock production, fuel production

[6] A market Outlook on Sustainable Aviation Fuel, Background Analysis, May 2022 (SkyNRG)

[7] A market Outlook on Sustainable Aviation Fuel, Background Analysis, May 2022 (SkyNRG)

[8] An overview of CORSIA Eligible Fuels (CEF). ICAO Secretariat, 2019.

and end use. Within each stage, the assessment exploits a range of criteria that influence environmental sustainability including impacts on water, soil, biodiversity, air, land use, and waste. These criteria are divided into different indicators to assign a value to the sustainability measurement. Different systems use "criteria" and "indicators" that may be different, however all certifications pursue the same goal, providing an organized and objective way to track sustainability down to the field level. Facilities and feedstock operations must undergo third-party site audits to verify the accomplishment of the criteria (and indicators) to be certified as sustainable.

The International Sustainability and Carbon Certification (ISCC)[9] is the leading voluntary scheme based on the RED, concerning the environmental and social aspects of biomass production, which is applicable worldwide. The ISCC covers the assessment of production and management criteria, traceability documentation and of GHG saving calculations. The ISCC distinguishes the pivotal chain actors in primary producers (certification not mandatory), first gathering points or collecting points, conversion units and traders of raw/intermediate materials for final fuel. The ISCC certification allows the participation of the certified company as an integral member of a RED-certified sustainable supply chain for Europe's sustainable biofuel market.

Similarly, the REDcert[10] offers certification scheme for sustainable biomass, biofuels and bioliquid, and, as opposed to ISCC, it focuses only on European supply chain.

The Green Gold Label (GGL)[11] is a biomass certification scheme, appliable worldwide, that takes into account both the origin (forest management or agricultural) and the supply chain information (energy and carbon). The GGL is recognized as the global certificate for sustainable biomass.

The Roundtable on Sustainable Biomaterials (RSB)[12] is an international multi-stakeholder initiative that brings together farmers, companies, non-governmental organizations, experts, governments, and inter-governmental agencies concerned with ensuring the sustainability of biomass and biomaterial production and processing. The RSB certification can help a company to identify and mitigate risks, to access to new or developing market (including aviation and EU markets), to increase trust and reputation among investors, stakeholders and customers and to overcome negative perception regarding biomaterials.

The SUstainable REsources (SURE)[13] verification scheme was developed for the supply chains of solid and gaseous biofuels according to the requirements of EU REDII. The SURE system can be applied to biomasses (agricultural raw materials, wastes and residues; forestry production, waste and residues; biogenic wastes and residues), to producers or sources (energy crop, straw and manure; crop residues, sawdust, woodchips, wood pellets and wood briquettes) and to companies (with activities in process or trade the biomass; in trade the fuels; in use the fuel for the generation of energy; in trade energy).

[9] Solutions for sustainable and deforestation free supply chains › ISCC System (iscc-system.org)

[10] Home (redcert.org)

[11] Green Gold Label

[12] Home | Sustainable Development and Biomaterials | RSB

[13] Sure (sure-system.org)

The Council on Sustainable Biomass Production (CSBP)[14] is a multi-stakeholder's organization with the aim of developing a voluntary sustainability standard for biomass production, in particular for liquid transportation fuel and biopower.

The Roundtable on Sustainable Palm Oil (RSPO)[15] is a multi-stakeholder nongovernmental organization with the purpose of maximizing the environmental and social impacts of palm oil cultivation through the introduction of a sustainability standard composed of various social, economic and environmental parameters. The RSPO certifies palm oil, palm kernel oil and derivatives, guaranteeing and enhancing the values of product derived from crops managed according to environmental and social sustainability criteria.

The Roundtable on Responsible Soy (RTRS)[16] is a non-profit organization promoting the growth of production, trade, and use of responsible soy. It works through cooperation with those in, and related to, the soy value chain, from production to consumption, including fuel production.

In Italy, the Ministerial Decree of 14th November 2019 introduces certification for the entire delivery chain of biofuels and bioliquids. The conformity assessment scheme, the result of collaboration between the Ministry of Environment and Accredia, is already active and can be verified by bodies accredited according to the technical standard UNI CEI EN ISO/IEC 17065 and other applicable mandatory documents. Accredia is the body designated by the Italian government to certify the competence, independence and impartiality of bodies and laboratories that verify the conformity of goods and services to standards[17].

2.3 European and Italian Legislation

2.3.1 *EU Fuel Quality Directive (FQD)*

The EU Fuel Quality Directive 98/70/EC of October 13, 1998, was first launched with the objectives of ensuring the quality of petrol and diesel fuels. In terms of biofuels, only low blends of biofuels below 30% biofuel content are within the goal of the FQD. The FQD contributed to the reduction of pollutants from the transportation sector. Over the 1995-2013 period, sulfur oxides (SO_x), lead, nitrogen oxides (NO_x), PM10, and PAHs reduced by 98%, 95%, 51%, 42%, and 62%, respectively.

2.3.2 *EU Renewable Energy Directive (RED II)*

The European Commission (EC) recognizes the need to face air pollution and climate change, setting a process to achieve climate neutrality by 2050. Decarbonization of economic activities in all sectors and reducing GHG emissions are the main targets to fulfil the purpose. In 2009, the EC started to set nationally binding targets of 20% renewables by 2020 through the original Renewable Energy Directive (2009/28/EC). The Directive defines individual national targets to member states, which must also have 10% transport fuels originating from renewable sources by 2020 under the 10% RES-T target[18].

[14] Council on Sustainable Biomass Production (CSBP) (fao.org)

[15] RSPO - Roundtable on Sustainable Palm Oil

[16] RTRS – Round Table on Responsible Soy Association

[17] Accredia - L'Ente Italiano di Accreditamento

[18] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

RED was revised in 2018 as Renewable Energy Directive 2018/2001/ EU[19], also known as RED II, establishing a new threshold of at least 32% for 2030. Concerning the transport sector, the share of renewable fuel target was increased to 14% by 2030.

Advanced biofuel sources are also explicitly defined into two separate groups, defined as part A and part B in Annex IX of the RED II.

Part A refers to a list of feedstocks for biogas and advanced biofuels production, which are classified as wastes, residues or by-products. Biofuels produced from these materials have a specific sub-target starting at 0.2% in 2022, at least 1% in 2025 and increasing to at least 3.5% in 2030 (Directive 2018/2001/ EU, Art. 25). Part B of the Annex encompass Used Cooking Oil (UCO) and animal fats (as categories 1 and 2, according to EC Regulation 1069/2009[20]), as feedstocks for the production of biofuels and biogas for transport. The share of biofuels and biogas produced from the feedstock listed in part B shall be limited to 1,7% of the energy content of transport fuels supplied for consumption or use on the market (Directive 2018/2001/ EU, Art.27b).

The contribution of biofuels produced from feedstock listed in Annex IX towards the minimum shares referred to Article 25 may be considered to be twice their energy content.

Article 3 of the RED defines the overall renewable energy in transport as in the following equation[4]:

$$RED(\%) = \frac{All\ types\ of\ energy\ from\ renewable\ sources\ consumed\ in\ all\ forms\ of\ transport}{Petrol, diesel, biofuels\ consumed\ in\ road\ or\ trail\ transport, and\ electricity\ (in\ transport)\ but\ excluding\ off-road}$$

Multipliers for the denominator can be used in specific end sector: for example, a 1.2 value is assigned to non-food renewable fuels supplied to the aviation (and maritime) sector, which, in other words, will count 1.2 times their energy content Multipliers, used to demonstrate the compliance with the minimum share, represent a tool to promote alternative fuels that are not food or feed based.

The RED II introduces the concept of “low ILUC-risk” biofuels, bioliquids and biomass fuels, which will represent one of the main options for maintaining the current shares of renewables in transport, and for the further development of the market potential for sustainable biofuels in Europe, especially in sectors with limited short-term alternatives, such as the aviation sector.

The criteria for certification of low-ILUC risk biofuels, bioliquids and biomass fuels have been outlined in Commission Delegated Regulation (EU) 2019/807 of 13 March 2019[21], supplementing Directive (EU) 2018/2001. This Delegated Regulation defines low-ILUC risk biofuels, bioliquids and biomass fuels as those that are produced under circumstances that avoid ILUC effects, by virtue of having been cultivated on unused, abandoned or severely degraded land or emanating from crops which benefited from

[19] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources.

[20] Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (Animal by-products Regulation).

[21] Commission Delegated Regulation (EU) 2019/807 of 13 March 2019 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council as regards the determination of high indirect land-use change-risk feedstock for which a significant expansion of the production area into land with high carbon stock is observed and the certification of low indirect land-use change-risk biofuels, bioliquids and biomass fuels

improved agricultural practices. The share of renewable fuels produced from food/feed crops shall be no more than one percentage point higher than the share of such fuels in the final consumption of energy in the road and rail transport sectors in 2020 (referred to the relative Member State), with a maximum 7% of final consumption of energy. Fuels originated from feedstock recognized ad "high ILUC-risk" will undergo to a more restrictive cap: the share of such fuels shall not exceed the level consumption in that Member State in 2019. From 2023 to the end of 2030 (at the latest), that limit shall gradually decrease to 0%.

The EU Directive 2015/1513[22] amended and harmonized both the Fuel Quality Directive, (FQD) and the RED. The European policymakers have decided that for the transport target, member states are no longer obliged to use crop-based biofuels, pushing toward advanced biofuels.

2.3.3 EU White Paper on Transport

While not a policy or a regulation, the European Commission adopted a White Paper on Transport in 2011[23], which consists of a roadmap of 40 concrete initiatives for the next decade to promote the transport system, increasing mobility, removing major barriers in key areas and sustaining growth and employment. At the same time, the proposals aim to strongly reduce Europe's dependence on imported oil and to reduce carbon emissions in transport by 60% by 2050. The white paper defines 10 key goals to guide policy actions to achieve the target reduction by 2050:

1. No more "conventionally fuelled" cars in cities
2. 40% low-carbon sustainable fuels in aviation and 40% reducing EU CO_2 emissions from maritime sector
3. More than 50% of road freight over 300 km should shift to rail or waterborne transport.
4. Enhancing the high-speed rail network.
5. Fully functional and EU-wide network and information services.
6. Efficient connection between the main transport network (airports, rail, seaport and inland waterway system)
7. Deployment of traffic and transport management infrastructures
8. Establishment of the framework for a European multimodal transport information, management and payment system, by 2020
9. Enhancing the safety and security of transport in all modes of transport
10. Move towards full application of 'user pays' and 'polluter pays' principles and private sector engagement.

[22] Directive (EU) 2015/1513 of the European Parliament and of the Council of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources

[23] White paper on transport. Roadmap to a single European transport area: towards a competitive and resource efficient transport system. Directorate-General for Mobility and Transport (European Commission)

2.3.4 *Italian Legislation on Biofuel*

Italian legislation provides that fossil fuel producers should annually supply a minimum quota of biofuels based on the total amount of fuel supplied. The decree n. 128/2005 established a national indicative target of 5.75% of substitution of traditional fuels with biofuels by 31 December 2010 (article 3).

The Budget Law 2007 and its subsequent amendments established an obligation for all traditional fuel producers to supply, each year, a minimum quota of biofuels determined as a percentage of the previous year total supply volume. The initial quota was 1% for 2007; subsequently it has been increased to 2% for 2008 and 3% for 2009 and to 4.5% by 2014 according to the provisions of the Legislative decree n.28/2011.

Non-compliance with the quota is subject to penalties: starting from 1st January 2013 responsibilities related to the verification of compliance with this obligation has passed from the Ministry of agriculture and forestry to the Ministry of Economic Development which performs such activity through GSE - Gestore dei Servizi Energetici. Biofuel from waste and residues are double counted for the compliance with the quota.

The 2015 amendments established the trajectory from 2015 (5%) onwards for biofuel blending quota obligation (5.5% from 2016, 6.5% from 2017, 7.5% from 2018, 9% from 2019 and 10% from 2020), updating the provision of previous legislation. A mandatory quota for "advanced biofuels" has been introduced, as well 1.2% in 2018, 1.2% in 2019, 1.6% in 2020, 2% in 2022). The concept of "Advanced biofuels" has been introduced by the ministerial decree: those are biofuels produced from materials listed in Annex 3 of the Decree and include agricultural and industrial wastes (apart from UCOs and animal fats), residues, ligno-cellulosic materials, cellulosic materials and algae[24].

Lastly, the Decree of the Ministry of Economic Development of 13th December 2017, which amended the previous 10th October 2014 Decree, modified those quotas as follow: in year 2018 biofuel blending obligation must be 7.0% of which at least 0.1% advanced biofuels, in year 2019 8.0% of which at least 0.2% advanced biofuels and in year 2020 9.0% biofuels of which at least 1.0% advanced biofuels.

In Table 1 the main Italian normative is presented according to the several decrees that regulate biofuel production and utilization.

Table 1 Main normative regulating biofuel production and consumption in Italy.

DECREE	DATE	SUBJECT
LEGISLATIVE Decree n. 128	30/05/2005	Implementation of European Directives 2003/30/EC
		Promotion of the use of biofuels or other renewable fuels in transportation.
MINISTRY for AGRICULTURAL and FORESTRY POLICIES Decree n. 110	29/04/2008	Obligation to release a minimum share of biofuels for consumption in the national territory.
MINISTRY of ECONOMIC DEVELOPMENT Decree n. 100	23/04/2008	Administrative penalties for failure to meet the obligation to release a minimum proportion of biofuels for consumption.

[24] International Energy Agency (IEA). Biofuel aid scheme: quotas (Biofuels aid scheme: quotas).

LEGISLATIVE Decree	03/03/2011	New ways of incentivizing biomethane and other advanced biofuels and a reshaping of the different obligation percentages between conventional and advanced biofuels.
LEGISLATIVE Decree n. 28	23/03/2011	implementation of directive 2009/28/EC: promotion of energy use from renewable sources.
		Support schemes for the use of renewable sources in transport.
		Operational and management powers assigned to the Ministry of Agricultural, Food and Forestry Policies are assigned to the Ministry of Economic Development, which exercises them using the GSE.
LEGISLATIVE Decree n. 55	31/03/2011	Implementation of European Directives 2009/28/EC and 98/70/EC: specifications for gasoline, diesel fuel and gasoil, introducing a mechanism to control and reduce greenhouse gas emissions.
		The specifications for fuel used by inland waterway vessels.
MINISTRY of ENVIRONMENT, LAND and SEA Decree	23/01/2012	National certification system for biofuels and bioliquids.
DECREE-LAW n. 134	07/08/2012	Amendment of Legislative Decree n. 28 (28th March 2011).
		Urgent measures for the country's growth.
MINISTRY of ECONOMIC DEVELOPMENT Decree	13/02/2013	Conventional specifications of fuels and biofuels for the purpose of mandatory release for consumption in the national territory of a minimum share of biofuels.
MINISTRY of ECONOMIC DEVELOPMENT Decree	05/12/2013	Incentive arrangements for biomethane fed into the natural gas grid.
MINISTRY of ECONOMIC DEVELOPMENT Decree	11/12/2013	Management charges and related payment arrangements to the energy services manager GSE S.p.A. for carrying out operational and management responsibilities for biofuels.
DECREE-LAW n. 9	21/02/2014	Urgent measures to launch the "*Destinazione Italia*" plan, for the containment of electricity and gas tariffs, for the reduction of RC-auto premiums, for the internationalization, development and digitalization of enterprises, as well as measures for the implementation of public works and EXPO 2015.
		New provisions for the biofuel release system.
		Update of the conditions, criteria and methods of implementation of the biofuel release obligation.
DECREE-LAW n. 116	11/08/2014	Urgent provisions for the agricultural sector, environmental protection and energy efficiency of school and university buildings, the revitalization and development of enterprises, the containment of costs burdening electricity tariffs, as well

		as for the immediate definition of obligations arising from European legislation.
		Arrangements for covering charges incurred by the energy services manager GSE S.p.A. and in the field of the obligation to release for consumption of biofuels.
		Administrative pecuniary penalties, proportional and dissuasive, for failure to meet the established obligations.
MINISTRY of ECONOMIC DEVELOPMENT Decree	10/10/2014	Update of the conditions, criteria and methods of implementation of the obligation to release for consumption of biofuels including advanced biofuels.
		The Ministry may adjust the minimum percentage of the obligation to release for consumption, in relation to biofuels, in order to take into account technological development, the actual availability of such biofuels on the market, ongoing investments in the sector and the development of other forms of renewable energy that can be used in transport.
MINISTRY of ECONOMIC DEVELOPMENT Decree	15/01/2015	Administrative penalties for failure to meet the obligation to release for consumption a minimum share of biofuels.
LEGISLATIVE Decree	21/03/2015	Implementation of the European Directive (EU) 2015/652: calculation methods and reporting requirements under Directive 98/70/EC relating to the quality of gasoline and diesel fuel.
		Implementation of the European Directive (EU) 2015/1513 (amend. 98/70/EC): quality of gasoline and diesel fuel
		Implementation of the European Directive (EU) 2009/28/EC: promoting the use of energy from renewable sources
MINISTRY of ECONOMIC DEVELOPMENT Decree	21/03/2017	Amendment 10th October 2014 Decree.
		the sentence "year 2018 = 7.5 % biofuels of which at least 1.2 % advanced biofuels; year 2019 = 9.0 % biofuels of which at least 1.2 % advanced biofuels; year 2020 = 10.0 % biofuels of which at least 1.6 % advanced biofuels;" is replaced with the phrase "year 2018 = 7.0 % biofuels of which at least 0.1 % advanced biofuels; year 2019 = 8.0 % biofuels of which at least 0.2 % advanced biofuels; year 2020 = 9.0 % biofuels of which at least 1.0 % advanced biofuels.

3 Waste feedstock market analysis

3.1 Biofuel and feedstocks

Biofuels are defined in the Article 2 of the Directive 2009/28/EC (RED) as "liquid or gaseous fuel for transport produced from biomass", *i.e.* agricultural, forestry or fishery products, waste or residues of biodegradable nature from industries or municipalities".

The pivotal characteristic of biofuel lays on fewer GHG emissions than fossil fuel, as the source for biofuel production captures CO_2 minimizing the total emissions due to combustion. Moreover, this can be asserted if there are no additional emissions due to direct or indirect land use change, which impacts the need of new areas to cultivate food crops. The competition with food supply does not occur when biofuel is produced from waste and/or residues.

At present, the only biofuels produced in significant quantities in the EU are bio-gasoline (including bioethanol) and biodiesel.

The usual feedstock for biodiesel production is refined vegetable oil, which has a different agronomic source based on location availability. Four crops are globally dominating the source used for biodiesel production: rapeseed and sunflower oils are mainly used in Europe (EU), palm oil is predominant in tropical countries, and soybean oil (together with animal fats) is the most used feedstock in the United States. Overall, rapeseed oil is the leader in this sector with a global share of about 85%, followed by sunflower, soybean and palm oils. All four the feedstocks produce the so called "first-generation" biodiesel, since they belong to the edible oils category. This kind of source has raised many issues linked to the competition between food supply and oil demand (food vs. fuel), considering, also, the ongoing deforestation events that lead to soil destruction for the purpose of cultivating dedicated crops.

As alternatives inedible oils can replace edible oils for the production of "second-generation" biofuels. The inedible oils crops can be cultivated in marginal lands, wasteland or in other sites unsuitable for edible oil crops, maintaining high level of production and yield. Moreover, waste oils (such as UCO) and animal fats are suitable for producing second-generation biofuels, reducing, at the same time, the problem of waste disposal and, potentially, the production cost of biodiesel. Wastes likely produce lower oil quality, compared to virgin oils.

Recently, microalgae are gaining great awareness to produce "third-generation" biodiesel. Algae has the advantage of growing at a faster rate, with higher yield and they have no need to be cultivated on field, compared to both edible and non-edible oil crops. Despite several studies agreed that algae-based biodiesel has lower carbon footprint, more researches are needed to assess production cost and energy output for mass production[25].

[25] Umer Rashid and Balkis Hazmi. Advances in Production of Biodiesel from Vegetable Oils and Animal Fats. Biodiesel Production: Feedstocks, Catalysts, and Technologies, First Edition (2022).

From an environmental point of view, wastes have the lowest impact in CO_2 emissions in the atmosphere. Hosseinzandeh-Bandbafha et al. (2022)[26], in a LCA review, compare the environmental impact of UCO-based biodiesel with other biodiesel sources. They assert that the production of UCO biodiesel can led to about 30% reduction in CO_2 emissions and about 70% reduction in GWP when compared to jatropha oil biodiesel. Moreover, a reported study found that UCO biodiesel could results in a 97% reduction in damage to resources compared with algae-based biodiesel. They showed decreased water acidification and water eutrophication compared to both jatropha oil and algae oil.

3.1.1 Biofuel feedstock availability

The Concawe, a division of the European Fuel Manufacturers Association, released a document entitled "Sustainable biomass availability in the EU, to 2050"[27] with the goal of identifying the potential availability of sustainable biomass included in Annex IX of Renewable Energy Directive II (2018/2001).

Based on a high technology scenario, taking into account the maximum yield per pathway and the total sustainable biomass for bioenergy, the potential advanced biofuel quantity is expected to reach 1.9 million tons of oil equivalent (Mtoe) and 2.6 Mtoe from waste oils and fats and from UCO, respectively, in 2030; 1.9 Mtoe and 6.5 Mtoe, respectively, in 2050. Total sustainable biomass, available for bioenergy, could potentially be used, mainly, for power, industry, services and agriculture, and residential heat demand in 2030 and 2050; this will decrease the amount of feedstock available for advanced biofuel production.

The total estimated net biomass available for biofuel production, including imports and allowing for uses not related to transport, is estimated between 126–262 Mtoe for 2030 and 101–252 Mtoe for 2050.

The potential sustainable biofuel availability for the EU domestic production of advanced and waste-based biofuels could range from 76.7 Mtoe to 127.5 Mtoe in 2030, with 28.9-79.2 Mtoe considered as allocated to transport sector; while in 2050 is predicted to be 158.5-252.8 Mtoe with 31.5-137.2 Mtoe aimed to be used for transport.

The fact that a lower availability of biomass in 2050 compared to 2030 leads to a higher production of biofuels in 2050 compared to 2030 is due to the expected increase in conversion yields that could be achieved in 2050 thank to technology development.

The Food and Agriculture Organization of the United Nations (FAO) estimates that the annual average consumption of vegetable oil for food use will reach 23.5 kg per capita, with a prediction to grow by 0.9% per year until 2025, and after processing and consumption, these edible vegetable oils will generate about 20–30% of their total waste fats and oils, equivalent to more than 50 million tons[28].

[26] Homa Hosseinzadeh-Bandbafha *et al.* Environmental life cycle assessment of biodiesel production from waste cooking oil: A systematic review. Renewable and Sustainable Energy Reviews (2022).

[27] Sustainable biomass availability in the EU towards 2050 (RED II Annex IX, Parts A and B). Concawe Review. Volume 30, Number 2, January 2022.

[28] Fu Zhang *et al.* A new process for the production of second-generation biodiesel from waste oils and fats. Biomass Conversion and Biorefinery (2022)

3.1.2 Used Cooking Oils (UCOs) and Animal Fat definitions

UCOs are oils and fats that have been used for cooking or frying in the food processing industry, restaurants, fast foods and at consumer level, in households[29].

Animal Fats are fats from slaughtered animals that are rendered into a variety of products. Animal fats can be general fats and tissues or can be rendered from internal organs, bones, heads and to a small extent from hides or skins. They provide important amounts of fats used in the world today, both for foods and for non-food applications.

Animal fat is a versatile and natural basis for many products and are part of the wider group of animal by-products (ABPs) and are classified by degree of quality, from high to low, as defined by the European By-Products Regulation 1069/2009, which, together with the implementation legislation 142/2011, regulates the rendering industry in Europe for derived products fit for animal feed and for raw materials and derived products for technical applications.

Category 3 material is derived exclusively from approved animals, slaughtered fit for human consumption, but is considered as an animal by-product not intended for human consumption. The animal by-products of category 3 material have to be processed in conformance with rigorous production methods and sanitizing processing conditions, avoiding the possibility of cross-contamination. The final derived products, animal fats and proteins, are used in the animal feed chain, but also in the oleochemical industry and for the production of biodiesel.

Animal by-products only for technical application are defined in the regulation as category 1 and category 2 material. Category 1 material consists mainly of specified risk material but also includes animal by-products contaminated with environmental contaminants. The latter is only permitted to be used for energy generation. Category 2 material may also be used for technical applications. Category 2 material comprises slaughterhouse by-product and farm dead stock[30].

In general, after the rendering process, of the total animal material on average about 55% is used for food while about 15% ends up as rendered animal fats[31].

Figure 5 shows the applications of by-products obtained from rendering processes, according to their classification (categories) and their composition (protein or fat product). Notably, food- and combustion-related product can be produced by both composition classes; fertilisers, biogas and pharmaceutical products derive from only protein-based by-product, while biodiesel and oleochemicals could be exclusively obtained from fat-based by-product[32].

[29] European Biomass Industry Association – European Biomass Industry Association (eubia.org)

[30] Stephen L. Woodgate and Johan T. van der Veen. Fats and Oils – Animal Based. Food Processing: Principles and Applications, Second Edition. Edited by Stephanie Clark, Stephanie Jung, and Buddhi Lamsal (2014).

[31] D. Peters et al., Information sheet on RED double counting of wastes and residues, Ecofys 2010

[32] European Fat Processors and Renderers Association (EFPRA).

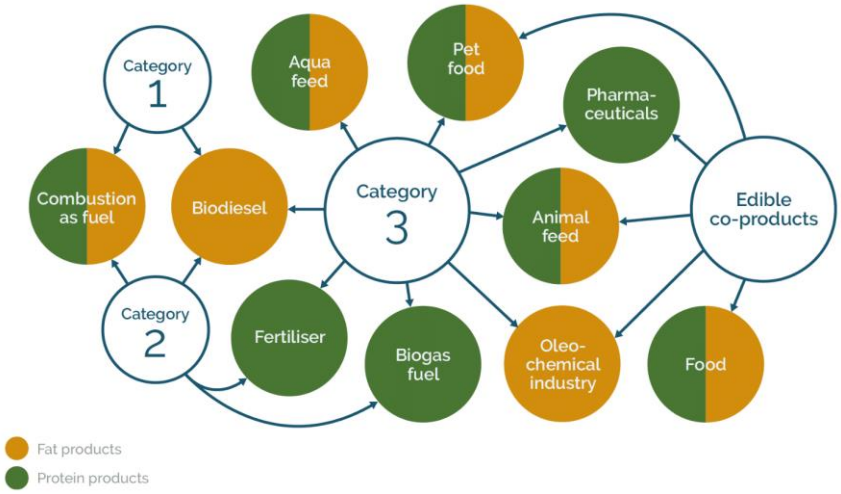

Figure 5 Utilization of by-product produced from rendering processes[31].

According to the European Waste Catalogue[33], UCOs and animal fats can be included in several waste classes (code labelled with an asterisk stands for "hazardous material"):

- 02 03 04: "Wastes from fruit, vegetables, cereals, edible oils, cocoa, coffee and tobacco preparation and processing; tobacco processing; conserve production" – "materials unsuitable for consumption or processing"
- 19 08 09*: "wastes from waste water treatment plants not otherwise specified" – "grease and oil mixture from oil/water separation containing only edible oil and fats"
- 20 01 25: "Municipal Waste and similar commercial, industrial and institutional wastes including separately collected fractions" – "edible oil and fats"

Animal fats:

- 02 02 03: "wastes from the preparation and processing of meat, fish and other foods of animal origin" – "materials unsuitable for consumption or processing"
- 20 01 25: "Municipal Waste and similar commercial, industrial and institutional wastes including separately collected fractions" – "edible oil and fats"

Greases:

- 19 08 09*: "wastes from waste water treatment plants not otherwise specified" – "grease and oil mixture from oil/water separation containing only edible oil and fats"

Edible oils and animal fats, fit for human consumption in Europe, must comply with legislation regulating the food sector includes the Regulation on hygiene for foodstuffs (852/2004), together with the Regulation with specific hygiene rules for food of animal origin (853/2004). Movement documentation, combined with HACCP systems at the various processing locations, ensures that a fully traceable system is in place from farm to fork.

[33] Environmental Protection Agency (EPA). European Waste Catalogue and Hazardous Waste List

Transport and storage have to comply with CEN/TR 15367-3 "Prevention of Cross Contamination".

Collection of UCOs and animal fats is regulated by several Regulations, Directives and Decisions of the European Legislation, which are listed on Table 2.

Table 2 List of EU normative concerning UCO and animal fat collection and disposal.

Normative	Institutional Body	Subject
Regulation (EC) 1013/2006	EU Parliament and Council	Shipment of waste
Directive 1975/439/EEC	EU Council	Disposal of waste oils
Directive 1991/689/EEC	EU Council	Hazardous waste
Directive 1999/31/EC	EU Council	Landfill of waste
Directive 2006/12/EC	EU Parliament and Council	Waste
Directive 2008/98/EC	EU Parliament and Council	Waste and repealing certain Directives
Decision 3 May 2000	EU Commission	List of hazardous wastes
Decision 16 January 2001	EU Commission	List of wastes
Decision 19 December 2002	EU Council	Criteria and procedures for the acceptance of waste at landfills

3.1.3 The availability of UCO in Europe

In regard to UCO collection from the **professional** sector, currently more than 650,000 tons are annually collected in Europe, with a growth potential to be still collected of about 130,000 tons. In Italy, it is estimated that about 82% of UCO is already being collected; differently, a potential availability is expected from countries for East Europe, where the sector has still to reach its maturity and thus has substantial room for development.

A wide source of potential is instead expected from the **domestic** sector: the collected amount in EU countries has been estimated at more than 850,000 tons, versus a current collection at 47,700 tons. However, household collection has to be completely organized: there are still 14 EU countries without an organized household collection system (e.g. France and Poland) and others where only pilot projects and local initiatives have been introduced (e.g. UK, Slovakia, Greece, Denmark and Spain).

3.1.4 The availability of UCO in Italy

Italy has a very well-organized UCO collection system from the professional sector, while the household side is still in an early stage of development. There are only a few local initiatives aiming at establish a domestic UCO collection system, and, to date, there is a gap of about 165,000 tons of total UCO still available in Italy between the estimated collected and the estimated potential by official sources.

3.1.5 The availability of animal fats in Europe

According to "Render: The International Magazine of Rendering"[34] (2020), in Europe, each year, about 328 million of livestock (pigs, sheep, goats, beef and dairy cattle) and about 6 billion poultry (chickens, turkey and others) are slaughtered. Moreover, about 2.45 million tons of fallen stock is safely collected and processed each year.

From meat and dairy industry, European renders handle 17 million tons of waste in Europe each year. This is processed into fuel, feed, fertiliser and a range of other uses, as discussed before.

About 12 million tons of waste is classified as "low risk" and about 5 million tons are classified as "high risk". The risk levels are generally based on whether food is colonized by bacteria easily or not when placed in specific conditions: "high-risk" food have the potential to grow bacteria at an accelerated rate, and the bacteria have the potential to cause food poisoning.

Within the "low risk" class, about 186,000 tons can fit for human consumption as edible fats; while the proper "low risk" by-products can be used in the agricultural and industrial sector:

- 1.67 million tons are used in pet food industry, as replacement of imported soy meal, producing a lower carbon footprint, representing 10% of GHG emissions of soy meal.
- They are used as substitute of palm oil in both animal feed and pet industry (950,000 tons) and oleochemicals industry (575,000 tons), representing about 10% of GHG emissions of palm oil
- 99,000 tons are used for feed on fish farm, replacing feed made from wild fish.
- Animal by-products provide enough phosphorus to fertilize about 2 million hectares of arable land and enough nitrogen to fertilize about 350,000 hectares of arable land.

"High risk" by-products are mainly used as fuel: about 1 million tons is used as solid fuel as substitute of fossil coal, the remaining is used as liquid fuel. Both "low risk" and "high risk" by-product are used to power vehicles, reducing GHG emissions from fossil fuel by 85%: it is estimated that both categories can supply enough biodiesel to power 650,000 cars.

Of the 18 Million metric tons (Mmt) of raw material, just less than one-third is classified as category 1 and category 2 material that cannot be used in feed. While 1 Mmt category 1 meat and bone meal are incinerated in power stations or cement kilns, 174,000 metric tons category 2 meat and bone meal goes mainly into fertilizers.

About 522,000 metric tons of fats from both categories are used in the production of biofuels, with the remaining 10% burned as biofuels in boilers. While the biofuels industry has been the main user of category 1 and category 2 fats for many years, it also became the largest single market for category 3 fats in 2019; 30% of all food- and feed-grade fats were used in biofuels.

Terrestrial animal feed is the second largest leading user of animal fats at 26%, followed by the oleochemicals industry at 21% and petfood at 13%.

Of the 2.4 Mmt of fats produced, 50% comes from multi-species rendering, 16% from poultry and 15% from pork; 13% are edible fats, such as lard or beef tallow. As opposed to edible fats, there is only a small production of edible animal proteins and blood products. Due to their functionality and high

[34] Render: The International Magazine of Rendering (Home - Render Magazine)

protein content, these proteins are often used in feed. Of the about 4-5% edible proteins produced, only 1.2% is used in food. Overall, 2.9 Mmt of feed- and food-grade proteins were produced in 2019.

3.1.6 The availability of animal fats in Italy

Data on Italian production and utilization of animal fats have been collected by interviews to Assograssi[35], the national association of fats and protein by-products producers, which represents the 85% of Italian rendering plants. Following data refer to 2016.

- Category 1
  - 10,000 tons for biodiesel production
  - 9,500 tons for combustion
- Category 2
  - 17,000 tons for biodiesel production
- Category 3
  - 109,300 tons for animal feed industry (67% from mixed origin, 18% from pork industry and 15% from poultry industry)
  - 13,900 tons for petfood industry (50% from mixed origin, 17% from pork industry and 32% from poultry industry)
  - 67,000 tons for oleochemicals industry (90% from mixed origin and 10% from pork industry)
  - 21,600 tons for biodiesel production (81% from mixed origin 19% from poultry industry)
  - 22,700 tons for combustion (66% from mixed origin, 19% from pork industry and 15% from poultry industry)

[35] Associazione Nazionale Produttori Grassi e Proteine Animali (Associazione Assograssi)

3.2 Market size

It is estimated that currently around 90% of cooking oils and fat used in the EU are produced from vegetable oils, whereas in countries such as Belgium relatively large quantities of animal fats are used. According to EU estimations, the potential UCO to be collected is around 8 Liters/capita/year. Extrapolated to the total EU population of around 500 million, this means that about 4 Mtons of UCO are theoretically collectable annually. This amount has a potential growth of about 2% per year, following the annual increase of cooking oil usage in the EU-15. In order to achieve this level of collection, related infrastructures should be improved[36].

3.2.1 The trend in the global production and consumption of UCOs and animal fat

According to REA Annual Report[37], in 2021, worldwide production of the major vegetable and animal oils and fats increased by 1.0% to 240.0 million tons and consumption increased by 0.7% to 240.9 million tons. Production of vegetable and animal oils and fats is forecast to increase by 2.3% in 2022 to 245.5 million tons and consumption by 1.1% to 243.4 million tons. Crude palm oil is the major product, as it represents more than 30% of worldwide oil produced and consumed. Vegetable and animal oils and fats have conventionally been used principally for the production of cooking oil, margarine and soap.

Demand is therefore driven by the increasing world population and economic growth in the key markets, such as China and India.

According to Oil World[38], biofuel production in the year to 30 September 2021 accounted for about 18% of global consumption of the major vegetable and animal oils and fats. An increasing percentage of biofuel use reflects government awareness. In Indonesia, for example, fuel for use in transport and in power stations is required to contain a certain minimum percentage of biodiesel. Moreover, a levy on exports of crude palm oil is used in part to subsidise biodiesel production. As a result, an increasing amount of Indonesian crude palm oil is being converted to biodiesel for internal consumption.

The global market trends of used cooking oils and animal fats are described in paragraphs 3.2.2, 3.2.3 and 3.2.4, according to the available information collected amongst market experts website, which are listed in Table 3.

[36] European Biomass Industry Association – European Biomass Industry Association (eubia.org)

[37] R.E.A. Holding PLC. Annual Report and Account 2021.

[38] Oil World: Independent Global Market Analyses & Forecast Since 1958.

Table 3 List of consulted market experts.

Market Expert	Abbreviation	Web-site
Allied Market Research	AMR	Market Research Company offers Syndicate & Custom Market Research Reports with Consulting Services - Allied Market Research
Expert Market Research	EMR	Expert Market Research: Industry Reports | Analysis | Consultant
Fortune Business Insights	FBI	Fortune Business Insights™ | Global Market Research Reports & Consulting
Markets and Markets	M&M	MarketsandMarkets - Revenue Impact & Advisory Company | Market Research Reports | Business Research Insights
Maximize Market Research	MMR	The Global Business Consultancy Firm (maximizemarketresearch.com)
Polaris Market Research	PMR	Polaris Market Research: Global Market Research Reports and Consulting | Global Research Company | Reports and Consulting
Research and Markets	R&M	Research and Markets - Market Research Reports - Welcome
Imarc Group	IG	Market Research Company, Market Research Reports and Consulting Services (imarcgroup.com)

3.2.2 UCOs Market Size

Global UCO market will grow considerably due to rising awareness of sustainable energy resources and environmental conservation. Recent advancements in technologies, used to process waste cooking oil into high-quality refined oil, will assist the growth of the overall market. The rapidly evolving food and foodservice industry impacted the overall production of UCO. Increasing government initiatives to promote UCO utilization for industrial purposes are expected to drive the used cooking oil market growth in the forecast years [FBI].

In Table 4 the global market size is shown, whose values are expressed in billion dollars and are referred to a reference and a forecast year, according to market expert estimation. Moreover, the CAGRs are highlighted, based on the information provided by the different market analysis experts consulted.

Table 4 Global Market Size of Used Cooking Oil according to forecast analyses.

Market Expert	Reference Year (RY)	Forecast Year (FY)	Market size - USD Billion (RY)	Market size - USD Billion (FY)	CAGR (%)
FBI	2021	2028	5.97	10.08	7.76
AMR	2019	2026	6.04	8.89	5
PMR	2020	2028	6.49	9.57	5.1
IG	2021	2027	5.65	8.46	6.6
MMR	2021	2027	6.67	9.52	6.1
R&M (Before covid-pandemic)	2020	2028	12.27	17.31	4.4
				(18.64)	(5.2)

Europe accounted for the highest market share, due to the rise in environmental concern and supportive government regulation for the production of second-generation fuels including biodiesel production from majorly by using UCO [AMR, MMR, PMR, R&M]. For instance, in the UK 89% of feedstock used to produce biodiesel for transportation is obtained from UCO [AMR, MMR].

Based on the application, the market is segmented into biodiesels, oleochemical products, animal feed, others. Biodiesels sector is dominating the global market, due to easy availability and low cost of UCO over vegetable oil, and it is expected to grow at a faster rate. This in turn fosters the UCO demand [AMR, MMR, PMR, R&M]. Moreover, there is an increase in the UCO-biodiesel production as it saves 21% of fossil energy as compared to crude oil and also saves 95% of energy as compared to fossil diesel production [AMR].

According to the Biomass Board of Research and Development, the global biodiesel supply reached almost 40,000 million litres in 2015 and is expected to overcame 50,000 million litres by 2025 [FBI].

On the other hand, the oleochemical segment is the fastest growing segment. Rising environmental concerns and increasing focus on the use of sustainable and renewable raw materials in the chemical industry have encouraged the oleochemical industry to use UCO in the production of soap, candles, plastics, others [MMR, R&M].

Based on source the market is segmented into household and commercial sector, which is further segmented into food manufacturing, Horeca, others. Among these, the commercial segment is dominating the global UCO market, due to the increase in the number of food service industries and hotels [MMR, R&M].

Simultaneously, the household sector is expected to grow at the quickest rate, due to the logistical challenges of collecting tiny amounts of waste cooking oil from a large number of different houses [MMR].

3.2.3 Animal fat Market size

The global market for fats and oils is estimated at about USD 237 billion in 2021 an it is predicted to grow at a CAGR, ranging from 3.8% [M&M] to 8% [MR] to reach about USD 285-360 billion by 2026 [M&M, MR].

The growth of this market is attributed to the increased awareness about healthier substitutes to trans-fat, demand for a more nutritious and balanced diet among consumers, and sustainable food and energy systems [M&M].

The global market for animal fat reached a volume of nearly 27.1 Mmt in 2020. The market is further expected to grow at a CAGR of 2.8% between 2022 and 2027, owing to the increase in demand from the foodservice sector and the rising application of lard as bread spreads in the baking industry (especially for German bakery). Food companies, especially the bakery sector, obtain lard to be used as a substitute for butter at a volume, which could be between 500–600 million tons on a half-yearly basis. Due to the rise in demand from downstream sectors, such as biodiesel, food, oleochemical, and pet food industries, the market for animal fat is witnessing a robust growth, especially the demand for tallow, which is used in both animal food and biodiesel markets [EMR].

Animal fats accounts for over 10% of the overall demand in the global oils and fats industry [MR]. Tallow is the most common form of animal fat, accounting for 4.4% of global oil and fat intake. Tallow market is fast developing by increasing demand from the biodiesel market, where it accounts for 9% of biodiesel feedstock, with 2.37 Mmt generated during 2017-2018 [MR]. Tallow is followed by lard, which accounts

for 4.1% of overall oils and fat intake. China, Brazil, Germany, the United States, and Italy are the top lard manufacturers, while the United States, Europe, China, Brazil, and Australia are the top tallow producers [EMR, MR].

Based on region, the Asia Pacific region is expected to have the highest growth in consumption of the animal fat, like lard, as a result of advancement in technology, increase in population, and growing consumption of lard by the bakery sector [M&M, EMR, MR]. China and India resulted as the major drivers of the Asia Pacific region [M&M].

The market in the North American region, also, is expected to increase significantly, owing to the rising use of edible animal fat in the food and non-food sectors. Tallow is mainly used in the production of animal feed in the industrial sector in North America [M&M, EMR]. The use of lard for biodiesel has pushed Germany to the top of the European economy [MR].

Animal fats find major applications in pet food, animal feed, and other industrial purposes such as biodiesel and oleochemicals. Oils of plant origin have been mainly used for food-based applications. Liquid forms of fats and oils are estimated to likely dominate the respective markets [M&M].

The biodiesel segment is dominating the global animal fat market as it occupies more than a half of the market share, followed by animal feed sector, which is accounted for about one-fifth of the global animal fats market [EMR]. Other main applications considered are, in order of market share, oleochemicals (about 7%), food application (about 7%) and pet-food industry (about 5%).

The major players in the market, according to the market experts, are SARIA SE & Co. KG, Darling Ingredients Inc., Ten Kate Vetten BV, Baker Commodities Inc., Jacob Stern & Sons Tallow, Tallow Products Pty Ltd, and Australian Tallow Producers [MR, EMR], Associated British Foods PLC (UK), Archer Daniels Midland Company (US), Bunge Limited (US), Wilmar International Limited (Singapore) [M&M].

3.2.4 Major Challenges and COVID-19 Impact

Major consumers of fats and oils, which including households, hotels, restaurants, café, were greatly affected by COVID-19. During the lockdowns, the consumption pattern shifted from ordering to self-cooking, the households as the retail chains were disrupted and the supermarkets were closed.

The shifted supply and demand for fats and oils in the global market has increased uncertainty related to prices. As an example, palm oil, the largest type of oil produced globally, underwent to a dropped demand across the world, leading to disorders in trade and hampering the production in Indonesia and Malaysia [M&M].

One of the most challenging aspects of fat and oil market rely on the significant gap between the demand and supply, especially concerning oilseed processed products, such as edible oil. For instance, India and European countries import palm oil on a large scale from Indonesia and Malaysia, which are the leading producers. Similarly, the European personal care product manufacturers depend on high-cost imports of shea butter from South Africa, which accounts for a significant share of its production. Due to the high dependence of these countries on imports of palm oil and shea butter, respectively, their import cost as well as the cost of the end products increases, which serves as a challenge for the market [M&M].

The global impact of COVID-19, UCO witnessed a negative demand shock across all regions:

global market in 2020 registered a decline of about 12.5% compared to average year-on-year growth during 2017-2019. The recent COVID outbreak has disrupted the global supply chain associated with

used cooking oil. The pandemic has led to the shutdown of the foodservice industry, which has significantly reduced the supply to the UCO processing companies. The recycling of waste cooking oil experienced a sudden drop due to the limited product supply and manpower scarcity [FBI]. Imports of UCO into Europe fell from a high of 865 USD/ton (863.8 Eur/ton) CIF Amsterdam-Rotterdam-Antwerp in 2019 to 690 USD/ton (689 Eur/ton). Since then, there has been a gradual, nearly complete recovery to 845 USD/ton (843.8 Eur/ton) in mid-2020 when COVID cases began to rise again, until dropped again below 800 USD/ton (798.9 Eur/ton) in 2021 [MMR].

In general, the impact of foodservice industry mirrors the impact on the global market. The re-establishment of the foodservice industry and renewed edible oil production is expected to contribute to the growing demand for UCO once the pandemic is brought under control [FBI].

3.2.5 Feedstocks and biofuel prices trend

Biofuels are primarily made from corn, sugar, vegetable oils and used cooking oil, which in 2022 are all near or at all-time highs, however, some feedstocks are more affected than others. For instance, vegetable oils rose across the board and prices, as of April 2022, are up 65-164% since 2019, which in turn increase biodiesel price. Corn prices are also higher, affecting ethanol price; on the other hand, sugar, used primarily in Brazil and India, is less impacted.

According to the USDA, several factors are responsible for the increase of agriculture commodities price, including the potential loss of exports from Ukraine, increased global demand, weather-related supply shortage, high energy prices, increased fertilizer costs and export restrictions on certain food crops. While higher prices should encourage farmers to grow more crops, the increased fertilize price likely undermines the benefits on a wider planting.

Moreover, governments are required to assess the impact of bio-based fuel production and use on fuel prices, energy supply, food security, and GHG emissions policies.

Biodiesel and renewable diesel will likely be the most challenging market, since prices for these fuels have risen faster than oil prices, and the vegetable oil market, which most of these fuels are produced from, continues to witness an increase of prices. Part of the production may shift to wastes like UCO and tallow, however, these feedstocks are limited in availability and, as a result, the price is not yet competitive[39].

[39] International Energy Agency (IEA). Transport Biofuel: Renewable Energy Market Update, May 2022.

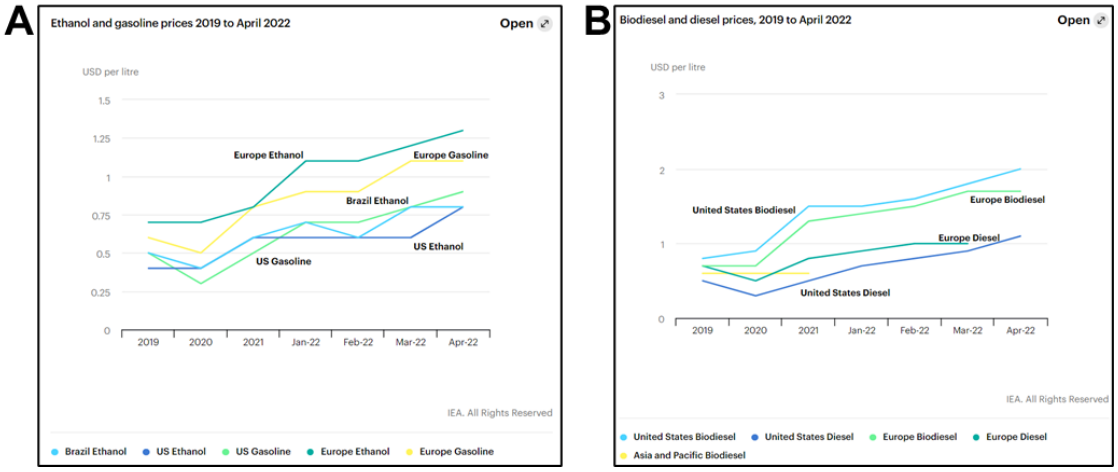

Figure 6 Fuels prices (USD per litre) 2019 to April 2022 in Europe and US. A: ethanol and gasoline prices. B: biodiesel and diesel prices[38].

In Table 5 the prices of animal oils and fat and the four main vegetable oils for biofuel production are presented. These values are calculated from available in FAOstat database, which are referred to the total annual quantity of product shared through the market and the total value in macro-region of the world, regardless of the market in which these products will be located (e.g. food or non-food market). In Table 5Global and European prices are shown, referred to a period of time ranging from 2017 to 2020. Lastly, Table 6 refers to price variation, calculated as percentage, considering the 2020 as base year and toward the three previous years (2017, 2018 and 2019).

Data concerning animal fats, as residue, are scarce, however, the price trend of meat can be representative of the trend in the price of wastes generated by that sector and, therefore, animal fats. In 2021, all meat prices in EU were higher compared to the previous year and above the five-year average. High feed costs are a main challenge for food animal producers. Falling pork prices in China are also a concern, given the sensibility of the sector following the significant drop in prices in 2019. In certain countries in UE, such as Latvia and Spain, the livestock sector continues to be vulnerable in the face of reduced production and increased inputs costs that lowers producers' income.

Table 5 Prices (USD/ton) in 2017-2020 period of animal fats and oils and the four main oil crops for biofuel, referred to the global and the European average.

	year	WORLD		EASTERN EUROPE		NORTHERN EUROPE		SOUTHERN EUROPE		WESTERN EUROPE	
		EXPORT	IMPORT	EXPORT	IMPORT	EXPORT	IMPORT	EXPORT	IMPORT	EXPORT	IMPORT
		USD/ton		USD/ton		USD/ton		USD/ton		USD/ton	
ANIMAL OILS AND FATS	2020	897.5	868.2	704.1	1586.3	1158.3	810.7	685.9	610.5	786.3	855.2
	2019	781.5	806.9	673.2	1003.7	1956.8	748.8	526.8	467.9	689.5	711.9
	2018	781.0	694.5	562.1	643.2	1309.4	882.4	542.5	521.4	723.7	704.1
	2017	838.7	929.3	695.4	745.9	1422.8	1016.3	1067.3	645.7	794.3	847.2
PALM OIL	2020	685.0	742.3	859.1	816.3	1235.6	838.1	1101.7	731.9	851.9	745.2
	2019	564.3	617.5	732.1	673.2	1101.4	723.7	978.5	628.0	754.7	642.3
	2018	628.4	713.1	807.4	759.9	1187.8	835.5	1079.6	708.5	869.7	745.3
	2017	705.7	787.0	913.8	829.8	1243.6	872.1	1105.8	758.5	893.0	810.7
RAPESEED CRUDE OIL	2020	892.8	912.5	874.0	916.2	983.0	916.2	1062.3	925.9	970.4	958.4
	2019	845.0	869.4	793.8	852.7	917.0	848.9	972.5	897.0	904.6	890.6
	2018	868.2	893.4	800.5	861.2	901.2	851.0	1010.3	952.1	931.9	909.1
	2017	913.9	918.0	880.3	956.4	976.8	895.9	1072.2	966.1	952.2	958.6
SOYBEAN OIL	2020	756.4	816.3	802.6	793.7	869.4	796.6	804.0	858.5	789.2	818.3
	2019	689.3	742.6	654.6	683.6	815.0	742.9	719.6	763.9	727.5	763.0
	2018	749.6	821.1	720.7	772.3	927.9	836.0	798.6	860.8	796.5	828.9
	2017	790.8	866.9	756.4	878.6	954.1	876.9	899.4	867.6	865.1	955.0

SUNFLOWER CRUDE OIL	2020	845.9	889.7	789.5	928.4	1231.0	977.0	1028.7	875.3	1031.9	919.6
	2019	769.0	822.5	706.8	867.7	1189.8	955.5	902.1	783.9	972.8	863.4
	2018	821.9	886.6	761.8	913.9	1196.9	974.2	962.3	840.4	986.9	951.0
	2017	830.0	908.4	768.8	916.5	1163.8	955.1	993.1	854.2	1002.0	951.9

Table 6 Price fluctuations (%) of animal oils and fats and the four main oil crops for biofuel in 2020 compared to 2016-2019.

	year	WORLD		EASTERN EUROPE		NORTHERN EUROPE		SOUTHERN EUROPE		WESTERN EUROPE	
		EXPORT	IMPORT	EXPORT	IMPORT	EXPORT	IMPORT	EXPORT	IMPORT	EXPORT	IMPORT
		%		%		%		%		%	
ANIMAL OILS AND FATS	2019	+14.8	+11.2	+33.3	-10.6	-54.1	+19.9	+70.4	+91.8	+30.2	+26.1
	2018	+14.9	+29.2	+59.7	+39.5	-31.5	+1.7	+65.4	+72.1	+24.0	+27.5
	2017	+7.0	-3.4	+29.1	+20.3	-36.9	-11.7	-15.9	+39.0	+13.0	+5.9
PALM OIL	2019	+59.0	+45.4	+22.6	+33.3	-18.5	+24.0	-8.3	+42.9	+18.9	+39.7
	2018	+42.8	+25.9	+11.2	+18.1	-24.4	+7.4	-16.9	+26.7	+3.2	+20.4
	2017	+27.2	+14.0	-1.8	+8.2	-27.8	+2.9	-18.8	+18.3	+0.5	+10.7
RAPESEED CRUDE OIL	2019	+6.2	+3.2	+13.1	+5.2	-2.1	+5.7	-7.7	+0.1	-0.8	+0.8
	2018	+3.4	+0.5	+12.1	+4.2	-0.4	+5.5	-11.2	-5.7	-3.7	-1.3
	2017	-1.8	-2.2	+2.0	-6.2	-8.1	+0.2	-16.3	-7.1	-5.7	-6.4
SOYBEAN OIL	2019	+30.2	+20.9	+37.1	+31.3	+10.1	+20.8	+24.7	+17.5	+23.4	+17.6
	2018	+19.7	+9.3	+24.5	+16.2	-3.3	+7.4	+12.4	+4.3	+12.7	+8.3
	2017	+13.5	+3.5	+18.6	+2.2	-5.9	+2.3	-0.2	+3.4	+3.7	-6.0
SUNFLOWER CRUDE OIL	2019	+16.7	+9.1	+27.0	+3.4	-24.6	-6.1	-0.5	+14.5	-7.7	+3.9
	2018	+9.2	+1.2	+17.8	-1.8	-25.0	-7.9	-6.7	+6.8	-9.1	-5.6
	2017	+8.1	-1.2	+16.7	-2.1	-22.9	-6.0	-9.6	+5.1	-10.4	-5.7

3.2.6 Biofuel demand

Biofuel demand recovered in 2021 from Covid-19 lows, to near 2019 levels, and growth is expected to expand by 5% in 2022 and by 3% in 2023. On the other hand, increasing feedstock prices and policy reaction from multiple countries slows growth in the short term.

Biofuel demand in 2021 reached 155,400 million litres, returning to near 2019 levels and it rose 8,700 million litres year-on-year. Ethanol demand rose 6% year-on-year in 2021 but remained 7% below 2019 levels; by contrast, renewable diesel use expanded by around 70% from 2019 and biodiesel demand rose 0.2% from 2019[40].

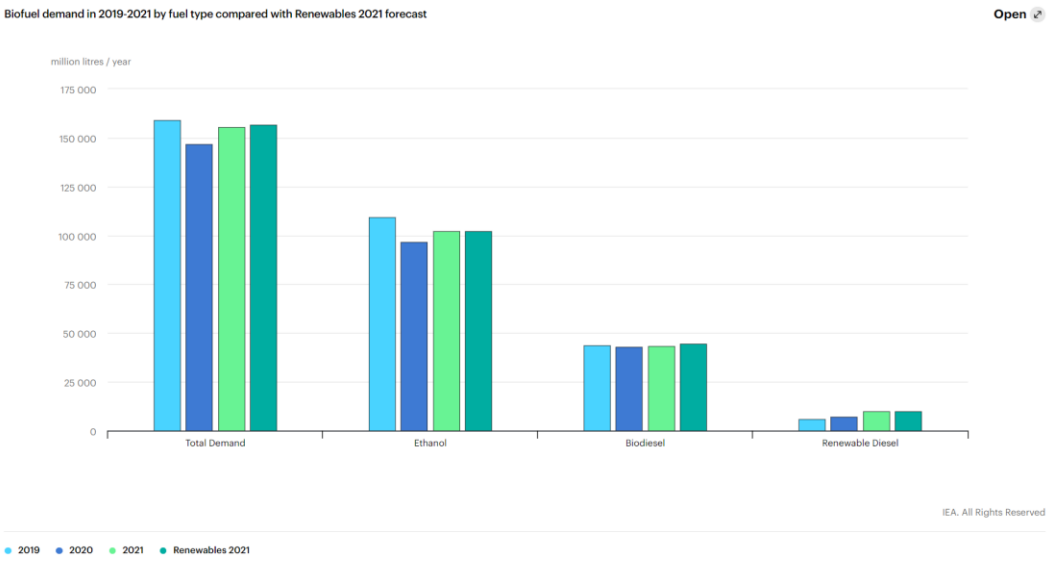

Figure 7 Biofuel demand in 2019-2020 by fuel type[39].

Ultimately, the forecast of renewable markets for 2023 and beyond will depend on whether new and stronger policies will be introduced and implemented in the next months.

Russia's invasion of Ukraine is leading to strong distortions concerning energy and agriculture markets, increasing already high prices. As a result, biofuel demand growth is now forecast to slow by 20% in 2022, equivalent to 2,200 million litres. The agricultural industry is struggling with its own price shocks, which in turn have driven up biofuel prices in most markets. Globally, biodiesel prices have risen between 20-30% in 2022 alone. In response, several governments are relaxing or delaying policies, which also contribute to slowing demand growth. In Europe, 2022 gasoline and diesel demand are expected to be 1.5% and 1.1% lower, respectively, than forecasted in January the same year. Several governments also proposed reduced blending obligations because of high biofuel prices. The impacts of these changes in various regions remain unclear, however, Member States will still have to comply with other policies like the EU's Fuel Quality Directive (FQD), which defines GHG reduction targets. Combined, biofuel demand growth expectations are reduced by 16% compared to January 2022 levels.

[40] International Energy Agency (IEA). Biofuels – Analysis - IEA

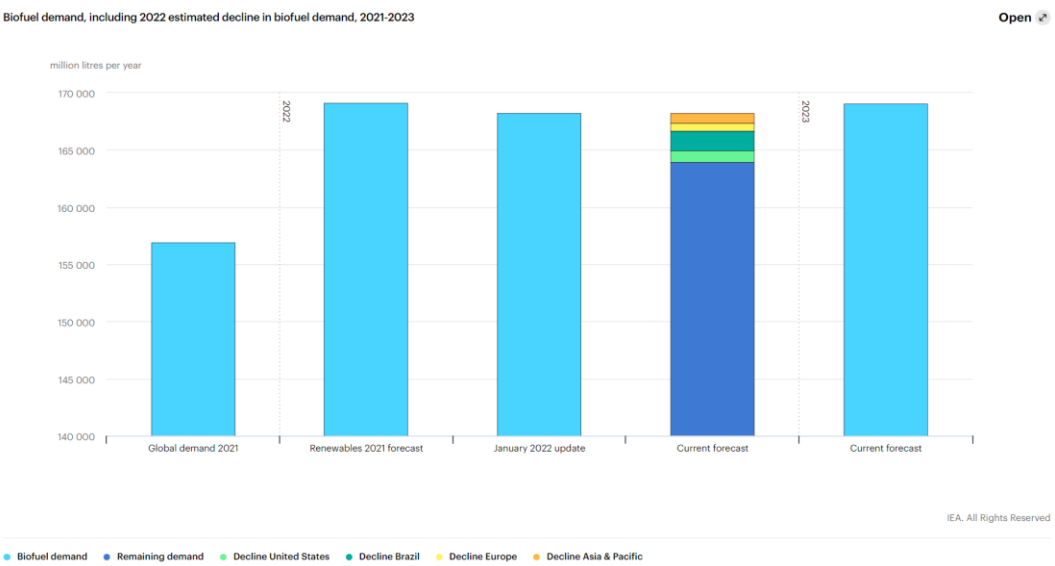

Figure 8 Biofuel demand in 2021-2023[39].

While growing more slowly than previously forecast for 2022, global biofuels demand is still expected to increase by 5% on a yearly basis - equivalent to 8,500 million litres - and rise by a further 3%, or 5,200 million litres, in 2023. Europe biofuel demand is expected to expand by 6% or 1,600 million litres in 2022, compared to 2021. Growth is supported by stronger state-level policies and rising gasoline and diesel demand recovering from Covid lows.

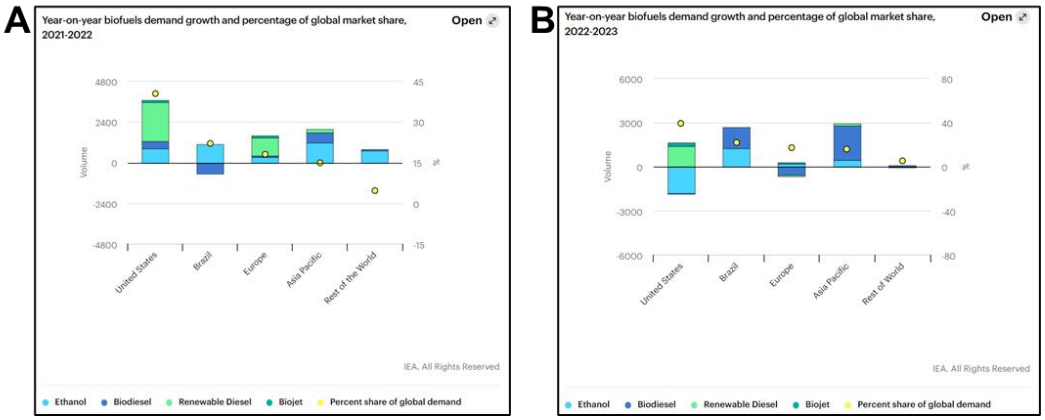

Figure 9 Biofuels demand and percentage of global market share in 2021-2022[39].

The main factors that influence biofuel demand in the coming years are virgin oil prices, biofuel prices and how governments evaluate the role of biofuels in navigating energy security, food security and greenhouse gas objectives.

4 Conclusions

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.

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 conflict in Ukraine. This has led to a general increase in the price of most foodstuffs, disrupting domestic markets both in terms of imports and exports. To date, the market price trend is directed toward pre-pandemic values, however, it is not possible yet to estimate completely the real impact and aftermath from the ongoing war on the global market.

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.

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 fact, the European Concawe estimates that there will be an increase in the production of advanced biofuel from waste fats and oils production and use. 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.

Probably this thesis can only be supported by a simultaneous enhancement in the collection efficiency of such waste. To date, in Europe, about 650 million tons of UCO is collected from the professional sector, and an increase of about 130 million tons 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 the 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 million tons 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 virgin 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, at the moment, 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 wastes (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.