European Commission

Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels

Final Report

Research and Innovation

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European Commission
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EUROPEAN COMMISSION

Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels

Final Report

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Abbreviations

AFIR	Alternative Fuel Infrastructure Regulation
ATJ	Alcohol to Jet
BECCS	Bioenergy with Carbon Capture and Storage
CCU	Carbon Capture Utilization
DAC	Direct Air Capture
DDGS	Distiller's Dried Grains with Solubles
DME	Dimethyl Ether
ESR	Effort Sharing Regulation
ETD	Energy Taxation Directive
ETS	Emissions Trading System
FAME	Fatty Acid Methyl Ester
FTE	Full Time Equivalent
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HEFA	Hydroprocessed Esters and Fatty Acids
HTL	Hydrothermal Liquefaction
HVO	Hydrotreated Vegetable Oil
ILO	International Labor Organization
ILUC	Indirect Land Use Change
IPCEI	Important Projects of Common European Interest

JRC	Joint Research Centre
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LFS	Labor Force Survey
LNG	Liquefied Natural Gas
LTD	Limited Technology Deployment
MSW	Municipal Solid Waste
MTJ	Methanol to Jet
RCF	Recycled Carbon Fuel
RCG	Reed Canary Grass
RFNBO	Renewable Fuels of Non – Biological Origin
RITA	Relatively Increased Transport Activity
SAF	Sustainable Aviation Fuel
SBS	Structural Business Statistics
SNG	Synthetic Natural Gas
SPK	Synthetic Paraffinic Kerosene
SRC	Short Rotation Coppice
TRL	Technology Readiness Level
UCO	Used Cooking Oil
WTT	Well – to – Tank

Abstract

The project "Development of Outlook for the Necessary Means to Build Industrial Capacity for Drop-in Advanced Biofuels" aims to investigate and analyze factors contributing to the development of advanced and sustainable biofuels production within the relevant European policy and regulatory framework. Its primary goal is to facilitate the timely market entry of advanced biofuels and endorse technological solutions through reliable findings to achieve the 2030 and 2050 targets. This study takes into account the evolving EU policy context for sustainable alternative fuels, which is undergoing significant revision and forms a core component of both the Fit for 55 package and the REPowerEU plan.

Based on the analysed policy scenarios, the project estimates that the demand for biofuels in the transport sector might exceed the anticipated 24 Mtoe/yr by 2030. If the electrification of vehicles, e-mobility, e-fuel availability, and RFNBO supply fall short of the current expectations, biofuels uptake could increase to between 38 and 42 Mtoe/yr to meet the RED emissions intensity reduction target in transport[1]. Post-2030, the biofuels market in the EU is projected to expand, reaching approximately 46 Mtoe/yr by 2050. With the impending implementation of the revised ReFuelEU Aviation[2] and FuelEU Maritime[3] regulations, both the aviation and shipping sectors are likely to increase demand for advanced biofuels, potentially redirecting them from the road sector (3 Mtoe/yr in 2030 and 36.6 Mtoe/yr in 2050). This surge in advanced biofuels, coupled with potential delays in mitigating regulatory and financial investment risks, could lead to significant economic implications. Biofuel imports may constitute up to one-third of the total biofuels' turnover by 2030, potentially affecting EU competitiveness. The deployment of advanced biofuels could account for about 0.07% to 0.2% of the projected 2030 EU-27 GDP. Employment in the sector, currently at approximately 140,000 jobs, is expected to grow substantially, adding 160,000 to 220,000 new jobs by 2050.

The overarching conclusion is that **biofuels are crucial for reducing emissions in the transport sector,** contributing significantly to the objectives of the Fit for 55 package and climate neutrality goals. This role is anticipated to grow in the future as advanced biofuels become increasingly accessible. This expansion will be driven by the full commercial-scale development of technologies, processes, and value chains, supported by ambitious policies and sector-specific targets that will encourage their deployment.

[1] DIRECTIVE (EU) 2023/2413 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 October 2023
[2] REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on ensuring a level playing field for sustainable air transport (ReFuelEU Aviation), September 2023
[3] REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC, July 2023

Introduction

This report serves as the **Final Report** of the project **"Development of Outlook for the Necessary Means to Build Industrial Capacity for Drop-in Advanced Biofuels."** It aims to present the overall assumptions and results achieved within the various activities of the project and to pinpoint the key findings. The report, in principle, covers the requirements of the Grand Agreement by encapsulating the work executed across Tasks 1 to 6. Elaborate details on these tasks, inclusive of the principal text and numerous appendices, are systematically documented in the corresponding Annexes 1 to 6 that are appended to this report.

The Project

The **objective of the project is to investigate and analyze the factors contributing to the industrial growth of advanced and sustainable biofuels production**, within the scope of pertinent EU policies and regulations. The main goal is to support the timely market penetration of advanced biofuels providing sound evidence to achieve the 2030 and 2050 targets. This endeavor will harness the latest industrial data and projections from key stakeholders (e.g., fuel producers) within the sustainable transportation sector. The examination will cover the anticipated demand for advanced drop-in biofuels, the availability of resources, potential supply, technological maturity, technical limitations, and pinpointing crucial investments and initiatives to expedite the industry's development.

In the EU and around the world, the **development of sustainable alternative fuels** is widely viewed as an essential step toward the decarbonization of the transport sector, particularly for hard-to-abate sectors such as road freight, maritime, and aviation transport. However, the policy environment greatly affects industrial progression, market entry, and the willingness of stakeholders to invest in new and pioneering industrial ventures and market conditions. The policy context for sustainable alternative fuels is rich and complex, undergoing deep revision as one of the pillars of the Fit for 55 package currently under discussion.

The **Consortium (Consultant)** managing and implementing this project consists of EXERGIA SA (Lead), Politecnico di Torino (POLITO), BEST - Bioenergy and Sustainable Technologies GmbH, BTG Biomass Technology Group BV, Wageningen Institute for Environment and Climate Research (WENR), and E3-Modelling S.A. Their approach merges a precise quantification of the needs to meet EU objectives, an in-depth assessment of the existing industrial gap related to these objectives, the integration of core expertise from principal partners, collaboration with a group of specialists in relevant fields, and direct interaction and consultation with industry stakeholders.

The project focuses on drop-in advanced biofuels, defined as **liquid or gaseous biofuels produced from the feedstocks listed in Part A of Annex IX in Renewable Energy Directive II**, such as lignocellulosic feedstocks (e.g., agricultural and forestry residues, such as wheat straw/corn stover/bagasse, wood-based biomass), non-food crops (e.g., grasses, miscanthus, algae), or industrial waste and residue streams. Advanced biofuels must have low CO2 emissions or significant Greenhouse Gas (GHG) reduction and reach zero or low ILUC impact[4].

[4] Adapted from https://www.etipbioenergy.eu/everyone/advanced-boifuels

In addition to the advanced biofuels related to biomass feedstock categories, some more feedstock potentials were analyzed, such as RED II Annex IX Part B. While not currently classified as "advanced," they may be in the future. The technical potential of sustainable residual feedstocks and wastes (Annex IX) surpasses the estimated demand needed to fulfill the policy targets, yet the mobilization of these feedstocks is a pivotal consideration.

The cultivation of biomass for advanced biofuels on abandoned or unused lands presents considerable potential and offers a sustainable means of land utilization, while also promoting biodiversity and generating renewable feedstocks. This practice holds the promise of profitable marginal land use and biodiversity benefits through the cultivation of non-food, industrial-use crops that are resilient to climate change and biodiversity-friendly.

The project accounts for recent developments in EU policy influencing biofuels development to cover the demand of the **main transport segments**, i.e., the road segment (distinguished for light- and heavy-duty vehicles), aviation, and maritime.

Six tasks structured the project's execution, focusing on: the analysis of demand potential of alternative to fossil fuels for transport using specialized models for the EU (Task 1), the analysis of the resource potential for drop-in advanced biofuels collecting updated data for feedstock availability in the EU (Task 2), the analysis of the potential for industrial capacity of drop-in advanced biofuels based on the industry's perspective for the expansion plans and capacity of production (Task 3), synthesis of the outlook for industrial capacity with a focus on the identification of gaps between demand/supply/feedstock availability (Task 4), the analysis of socio-economic impacts, including GHG emissions and costs, GDP, and employment generation (Task 5), and the organization of a workshop to collect feedback from competent thematic and industry experts on the project findings (Task 6).

1. Analysis of demand potential of alternative to fossil fuels for transport (Task 1)

1.1. Aim of Task 1

The aim of this task is to quantify the potential demand for advanced biofuels in the transport sector within the policy framework of the legislative package Fit for 55[5] (July 2021) and the targets outlined in the REPowerEU[6] communication. These targets are designed to contribute to achieving the EU Green Deal goals for greenhouse gas emissions reduction in 2030 and 2050.

1.2. Methodology, procedure, and approach

Framework conditions and policy portfolio

In developing scenarios to quantify the demand potential for alternatives to fossil fuels, as outlined in Task 1, the analysis incorporates the ambitions of the EU Green Deal[7]. This

[5] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality
[6] Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the regions REPowerEU Plan
[7] Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the regions the European Green Deal

encompasses crucial aspects such as:

- The target for the transport sector to contribute to a 55% reduction in GHG emissions by 2030 and to achieve climate neutrality by 2050, aligning with the broader context of the EU Green Deal.

- Considerations of transport activity and macro-economic trends, including the repercussions of the COVID-19 pandemic, akin to those depicted in the EU Reference Scenario 2020.

- Considerations of transport activity and macro-economic trends, including the repercussions of the COVID-19 pandemic, akin to those depicted in the EU Reference Scenario 2020.

The policy portfolio integrates essential EU energy, climate, and transport policies, along with European Commission legislative proposals within the scope of the Fit for 55 package or the REPowerEU plan. This suite of policies includes the Renewable Energy Directive (RED)[8], the EU Emissions Trading System (ETS)[9], the new ETS covering road transport[10], the Energy Taxation Directive (EU ETD)[11], CO_2 emissions standards for cars, vans and heavy-duty vehicles[12,13], FuelEU Maritime[14], ReFuelEU Aviation[15], and the Alternative Fuel Infrastructure Regulation (AFIR)[16]. Since the submission of the EC proposals, several have been adopted or progressed to the stage of provisional political agreement. These advancements are factored into the analysis undertaken in this task, either qualitatively or, in instances such as the provisional agreement on RED, quantitatively.

Transport activity provides a service that is essential for the transport sector's functionality. This activity is shaped by demographics, economic parameters (e.g., economic growth, trade), and the development of transport infrastructure. In the formulation of the EU Reference Scenario 2020, projections for transport activity are delineated by transport mode and Member State, founded on historical data as well as projected demographic and economic developments, and advancements in infrastructure. A baseline for transport activity, in accordance with these elements, is utilized. The PRIMES-TREMOVE model then

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[8] 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 (recast)
[9] Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC
[10] Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system
[11] Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity
[12] Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles, and repealing Regulations (EC) No 443/2009 and (EU) No 510/2011 (recast)
[13] Regulation (EU) 2019/1242 of the European Parliament and of the Council of 20 June 2019 setting CO2 emission performance standards for new heavy-duty vehicles and amending Regulations (EC) No 595/2009 and (EU) 2018/956 of the European Parliament and of the Council and Council Directive 96/53/EC
[14] Regulation of the European Parliament and of the Council on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC, July 2023
[15] Regulation of the European Parliament and of the Council on ensuring a level playing field for sustainable air transport (ReFuelEU Aviation), September 2023
[16] Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU

endogenously alters activity levels for particular scenarios based on factors such as energy carrier prices, vehicle costs, and the policies and measures in effect, which can lead to varying activity levels by mode, for example, due to modal shifts.

1.2.1. Scenarios

Within the task, five scenarios are delineated, accounting for two sets of basic drivers:

- “Limited Technology Deployment" (LTD), where the progression of electric vehicle battery technology, alternative fuels infrastructure, electrolyzers, and direct air capture technologies lags behind expectations by 2030. This scenario also postulates Renewable Fuels of Non-Biological Origin (RFNBOs) sub-targets within policies as non-binding (LTD and RED variants).

- “Effort Sharing Regulation (ESR variants)”[17]: Conditions were modeled in which transport segments achieve 40% greenhouse gas (GHG) emissions reduction by 2030 compared to 2005, aligning with the scope and overall target of the ESR.

The sensitivity of the scenarios is further examined under conditions of heightened demand for road transport activity compared to the primary scenarios. Such increased demand stems from factors including more significant population growth, a shift toward private transport modes due to the COVID-19 pandemic, and other trends. The representations of these scenarios are schematically depicted in Figure 1-1.

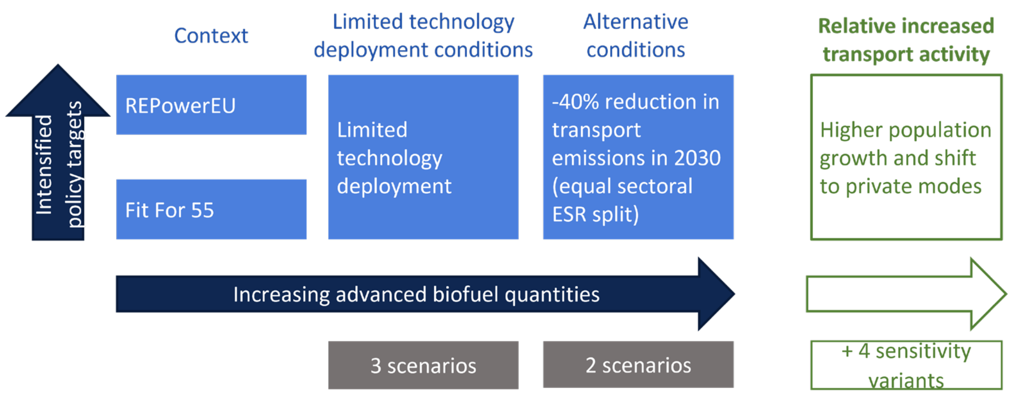


Figure 1-1 Schematic representation of scenarios

Specifically, under the LTD conditions within the Fit for 55 framework, the scenarios investigate the potential uptake of advanced biofuels in 2030 by presupposing the achievement of a 13% GHG intensity target, with a minimum 2.2% contribution from advanced biofuels within a 28.5% Renewable Energy Sources (RES) share in transport. These binding targets are the basis for the modeling. Notably, in the enactment of RED as part of the Fit for 55 package, the RES-T target was supplanted by the GHG intensity target.

[17] Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013

The interplay of these targets indicates that achieving an ambitious GHG intensity target surpasses the RES-T target/indicator. Additional drivers considered for increased biofuel uptake include lower electrification contributions due to, for example, a slower expansion of recharging infrastructure or a slower adoption rate of electric vehicles. Furthermore, the scenario takes into account a slower increase in e-fuels, such as those caused by delayed electrolyzer deployment for hydrogen production or slower advancements in Direct Air Capture (DAC). Consequently, this scenario evaluates the additional potential for biofuels in maritime transport, with targets set on a technology-neutral basis. For aviation, it contemplates the Sustainable Aviation Fuels (SAF) mandate without considering the sub-obligation of RFNBOs in 2030, potentially resulting in a lesser RFNBO contribution than outlined in the RED II recast. Other policies with indirect influence on advanced biofuel uptake, such as CO2 standards for cars and vans, remain constant. Under alternative conditions variants, the transport sector is assumed to meet a sector-specific Effort Sharing Regulation (ESR) target, achieving a 40% emission reduction by 2030 compared to 2005. This would exceed certain targets established under the LTD conditions, such as GHG intensity reduction, with the additional effort in transport expected to lead to a mix of low- and zero-carbon alternatives, including a greater uptake of advanced biofuels and electrification, as well as RFNBOs.

Compliance with the RED provisional agreement through the RES-T target is achieved in the FF55_LTD scenario. An additional scenario, FF55_RED, assesses compliance with the RED provisional agreement via the GHG intensity target within the Fit For 55 context. The FF55_RED scenario builds on the FF55_LTD, incorporating further assumptions such as:

- Additional challenges in EV uptake due to a lower rate of infrastructure (charging points) deployment;
- Additional barriers in long-distance EV travel owing to a slower improvement rate in battery range;
- Potential contribution of advanced biofuels in meeting CO2 standards in 2030 (i.e., a contribution up to 2 gCO2/km or less than 4% of the target; noting that the ICE ban is fully enacted starting 2035);
- Expectation that conventional biofuels production capacity will be utilized to at least 45%.

In the REPowerEU context, under LTD conditions, policies are strengthened to reduce the EU's reliance on Russian imports of gas (and oil), resulting in an upward revision of several Fit for 55 targets as of July 14, 2021. The scenarios developed in this setting explore the potential uptake of advanced biofuels in 2030 based on the REPowerEU targets, assuming the attainment of the 14.5% GHG intensity target, with at least 2.2% contribution from advanced biofuels, within an approximate 32% RES share in transport. As with the Fit for 55 scenarios, factors influencing additional biofuel demand include lower achievements in electrification contributions. REPowerEU posits that a significant portion of the strengthened targets over the Fit for 55 objectives will be met by hydrogen and e-fuels. The scenarios developed in this context, therefore, explore the situation in which the additional quantities of hydrogen and e-fuel do not become fully available. Consequently, the scenario examines the potential increase in biofuels usage in different road sectors (e.g., heavy-duty trucks) and non-road transport sectors (e.g., maritime, aviation). This leads to a lower contribution of RFNBOs than originally envisioned by the REPowerEU targets. Other policies and related targets that indirectly influence advanced biofuel uptake such as the CO2 standards for cars and vans remain unchanged. Similar to the Fit for 55 context, under these alternative conditions, an additional variant is explored where a sector-specific target is assumed based on which the transport sector achieves a 40% emission reduction in 2030 compared to 2005 levels.

For the time horizon up to 2050, the achievement of the EU Climate Law[18] targets is assumed (i.e., net zero EU GHG emissions in 2050). Subsequently, the transport sector will need to approach zero emissions.

1.2.2. Model description

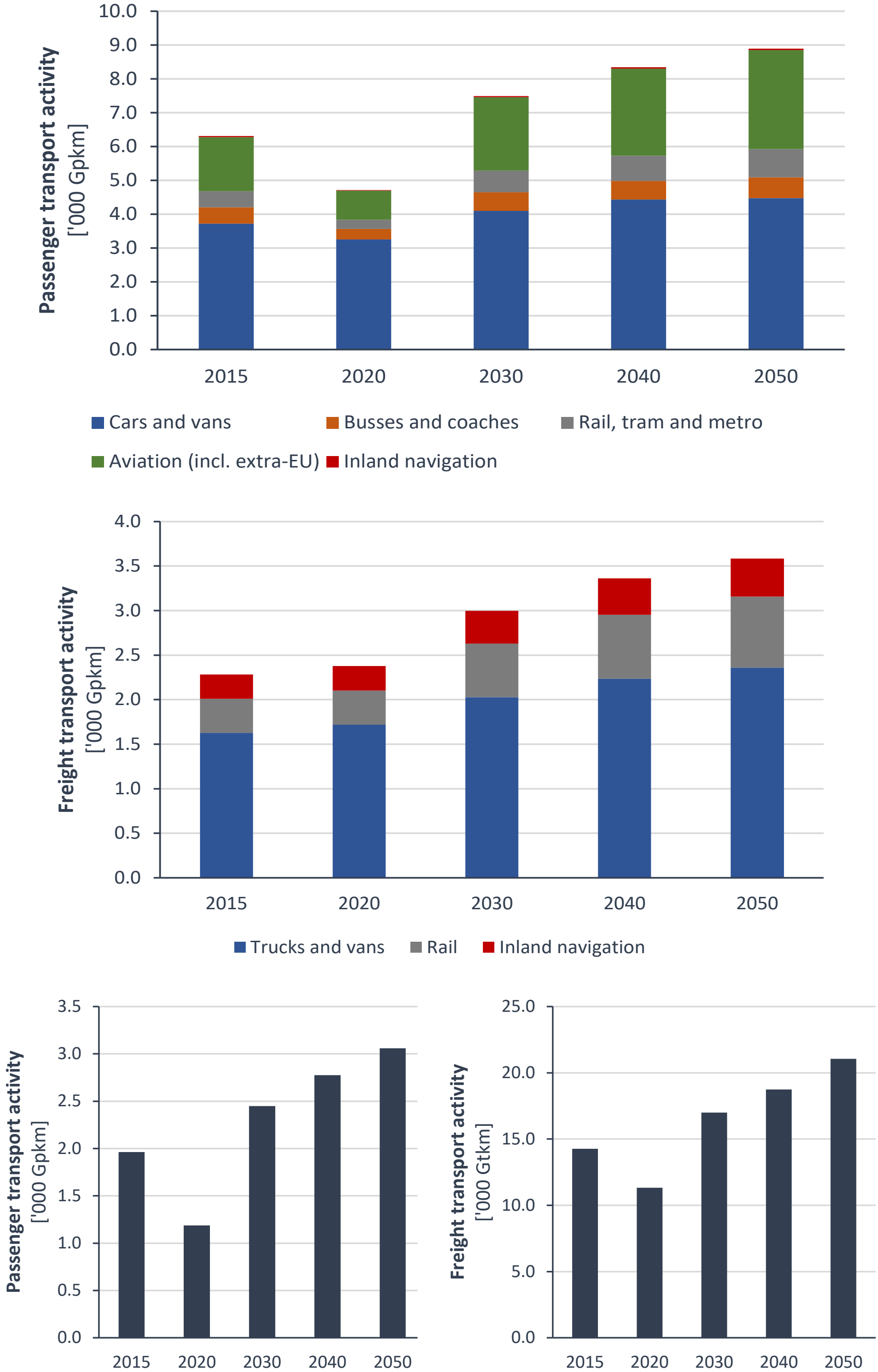
The transition from fossil fuels to alternative fuels in the transport sector is driven by policy decisions and economic preferences for different fuels and powertrain technologies. To analyze the complex interplay of these multifaceted, often cross-sectoral policies, alongside economic rationality and behavioral dynamics, the PRIMES-TREMOVE transport model is utilized. This model is a large-scale economic-engineering model that simulates passenger and freight transport and is part of the PRIMES modelling suite, a family of linked models covering all aspects of the energy system including both demand and supply. The model is specifically designed to forecast long-term trends of passenger and freight transport detailing variations across modes, vehicle types, and fuels. t functions as a dynamic, multi-agent system, capturing a range of choices under diverse constraints, which may not always be concurrently active. The model accounts for the endogenous decision-making processes concerning fuel and vehicle selection, based on internal and perceived costs (such as market acceptance of each technology) and the availability of infrastructure for energy carriers, like recharging networks. In the consideration of new vehicle acquisitions, the model evaluates multiple technological alternatives. This includes various configurations and technologies that influence fuel consumption and type. Vehicle technology and fuel choices are made using discrete choice modeling, complemented by a sub-module that tracks vehicle stock.

1.3. Modelling results

In the post-COVID-19 era, a surge in mobility demand, driven by economic and demographic growth, encompasses both passenger and freight transport in various modes (passenger- and ton-kilometers). This trend suggests a continued rise in EU transport activity until 2050 (Figure 1-2).

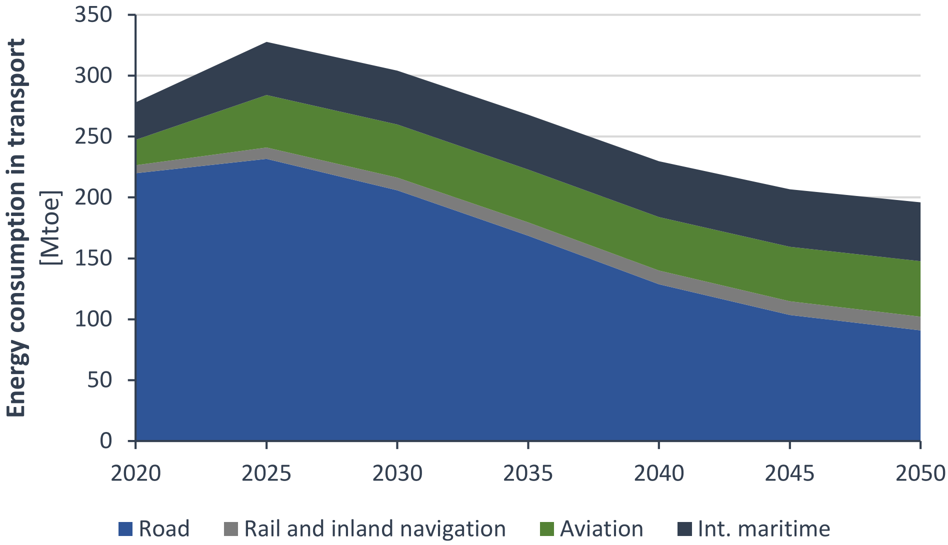
The transition to a more sustainable transport system in line with the EU Green Deal targets leads to a decoupling of activity growth from energy consumption. This is achieved through the adoption of efficient technologies like hybrid or electric vehicles, modal shifts from private to public transport, and behavioral changes like higher vehicle occupancy. However, road transport continues to dominate, accounting for approximately 75% and 70% of total passenger and freight transport activity, respectively. By 2050, road transport's modal share is projected to reduce to 62% in 2030 and 57% by 2050, with cars and vans primarily fulfilling road transport demands and public modes like buses and coaches contributing about 7%. The energy demand in transport is expected to peak in 2025, subsequently reducing from about 300 to 310 Mtoe in 2030 to around 196 Mtoe in 2050 (Figure 1-3).

[18] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 (‘European Climate Law’)



Source: PRIMES-TREMOVE

Figure 1-2 Activity levels of passenger (top), freight (middle) and international maritime transport activity (bottom)



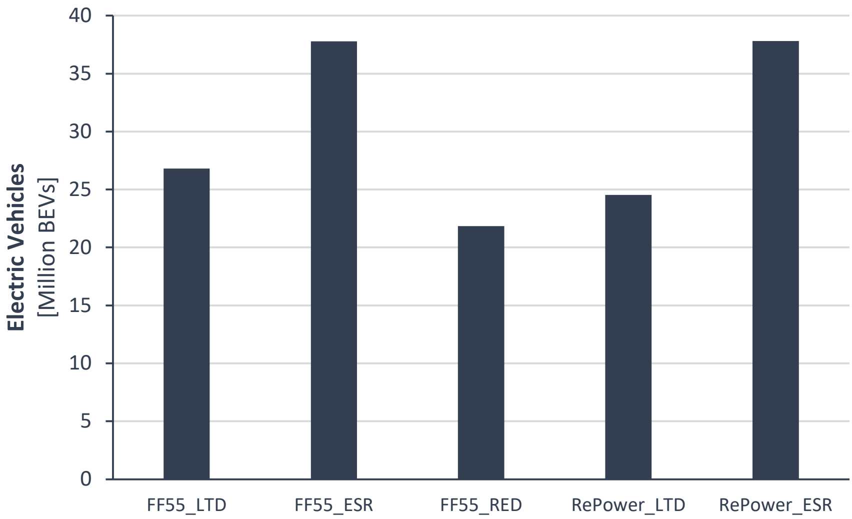
Source: PRIMES-TREMOVE

Figure 1-3 Energy demand in transport by mode

The LTD variants quantify the amount of biofuels required should the deployment of electric vehicles (EVs) not follow the envisaged pathway, and factors such as cost reduction, infrastructure deployment, and market acceptance do not materialize as rapidly as expected. In this scenario, two key dynamics come into play:

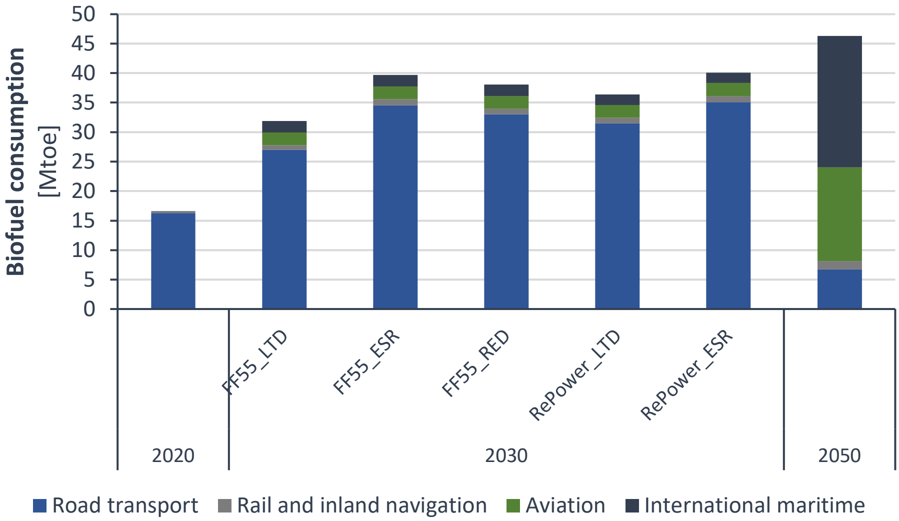
- On one hand, the CO2 standards on new vehicle sales will still stimulate the uptake of zero-emission technologies, as manufacturers would need to reduce tailpipe emissions of vehicles sold by 55%. However, due to the barriers applied in the LTD variants, overall new car sales are projected to decline, leading to the prolonged presence of legacy internal combustion engines in the fleet and, consequently, sustained consumption of both liquid fossil fuels and biofuels. Despite these challenges, EV sales are expected to keep rising, reaching close to 25 to 27 million units (and 22 million in the FF55_RED variant), spurred by cost reductions and technological advancements (Figure 1-4). Nonetheless, conventional and hybrid vehicles are anticipated to maintain a larger share of the market.

- On the other hand, the transport sector will still need to meet its emission reduction targets as stipulated in the scenarios, notably the GHG intensity target and the sub-target for advanced biofuels in transport. With a higher use of internal combustion technologies in the fleet, the uptake of biofuels will also increase. Therefore, the LTD variants anticipate that emission reduction will be achieved through the increased use of biofuels. The projections suggest a significant uptake of biofuels in 2030, ranging from 32 to 40 Mtoe across scenarios. Meanwhile the combined demand for renewable electricity and RFNBOs ranges from 11 to 17 Mtoe (Figure 1-5 and Figure 1-7). The majority of biofuels demand is projected to occur in road transport (85-88% of total biofuel consumption). In the aviation and maritime sectors, their uptake is primarily driven by the Sustainable Aviation Fuel (SAF) mandates and the need to reduce GHG intensity of energy use, respectively.



Source: PRIMES-TREMOVE

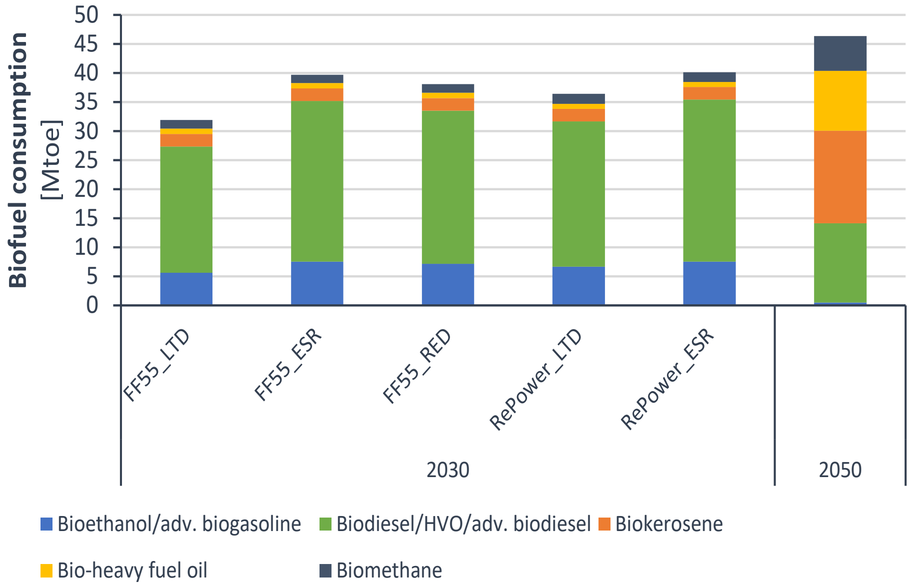
Figure 1-4 Uptake of battery electric vehicles across scenarios in the EU in 2030



Source: PRIMES-TREMOVE

Figure 1-5 Biofuel consumption by segment

Figure 1-5 shows a notable increase in biofuel consumption compared to current levels, predominantly originating from road transport. This trend indicates that up to 2030, the higher the emission reduction target set for the transportation sector, the greater will be the reliance on biofuels, as exemplified by comparing scenarios such as FF55_LTD and FF55_ESR. In this timeframe, biodiesel, encompassing first generation and advanced forms, emerges as the primary biofuel. Specifically, the majority of biofuel consumption until 2030 is projected to concentrate in road transport, predominantly involving biodiesel varieties such as first generation, HVO, or advanced drop-in biodiesel. Conversely, ethanol blends and advanced biogasoline are expected to play a secondary role in this period, as depicted in (Figure 1-6). The impact of initiatives like ReFuelEU Aviation and FuelEU Maritime is anticipated to significantly boost the penetration of biofuels in the aviation and maritime sectors by 2030. It is projected that biokerosene and marine biofuels, combined, could account for about 10% to 13% of the total biofuel consumption in the transportation sector depending on the scenario.

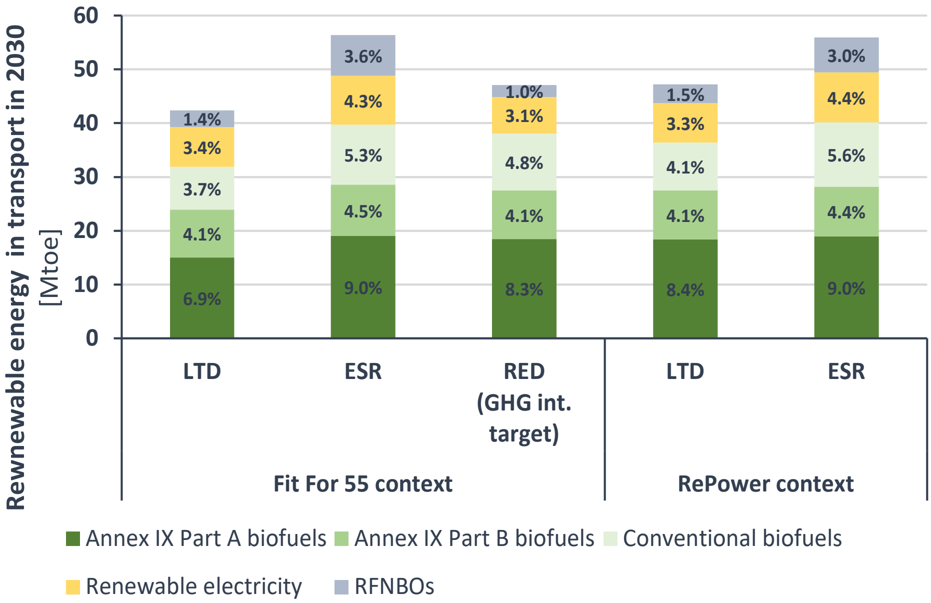


Source: PRIMES-TREMOVE

Figure 1-6 Biofuel consumption by biofuel type

For 2030, conventional biofuels, primarily utilized in road transport, are expected to range from 8 to 12 Mtoe. In contrast, advanced biofuels (categorized under Annex IX Part A) are estimated to constitute approximately half of the total biofuel consumption in transport, representing 47% to 51%. Additionally, biofuels derived from waste oil and fats (under Annex IX Part B) are also set to make a significant contribution, approximating 9 to 10 Mtoe, which equates to roughly a quarter of the total biofuel consumption in 2030. Notably, the ESR scenarios indicate a higher uptake of biofuels and renewable energy overall compared to the LTD variants, attributed to the broader involvement of transport segments in achieving the ESR target. Likewise, biofuel uptake is projected to be higher in the RED variant than in the LTD variant due to the former's assumption of a more stringent GHG intensity reduction target for fuel use in transport, as outlined in (Figure 1-7).

The analysis also suggests the possibility of an additional demand for biofuels beyond the scenario projections, particularly in place of RFNBOs, if scenarios like FF55_RED exceed the RFNBO sub-target by a marginal amount (i.e., achieving 0.7%-0.8% instead of the aimed 0.5%, excluding multipliers in 2030). This difference, amounting to 0.2%-0.3%, could necessitate an additional 0.6-0.9 Mtoe of conventional or advanced biofuels in road transport, effectively compensating for the reduced use of e-fuels while still aligning with the GHG intensity target. Moreover, considering the heightened SAF target in the provisional agreement on ReFuelEU Aviation (about 0.4 Mtoe additional; see section 3.2.1), the overall biofuel quantities might increase by up to 1.3 Mtoe on top of what is shown in Figure 1-7.

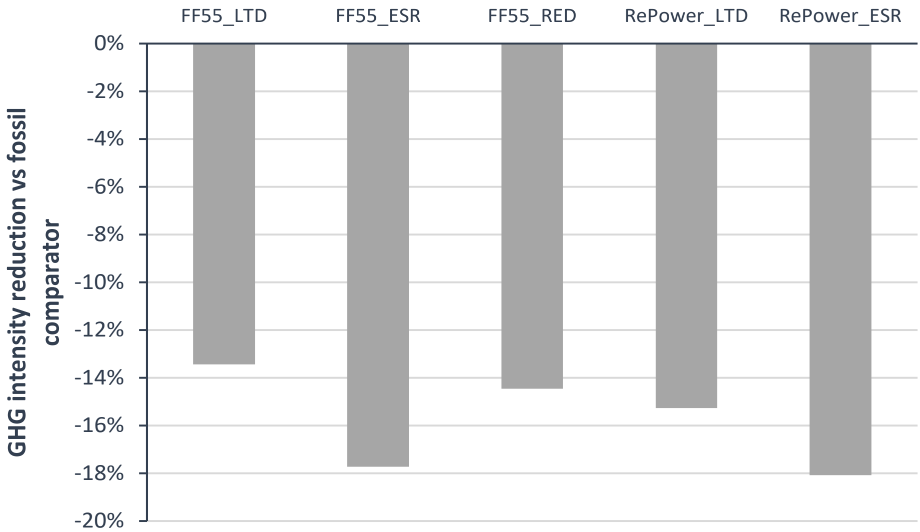


Note: Excluding caps and multipliers. The 29% RES-T minimum target of the RED provisional agreement is met in the LTD scenarios. The conditional -14.5% GHG intensity reduction target is met in the RED scenario. Source: PRIMES-TREMOVE

Figure 1-7 Renewable energy in transport

Apart from the focus on renewable energy in transport, the GHG intensity target remains a pivotal policy objective across various contexts (Figure 1-8). The GHG intensity reduction for the transport fuel mix in 2030 is calculated against a fossil fuel comparator of 94.1 gCO2eq/MJ. The Well-to-Tank (WTT) emission factors for biofuels used comply with the sustainability criteria of RED and are estimated through a bottom-up using the PRIMES-Biomass Supply model. These factors are subject to slight variations based on the fluctuating demand for biofuels across different scenarios. It's noteworthy that the WTT factors for bioethanol, as used in the modeling, are somewhat higher than the estimates provided by experts in Task 3.

In the modeling framework, RFNBOs are attributed zero WTT emission factors, under the premise of their production from green hydrogen derived from renewable electricity. Should RFNBOs be produced using grid electricity with fossil-origin carbon, they would incur a WTT emission factor, notably higher for e-fuels compared to hydrogen due to the additional synthesis step involved. The projected WTT emission factor for electricity in 2030 ranges from 26 to 29 gCO2eq/MJ, reflecting the accelerated decarbonization of the electricity supply system in alignment with the EU Green Deal objectives. This projection is based on the PRIMES energy system model, operating under the same scenario context as the current study (i.e., Fit for 55 and REPowerEU scenario frameworks). If the emission factor of electricity exceeds these model projections, for instance, due to a lower penetration of Renewable Energy Sources (RES), it would necessitate a higher consumption of biofuels within the transport sector to meet the GHG intensity target. This adjustment would be crucial to ensure the sector's alignment with the overarching goals of the EU Green Deal, particularly in terms of reducing greenhouse gas emissions in line with established targets.



Source: PRIMES-TREMOVE

Figure 1-8 GHG intensity target in the scenarios

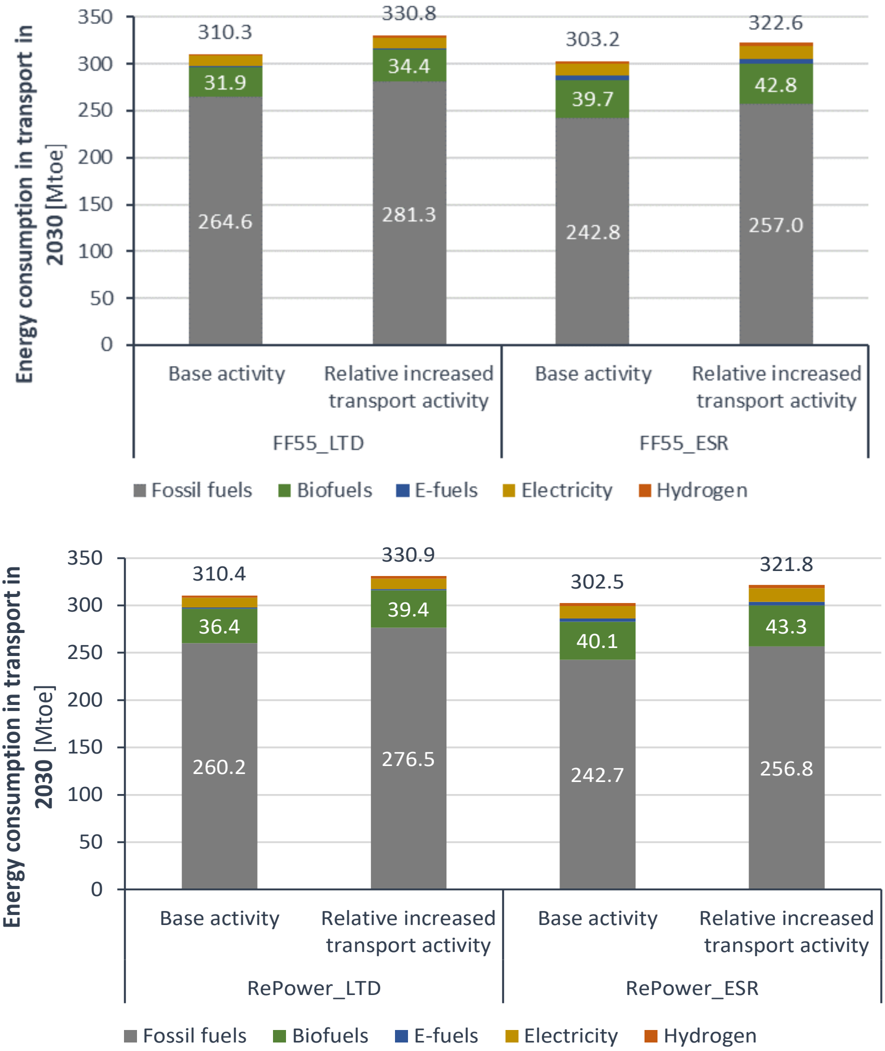
The increase in the GHG intensity target from 13% to 14.5% in 2030, based on the RED provisional agreement[19] and under the additional assumptions previously stated, is anticipated to be met through an augmented use of biofuels at the expense of fossil fuels, electric vehicles, and RFNBOs. As a result, overall biofuels consumption exceeds 38 Mtoe in 2030. Conventional biofuels demand reaches about 11 Mtoe in 2030 (higher by about 2.6 Mtoe compared to FF55_LTD)[20.] Specifically, the demand for conventional biofuels is expected to reach about 11 Mtoe in 2030, an increase of approximately 2.6 Mtoe compared to the FF55_LTD scenario. Furthermore, this scenario also indicates a heightened demand for advanced biofuels in 2030, estimated at 18.4 Mtoe, which is 3.4 Mtoe more than in the FF55_LTD scenario. Additionally, biofuels categorized under Annex IX Part B are projected to reach 9 Mtoe, about 0.1 Mtoe higher than in FF55_LTD. The increase in biofuel consumption is primarily attributed to (a) the reduction in liquid fossil fuel use (i.e., a decrease of 2 Mtoe in FF55_RED compared to FF55_LTD), and (b) a decrease in the rate of electrification.

The sensitivity variants were designed to explore scenarios with a significantly higher increase in road transport activity, revealing an even greater uptake of biofuels, ranging from 34 to 43 Mtoe. This represents an increase of at least 2 to 3 Mtoe, which is primarily satisfied by advanced biofuels (Figure 1-9). These variants also project an increase in the consumption of liquid fuels, between 14 to 17 Mtoe by 2030, suggesting that these could potentially be substituted by advanced biofuels instead of fossil fuels, indicating additional potential for biofuel uptake.

Looking towards 2050, projections indicate that electrification in road transport will become more prevalent, contributing to the phasing out of internal combustion engines. This transition is further accelerated by the implementation of the ICE ban in passenger cars and vans post-

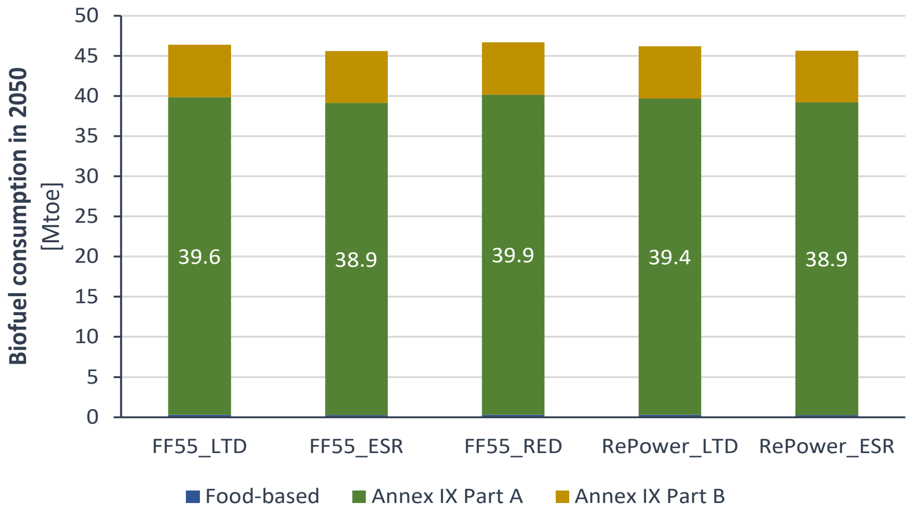
[19] The RED provisional agreement via the RES-T target is met in the FF55_LTD variant.
[20] Current consumption of biofuels in 2021 is about 16.5 Mtoe, based on Eurostat.

2035. Concurrently, advanced biofuels are expected to mature significantly (Figure 1-10). The volume of these advanced biofuels is projected to increase, with their primary use shifting towards the aviation and maritime sectors. This shift is driven by the intensification of SAF blending and the pursuit of GHG intensity reduction targets post-2030. By 2050, the EU's demand for biofuels is anticipated to reach 45 Mtoe, with almost 90% comprising advanced biofuels.



Source: PRIMES-TREMOVE

Figure 1-9 Energy consumption in transport in the Relative increased transport activity (RITA) variant under the Fit for 55 (upper) and the REPowerEU (lower) context in 2030



Source: PRIMES-TREMOVE

Figure 1-10 Biofuel consumption by classification in RED in 2050

1.4. Main findings

The modeling results indicate a potential increase in biofuels uptake, particularly in 2030. This is primarily in response to the revised SAF aviation target based on the provisional agreement and the minimum compliance with the RFNBO sub-mandate under the RED provisional agreement. It's crucial to acknowledge that the modeling, aiming to align with the broader goal of decarbonizing sectors beyond transport, incorporates significant reductions in CO2 intensity of electricity supply (envisioning almost zero-carbon electricity by 2040), the production of RFNBOs from renewable electricity, and a conservative approach to emissions reduction from conventional biofuel production that complies with sustainability criteria. While policy inputs mainly drive these results, the assumptions made in the modeling could significantly influence the analysis outcomes regarding biofuels demand. Additionally, factors not explicitly covered in the modeling, particularly by 2030, such as delays or barriers in the deployment of novel technologies (especially in electric vehicles/batteries), the rapid scaling of renewable energy and power grids for extensive electrification, or biofuels crediting towards CO2 standards targets, may serve as key drivers for an increased uptake of biofuels compared to current projections.

The man findings of the model-based analysis can be summarized as follows:

- For the transport sector to contribute effectively to the EU Green Deal goals on GHG emissions reduction by 2030, a holistic approach is required. This includes utilizing lower carbon intensity fuels, improving the efficiency of internal combustion engines, and adopting zero-emission transport technologies.

- In scenarios with limited technology deployment (such as electromobility, hydrogen, e-fuels, DAC, and related infrastructure), the electric vehicle stock in the EU car fleet is projected to vary between 22 to 38 million by 2030, depending on the GHG intensity reduction ambitions in transport.

- Despite the significant uptake of electromobility, meeting the RED targets on Renewable Energy Sources in Transport (RES-T) and/or GHG intensity reduction by 2030 under the "Fit for 55" framework will require additional efforts. As the fleet predominantly consists of internal combustion engines, and considering a potential delay in e-fuels deployment, biofuels are expected to play a crucial role, with their consumption ranging from 32 to 40 Mtoe in 2030, marking an increase of 2 to 2.5 times compared to current levels.

- By 2030, the demand for conventional biofuels is anticipated to be between 8 to 12 Mtoe, while advanced biofuels demand could range from 15 to 19 Mtoe. Biofuels derived from waste fats and oils are projected to range from 9 to 10 Mtoe.

- Road transport is expected to account for 27 to 35 Mtoe of biofuel consumption (85-88% of total biofuels), with about 30% being conventional. The aviation sector is likely to consume around 2 Mtoe (5% to 7% of total biofuels), and international maritime slightly less than 2 Mtoe (4% to 6% of total biofuels). Advanced biofuels and biofuels from waste fats and oil are expected to contribute in roughly equal proportions to both aviation and maritime.

- In non-transport sectors, bioenergy supply is projected to reach 116 to 130 Mtoe by 2030, predominantly in the form of solid biomass and biomethane. Transport is expected to represent about 20% to 25% of the total bioenergy demand in the energy system by 2030.

- Continuing to 2050, the supply of biofuels in transport and other sectors is expected to grow. In line with the EU Green Deal objectives of net-zero GHG emissions, conventional biofuels are likely to be largely phased out by this time. Advanced biofuels are projected to dominate the biofuels supply in aviation and maritime (about 40 Mtoe out of a total of 46 Mtoe are advanced biofuels, with the remainder primarily being biofuels from waste fats and oils).

- The increase in bioenergy supply in non-transport sectors is primarily directed towards power and heat production, including Bioenergy with Carbon Capture and Storage (BECCS) facilities, which generate negative emissions to offset residual emissions from sectors like aviation and maritime that do not fully decarbonize.

- The analysis demonstrates that the projected demand for biofuels is contingent on the framework conditions and scenario context, as well as several other assumptions related to the analysis (e.g., increases in transport activity, decarbonization of the power supply). These factors may ultimately lead to a higher demand for biofuels than currently anticipated.

A more detailed presentation of the work carried out in Task 1 is provided in Annex 1 of this Final Report.

2. Resource potential for drop-in advanced biofuels (Task 2)

2.1. Aim of Task 2

The scope of Task 2 is to provide an analysis of the resource potential for drop-in advanced biofuels. This task involves developing cost-supply curves at a regional level to assess biomass resources designated for generating drop-in advanced biofuels in the EU, the UK, and Associated Third Countries by 2030 and 2050. The focus is on quantifying biomass cost-supply potentials, aiming to gauge the extent to which the demand for advanced biofuels can be met through biomass sourced from EU regions and Associated countries. Additionally, the task explores how this biomass potential could support the industrial capacity development necessary for producing drop-in fuels.

2.2. Methodology

Overall, the methodology builds upon existing studies of biomass potential. However, for most of the biomass potentials, new and more up-to-date baseline data, methodologies, and scenario assumptions were used and developed, as follows:

Cost levels from earlier studies were adjusted to 2020 figures accounting for inflation up to that year.

Novel biomass resources such as algae, Direct Air Capture (DAC) were not considered in this study.

- The biomass assessments in S2BIOM, Biomass Policies, ENPRESO, and CONCAWE use 2015 baseline data to generate future biomass potentials. In this study, latest CAPRI baseline run data for 2030 and 2050 published in the 2022 report were utilized providing new agricultural land use baseline scenarios. (CAPRI, 2022[21]).

- Waste assessments for 2030 and 2050 projections considered the most recent regional EUROSTAT waste statistics as a starting point.

- For forest biomass potential, the study leverages S2BIOM data, as no more updated EFISCEN model runs are available. Specific scenarios from S2BIOM are selected to align with the drop-in fuel low, medium, and high mobilization scenarios, accommodating variations in competing use levels and sustainability requirements.

- New quantification approaches were developed for the proposed new types of Annex IX Part A and B biomass, not previously assessed, involving extensive data collection.

- Data were processed at NUTS 2/3 regional level, necessitating several disaggregation and data processing steps.

- Cost assessments for all biomass types are updated with new data and revised to reflect 2020 cost levels, taking into account inflation developments up to that year.

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[21] CAPRI model documentation version 18/01/2022. https://www.capri-model.org/dokuwiki_help/

- The study does not consider novel biomass resources such as algae and Direct Air Capture (DAC)

- Increased yields due to targeted R&I for breeding, agricultural practices, sequential cropping, etc., were not included beyond basic assumptions in CAPRI.

The overall assessment of the biomass potentials is based on the following formula:

Availability = Presence – (T1 + T2 + T3)

- ***Availability*** = Availability under certain minimum sustainability requirements and competing use assumptions (depending on the scenario situation) and within a certain time period (2030 & 2050).

- ***Presence*** = Presence of sustainable (according to RED for land, forest and type of feedstocks, i.e., only Annex IX)[22] biomass currently and in the future (2030 & 2050)

- ***T1*** = part of biomass has to be left behind for soil conservation/biodiversity/erosion control

- ***T2*** = known conventional competitive uses (food, feed, bedding, fiber, etc.)

- ***T3*** = new competitive uses (particularly for (non-energy) more circular material and biochemical uses (in the future)

It is important to note that factors T1, T2, and T3 will be influenced by specific factors in the scenario assumptions, leading to varied supply and cost levels by 2030 and 2050. These variations and their implications are further explored in the sensitivity analysis.

2.3. Results

The cost-supply assessment in this task is centered on biomass feedstock types that form part of the advanced biofuel group, as listed in Part A of Annex IX of RED II. In addition, certain biomass types from Part B of Annex IX were also taken into consideration.

A comprehensive overview of the selected biomass categories is provided in Table A2-1 of the Task 2 report (see Annex 2). This table features two initial columns that display a unique code and a brief name for each biomass category. These identifiers are consistently used in the Excel files containing the final cost-supply results to reference each type of biomass.

Out of the 61 biomass types initially considered, 13 were not assessed for their biomass potential, with the reasons for this exclusion explained in Appendix 2-1 of the Task 2 report (see Table 2-1 below)[23]. Among the feedstocks that were quantitatively assessed are Tall Oil Pitch, Crude Glycerin, Bagasse, Nut Shells, Crude Methanol, Vinasse, DDGS, and secondary residues from beverage products.

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[22] It is noted that the considered biomass is also potentially compliant with RED III sustainability criteria

[23] These 13 types of biomass were not assessed because (a) they are residues or co-products generated in conversion processes of biomass to 1G transport fuels and therefore there is a wide palette of biomass to biofuel conversion technologies, and therefore uncertainty for the analysis, (b) they overlap too much with other categories, and an allocation of what can be included where, is not straightforward, (c) concern algae categories, and data is still too limited and their estimate is challenging.

Ultimately, a total of 48 biomass types remained subject to potential assessment. It is important to note that the aforementioned unassessed biomass types, though eligible under RED criteria, are expected to be significant in volume, yet not readily available by 2050. As such, these types do not impact the final potential estimates for the 2030 and 2050 horizon in this study. However, it is also worth noting the potential for higher crop yields through targeted Research & Innovation (R&I) or advanced agricultural practices, such as sequential cropping and the utilization of related residues.

The total biomass potentials available for the energy markets across the three mobilization scenarios for 2030 are presented in Figure 2-1. The results indicate that the total biomass potential varies from 310 to 524,836 million dry tons (equivalent to 132 to 221,353 Mtoe). For 2050, this range is estimated to be between 294 to 520,892 million tons (128 to 222,382 Mtoe). The 'technical potential' refers to the biomass potential that complies with RED III[24]. In the low mobilization scenario, it is assumed that only 20% and 16% of the technical potential in 2030 and 2050, respectively, will be available for energy uses such as heat, electricity, and biofuels. In the medium mobilization scenario, these shares increase to 34% and 33% for 2030 and 2050, respectively. In the high mobilization scenario, the percentages rise to 55% and 54% for 2030 and 2050, respectively. Lastly, Figure 2-2 presents the distribution of the estimated biomass potentials across sectors.

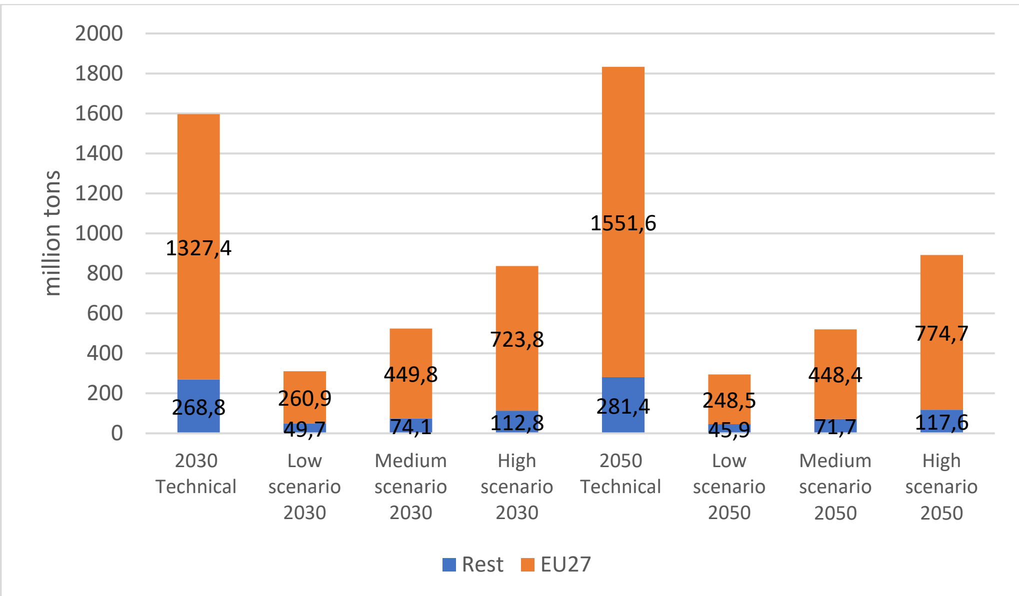

Figure 2-11 Total biomass potentials in Technical, low, medium, and high mobilization scenarios in 2030 and 2050 in million dry tons

[24] Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023

Annex IX Part A	DI codes	PRIMES groups	Agricultural feedstocks (virgin, primary and secondary biomass)	Forest feedstocks (primary secondary biomass)	Biowastes (tertiary biomass)
(b) Biomass fraction of mixed municipal waste, but not separated household waste subject to recycling targets under point (a) of Article 11(2) of Directive 2008/98/EC	5102	Solid waste (incl. secondary forestry residues)			Organic fraction in municipal solid waste (MSW),
(c) Biowaste as defined in point (4) of Article 3 of Directive 2008/98/EC from private households subject to separate collection as defined in point (11) of Article 3 of that Directive;	5211; 5212; 5101; 5104	Solid waste (incl. secondary forestry residues);			Post consumer wood waste, separately collected organic waste Animal & mixed food waste, waste fruit and vegetable
(d) Biomass fraction of industrial waste not fit for use in the food or feed chain, including material from retail and wholesale and the agro-food and fish and aquaculture industry, and excluding feedstocks listed in part B	4206; 4207; 4208; 4209; 4210; 4211; 4214	Solid waste (incl. secondary forestry residues);	Bagasse from sugar beet; Olive stones; deoiled olive pomace; Brewers spent grain; liquid whey; alcoholic distillery products; bakery residues and waste; Dextrose ultrafiltration retentate		
(e) Straw	2201; 2202; 2203	Agricultural residues	Cereal straw (from barley, wheat, rye, and oats), maize stover, straw from oil crops, sugar beet leaves		
(f) Animal manure and sewage sludge	2301; 2302; 5108;	Gaseous biomass (incl. manure)	Solid and liquid manure from poultry, pigs, cattle, sheep & goats		Organic fraction in sewage sludge
(k) Grape marcs and wine lees	4202	Solid waste (incl. secondary forestry residues);	Grape marcs and wine lees		
(m) Husks	4201; 4203	Solid waste (incl. secondary	Rice husk;		

Annex IX Part A	DI codes	PRIMES groups	Agricultural feedstocks (virgin, primary and secondary biomass)	Forest feedstocks (primary secondary biomass)	Biowastes (tertiary biomass)
		forestry residues);			
(n) Cobs cleaned of kernels of corn	4204	Solid waste (incl. secondary forestry residues);	Cob cleaned from grain		
(o) Biomass fraction of wastes and residues from forestry and forest-based industries, namely, bark, branches, pre-commercial thinning, leaves, needles, treetops, saw dust, cutter shavings, black liquor, brown liquor, fibre sludge, lignin and tall oil;	1200; 1220; 4111; 4112; 4121; 4122; 4131; 4132	Solid waste (incl. secondary forestry residues);		Primary forestry residues; Secondary forest residues; Primary forest stumps; sawdust, other sawmill residues, residue from industries producing semi-finished wood-based panels; residues from further wood processing, bark, black liquor	
(p) Other non-food cellulosic material	2204; 2205; 4205;	Solid waste (incl. secondary forestry residues);	Agricultural pruning from permanent crops; damaged crops;		
(q) Other lignocellulosic material except saw logs and veneer logs	1100;	Solid waste (incl. secondary forestry residues);		Stemwood (fuelwood)	
(a) Algae if cultivated on land in ponds or photobioreactors	7101; 7102;7103;7104	-			
Annex IX Part B					
(a) Used cooking oil	5106; 5107	Non-agricultural oils			Used Cooking oil; Brown grease
(b) Animal fats classified as categories 1 and 2 in accordance with Regulation (EC) No 1069/2009	4216	Non-agricultural oils			Animal fats (cat 1&2)

Annex IX Part A	DI codes	PRIMES groups	Agricultural feedstocks (virgin, primary and secondary biomass)	Forest feedstocks (primary secondary biomass)	Biowastes (tertiary biomass)
Dedicated crops					
Lignocellulosic crops from unused & abandoned lands	2101	Perennial lignocellulosic crops	Biomass sorghum, miscanthus, switchgrass, giant reed, RCG, cardoon		
Oil crops from unused & abandoned lands	2102	Oil crops	Cardoon, Camelina, Castor		
Woody crops from unused & abandoned lands	2103	Perennial lignocellulosic crops	SRC Poplar, willow		
Lignocellulosic crops from severely degraded lands	2104	Perennial lignocellulosic crops	Biomass sorghum, miscanthus, switchgrass, giant reed, RCG, cardoon		
Oil crops from severely degraded lands	2105	Oil crops	Cardoon, Camelina, Castor		
Woody crops from severely degraded lands	2106	Perennial lignocellulosic crops	SRC Poplar, willow		
Intermediate crop lignocellulose (biomass sorghum)	2107	Annual lignocellulosic crops	Biomass sorghum		
Intermediate oil crop	2108	Oil crops	Camelina		
Cover crop - harvested	2109	Annual lignocellulosic crops	Unknown crop but assume 4-ton dm/ha/yr		
**Not considered: (h) tall oil pitch; (i) Crude glycerin; (j) Bagasse, (L) Nut shells; crude methanol, Vinasse, DDGS; secondary residues of drinking products*					

Table 2-1 The overview of biomass categories selected for this study, ordered according to Annex IX (Part A and B), according to sector (agriculture, forest and biowastes) and according to PRIMES[25] classification

[25] Relevant for the comparison between PRIMES demands and biomass potential assessment

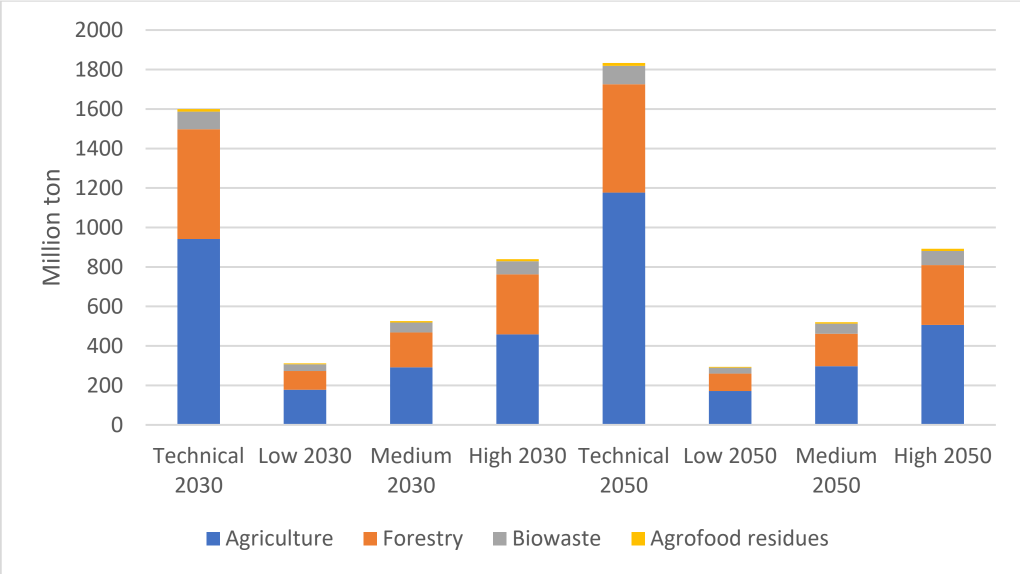

Figure 2-12 Biomass potentials in technical, low, medium and high potentials in 2030 and 2050 and distribution over sectors delivering biomass.

2.4. Main findings

The main findings of Task 2 are summarized as follows:

- The agricultural sector emerges as the predominant source of biomass. In the technical, low, medium, and high mobilization scenarios for 2030, it contributes 59%, 57%, 55%, and 55% of biomass, respectively. This contribution is projected to increase by 2050, accounting for 64%, 58%, 57%, and 57%, respectively. The most significant biomass types identified are manure (yielding 93, 46, 56, 75 Mtoe/yr in 2030 and 87, 43, 53, 70 Mtoe/yr in 2050), primary residues from arable crops (providing 180, 27, 59, 102 Mtoe/yr in 2030 and 171, 21, 52, 96 Mtoe/yr in 2050), and primary forest sources such as pulp stemwood & primary residues (supplying 219, 31, 61, 110 Mtoe in 2030 and 214, 27, 54, 108 Mtoe/yr by 2050).

- The biomass required for bioenergy (comprising heat, power, and transport fuels) according to PRIMES aligns only with the technical potential under the high mobilization scenario by 2050. However, by 2030, the potential is adequate in both the medium and high mobilization scenarios.

- An increased focus on conversion technologies for drop-in fuels is necessary, especially for under-utilized biomass categories such as gaseous biomass (including manure and sewage sludge) and primary and secondary agricultural residues.

- One viable strategy to enhance biomass availability is to significantly boost biomass production on currently unused, degraded lands, and through inter- and cover cropping. While the low, medium, and high mobilization scenarios present modest expectations for mobilizing such biomass, the technical potential for these groups suggests that a faster mobilization is feasible.

- For the yield increases from dedicated cropping on unused and degraded lands, as well as from inter and cover crops, growth rates of 1% (in Technical Potential and High), 0.2% (Low), and 0.5% per annum were presumed. These rates are conservative; with intensified R&D efforts, these yields could further improve, substantially increasing the potential from these dedicated crops.

- Additional biomass resources could be derived from algae by 2050. However, this area requires considerable research, and it is currently challenging to project the potential contribution based on the existing knowledge.

- It should be acknowledged that this study did not assess the potential from tall oil pitch, crude glycerine, bagasse, nut shells, crude methanol, vinasse, DDGS, and secondary residues of beverage products. Including these could further augment the overall biomass potential.

A more detailed presentation of the work carried out in Task 2 is provided in Annex 2 of this Final Report.

3. Analysis of capacity potential for the industrial supply of drop-in advanced biofuels (Task 3)

3.1. Aim of Task 3

The objective of Task 3 is to analyze and evaluate the industrial capacity for supplying advanced biofuels and biogas for transport, particularly those fuels derived from feedstocks mentioned in Annex IX Part A of the Renewable Energy Directive. These fuels, along with RFNBOs, aim to achieve a dedicated sub-target of 5.5% by 2030. To this end, the analysis reviewed existing infrastructure, technical expertise, and stakeholder capabilities spanning both current operations and prospective value chains. Authentic data were sourced directly from industries and associations engaged in technological advancements, biofuel production, and distribution. This review encompasses a range of technologies associated with advanced biofuels, across different Technology Readiness Levels (TRLs), and originating from various EU regions.

3.2. Methodology

To gather insights from biofuel producers and developers, an online survey was deployed. Out of roughly 140 companies contacted, 41 provided responses that were subsequently analyzed. Regional specialists were engaged to aid in identifying and communicating with these entities. Nevertheless, the response rate proved insufficient to reliably forecast future production capacities based on quantitative data alone. Inconsistencies in company-reported investment plans further complicated the projection. Consequently, a more direct follow-up with the companies is planned prior to finalizing the data for inclusion in the final report. While the qualitative information obtained is of significant interest, it could have been acquired more effectively through targeted interviews with a select group of companies. Regional experts also helped pinpoint national funding initiatives for constructing advanced biofuel facilities.

Further insights were gained through interviews with 11 industry associations or key stakeholders, enriching the data with the consultant's investigation of pertinent statistical reports. A cohort of technology specialists was engaged to provide forecasts on technological progress and application within their respective fields. In addition, the consultant undertook independent research on EU funding mechanisms.

The collated information was synthesized into datasets and reports, which were then reviewed by a third panel of broad-spectrum experts. This group convened online seven times over three weeks to deliberate on the progression and adoption of advanced biofuels technologies. Their initial production capacity ramp-up projections were tempered by investor reticence. To augment this assessment, the consultant also made independent estimates of the potential for technical capacity expansion—what could be realistically achieved with sufficient financing. These estimates drew from dialogues with leading technology developers, yielding a secondary dataset. For technologies at lower TRLs or those from competing firms not interviewed, adjustments were made to the 2030 production capacity projections. However, these estimates were ultimately constrained by the availability of biomass within the EU, resulting in a third dataset. It's important to note that feedstocks for biofuels could be sourced via imports. Algae-based pathways, while not considered due to the absence of algae biomass supply estimates, might still play a role in the 2050 biofuels landscape. The final report will address this by projecting capacities associated with algae-based biofuels.

3.3. Results

Results of the assessments conducted in the frame of Task 3 of the project are described as follows.

3.3.1. Current production and production capacity

As of 2023, four technologies have reached market maturity and are widely deployed in Europe. Regarding EU biofuel production, FAME[26] is currently the frontrunner with approximately 9.9 million t/yr, followed by HVO[27] and ethanol[28] with 5.1 million t/yr each, and biomethane from anaerobic digestion[29] with approximately 3.8 billion m³ per year.

Production facilities may not always operate at full capacity, particularly during times when feedstock prices are high, suggesting that production can be readily increased when conditions become profitable. Installed production capacities are estimated at 12 million t/yr for FAME and 5.8 million t/yr for ethanol[30]. HVO[27] capacities have seen a rapid expansion recently and continue to increase, especially in refineries, and it is assumed that current production and production capacity are at 5.1 million t/yr. Advanced biofuel production capacities still remain modest in Europe, with advanced ethanol production estimated at 200,000 t/yr and pyrolysis oil at 100,000t/yr[31].

It's worth noting that not all biofuel production is destined for the transport sector. Ethanol, for example, also supplies the chemical industry, and biomethane has a variety of applications. With the EU's goal to reduce natural gas imports from Russia, the demand for biomethane has surged. It is estimated that only about 10% of biomethane production is allocated to the transport sector. Presently, biomethane's share in renewable fuels for transport is merely 2%, as per EurObservER statistics.

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[26] Combined FAME and HVO production of 15 million t/yr according to EBB interview conducted on 21.03.2023
[27] HVO production capacity estimated according to EU Biofuels Barometer 2020 and ETIP Bioenergy database on production facilities
[28] ePURE members produced 5.57 billion litres in 2020 and constitute around 85% of EU production capacity, according to ePURE interview conducted 03.03.2023
[29] 37 TWh of biomethane production in EU in 2021, according to EBA interview conducted 14.03.2023
[30] ePURE members have installed production capacity of 6.38 billion litres per year in 2022 and constitute around 85% of EU production capacity, according to ePURE interview conducted 03.03.2023
[31] ETIP Bioenergy database on production facilities

3.3.2. Outlook to 2030 and 2050: Capacity estimates

Current market conditions

Under current market conditions, a notable barrier to the advancement and implementation of advanced biofuels technology, as well as the establishment of supply chains for previously unutilized feedstocks, is the paucity of investment in large-scale demonstration plants. The appeal of such ventures is a pivotal consideration when forecasting future production capacities. Regulatory uncertainty and complexity stand out as significant concerns. For instance, the development of RED III immediately following the finalization of RED II introduced serious regulatory ambiguity, deterring investments in advanced biofuels capacities. Furthermore, the combination of steep investment costs and perceived project risks by financiers diminishes investment allure. Considering the current technological maturity, capital expenditure requirements, and market demand, the following investment hierarchy was envisioned:

- Anaerobic digestion with upgrading, and HVO/HEFA.
- Second-generation (2G) ethanol, gasification for the production of biomethane, gasification for the production of biomethanol/DME/ammonia, and pyrolysis.
- Alcohol-to-Jet (ATJ), gasification for the production of Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK) production, and Hydrothermal Liquefaction (HTL).
- RFNBOs[32]

The estimated capacity for biofuel and biomethane expansion that can be supplied to the transport sector is projected to increase from the current production of 18 Mtoe/yr to 27 Mtoe/yr by 2030, and to 49 Mtoe/yr by 2050. Detailed breakdowns for various value chains are provided in Table 3-1 below. The estimated contributions for specific fuels in 2023 are: conventional biofuels at 13 Mtoe/yr, advanced biofuels and biomethane at 1.7 Mtoe/yr, and biofuels based on Annex IX Part B feedstocks at 3.1 Mtoe/yr. By 2030, these figures are expected to be: conventional biofuels at 14.1 Mtoe/yr, advanced biofuels and biomethane at 4.3 Mtoe/yr, and biofuels based on Annex IX Part B feedstocks at 9.0 Mtoe/yr. By 2050, projections include: conventional biofuels at 10.4 Mtoe/yr, advanced biofuels and biomethane at 26.2 Mtoe/yr, and biofuels based on Annex IX Part B feedstocks at 12.0 Mtoe/yr. It is important to note that only 10% of the current and future biomethane production capacity is considered since biomethane has many competing uses, and only a small portion of the current vehicle fleet can utilize biomethane.

[32] Note that this conclusion was reached before the sub-target for advanced biofuels was unexpectedly merged with RFNBOs during negotiations on RED-III.

Technology	2023	2030	2050
transesterification of f/f crops	4.60	5.13	5.13
hydrotreatment of f/f crops	5.25	5.25	5.25
ethanol fermentation of f/f crops	3.16	3.74	-
biomethane from AD	0.32	1.50	4.51
transesterification of IX-A feedstocks	1.06	1.50	1.50
hydrotreatment of tall oil	0.14	0.21	0.42
lignin boost of fatty acids	-	0.14	0.70
advanced ethanol	0.13	0.32	-
ATJ	-	0.10	7.70
gasification + methanol	0.00	0.21	2.87
gasification + SNG	0.00	0.03	0.75
gasification + FT	-	0.05	5.25
pyrolysis	0.04	0.18	0.81
HTL	0.00	0.03	1.67
trans. of intermediate crops	-	2.83	2.83
transesterification of UCO and AF	3.09	2.21	2.21
hydrotreatment of intermediate crops	-	2.42	5.36
hydrotreatment of UCO and AF	-	1.58	1.58
Total	**17.79**	**27.43**	**48.54**

Table 3-2 Production and estimated capacity expansion of biofuels and biomethane in Europe under current market conditions available to different transport sectors (in Mtoe/yr, all feedstocks; note that some production has been allocated to other sectors than transport)

Technically possible capacity

From a technical standpoint, capacity expansion has the potential to proceed much more swiftly given that numerous technology providers are on the brink of commercializing their technologies and are prepared to support multiple projects simultaneously. When estimating capacities under the premise that the regulatory environment is entirely favorable, investment funding is readily accessible, and assuming the same distribution of fuels to different sectors as in the previous scenario, the technically possible capacity for biofuel and biomethane production could escalate to 61 Mtoe/yr by 2030 and 207 Mtoe/yr by 2050. In this scenario, conventional biofuels are expected to deliver 21 Mtoe/yr in 2030 and 17 Mtoe/yr by 2050. Advanced biofuels and biomethane, produced from Annex IX Part A feedstocks, are projected to contribute 30 Mtoe/yr in 2030 and 174 Mtoe/yr in 2050, while biofuels from Annex IX Part B feedstocks are anticipated to offer 10 Mtoe/yr in 2030 and 16 Mtoe/yr in 2050.

However, when the anticipated feedstock requirements are compared with the potential EU biomass supply—as outlined in the high mobilization scenario of Task 2—it becomes clear that the demand cannot be fully satisfied by EU feedstock production alone. Consequently, capacities have been constrained by feedstock availability, resulting in overall biofuel and biomethane production capacities that are expected to be accessible to the transport sector at 57 Mtoe/yr in 2030 and 129 Mtoe/yr in 2050.

Values for all three scenarios—current market conditions (cmc), technically possible capacities (tpc), and capacities capped by feedstock availability (cbf)—are delineated in Table 3-2 and Table 3-3. It is important to note that the values for 2023 reflect the current production (the existing capacity is greater than the actual production). While Table 3-2 presents the entire production capacities, Table 3-3 shows the amounts assumed available to the transport sector.

The evolution of technically possible capacity derived from Annex IX Part A feedstocks (without allocation to different sectors) is illustrated in the figure hereafter.

	Capacity 2023	Capacity 2030	Capacity 2050
Current market conditions (cmc)			
Total volume	**20.7**	**41.5**	**111.9**
Conventional	13.0	14.1	14.1
Annex IX Part A	4.6	18.4	85.8
Advanced biofuels	*1.4*	*3.4*	*40.7*
Biomethane	*3.2*	*15.0*	*45.1*
Annex IX Part B	3.1	9.0	12.0
Technically possible capacities (tpc)			
Total volume	**20.7**	**88.8**	**390.7**
Conventional	13.1	21.0	21.0
Annex IX Part A	4.6	57.7	353.8
Advanced biofuels	*1.4*	*42.7*	*308.7*
Biomethane	*3.2*	*15.0*	*45.1*
Annex IX Part B	3.1	10.1	15.9
Capped by feedstock (cbf)			
Total volume	**20.7**	**85.1**	**238.5**
Conventional	13.1	21.1	21.0
Annex IX Part A	4.6	58.0	206.5
Advanced biofuels	*1.4*	*43.0*	*179.0*
Biomethane	*3.2*	*15.0*	*27.5*
Annex IX Part B	3.1	5.9	11.0

Table 3-3 Evolution of total biofuels and biomethane production and capacities in all three scenarios (in Mtoe, all feedstocks, entire production)

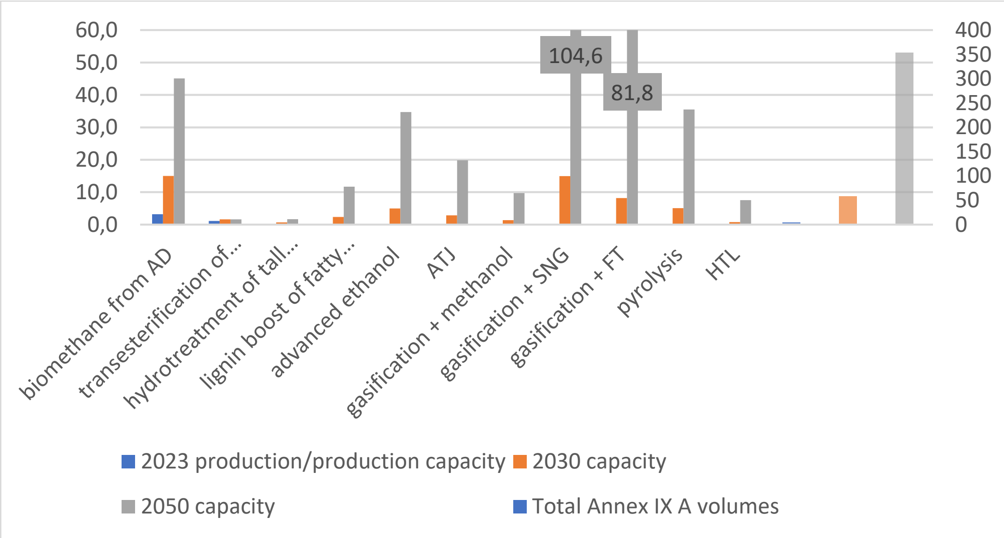


Figure 3-13 Technically possible capacity evolution from Annex IX Part A feedstocks in Mtoe/yr by technology (no allocation to specific sectors)

	Capacity 2023	Capacity 2030	Capacity 2050
Current market conditions (cmc)			
Total volume	**17.8**	**27.4**	**48.5**
Conventional	13.0	14.1	10.4
Annex IX Part A	1.7	4.3	26.2
Advanced biofuels	*1.4*	*2.8*	*21.7*
Biomethane	*0.3*	*1.5*	*4.5*
Annex IX Part B	3.1	9.0	12.0
Technically possible capacities (tpc)			
Total volume	**17.8**	**61.1**	**207.0**
Conventional	13.1	21.0	16.9
Annex IX Part A	1.7	30.0	174.3
Advanced biofuels	*1.4*	*28.5*	*169.7*
Biomethane	*0.3*	*1.5*	*4.5*
Annex IX Part B	3.1	10.1	15.9
Capped by feedstock (cbf)			
Total volume	**17.8**	**57.4**	**129.2**
Conventional	13.1	21.1	16.9
Annex IX Part A	1.7	30.3	101.3

	Capacity 2023	Capacity 2030	Capacity 2050
Advanced biofuels	*1.4*	*28.8*	*98.5*
Biomethane	*0.3*	*1.5*	*2.7*
Annex IX Part B	3.1	5.9	11.0

Table 3-4 Evolution of total biofuels and biomethane production and capacities available to the transport sector in all three scenarios (in Mtoe, all feedstocks)

3.3.3. Comparison with estimated demand

The expected biofuel demand in 2030, as calculated in Task 1, ranges between 23 and 40 Mtoe/yr, while our first estimate (based on current market and regulatory conditions) suggests 27 Mtoe/yr. The most formidable challenge lies in supplying biofuels and biomethane derived from Annex IX Part A feedstocks. Predicted demand for these Annex IX Part A biofuels and biomethane is between 6 and 18.4 Mtoe/yr, as per Task 1, but our estimates show that only 4.3 Mtoe/yr could be available to the transport sector. It is anticipated that oil crops grown as intermediate crops will be classified under Annex IX Part B in the future, potentially contributing an additional 9.0 Mote/yr by 2030 once combined with UCO and animal fats. However, establishing supply chains for such intermediate crops will be necessary to fulfill this demand. The current estimate includes merely 10% of the estimated biomethane production capacity from anaerobic digestion, which is 15 Mtoe/yr; increasing the proportion available to the transport sector—assuming the requisite vehicles, likely LNG trucks, are available despite market trends favoring truck electrification—would greatly assist in meeting the 2030 targets for advanced biofuels and biomethane for transport. If the total biomethane production capacity is considered, production of advanced biofuels and biomethane based on Annex IX Part A could meet the expected demand of 18.4 Mtoe/yr in 2030.

When comparing the expected biofuel demand in 2030 to the second estimate (technically possible capacity), the possible expansion of advanced biofuels and biomethane production capacities from Annex IX A feedstocks that is assumed available to the transport sector of 30 Mtoe/yr can easily meet the expected demand. This remains unchanged even when EU feedstock availability is taken into account. Hence, if the regulatory framework is modified to successfully stimulate investment, the production capacities for advanced biofuels can be scaled up sufficiently to achieve the 2030 objectives.

A significant number of companies with diverse sectoral backgrounds (including chemicals, pulp & paper, refining) are developing a range of technologies for transport biofuel production. The firms interviewed are fully prepared to support a rapid industrial-scale implementation of advanced biofuel production, provided the conditions become conducive. Currently, there exists a window of opportunity for such investments as EU regulations are being finalized and are expected to remain unchanged until the next European Commission takes office, possibly redirecting priorities towards the end of 2024.

3.3.4. Feedstock

Survey feedback and interviews with associations indicate that, generally, feedstock supply should not pose a major problem, barring competition for UCO and sawdust, and scaling up SAF production. Initially, SAF production will depend on waste oils and fats; however, as the limits of lipid feedstock supply are approached, alternative conversion routes capable of processing more plentiful feedstocks will need to be explored. Leading alternatives include the alcohol-to-jet (ATJ) process and gasification, followed by Fischer-Tropsch synthesis and subsequent upgrading to SAF. Since SAF must be sourced from wastes and residues, any ATJ production will have to rely on advanced ethanol—a technology that has faced challenges establishing its technical and economic viability over the last decade. Strong incentives will be essential to foster investment into advanced ethanol production facilities to avoid dependence on imports.

Feedstock costs are projected to rise, subsequently increasing biofuel production costs. Capital expenditures for advanced biofuels are notably high, with most technologies demanding significant CAPEX (e.g., ranging from 2,000 to 4,500 EUR/kW product for advanced ethanol, pyrolysis, and gasification technologies, versus 200 to 600 EUR/kW for HVO/HEFA).

3.3.5. Technologies and innovation

Biofuel producers do not view the availability of skilled workers as a challenge. The refining sector, expecting a downturn in fossil fuel operations, foresees a surplus of skilled workers who can transition to operating advanced biofuel biorefineries.

The vast array of biofuel technologies, the diversified sourcing of feedstocks from different sectors, and the adaptability of most technologies concerning the end-product, are significant advantages. This flexibility enables adaptation to evolving market requirements. Moreover, the presence of multiple technology providers increases the likelihood of meeting advanced biofuel targets, even if some planned facilities fail economically. As a society, we must be prepared to absorb some financial losses from these failures to benefit from the development and deployment of the most efficient technologies.

Developing viable production technologies can span years or even decades, as evidenced by the time already invested by many players in the biofuels sector. Additionally, the lead time for viable projects is substantial; pre-feasibility and feasibility studies, which are necessary to ensure adequate access to biomass feedstock, alone can take up to 2 years. From the final investment decision to reaching full operational capacity at the designated nameplate level of the facility can take up to three years. This tight timeline poses a challenge to establishing advanced biofuel production facilities that can contribute to the 2030 targets. Therefore, it is imperative to finalize and publish the regulations and to introduce robust incentives that will catalyze the deployment of these technologies.

3.4. Main findings

The main findings from the analysis of Task 3 can be summarized as follows:

- Advanced biofuel production capacities in Europe are currently limited, with advanced ethanol production estimated at 200,000 t/yr and pyrolysis oil at 100,000 t/yr.

- Present market conditions reveal that a lack of investment in large-scale demonstration facilities for advanced biofuel production is a significant barrier. This hinders further technological development, deployment, and the establishment of supply chains for previously untapped feedstocks.

- Under the existing market dynamics, without considering competition from other sectors, the estimated capacity expansion for advanced biofuels and biomethane from Annex IX A feedstocks is projected to achieve 18.4 Mtoe/yr by 2030. The contributions are expected to be:

- Biomethane: 15.0 Mtoe/yr with uncertainty surrounding its full availability for the transport sector and the fleet's readiness for such an increase in usage.

- FAME and HVO based on Annex IX A materials: 1.7 Mtoe/yr.

- Technologies based on lignocellulosic materials: 1.6 Mtoe/yr with deployment likely constrained to this level by 2030 if current trends persist.

- From a technical perspective, the capacity expansion of technologies that utilize lignocellulosic materials could accelerate substantially, potentially reaching 42.7 Mtoe/yr by 2030 under highly favorable market conditions.

- In this optimistic scenario, and based on the availability of European feedstocks, the total capacity for biofuel and biomethane from Annex IX A feedstocks could expand to 58 Mtoe/yr in 2030 and 206 Mtoe/yr by 2050.

- The policy-driven anticipated demand for Annex IX Part A biofuels and biomethane, which ranges between 6 and 18.4 Mtoe/yr, can be met by both the current market conditions and the technically feasible capacity expansions.

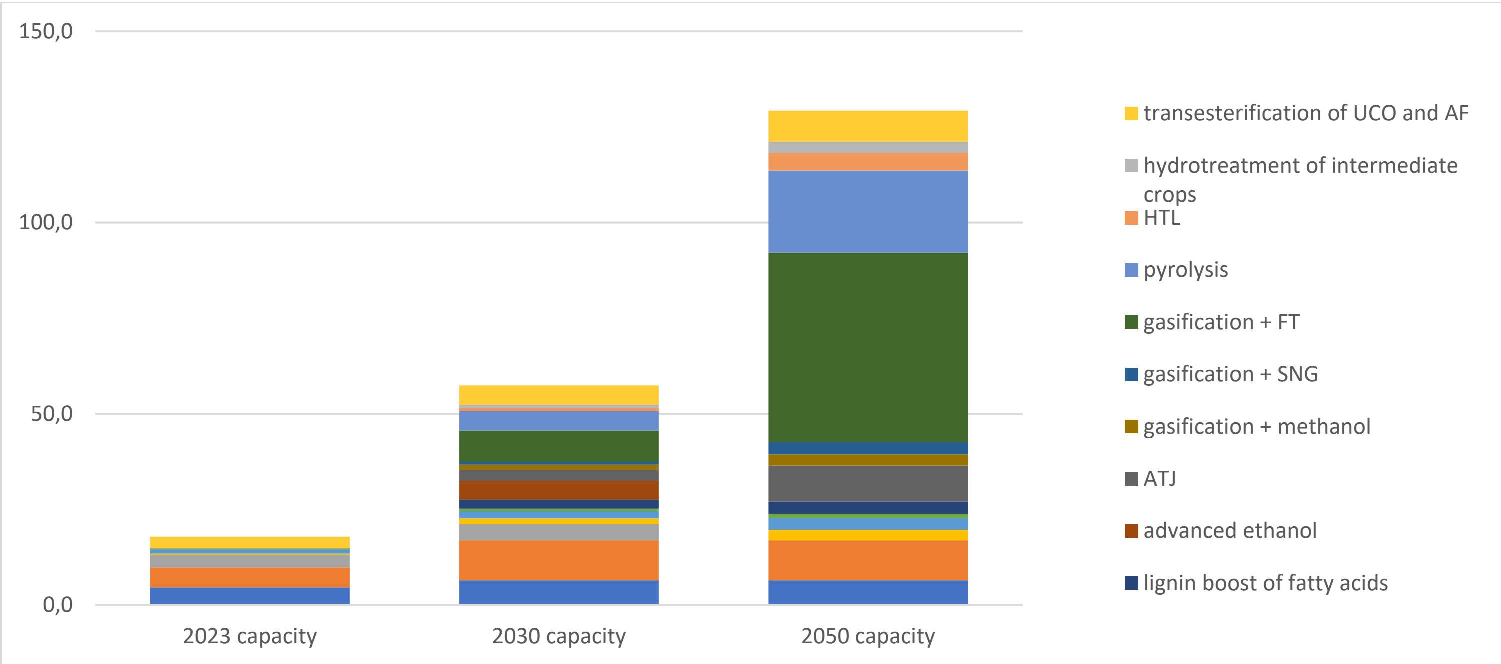
- Depending on the evolution of the regulatory environment, the principal contributions will stem from either biomethane, transesterification, or hydrotreatment of Annex IX A feedstocks, or from technologies that process lignocellulosic materials.

- The feedstock base for lignocellulosic materials is substantially broader than that for oil crops. Thus, advancing technologies that process these materials to market maturity is critical for achieving high biofuel production volumes in the future.

- The development of viable production technologies is a long-term process, often spanning years or even decades. It is imperative that final regulations are enacted and strong incentives are introduced promptly to catalyze industry progress.

- The diversity of technology providers is beneficial, enhancing the probability of meeting advanced biofuels targets, despite the likelihood of some installations failing economically. It is important for society to be prepared to absorb some financial losses due to these failures, which are part of the broader process of developing and deploying the most effective technologies.

A more detailed presentation of the work carried out in Task 3 is provided in Annex 3 of this Final Report.



*note that volumes have been allocated to different sectors (some of them not for transport)

Figure 3-14 Technically possible capacity evolution capped by feedstock availability of biofuels and biomethane production available to the transport sector in Mtoe/yr

4. Synthesis of industrial capacity outlook (Task 4)

4.1. Aim of Task 4

Task 4 provides factual evidence and rigorous analysis of industries' outlooks and defines strategic research and innovation directions for industrial developments, such as those concerning fuel producers. This encompasses:

- Determination of whether additional advanced biofuels capacity is needed in 2030 and 2050. This involves comparing the calculated demand for advanced biofuels (Task 1) with the current and projected capacities in 2030 and 2050 (Task 3).
- Gap analysis to identify actions and investments that the advanced biofuels industry should undertake to meet the targeted demand.
- Provision of evidence for the renewable fuels capacity foreseen in 2030 and 2050.
- Provision of recommendations for strategic research directions for novel and improved technologies for conversion and feedstock diversification in advanced biofuels and renewable fuels. These innovations will be necessary to achieve the EU's 2030 and 2050 GHG reduction targets in the transport sector.

4.2. Methodology

As depicted in Figure 4-1, Task 4 consists of four interrelated subtasks, which are connected to each other and to other Tasks, particularly Tasks 1, 2 and 3:

- Task 4.1: Determination of additional needed advanced biofuels capacity in 2030 & 2050
- Task 4.2: Gap analysis to identify actions and investments the advanced biofuels industry should take in order to be able to meet the targeted demand
- Task 4.3: Evidence for renewable fuels capacity foreseen in 2030 & 2050.
- Task 4.4: Roadmap and recommendations for strategic research directions.

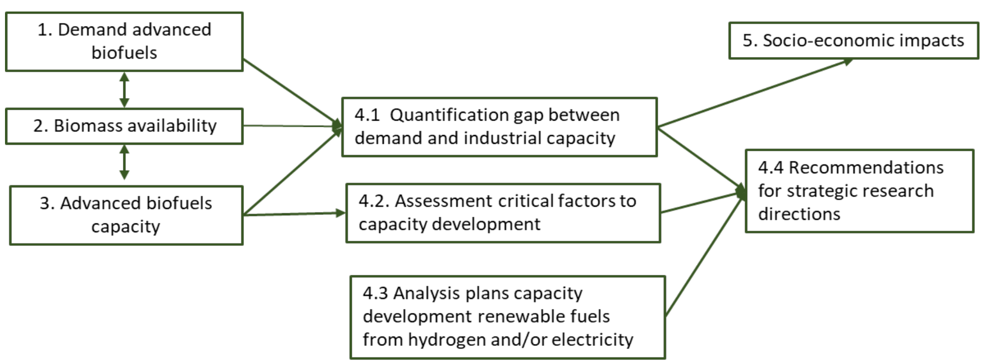


Figure 4-15 Linkages between the different subtasks of Task 4

Determination of gap between demand and foreseen capacity

The demand scenarios for advanced biofuels in 2030 and 2050 (Task 1) were compared with the current advanced biofuels production and capacities foreseen by internal and external experts for 2030 and 2050 (Task 3), as illustrated in Figure 4-2.

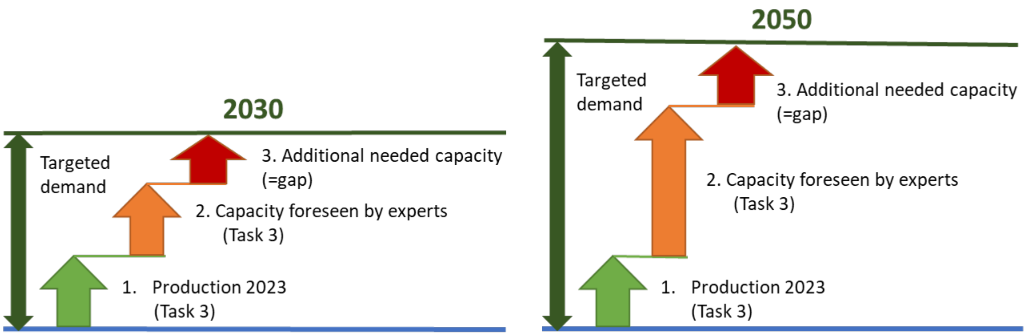


Figure 4-16 Available, foreseen and required additional advanced biofuels production capacity in 2030 and 2050

This gap has been quantified for a low, central, and high biofuels demand scenario. An investigation into how this gap might be filled with additional advanced biofuels capacity was conducted, determining which technologies could contribute and assuming that these will do so in proportion to the capacity growth already anticipated by experts between 2023 and 2030.

It was also verified whether the EU27 has sufficient biomass available to meet the targeted demand (with the gap filled), using the low, medium, and high biomass feedstock mobilization scenarios from Task 2. This consideration included (1) the advanced biofuels technologies' capability to process different feedstocks by 2030 and 2050, and (2) the current utilization of the feedstocks for heat and power production.

RFNBO capacity development

Insight into the capacity development of renewable fuels (e-fuels) were gleaned by collecting evidence on the status of the pipeline for planned renewable fuel installations. A distinction was made between:

- Implemented capacity;
- Capacity under development, i.e., a positive investment decision has been taken;
- Planned capacity at any stage before the investment decision.

Databases such as the demo-plant database of BEST[33], the IEA Hydrogen Projects Database[34], the CCU projects database of CO2ValueEurope[35] and the PtX Atlas[36] were

[33] https://demoplants.best-research.eu/
[34] https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database
[35] https://database.co2value.eu/
[36] https://maps.iee.fraunhofer.de/ptx-atlas/

accessed in May and June 2023, as well as renewable fuel outlook reports. Identified announced and implemented capacities were collected in a dataset template and subsequently structured in a table for the discussions with industrial stakeholders and the subcontracted renewable fuel experts.

Critical factors to advanced biofuels capacity development

An in-depth analysis of the prerequisites and critical factors influencing the industry's readiness to invest in advanced biofuel capacity was conducted through interviews with experts, technology developers, and producers in the advanced biofuels sector. An initial prioritization of potential critical factors impeding investment in advanced biofuel capacity was established. Following this, interviews with twelve advanced biofuel producers/technology providers were conducted in June and July 2023. The central topic of discussion was 'what factors are most critical to the capacity development of advanced biofuels,' alongside the predetermined list of potential critical factors.

Recommendations for strategic research directions

Informed recommendations were formulated for strategic research directions for novel and improved technologies for the conversion and feedstock diversification of advanced biofuels and renewable fuels. These technologies will be necessary to achieve the EU's 2030 and 2050 GHG reduction targets in transport. The recommendations collected in this task have various sources, such as the extensive assessment of interviews with the advanced biofuels industry and interviews with various groups of experts and stakeholders, including experts with a broad view, sector organizations, and technology developers. Recommendations on the development of RFNBOs were addressed as well.

4.3. Additional needed advanced biofuels capacities

4.3.1. Gap analysis

From the various scenarios developed within Task 1, three scenarios were chosen for the gap analysis: the scenario with the highest and lowest demand for advanced biofuels in 2030, and a central scenario (FF55_RED). Figure 4-3 provides an overview of the current production of all biofuels (EU-27, 2023), and the total biofuels demand as projected in the selected demand scenarios. This figure illustrates that the current biofuels production is predominantly centered on road transport, with minimal contributions from biofuels in aviation and maritime applications.

More details on the central scenario are presented in Table 4-1, and a comprehensive breakdown of the contribution per technology for 2030 can be found in the first four columns of Table 4-2. The third column indicates the demand in Mtoe according to the FF55_RED scenario (D). The existing production (P) is presented in the adjacent column. Following that, the "growth foreseen (by experts)" (F) is provided. This represents the production anticipated by experts, exceeding the current 2023 production, as outlined in the framework of Task 3. The gap is defined as the disparity between demand and the combined 2023 production and anticipated production (D - P - F).

The anticipated growth of 9.6 Mtoe/yr in 2030, was evaluated by experts in Task 3 (See Table 3-1). In Table 4.2 the current production (P) and projected growth (F) are presented for each technology pathway, including Annex IX Part A, Part B, and conventional biofuels. The gap represents the amount of biofuels that remains after incorporating the growth foreseen by experts into the current production.

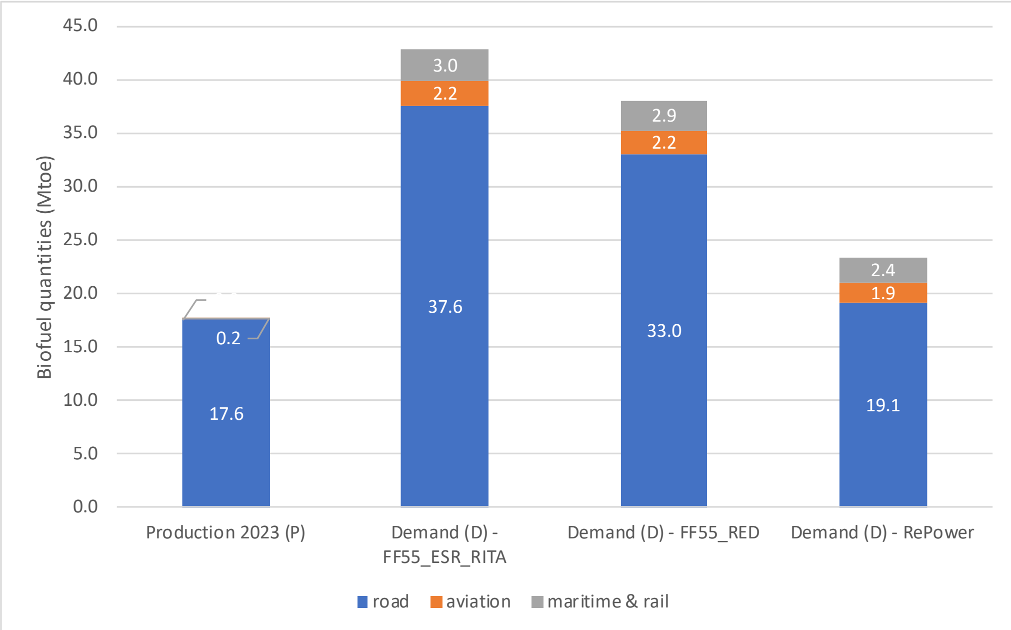


Figure 4-17 Biofuels production 2023 versus 2030 demand scenarios[37]

As evident from Table 4-1 the 2030 gap for biofuels in road transport is substantial, whereas the gap for aviation and maritime transport is smaller. For 2050, the total biofuel demand is pegged at 46.7 Mtoe, which falls below the 48.5 Mtoe total capacity projected by experts, suggesting no need for additional measures beyond what experts have forecasted. In 2050, a significant portion of biofuels capacity for road transport is expected to decline, while aviation, maritime & rail transport are projected to emerge as the largest consumers of biofuels.

[37] This figure includes all biofuels, i.e. both conventional and advanced biofuels.

		Demand (D)	Current production (P)	Growth foreseen (F)	Gap (D-P-F)
2030	**totals**	**38.1**	**17.8**	**9.6**	**10.6**
	road	33.0	17.6	5.9	9.6
	aviation	2.2	0.0	1.5	0.7
	maritime + rail	2.9	0.2	2.3	0.4
2050	**totals**	**46.7**	**17.8**	**30.7**	**-1.8**
	road	7.1	17.6	-10.1	-0.4
	aviation	15.9	0.0	14.9	0.9
	maritime + rail	23.7	0.2	26.0	-2.4

Table 4-5 Gap analysis between biofuels demand and current production & growth foreseen in transport FF55_RED scenario (Mtoe)

4.3.2. Filling the gap

To gain insight on how the remaining gap of 10.6 Mtoe between demand and (current and foreseen) biofuels production (D-P-F in Table 4-1) could be addressed, an evaluation was conducted to identify technologies that could provide this additional contribution, beyond what is already foreseen by the experts (F in Table 4-2).

Technology	Production 2023 (Mtoe/yr)	Growth foreseen till 2030 (Mtoe/yr)	Total (2030) (Mtoe/yr)	Production assumed to fill the gap (2030) (Mtoe/yr)	Total incl. filled gap (2030) (Mtoe/yr)
	P	F	P+F	D-P-F	D
transesterification of food/feed crops	4.60	0.53	5.13	-	5.13
hydrotreatment of food/feed crops	5.25	-	5.25	-	5.25
ethanol fermentation of food/feed crops	3.16	0.58	3.74	-	3.74
transesterification of UCO and AF (animal fats)	3.09	-0.88	2.21	-	2.21
hydrotreatment of UCO and AF (animal fats)	-	1.58	1.58	-	1.58
transesterification of intermediate crops	-	2.83	2.83	-	2.83
hydrotreatment of intermediate crops	-	2.42	2.42	-	2.42
transesterification of Annex IX-A feedstocks	1.06	0.44	1.50	-	1.50
hydrotreatment of tall oil	0.14	0.07	0.21	-	0.21
biomethane from anaerobic digestion	0.32	1.18	1.50	6.35	7.85
lignin boost of fatty acids	-	0.14	0.14	0.75	0.89
advanced ethanol	0.13	0.19	0.32	1.04	1.37

Technology	Production 2023 (Mtoe/yr)	Growth foreseen till 2030 (Mtoe/yr)	Total (2030) (Mtoe/yr)	Production assumed to fill the gap (2030) (Mtoe/yr)	Total incl. filled gap (2030) (Mtoe/yr)
	P	F	P+F	D-P-F	D
ATJ	-	0.10	0.10	-	0.10
gasification + methanol	0.00	0.21	0.21	1.16	1.37
gasification + SNG	0.00	0.03	0.03	0.16	0.19
gasification + FT	-	0.05	0.05	0.28	0.34
pyrolysis	0.04	0.14	0.18	0.77	0.95
HTL	0.00	0.02	0.03	0.13	0.15
Total	**17.8**	**9.6**	**27.4**	**10.6**	**38.1**
Total food/feed crops	13.01	1.11	14.12	-	14.12
Total hydrotreatment, transesterification (Annex IX B)	3.09	5.94	9.03	-	9.03
Total hydrotreatment, transesterification (Annex IX A)	1.20	0.52	1.71	-	1.71
Total anaerobic digestion (Annex IX A and B)	0.32	1.18	1.50	6.35	7.85
Total lignocellulosic advanced biofuels (Annex IX A)	0.17	0.90	1.07	4.29	5.36
Total	**17.8**	**9.6**	**27.4**	**10.6**	**38.1**

Table 4-6 Ways to fill the gap between production forecast and demand (FF55_RED) scenario, 2030 (Mtoe/yr)

The following technologies are not projected to make additional contributions to bridging the gap:

- Conventional biofuels, as these are capped in the RED and are not eligible to meet the targets of ReFuelEU Aviation and FuelEU Maritime.

- Technologies using Annex IX A or B fat-based feedstock (e.g., transesterification of e.g., brown grease, cover crops from marginal land, and hydrotreatment of tall oil and cover crops from marginal lands), as the growth foreseen by experts already includes 0.44 Mtoe transesterification of brown grease, 2.83 Mtoe of transesterification of cover crops and 2.42 Mtoe of hydrotreatment of cover crops, and 0.07 Mtoe of hydrotreatment of tall oil. Additional feedstock availability within the EU27 is limited.

- ATJ/MTJ, as in the relevant demand scenarios the gap between demand for aviation and additionally foreseen capacity is minor. To assume additional growth beyond the 0.1 Mtoe growth foreseen by experts, according to this methodology, would mean that more than the mandated amount of aviation fuel will be produced. This is not to be expected, due to the high costs difference of SAF and regular aviation fuel by 2030.

It is assumed that all remaining technologies, i.e., anaerobic digestion, lignin boost of fatty acids, advanced ethanol, gasification + methanol, gasification + SNG, gasification + FT pyrolysis and HTL contribute to filling the gap relative to their growth foreseen by experts in 2030 (F in Table 4-1). A single growth factor has been applied to the growth foreseen by experts in 2030, in such a way that the demand of the FF55_RED scenario is exactly met[38].

In Table 4-2 the result is shown in the case of the central FF55_RED scenario in 2030. The growth factor that is needed to fill the gap is determined to be 5.4 indicating that the predicted growth until 2030 must be multiplied by an additional factor of 5.4 for the selected technologies to bridge the gap. This additional advanced biofuel production per technology is shown in the column named “Production assumed to fill the gap (2030)”. All this leads to a total biofuel capacity of 38.1 Mtoe in 2030, in accordance with the central (FF55_RED) scenario.

The use of one growth factor for a selection of emerging technologies may mean that the growth for some technologies may be underestimated for some and overestimated for others. The applied extrapolation of the additional capacity forecasted by the experts gives however an initial impression on the contribution of the different technologies to filling the identified gap.

4.3.3. Feedstock availability

To determine whether sufficient sustainable feedstocks are available to meet the increased demand, a four-step approach was followed:

- Step 1: Determination of feedstock suitability and availability for each of the advanced biofuels production technologies, using biomass-technology matrices, and the low, medium, and high feedstock mobilization scenarios as developed in Task 2.
- Step 2: Subtraction of indigenous feedstocks production currently used for biofuels, power, and heat production, assuming that this biomass will not be available for additional production biofuels.
- Step 3: Determination of advanced biofuel production potential (in Mtoe/yr advanced biofuels) that could be produced with the available feedstock minus current use for bioenergy per technology pathway and under assumed feedstock-to- fuel conversion rates.
- Step 4: Comparison of the feedstock based advanced biofuels production potential - aggregated to wet biomass and manure, lipids and lignocellulosic biomass - with the demand as determined in Task 1, and with the gap filled as determined in the present task.

In Table 4-3 the results of this assessment are summarized for the FF55_RED scenario for 2030. The second column (p) shows the advanced biofuels demand. The third and fourth columns show the total amount of biofuels that can be produced for that subgroup, using the 'medium' (m) and 'high availability' (h) feedstock scenario minus current use of indigenous feedstock. The last two columns represent the surplus/shortage (m - p) and (h - p). It is to be

[38] An example of how these calculations have been carried out is as follows: for the technology pathway Advanced Ethanol, current production is 200,000 t/yr, or 0.13 Mtoe/yr (Conversion factor: 0.64 toe/t). Additional capacity foreseen is 300,000 t/yr, bringing the total – current plus foreseen production – to 500,000 t/yr, or 0.32 Mtoe/yr. To fill the gap, an additional growth of a factor 5.39 x 300,000 t/yr = 1,617,099 t/yr is needed. This brings the total advanced ethanol production to 2,117,099 t/yr, or 1.35 Mtoe/yr.

noted that the demand and supply of food/feed feedstocks for conventional biofuels are excluded in this study.

Feedstock subgroup	Advanced biofuel production demand (Mtoe/yr) (p)	Max feedstock (medium mobilization) (Mtoe/yr) (m)	Max feedstock (high mobilization) (Mtoe/yr) (h)	Surplus (+) or Shortage (-) medium mobilization (Mtoe/yr) (m – p)	Surplus (+) or Shortage (-) high mobilization (Mtoe/yr) (h – p)
Wet biomass and manure	7.9	13.4	22.9	5.6	15.0
Lipids	10.7	2.1	4.7	-8.6	-6.0
Lignocellulosic biomass	5.4	19.8	87.2	14.4	81.9

Table 4-7 Assessment of the availability of feedstocks for the needed additional biofuels production capacity in case of the FF55_RED scenario for 2030

The following observations can be made:

- There is sufficient feedstock for biogas transport fuel production, even if it is assumed that a portion of the biogas is used for applications other than transport.
- For lipids – used in hydrotreatment and transesterification – there is not enough biomass for all the required additional capacity, even in the high mobilization scenario. This shortfall is likely to be addressed through imports, a development that is already underway.
- Regarding biofuels produced from lignocellulosic materials, there is enough feedstock available in both the medium and high mobilization scenarios.

It should be noted that no import or export of biomass for the production of advanced biofuels, nor the import or export of advanced biofuels, has been considered in this analysis. This assessment focuses on whether EU biomass is sufficiently available to produce advanced biofuels within the EU to meet the EU demand.

4.4. Capacity development e-fuels

According to RED II, Article 2 (36) Renewable liquid and gaseous transport fuels of non-biological origin (RFNBO) means "liquid or gaseous fuels which are used in the transport sector39 other than biofuels or biogas, the energy content of which is derived from renewable sources other than biomass". In the context of this report, renewable fuels, synthetic fuels, e-fuels, and Power-to-liquid (PtL) are all considered synonyms for RFNBO. It is to be noted that Recycled Carbon Fuels (RCF) are not within the scope of this assessment.

Both advanced biofuels and RFNBOs contribute to the demand for alternatives to fossil fuels in the transport sector. If one of these fuel categories contributes less than expected, the other category may be able to compensate and provide a larger share of the total demand.

[39] According to the proposal for the RED III, found in the Fit for 55 package, this limitation of the use of RFNBOs to transport will be removed. The definition will thus apply to RFNBOs used in all sectors.

Therefore, insight into the capacity development of renewable fuels, especially within the EU27, is needed, and evidence is required to underpin this capacity development. In accordance with the reports from Concawe and[40] as well as the report from TNO[41], the following renewable fuel pathways are considered in the scope of this subtask:

- E-hydrogen, final product for fuel cell electric vehicles and feedstock for other e-fuels.
- E-kerosene (and E-diesel), mainly via Fischer-Tropsch and methanol-to-jet pathways
- E-methanol, through electrolysis and electrochemical processes.
- E-ammonia, synthesis of E-hydrogen and nitrogen in a Haber-Bosch reactor.
- E-methane, produced by methanation of syngas.

4.4.1. Eligibility criteria for RFNBOs

An important question is which electricity and carbon sources qualify for the production of RFNBOs. The basic conditions are set in RED II Article 27(3). Detailed rules on the eligibility of renewable electricity sources for the production of RFNBOs can be found in Delegated Regulation 2023/1184[42] and calculation rules for the required GHG emission reduction compared to the fossil comparator of 70% are outlined in the Delegated Regulation 2023/1185[43]. The main outcome of these regulations is that only renewable electricity that is additional to existing capacity can be used. CO2 from fossil energy-based electricity plants can be utilized until 2036, and CO2 from other EU-ETS companies can be used until 2041. After that date, CO2 from bioenergy installations and direct air capture will be the main eligible sources of carbon for RFNBOs.

4.4.2. Targets and demand for RFNBOs

The starting point for determining the targets for RFNBOs is the provisional agreements on RED III, ReFuelEU Aviation, and FuelEU Maritime, as known at the time of compiling this task (August 2023). The EU27 demand for RFNBOs in 2030 from different sectors is summarized in Table 4-4. The total demand for RFNBOs in 2030 is at least 1.0 Mtoe, with 0.54 Mtoe in aviation and 0.46 Mtoe in shipping, meeting the targets of ReFuelEU Aviation, FuelEU Maritime, and RED III (all based on the provisional agreement texts). RED III targets for the industry are also presented, as these targets are relevant in evaluating capacities, as RFNBOs production capacity can be used either for e-fuel or chemical applications.

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[40] Alba Soler, et al., E-fuels: A techno-economic assessment of European domestic production and imports towards 2050. Concawe, November 2022.

[41] Karin van Kranenburg, et al., E-fuels: towards a more sustainable future for truck transport, shipping, and aviation. TNO, July 2020.

[42] Commission Delegated Regulation (EU) 2023/1184 of 10.02.2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin.

[43] Commission Delegated Regulation (EU) 2023/1185 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a minimum threshold for greenhouse gas emissions savings of recycled carbon fuels and by specifying a methodology for assessing greenhouse gas emissions savings from renewable liquid and gaseous transport fuels of non-biological origin from recycled carbon fuels.

Legislation		ReFuel EU Aviation	FuelEU Maritime	RED III	RED III
Basis for target		Aviation	Shipping	Road and rail[a)]	H2 in industry [d)]
Total fuel consumption 2030	Mtoe	43.5[e)]	44.4 [e)]	225 [e)]	11.5[d)]
RFNBO target 2030	%	1.20%	1%	1%	33.6% - 42%
Multiple counting	factor	1	1	2 to 3[b)]	1
Effective RFNBO demand	Mtoe	0.52	0.44	0.75 – 1.12	3.9 – 4.8
Demand can be met by		RFNBOs for aviation	RFNBOs for shipping	RFNBOs for all transport modes	RFNBOs in industry (non-transport)
Net demand	Mtoe	0.52	0.44	0[c)] – 1.12	3.9 – 4.8

[a)] Inland navigation is also included in this figure. [b)] Next to double counting for all RFNBO, another factor 1.5 shall be applied if RFNBOs are supplied to maritime or aviation sectors. [c)] The RED III RFNBO target is already met if ReFuelEU Aviation and FuelEU maritime targets are met. [d)] Own elaboration. See the section on RFNBOs in the industry in the main Task 4 report (Appendix 1 Report on Task 4). [e)]The numbers are based on the total transport fuel consumption in 2030 as found in the F55_RED scenario.

Table 4-8 Summary of RFNBO demand in 2030 as a result of the provisionally agreed ReFuelEU Aviation, FuelEU Maritime and RED III legislation

While RED III provides RFNBO targets until 2030, ReFuelEU Aviation creates a demand for RFNBOs in transport beyond 2030, increasing to 15.9 Mtoe in 2050. The provisional agreement for FuelEU Maritime promotes 1% RFNBO use in the maritime sector from 2031, or 2% from 2034 if the 1% RFNBO target in 2031 is not met. However, FuelEU Maritime allows for flexibility in applying the target if there is evidence of insufficient production capacity and availability in the maritime sector, uneven geographical distribution, or excessively high prices.

4.4.3. Capacity outlook for 2030

The capacity development of all e-fuels has been determined through literature analysis and was scrutinized by renewable fuel experts through interviews with industrial stakeholders. The capacities of hydrogen for mobility as an end-use have been directly taken from the IEA database without detailed screening. An overview of the total capacity for e-fuels is summarized in Table 4-5 and visualized in Figure 4-4 (excluding E-hydrogen for mobility).

Capacity e-fuels	H2 for mobility	e-kerosene	e-methanol	e-ammonia	e-methane	Total
Implemented	0.025	0.001	0.003	0.002	0.005	0.04
Under development	0.146	0.063	0.083	0.116	0.043	0.45
Planned	7.485	1.129	0.666	0.798	0.085	10.16
Total capacity	**7.657**	**1.193**	**0.752**	**0.916**	**0.134**	**10.65**

Table 4-9 Capacity development of all assessed e-fuels for 2030, based on announced projects (Mtoe/yr)

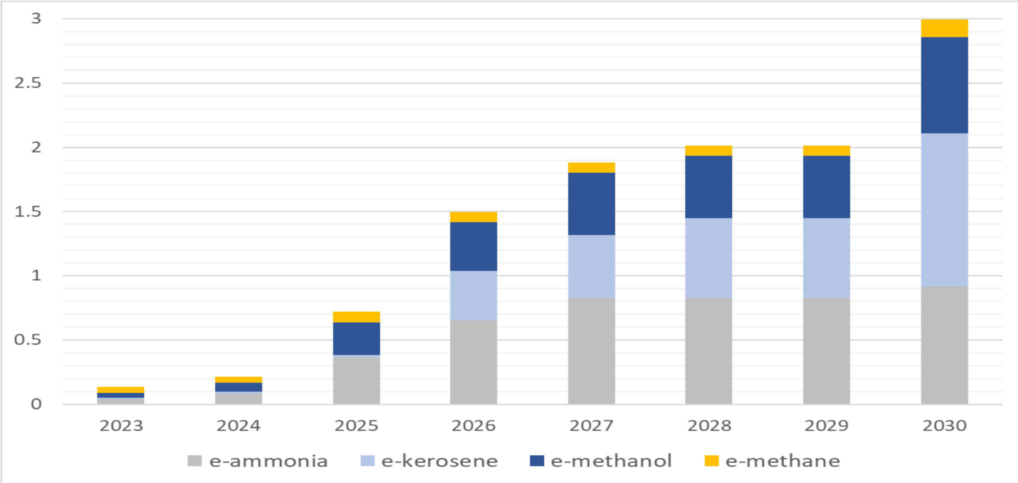

Figure 4-18 Cumulated evolution of all assessed e-fuel production capacities (Mtoe/yr) excluding e-hydrogen, including capacities for industrial applications

To this day, 0.04 Mtoe/yr of e-fuel capacity has been implemented, and 0.45 Mtoe is under development. Based on announcements, a 10-fold increase in e-fuel capacity is planned in 2030, reaching 10.65 Mtoe/yr. Notably, a fair share of e-methane capacity has already been implemented; however, e-methane does not seem to increase as much in capacity by 2030 compared to other e-fuels. It is acknowledged that not all capacity announcements will come to fruition or that all e-fuels will be used as transportation fuel. Furthermore, it can be reasonably assumed that pilot-scale facilities will not continue full operation after a significant scale-up of the technology and will, therefore, not be accounted for in the projections for 2030.

Table 4-6 presents an initial comparison between the capacity development based on the inventory of implemented, developing, and planned projects and the expected demand for e-fuels and RFNBOs for industrial purposes, as presented in Table 4-6. An optimistic 90% capacity utilization factor was assumed to derive the maximal potential production of e-fuels based on implemented, under development, and planned projects.

e-fuels production at 90% capacity utilisation (Mtoe/yr)	e-hydrogen	e-kerosene	e-methanol	e-ammonia	e-methane
Implemented	0.023	0.001	0.002	0.002	0.005
Under development	0.131	0.056	0.075	0.105	0.039
Planned	6.737	1.016	0.600	0.718	0.077
Total capacity	**6.891**	**1.073**	**0.677**	**0.824**	**0.120**
Demand e-fuel/chemical					
Sector e-fuel demand	Road	Aviation	Maritime	Maritime	Maritime
Targeted transport demand provisional agreement	1.12	0.52	0.44	0.44	0.44

e-fuels production at 90% capacity utilisation (Mtoe/yr)	e-hydrogen	e-kerosene	e-methanol	e-ammonia	e-methane
Percentage target met with e-fuel	100%	100%	90%	2%	8%
Transport demand for e-fuel	1.12	0.52	0.40	0.01	0.04
Industrial RFNBO demand - RED III	n.a.	n.a.	1.13*	2.67*	n.a.
Total demand	**1.12**	**0.52**	**1.53**	**2.68**	**0.04**
Percentage of demand covered by identified capacity (at 90% capacity utilisation)					
Implemented	**2%**	**0.1%**	**0.2%**	**0.1%**	**13%**
Under development	**12%**	**11%**	**5%**	**4%**	**109%**
Planned	599%	195%	39%	27%	217%
Total	613%	206%	44%	31%	339%

* Please note that the demand for hydrogen for e-methanol and e-ammonia in Table 4-4. has been converted to a demand for e-methanol and e-ammonia.

Table 4-10 Matching capacities with demand for RFNBOs as targeted in 2030 (project elaboration) (Mtoe/yr)

Aviation

In the case of e-kerosene, currently, only 0.1% of the target of 0.52 Mtoe/yr can be met, and 11% of the target if all projects under development are realized. This implies that, additionally, 50% of the planned e-kerosene projects need to be realized to meet the projected demand in 2030.

Maritime

Regarding e-fuels for the maritime sector, after discussions with e-fuels experts, considering technical, financial, and logistical feasibility, it was assumed that the demand in 2030 will be covered by e-methanol (90%), e-ammonia (2%), and e-methane (8%). The industrial RFNBO demand for methanol and ammonia production induced by RED III Article 22a (2030 target of 42% RFNBOs) was added.

In the case of e-methanol, in addition to the estimated demand of 0.44 Mtoe/yr from the maritime sector, the industry requires 1.13 Mtoe/yr of e-methanol. The total envisaged capacity of 0.677 Mtoe/yr (at 90% capacity utilization) does not cover this demand, and additional capacity is needed. If all e-methanol were to go solely to the maritime sector, there would be enough capacity to meet this demand; however, this is not realistic.

The total implemented, under development, and planned e-methane capacity is 0.120 Mtoe/yr (at 90% capacity utilization), which could theoretically cover 27% of the 2030 RFNBO demand in the marine sector. Most e-methane projects will provide e-methane to the grid. While RED III allows the use of biogas injected into the grid, it does not have provisions on the use of e-methane. Moreover, due to competition with other applications, it was estimated that the use of e-methane will cover a maximum of 8% of the RFNBO target for the maritime sector, i.e., 0.04 Mtoe/yr, which could be reached if about 29% of all e-methane projects supply the maritime sector.

The industrial demand for e-ammonia of 2.67 Mtoe/yr is much larger than the expected demand in the transport sector standing at 0.01 Mtoe/yr in 2030, and the total implemented, developing, and planned capacities do not meet this combined demand. However, the shipping sector only needs a modest share of the total e-ammonia capacity, and technical feasibility and safety issues are expected to be the limiting factors for application in shipping in 2030 rather than the availability of e-ammonia.

Road transport

As shown in Table 4-4 the RED III RFNBO target for transport can solely be met by the use of RFNBOs in aviation and the maritime sector. However, it is interesting to assess the status of e-hydrogen for direct use in mobility. If it is assumed that all hydrogen for direct use in mobility is directed to road transport, the implemented capacity is sufficient to meet 2% of the targeted demand of 1.12 Mtoe/yr for RFNBOs. Projects under development could cover 12% of the demand. There is sufficient planned capacity to cover 6 times the targeted demand.

Furthermore, during e-kerosene production, a fraction is co-produced that is suitable for road transport. If the aviation target of 0.52 Mtoe/yr is met, most likely about 15 – 20% e-diesel can be produced, sufficient for 0.08 – 0.10 Mtoe/yr, which is 7 – 9% of the RED III RFNBO target of 1.12 Mtoe/yr.

In total, 0.036 Mtoe/yr of e-fuels production capacity has been implemented, which could produce 0.032 Mtoe/yr of e-fuels at 90% capacity utilization, covering only 3 – 4% of the total RED III target of 0.75 – 1.12 Mtoe/yr in 2030, depending on the type of double counting. If all 0.41 Mtoe/yr of projects under development are added (at 90% capacity utilization), about 39 – 58% of the RED III RFNBO target for transport could be met. This implies that a significant number of planned projects has to reach the implementation phase; otherwise, the RED III target will not be met.

4.4.4. Developments towards 2050

After 2030, there will be an urgent need for alternatives to fossil fuels such as RFNBOs and advanced biofuels to achieve the targeted greenhouse gas emission reductions. RFNBOs, however, are not a cheap solution and, given the required inputs, are expected to be always more expensive than the current fossil fuels and most advanced biofuels. Concrete evidence (i.e., announced) of additional capacity development for those that have received a final investment decision or are at any stage before the final investment decision is limited to a timeframe until 2030. Many factors play a role in the development of RFNBOs for transport in the EU27 after 2030, such as:

- Targets and subsequent demand for RFNBOs
- The applicability of e-fuels, i.e., technical readiness level, technical and financial feasibility of the various RFNBO production technologies and their end use application
- The availability of renewable hydrogen produced from eligible electricity sources, which depend on the development of renewable electricity capacity available for RFNBO production
- The production costs of e-fuels
- The availability and eligibility of CO2
- The demand of RFNBOs in the industry versus transport
- The role of import of RFNBOs

- Regulatory complexity and uncertainty.

The applicability of e-fuels for road transport (especially heavy-duty vehicle long-distance transport), shipping, and aviation is summarized in Figure 4-5. Hydrogen, e-methanol, e-diesel, and e-LNG are attractive options for both trucking and shipping, while e-ammonia is considered applicable only for the shipping sector. For aviation, e-kerosene is regarded as the only viable e-fuel option (see). The main reason for the latter observation is that other e-fuels have higher volume and space requirements and require an adapted or completely new distribution system, including distribution infrastructure.

<table>
<tr><th></th><th></th><th></th><th></th></tr>
<tr><td>Hydrogen</td><td colspan="2">For short distances, in case of high electricity and CO_2 costs</td><td rowspan="5"></td></tr>
<tr><td>E-methanol</td><td colspan="2" rowspan="3">Feasible</td></tr>
<tr><td>E-diesel</td></tr>
<tr><td>E-LNG</td></tr>
<tr><td>E-ammonia</td><td>Unsafe</td><td>In case of high CO_2 cost</td></tr>
<tr><td>E-kerosene</td><td colspan="2"></td><td>Only feasible option</td></tr>
</table>

Source: TNO (2020)

Figure 4-19 Applicability of e-fuels for the road transport, shipping and aviation sectors

Regarding e-fuel production technologies the following observations can be made:

- Direct use of hydrogen in vehicles will be a preferred option considering efficiency losses. However, the vehicle needs to be suitable for the storage and usage of hydrogen.

- Methanol has the potential to become a future commodity for fuels and chemical production. E-methanol has great potential as it serves a wider array of applications, such as marine bunker fuel and chemical feedstock.

- The methanol-to-jet pathway is more selective towards kerosene-range hydrocarbons compared to FT-synthesis.

- FT-synthesis requires a by-product market (diesel and naphtha). Producers will need to seek out high-value end markets for the by-products to make a positive business case. Off-takers for diesel/gasoline could include trucking. Off-takers for light ends could include the chemical industry to produce olefins, which are the precursor monomers for plastics. Currently, the average product slate of an FT-synthesis facility is 60% jet fuel, 20% diesel, and 20% naphtha. Optimization up to 85% jet fuel is possible.

- E-diesel can still be used as fuel for trucking as the use of e-fuels in internal combustion engines (ICE) will be allowed after 2035.

- E-ammonia can potentially be used as marine fuel for chemical tankers that transport ammonia, therefore experience with handling. It is a globally traded commodity with around 17 – 18 Mt traded annually by ships[44]. This was also the case for methanol, where the first movers were chemical tankers exporting methanol. Still, safety risks need to be addressed, and regulations need to be in place. Without carbon being available and affordable, e-ammonia would be the preferred fuel in the shipping industry.

- E-methane could be used in LNG-fueled vessels and for heavy-duty truck transport, and a significant increase in LNG-fueled vessels has been observed. It has lower applicability in the chemical sector than methanol, though.

4.5. Preconditions and critical issues to advanced biofuels capacity development

In June and July 2023 interviews with advanced biofuels producers/technology providers were held to discuss *"what factors are most critical to the capacity development of advanced biofuels"*, as open central question, and thereafter discussion supported by the headings of the above-mentioned list of critical factors.

The analysis of these interviews involved counting the number of unique statements related to each topic. As depicted in Figure 4-6, regulatory issues, including specific EU regulations like RED III and ReFuel Aviation, were the most extensively discussed during the interviews. They were followed by discussions on access to capital and perceived project risks by investors, as well as research and technology development.

These interviews led to the identification of two primary groups of critical risks. Regulatory issues were cited as the most critical factor, mentioned five times, followed by access to capital and project risks, cited four times. The remaining three issues were all related to feedstocks, including their eligibility (mentioned once), access to them (mentioned once), and mobilization (mentioned once). The following section summarizes the main results gleaned from these interviews.

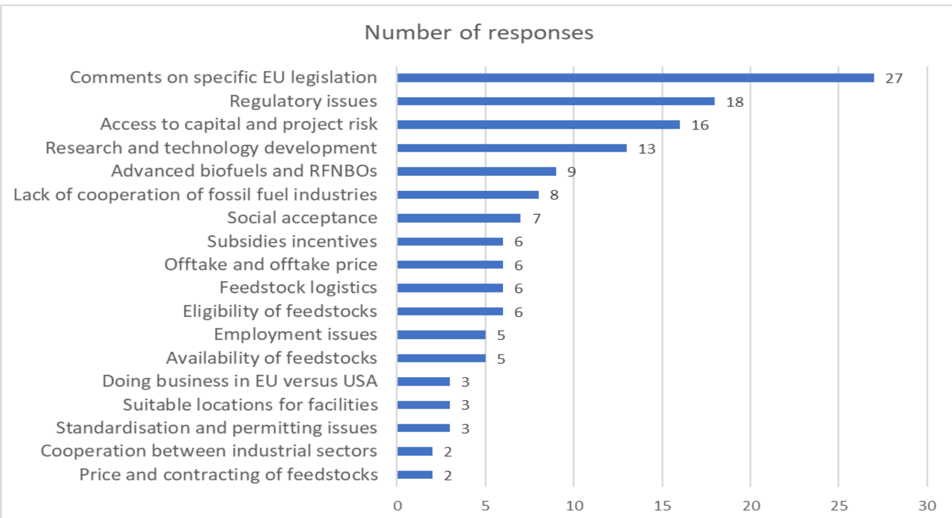

Figure 4-20 Number of responses to the topics addressed during the interviews with 12 companies

[44] Source: IEA Ammonia Technology Roadmap, towards more sustainable nitrogen fertiliser production.

Regulatory issues (highly critical)

The acknowledgment and appreciation of the EU's establishment of an overall framework supporting advanced biofuels across sectors, including maritime and aviation, are positive. However, respondents highlighted two major concerns: regulatory uncertainty and complexity.

An instance of regulatory uncertainty arose soon after RED II's establishment, setting a 1.75% target for advanced biofuels. The subsequent release of the RED III proposal cast uncertainty over the recently set target. Further uncertainty might arise in 2025 with the full evaluation of the Green Deal. Given that industrial projects span at least 20 years, frequent regulatory changes every 3 - 4 years pose challenges. Sustaining stable advanced biofuels targets and legislation for extended periods is recommended.

An important example of regulatory complexity is that the trialogue negotiations resulted in a joint target for both advanced biofuels and RFNBOs. In general, the respondents expect that there is no big risk that RFNBOs take more than the minimum of 1% in the combined target of 5.5%. But it adds complexity and uncertainty, as the RED III provisional agreement Article 25 point 1, second paragraph states *“Member States are encouraged to set differentiated target for biofuels and biogas produced from the feedstock listed in Part A of Annex IX and RFNBOs at national level in order to fulfil the obligation (…) in a way that the development of both fuels in incentivized and expanded”*. Therefore, advanced biofuels producers have to await what Member States decide with regard to this target, and Member States may ask for more than 1% RFNBOs on the cost of advanced biofuels at Member State level. It is recommended to limit the freedom of Member States to have their own interpretation of advanced biofuels targets.

Regulations that are directly applicable in all Member States (such as ReFuelEU Aviation) are preferred above Directives (such as the RED) that requires implementation in national law. Members States may need the flexibility of a Directive, but in this case of advanced biofuels in RED III, it became too complex and uncertain for industries.

Clarity is needed regarding the provisional agreement of the RED III, wherein Member States may count biogas injected into the grid toward advanced biofuels targets, possibly even if no methane is used as a transport fuel. The text lacks clarity on this point, creating uncertainty about whether Member States will indeed count biogas injected into the grid to meet advanced biofuels targets, without the use of biomethane in transport, even if this is not the intention of the legislator. Although an option, it is recommended that the legislative process results in clear legislation and proper procedures.

The Commission proposal of the Net Zero Industry Act (COM (2023) 161[45]) provides priority status and various types of support, such as shorter permit procedures and increased access to finance, to the Strategic Net-Zero Technologies. The proposed list does not include advanced biofuels, even though they meet all underlying criteria, such as GHG impact, TRL, and energy security. Particularly, the fast-track permitting would be very beneficial for the rapid implementation of advanced biofuels projects, as it is very challenging to have sufficient capacity installed by 2030. It is recommended to include advanced biofuels as a Strategic Net-Zero Technology in the Net Zero Industry Act.

[45] Proposal for a regulation of the European Parliament and of the Council on establishing a framework of measures for strengthening Europe’s net-zero technology products manufacturing ecosystem

Access to capital and perceived project risks (highly critical)

The combination of (1) high investment costs, (2) the perceived project risk by capital providers and (3) the required speed of capacity development to meet the targets is challenging and requires robust measures.

For larger companies, obtaining capital may not be a significant problem, but for many smaller companies, this poses a serious barrier. Many players in this emerging sector are project developers, not traditional entities in the oil and gas business. Project financing is a major hurdle for these new entrants in a capital-intensive field like advanced biofuels production. They encounter a "chicken-and-egg" problem: to attract sufficient capital easily, a full-scale reference is required, but developing this reference necessitates sufficient capital. Banks or conservative investors are reluctant to finance advanced biofuels projects with technological risks, and there is no time to de-risk by scaling up at a slower pace. Risks must be taken, and risk capital is required. It is recommended to support the development of a full-scale reference plant. An IPCEI for advanced biofuels could be a very appropriate tool to facilitate the large-scale deployment of advanced biofuels.

Research and technology development

None of the advanced biofuels production technologies has been established for decades. Technological development and support for technology development will be necessary especially in the early stages of development. The EU has supported research and development of advanced biofuels technologies, which is well appreciated by the advanced biofuels technology developers. These research programs are very important. It is recommended to keep research and technology development funds available for advanced biofuels production technologies.

Several technologies face the primary challenge of establishing a full-scale demonstration plant to demonstrate commercial viability. Providing appropriate support at this phase, such as through the EU Innovation fund, is advised.

Further development and optimization of advanced biofuels technologies could yield substantial benefits. Process optimization and yield improvement are feasible, and capacity development plays a pivotal role in reducing costs per unit.

Biomass feedstock eligibility

While not the primary focus of the current project centered on advanced biofuels, it's noteworthy that pathways like AJT could progress faster if first-generation bioethanol were accepted in ReFuelEU Aviation and FuelEU Maritime. The reduced use of first-generation bioethanol could then be directed towards maritime and aviation. Leveraging intermediate crops and cover crops for advanced biofuels production is seen as an opportunity, and it is recommended to explore these possibilities further.

Role of advanced biofuels versus RFNBOs

Concerns have been raised by many advanced biofuels producers regarding the high expectations set for RFNBOs at the political level, despite the projected unavailability of RFNBOs at scale before 2035. Formulating realistic RFNBO targets and measures is crucial. For advanced biofuels producers, demonstrating the potential and opportunities of advanced biofuels to policymakers and the public is essential.

While not directly linked to advanced biofuels, the eligibility of carbon sources for RFNBOs is a critical concern. The delegated regulation on carbon sources for E-fuels ((EU) 2023/1185) specifies that fossil CO2 sources will be ineligible after 2036 (for industries under EU ETS) and 2041 (from electricity plants). This significantly impedes the E-fuels sector's development. While a review is scheduled for 2027, it doesn't provide clarity. Including a grandfathering clause, allowing projects using a fossil carbon source at their initiation to continue using it, is recommended for consideration.

Other issues

Other issues regarded important by part of the respondents are:

- Slow regulation process especially related to 2030 targets

- Role of existing fossil industries that would like to keep the status quo; this requires clear and strictly enforceable advanced biofuels targets

- Social acceptance as advanced biofuels are suffering from conventional biofuels' poor fame; it may explain why so much emphasis has been put by parliamentarians on RFNBOs.

4.6. Main findings

In the central scenario, 'FF55_RED' for 2030, a total gap of 10.6 Mtoe was identified between the demand of 38.1 Mtoe and the current production of 17.8 Mtoe, plus additional capacity foreseen by the experts in Task 3 (9.6 Mtoe). It was shown that this gap could be filled with Annex IX Part A and B-based advanced biofuels and biomethane produced within the EU27. Since EU climate policy was the main driver of the demand modeling, it means that, in order to achieve the climate targets set by the EU, a very strong effort is needed to scale up advanced biofuels production capacity and mobilize the required sustainable biomass feedstock, especially lignocellulosic biomass, following the medium or high mobilization scenarios formulated in Task 2. Regulatory uncertainty and complexity are two major issues that most industry experts addressed in one way or another.

An impressive list of announced and planned projects for hydrogen production and various e-fuels could be established. However, the installed capacities are still very low. Only if the legislative framework with targets is fully in place will final investment decisions be made to develop capacity. The availability of hydrogen produced from eligible renewable electricity sources is an important barrier to RFNBO capacity development. In the long run, availability of CO2 will be more critical. The switch to direct air capture requires an additional supply of renewable electricity.

Regulatory issues and comments on specific EU regulations (such as RED III, ReFuel Aviation, etc.) were addressed mostly during interviews with advanced biofuels technology developers and producers, followed by access to capital and perceived project risks by investors, and research and technology development. Regarding regulatory issues, in general, it is acknowledged and appreciated that the EU has established an overall framework with support for advanced biofuels in several sectors, including maritime and aviation. This is positive, but regulatory uncertainty and complexity are two major issues that most respondents noted in some form. As long as legislation and targets are not fixed, investments in advanced biofuels capacity will be very limited. Secondly, the combination of (1) high investment costs, (2) the perceived project risk by capital providers, and (3) the required speed of capacity development to meet the targets is challenging and requires robust measures.

A more detailed presentation of the work carried out in Task 4 is provided in Annex 4 of this Final Report.

5. Analysis of socioeconomic impact, GHG emissions, and costs (Task 5)

5.1. Aim of Task 5

Task 5 aims at providing the quantification for the socio-economic and environmental impacts, associated with the deployment of drop-in advanced biofuels in the EU transport sector.

5.2. Methodology

Drawing from the outcomes of Tasks 1 to 4, Task 5 aims to quantify the socio-economic and environmental impacts associated with the implementation of drop-in advanced biofuels in the EU transport sector.

The estimated environmental and socio-economic impacts are evaluated through the four indicators described below.

- **GHG savings**: express the emissions avoided by replacing shares of conventional fossil fuels with alternative fuels and energy vectors (advanced and conventional biofuels, electricity and e-fuels).

- **Annual turnover including import**: the annual turnover of the biofuels sector is evaluated from the market prices and the annual demand for each pathway. The economic value of imports is also assessed and included in the total annual turnover.

- **Contribution to GDP including import**: the contribution to the EU's GDP related to the biofuels sector is estimated by analysing the added value provided by each pathway and by the imported biofuels. The contribution is expressed as the share of the total EU's GDP forecast for 2030.

- **Sectorial direct and indirect Employment**: the new jobs in the biofuels sector are evaluated for year 2030, 2040 and 2050 by using an Employment Factor multiplied with expected biofuels consumption. The Employment Factor calculation is subject to technology maturity, technology structure, imports/exports, replacement of fossil fuels, etc.

A set of **nine KPIs** (the KPI import value was evaluated together with Annual Turnover and Contribution to GDP) was defined, as summarized in Figure 5-1 here below.

Most of the analyzed Key Performance Indicators (KPIs) have been evaluated for 2030 and 2050. **A set of three scenarios** has been defined in which the expected biofuels demand **for 2030** is projected to be covered by **a mix of internal production capacity and import**. These three scenarios are referred to as the 'Import' scenarios. The individual scenarios include a **Central scenario**, FF55_RED, reflecting the recent Provisional Agreement on

REDIII; a **High scenario** (FF55_ESR_RITA), with the highest advanced biofuels demand in 2030, reflecting the EU policy Fit for 55 combined with an equal sectoral ESR (Effort Sharing Regulation)[46] split and an assumption for increased road transport activity; and a **Low scenario** (RePower), with the lowest advanced biofuels demand in 2030 reflecting the relevant RePowerEU context.

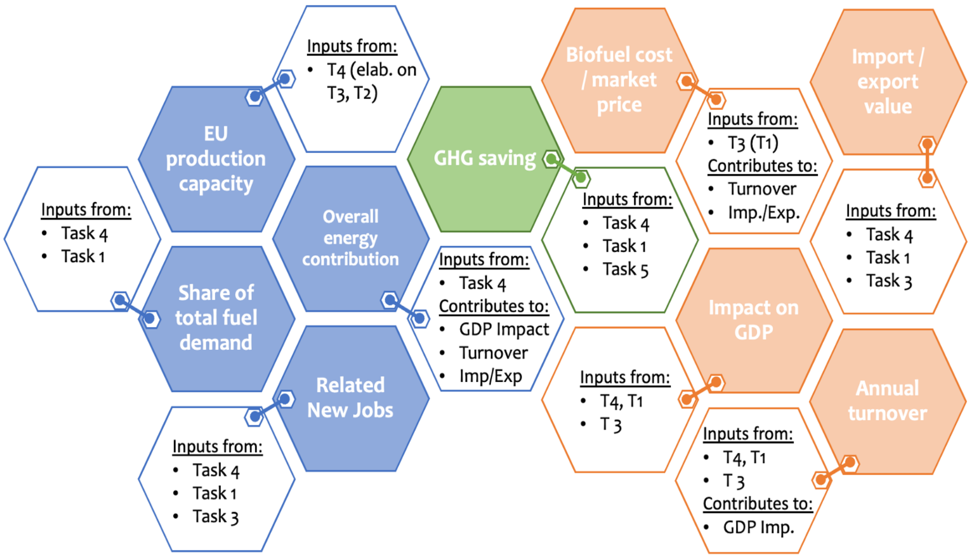

Figure 5-21 Summary of selected KPIs

In addition to these three 'Import' scenarios, two other scenarios have been analyzed for 2030, based on the results of the Gap Analysis carried out in Task 4.1. In this additional set, the expected biofuels demand for 2030 is projected to be covered only by an extended mix of internal production capacity. Thus, these two scenarios are referred to as the **"Extended Capacity" scenarios.** The individual scenarios are named and defined as follows: FF55 RED ExtCap and FF55 ESR RITA ExtCap.

The year 2050 is represented only by the FF55 RED scenario since all the demand scenarios from PRIMES tend to converge to similar biofuels demand values, and no significant import contributions are expected. The economic KPIs (i.e., market prices, annual turnover, and contribution to GDP) have not been evaluated in 2050, due to the lack of robust input data and the significant uncertainty of fuel prices in the long term.

Task 5 has been organized in the following sub-tasks:

- Subtask 5.1 Analysis of literature sources at global and European Level.

[46] The Effort Sharing Regulation establishes for each EU Member State a national target for the reduction of greenhouse gas emission by 2030 in the following sectors: domestic transport (excluding aviation), buildings, agriculture, small industry, and waste.

- Subtask 5.2 Interaction with Tasks 1, 2 and 4 work and review of reports.
- Subtask 5.3 Interaction with Stakeholders.
- Subtask 5.4 Analysis of results and collected data - consolidation by 2030 and 2050.

The main results of Task 5 are presented below.

5.3. Overview of subtasks 5.1 – 5.3

The outcomes from Task 3 and Task 4 reveal that while the overall **EU biofuels production capacity** is anticipated to increase in 2030 compared to present values, this growth is adequate only to match the corresponding demand escalation projected in one of the three analyzed scenarios—specifically, the Repower scenario—accounting for a total biofuels demand of 23.4 Mtoe. In the other scenarios, as depicted in Figure 5-2, the disparity between the expected demand and the projected capacity indicates the necessity to supplement this gap either through Extra-EU imports or by augmenting domestic capacity (as assessed in the Extended Capacity scenarios).

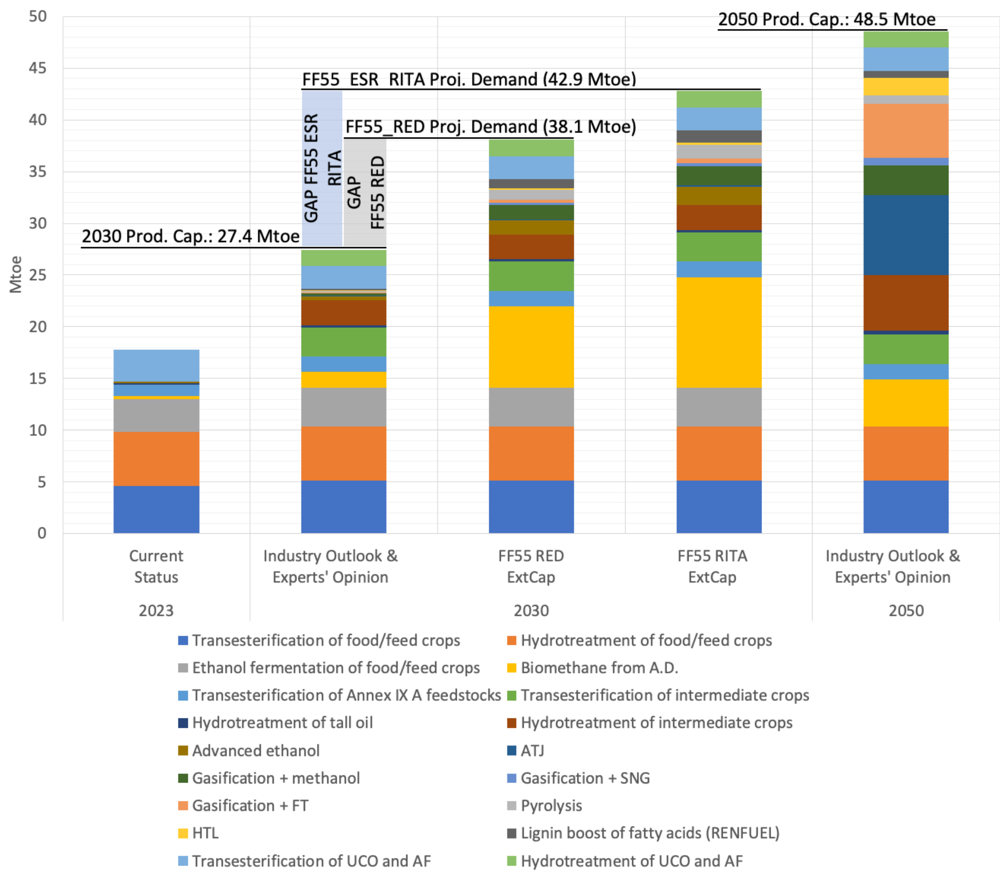

Figure 5-22 Repartition of the expected EU biofuels production capacity among the various pathways, in 2030 and 2050, for the various analyzed scenarios

While the demand versus capacity gap is anticipated in 2030, projections indicate an ample overall EU production capacity by 2050. However, under a sub-sectorial lens, the Aviation sector might still potentially rely on imports for 1 Mtoe out of a total projected demand of 15.9 Mtoe.

The anticipated capacities of the various EU production pathways remain constant in the three Import scenarios considered, while they fluctuate in the Extended Capacity scenarios to align with varying demand levels. Conversely, biofuel imports exhibit notable variations in the Import scenarios but drop to zero in the Extended Capacity scenarios. These dynamics significantly impact turnover and GDP contribution.

From an **economic perspective**, estimated biofuel prices in 2030 show an important degree of uncertainty, due to the many parameters that are involved (including variability across production pathways and output biofuel types, macroeconomic drivers, the volatility of oil prices, competing technologies, etc.). For this reason, the results are based on a variability range based on the minimum and maximum prices suggested by the experts.

A summary of the annual turnover of the biofuels sector, based on average price levels for all the different scenarios is reported in Figure 5-3. The estimated annual turnover of biofuels produced in the EU by 2030 ranges between 41 and 121 billion €2022, contingent on the scenario and market prices considered. The largest contribution stems from transesterification pathways (comprising 41%-43% of the total), followed by hydrotreatment pathways (35%-38%), ethanol (12%-17%), and biomethane from A.D. (approximately 3%). These contributions encompass biofuels produced utilizing RED II Annex IX feedstock.

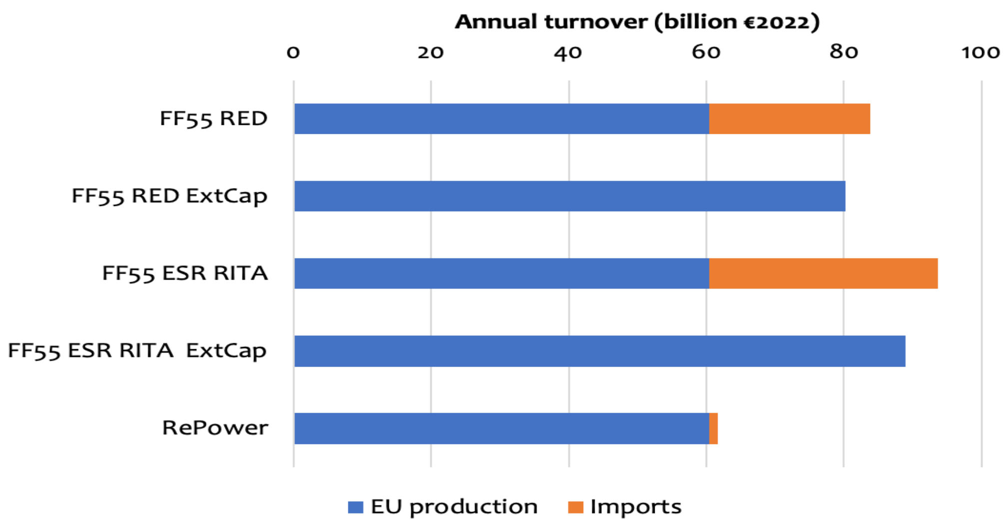

Figure 5-23 Comparison of annual turnover in Main and Gap Analysis scenarios with average prices, 2030 (values in billion EUR2022)

This clearly highlights that in 2030, road transport remains the primary sector for biofuel utilization. The outcomes indicate the substantial economic value of biofuel imports in certain scenarios, comprising up to a third of the total turnover of biofuels demand. Estimated total turnover for imported fuels ranges from 18 to 29 billion €2022 in the FF55 RED scenario and 25 to 41 billion €2022 in the FF55 ESR RITA scenario, thereby elevating the total turnover to 59 to 109 billion €2022 and 66 to 121 billion €2022, respectively. Conversely, the Repower scenario assumes a minimal number of imports.

Comparatively, the Extended Capacity scenarios exhibit lower annual turnovers in contrast to their corresponding Import scenarios. This effect predominantly arises from the Extended Capacity scenarios featuring a significant contribution from biomethane produced via anaerobic digestion, which holds a lower price compared to other biofuels, thereby reducing the overall turnover. If a larger proportion of advanced liquid biofuels were employed to replace fossil fuels, as in ESR and RITA, the turnover figures would likely increase.

The contribution to GDP is evaluated as the added value of the biofuels sector. As depicted in Figure 5-4, the impact ranges between 0.07% and 0.20%, contingent on the scenario and price level considered. The figures indicate that on average, the Extended Capacity scenarios exhibit a higher contribution compared to their corresponding Import scenarios. This trend arises because domestic production is anticipated to generate a higher added value than imported biofuels. A similar effect could be expected if other low-maturity pathways— not accounted for in Task 4's gap analysis—become commercially viable within the designated timeframe.

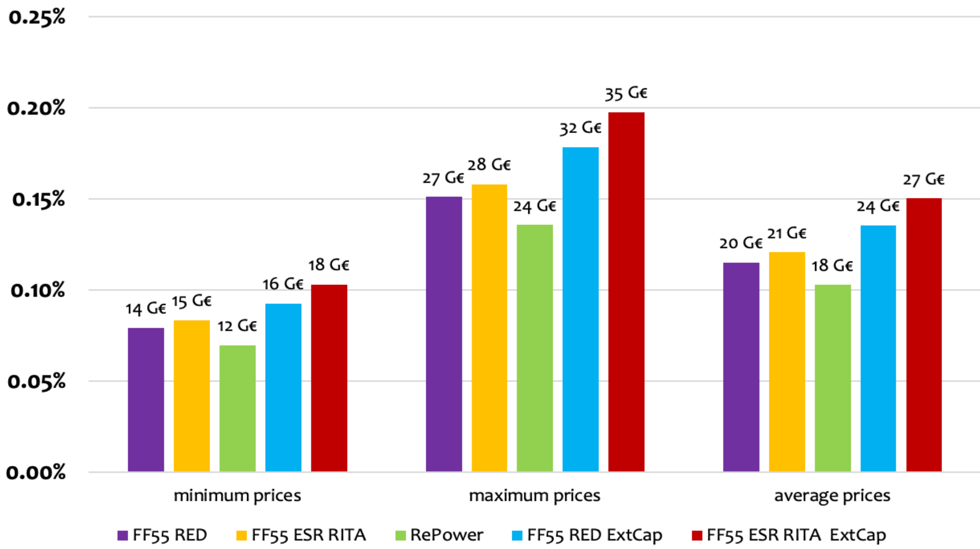

Figure 5-24 Biofuels sector contribution to EU's GDP, 2030, in all the considered scenarios

The **GHG savings** express the emissions avoided by replacing shares of conventional fossil fuels with alternative fuels and energy vectors (biofuels, electricity and e-fuels). A set of specific KPIs was defined to properly report the results of the analysis:

- **GHG_S:** Total GHG savings for the whole transport sector associated with alternative fuels (MtCO2eq).
- **GHG_S_Bf:** GHG savings associated with the specific contribution of biofuels (MtCO2eq).
- **AVG_CI:** Average Carbon Intensity of the fuels and energy carriers used in the whole transport sector (gCO2eq/MJ).

- **GHG_I_R%:** GHG intensity reduction relative to all alternative fuels (%). It is expressed as the percentage ratio of emission savings and avoided fossil fuel emissions.

GHG emissions from transport fuels were derived from the energy consumption data provided by Task 1, adjusted based on the gap analysis conducted in Task 4 concerning production capacity. If production capacity surpassed demand, the surplus quantity of biofuels was considered for export, thus excluded from emissions calculations. Energy consumption for each fuel was allocated across various production pathways using Task 2's estimates of European biomass production. Subsequently, GHG emissions for each scenario were computed by applying an emission factor to each pathway, comparing results to a hypothetical scenario where energy demand was met solely by fossil fuels.

In order to calculate these GHG emissions and related saving, the provided granularity of biofuels production pathways was not sufficient. With the aim to improve the resolution of the GHG analysis, it was therefore necessary to split the biofuel demand among the several available production pathways (considering both feedstock and conversion processes). This was accomplished by proportionally distributing the demand for a certain biofuel among the available feedstocks on the basis of their projected production capacity.

Assigning GHG emission factors to individual value chains utilized an in-house tool called HANDY. The POLITO tool selected appropriate GHG emission factors for each chain from available datasets, prioritizing EU policies like REDII and FuelEU Maritime Annexes. For chains not covered by these documents (e.g., jet fuels), other sources like the CORSIA scheme, JEC V5, and RICARDO vehicle LCA reports were used. When multiple values were available, a hierarchy was followed to select the most suitable factor (e.g., RED II > CORSIA, JEC V5 > RICARDO).

In order to calculate the GHG saving, a hypothetical scenario where the entire energy demand was met by conventional fossil fuels was used. This has allowed us to quantify the GHG mitigation potential that accompanies the use of alternative fuels, in the various transport segments.

The GHG saving analysis was performed for the three demand scenarios provided by the PRIMES model in Task 1 (namely, the FF55 RED, FF55 ESR RITA and the Repower scenarios), reflecting different policy frameworks. Moreover, two cases were considered, differing in the assumption about the missing production capacity. In the "gap-fill" scenario labelled Import the demand is filled by extra-EU imports; in the Extended Capacity (ExtCap) scenario the demand is covered by an expansion of selected value chains, according to the gap-fill analysis performed in Task 4. For The Repower scenario, instead, the EU production capacity results able to fulfil the internal demand, so no specific assumptions were needed. Table 5-1 summarizes the investigated scenarios.

Demand scenario (from Task 1)	Gap fill strategy	Scenario code	Years analysed
FF55 RED	Import	FF55 RED	2030
			2050
	Extended Capacity	FF55 RED ExtCap	2030
FF55 ESR RITA	Import	FF55 ESR RITA	2030

Demand scenario (from Task 1)	Gap fill strategy	Scenario code	Years analysed
	Gap analysis	FF55 ESR RITA ExtCap	2030
Repower	(biofuel demand is met internally)	Repower ExtCap	2030

Table 5-11 Summary of the scenarios investigated in the GHG saving analysis

The three scenarios analyzed are characterized by a significantly different energy demand and mix for the transport sector; this leads to perceptible differences (of about 5%) under the GHG emissions profile. They significantly differ in the way emissions are avoided (Figure 5-5). The FF55 RED achieve significant emissions savings primarily thanks to biofuels. the FF55 ESR RITA scenario shows a significant uptake of both biofuels and electricity. In the Repower ExtCap scenario, on the contrary, the contribution of biofuels to emission savings is low, but overall avoided emissions remain high due to large deployment of electricity end e-fuels.

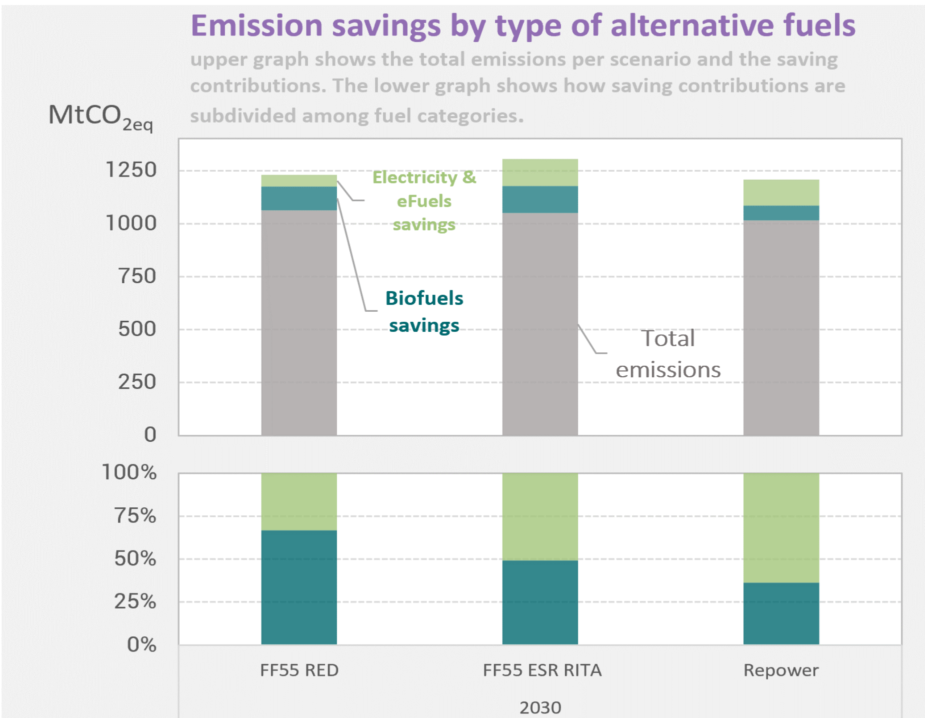

Figure 5-25 Emission savings across selected scenarios and absolute contribution of bio- and other alternative fuels

It is notable that the FF55 RED scenario indicates lower emission savings compared to the higher savings achieved by the FF55 ESR RITA scenario. This discrepancy arises due to the increased adoption of alternative fuels in the latter scenario. However, it's crucial to highlight that the overall emission savings in the FF55 ESR RITA scenario are higher, attributed to the increased use of alternative fuels, especially in light of the higher energy demand for fuels.

Additionally, for e-fuels (RFNBOs) and hydrogen, the GHG emissions are assumed to be zero, irrespective of the production chain.

This approach can change the results of a comparative analysis among different scenarios, like the one here proposed. In particular, the assumption of considering zero emissions is today formally correct form an accounting perspective (in line with the delegated act provisions), but it is debatable that the use of electricity (especially for 2030 when the grid will still have emissions) will not have direct or induced emissions, at EU level, resulting in higher real GHG emissions. A lower real GHG emission would imply an even higher contribution from the alternatives (e.g., advanced biofuels).

The scenario with the lowest overall emissions is the Repower ExtCap scenario, not solely due to the substantial emissions avoided through electricity deployment but also because of an overall reduction in energy demand within the transport sector (Figure 5-6).

It is essential to emphasize that the Carbon Intensity (CI) values of REDII default figures are conservative estimates. Real industrial processes' certified values are notably lower. This difference could directly impact the quantitative GHG savings resulting from the use of these fuels. Additionally, these CI values were presumed to be stable over time, yet ongoing innovations, such as incorporating green hydrogen and renewable electricity in biofuels production, are already underway. These innovations would potentially reduce the Carbon Intensity per MJ of finished fuel.

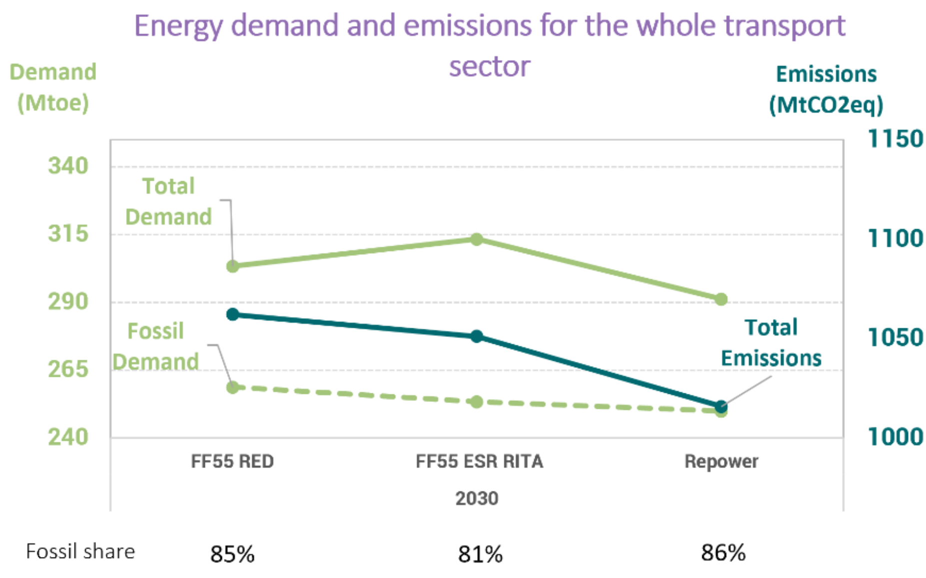

Figure 5-26 a) Energy demand and carbon intensity of the biofuel mix in selected scenarios b) Total emissions, fossil fuel demand and total energy demand in the transport sector in selected scenarios

5.4. Overview of subtask 5.4 on employment

This section primarily concentrates on job creation opportunities, specializing in the generation of knowledge and technological skills, and anticipates their expected impact until 2050.

When considering jobs in sustainable drop-in biofuels activities, including technology development, equipment manufacturing, installation, operation, and maintenance (O&M), as well as the collection, production, and transportation of feedstock to various phases of industrial processing were taken into account. The analysis captures both positive (job creation in RES-related sectors) and negative employment impacts (displaced jobs in conventional energy forms) during the low-carbon transition by 2030, particularly by 2040 and 2050.

Biofuels are mainly produced utilizing local feedstock, and their manufacturing value chain is, in most cases, technologically developed in the European Union. This fact results in a significant economic opportunity, serving as a vehicle for job creation and broader economic development, covering various sectors such as scientific research on innovative processes and technologies, plant construction and operation, and transportation of feedstocks and intermediate/final products. In this employment impact assessment, the focus was on direct and indirect employment, addressing biomass/waste feedstock production/preparation, industrial processing, and transportation of feedstock and intermediate products

The overall employment impact encompasses both permanent and short-term jobs, assuming short-term jobs are averaged over the activity's lifespan. This facilitates the calculation of the employment impact in permanent Full Time Equivalent (FTE) jobs for each biofuel-related activity. The assessment employs the **Employment Factor** (average jobs per unit of capacity or per unit of biofuel generated) and supply chain approaches to estimate both direct and indirect jobs.

The information/data which has been used in this employment impact assessment come from the following sources:

- Existing data for EU-27 employment, as a whole (not a country-by-country analysis), as they are available in Eurostat Labor Force Survey (LFS), Structural Business Statistics (SBS) and EurObservER annual reports (years 2014 to 2021).
- Data of biofuels consumed in the transport sector comes from all available EU and global sources.
- Analyses and findings of Tasks 1, 2 and 3 for biofuels demand, supply, and capacity developments by the years 2030 and 2050, as well the synthetic work on gaps to be faced in Task 4.
- Other relevant literature on employment related to bioenergy of European and international scientific community, IRENA, JRC, IEA, ECN, TNO, AgEcon, scientific papers, etc.

For the calculation of the Employment Factor for the future years, four steps are followed:

- **Step 1**: Calculation of the future number of employees in the transport biofuels sector based on the Employment Factor calculated for the base year 2020.
- **Step 2**: The first corrections to be considered is due to the upscaling of supply quantities due to new investments, which are more efficient, and/or the technology maturity effect in the biofuels supply sector.
- **Step 3**: To proceed to a net employment impact, it is indispensable to consider the reduction of employment in the relevant fossil fuel sectors.

- **Step 4**: The above-mentioned approach might be easily repeated if changing the assumptions, or the scenario outcomes, as they are argued in Tasks 1 and 2 and further elaborated in Task 4.

A series of interconnected spreadsheets, serving as a specialized calculation tool, were developed to streamline the assessment of employment impact. Calculations were performed for the years 2030, 2040, and 2050, considering the "Import" scenarios. These runs included: i) Employment assessment based on the initial Employment Factor (demand). ii) Adjusted employment based on EU production, incorporating imports/exports and feedstock availability. iii) Corrections involving technology maturity. iv) Evaluation of net employment considering impacts on fossil fuels.

In the FF55_RED (central) and the FF55_ESR _RITA (high) scenarios, the net employment impact is estimated to reach approximately 185,000 jobs (FTE) by 2030, compared to 132,000 jobs in 2020 and 162,000 jobs in the RePower (low) scenario by 2030. Projected employment figures in 2040 are expected to be 332,000, 314,000, and 260,000 jobs for the three scenarios, respectively. The convergence becomes more apparent by 2050, aligning with the corresponding estimates of biofuels consumption across the scenarios. This comparative employment evolution is depicted in Figure 5-7.

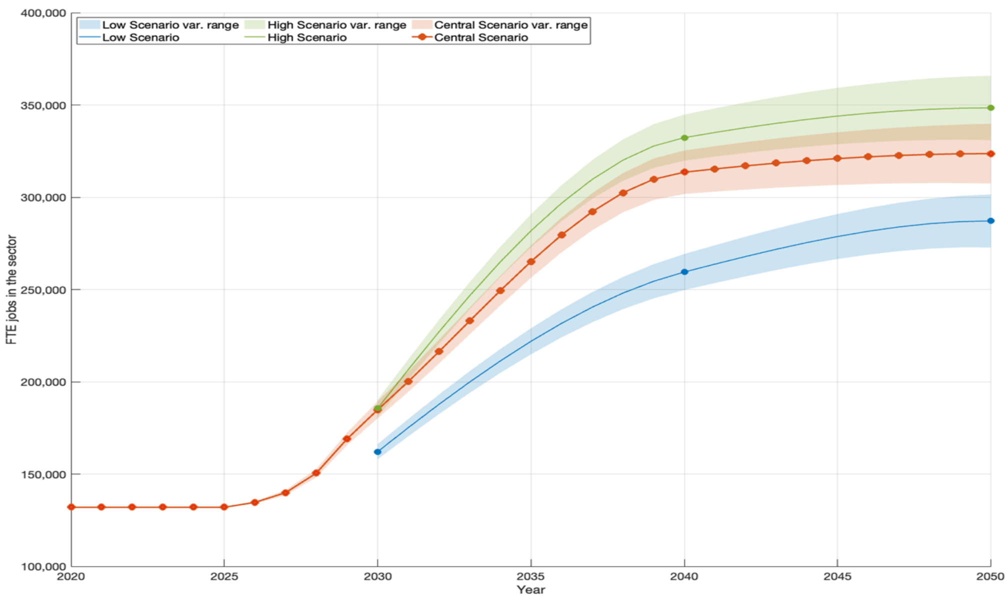

Figure 5-27 Comparative evolution of net employment in FTE for the three selected scenarios

The net Employment Factor, i.e., by incorporating the respective loss of jobs in the fossil fuel industry, in **2020 is around 8.28 FTE/ktoe/yr**. The range of the Employment Factor is 7.49 – 7.31 – 8.11 FTE/ktoe/yr for the central - max – min scenarios in 2030, thus indicating a range of less than 10% over the Employment Factor of the central scenario. The relevant range of the max/min scenarios (7.51 – 6.34 FTE/ktoe/yr) in 2050 is in the order of 7-8% compared to the central scenario (6.93 FTE/ktoe/yr).

The major conclusion of the employment exercise is that a **significant increase in net employment** is expected under all scenarios considered, as far as biofuel consumption and particularly production increase in the EU. This trend is more evident in scenarios with underlying policies of intensive decarbonization in the transport sector, particularly in the decade of 2020-2030, when the implementation of alternative EU policies has a significant impact on employment. This finding confirms the relevant argument of international literature on this issue. The higher increase in employment occurs in the decade 2030-2040 when the production from new biofuels technologies is implemented, and the use of conventional biofuels comes to the phase of production reduction and ceasing. About 70% of the overall employment increase for the central scenario takes place during this time period. A similar result is observed in the other two min/max scenarios.

A shift in the required education levels of the labor force, especially after 2030 when new production technologies are employed, can have considerable impacts on job creation, potentially causing a mismatch between labor supply and demand. However, due to the long period for the adaptation of labor supply to new technologies, it is anticipated that the necessary skilled labor will be available in the period 2030-2050 when the major technology transition in biofuels production will take place.

Regarding gender equity and non-discrimination, female employment in the bioenergy sector is low, accounting for only 10.6% of the total, according to the global green job study data of ILO. This situation is expected to improve, paving the way to 2050, especially in the EU where gender discrimination is not realized in the whole value chain of biofuels production.

5.5. Main findings

Table 5-2, Table 5-3 and Table 5-4 offer a summarized overview of the primary KPIs, illustrating the Import and Extended scenarios for the year 2030, and specifically for the main scenario in 2050. These tables break down the contributions from each production pathway and import, if applicable. Due to the high uncertainties regarding market price projections for biofuels in 2050, this particular KPI wasn't assessed for that year, hence the absence of related annual turnover and GDP impact.

Overall, the Extended Capacity scenarios exhibit superior performance across most KPIs compared to the Import scenarios, which incorporate a portion of biofuel imports. However, it's essential to note that while the assumptions shaping the composition of the Import scenarios, particularly in terms of production pathway mix and associated growth, were substantiated by numerous interviews with experts, industries, and associations, the Extended Capacity scenarios resulted from a more speculative exercise. Hence, these results should be regarded more as an aspirational scenario, where new investments in additional production capacity would aim to supplant imports to align with the anticipated demand. Nonetheless, several variables may influence the actual distribution among technological pathways and production capacity, encompassing factors like learning curves, investment and operational costs, as well as additional biomass demands in other sectors and countries.

The examined KPIs distinctly highlight the potential linked to the expansion of advanced biofuels production capacity within the EU. However, to actualize this potential, fostering **EU leadership** in advanced biofuels—both in feedstocks and conversion—must **be a priority, leveraging the substantial R&D expertise** prevalent in the region. Support for investment becomes particularly critical to **attain the 2030** results, and beyond.

For a more comprehensive understanding of the work undertaken in Task 5, Annex 5 in this Final Report provides a detailed presentation.

2030											
Scenario	Value chain	Average fuel selling price	Energy contribution	GHG saving				Socio-economic impacts		
		-	*Overall energy contribution*	*Average Carbon Intensity*	*Total Emissions**	*GHG savings potential**	*Average GHG Savings share*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/yr*	*tCO_{2eq}/Mtoe*	*$MtCO_{2eq}$*	*$MtCO_{2eq}$*	*%*	*FTE Jobs*	*%*	*M€/yr*
FF55 RED	Transesterification of food/feed crops	2,180	5.13	1.16	6.84	16.47	71	52,784	0.019%	11,174
	Hydrotreatment of food/feed crops	2,122	5.25	1.26	7.64	16.25	68		0.019%	11,149
	Ethanol fermentation of food/feed crops	2,016	3.74	1.22	4.55	10.18	69		0.013%	7,540
	Biomethane from AD	1,256	1.50	-0.70	-1.17	7.76	118		0.003%	1,884
	Transesterification of Annex IX-A feedstock	2,180	1.50	0.62	1.08	5.75	84		0.006%	3,275
	Transesterification of intermediate crops	2,180	2.83	1.16	3.77	9.08	71		0.010%	6,165
	Hydrotreatment of tall oil	2,715	0.21	0.64	0.17	0.86	84		0.001%	571
	Hydrotreatment of intermediate crops	2,715	2.42	1.07	3.22	8.62	73		0.011%	6,563
	Lignin boost of fatty acids (RENFUEL)	2,904	0.14	0.63	0.10	0.51	84		0.001%	407
	Advanced ethanol	2,016	0.32	1.10	7.71	19.87	72		0.001%	650
	ATJ	3,711	0.10	1.10	0.16	0.42	72		0.001%	381
	Gasification + methanol	2,905	0.21	0.60	0.15	0.83	85		0.001%	624
	Gasification + SNG	2,992	0.03	1.03	0.03	0.10	74		0.000%	89
	Gasification + FT	3,711	0.05	0.36	0.03	0.27	91		0.000%	195
	Pyrolysis	3,066	0.18	1.03	0.23	0.65	74		0.001%	560
	HTL	2,414	0.03	1.20	0.03	0.07	70		0.000%	61
	Transesterification of UCO and AF	2,180	2.21	0.71	1.80	8.24	82		0.008%	4,817

2030										
Scenario	Value chain	Average fuel selling price	Energy contribution	GHG saving				Socio-economic impacts		
		-	*Overall energy contribution*	*Average Carbon Intensity*	*Total Emissions**	*GHG savings potential**	*Average GHG Savings share*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/yr*	*tCO_{2eq}/Mtoe*	*$MtCO_{2eq}$*	*$MtCO_{2eq}$*	*%*	*FTE Jobs*	*%*	*M€/yr*
	Hydrotreatment of UCO and AF	2,715	1.58	0.74	1.44	6.28	81		0.007%	4,280
	TOTAL - w/o Imports	-	**27.43**	**-**	-	**-**	**-**		**0.102%**	**60,385**
	Import - HVO	2,122	1.19	-	-	-	-		0.001%	2,535
	Import - FAME	2,122	1.70	-	-	-	-		0.002%	3,613
	Import - Advanced ethanol	2,016	6.68	-	-	-	-		0.008%	13,461
	Import - SAF	3,711	0.66	-	-	-	-		0.001%	2,456
	Import - Shipping	3,290	0.40	-	-	-	-		0.001%	1,315
	TOTAL - Including Imports	-	**38.07**	**-**	**37.78**	**112.21**	**-**		**0.115%**	**83,766**
FF55 ESR RITA	Transesterification of food/feed crops	2,180	5.13	1.16	7.27	17.49	71		0.019%	11,174
	Hydrotreatment of food/feed crops	2,122	5.25	1.26	8.12	17.28	68		0.019%	11,149
	Ethanol fermentation of food/feed crops	2,016	3.74	1.22	4.55	10.18	69		0.013%	7,540
	Biomethane from AD	1,256	1.50	-0.70	-1.20	7.95	118		0.003%	1,884
	Transesterification of Annex IX-A feedstock	2,180	1.50	0.62	1.15	6.11	84	53,652	0.006%	3,275
	Transesterification of intermediate crops	2,180	2.83	1.16	4.01	9.65	71		0.010%	6,165
	Hydrotreatment of tall oil	2,715	0.21	0.64	0.17	0.90	84		0.001%	571
	Hydrotreatment of intermediate crops	2,715	2.42	1.08	3.38	9.00	73		0.011%	6,563
	Lignin boost of fatty acids (RENFUEL)	2,904	0.14	0.63	0.10	0.53	84		0.001%	407

2030										
Scenario	Value chain	Average fuel selling price	Energy contribution	GHG saving				Socio-economic impacts		
		-	*Overall energy contribution*	*Average Carbon Intensity*	*Total Emissions**	*GHG savings potential**	*Average GHG Savings share*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/yr*	*tCO_{2eq}/Mtoe*	*$MtCO_{2eq}$*	*$MtCO_{2eq}$*	*%*	*FTE Jobs*	*%*	*M€/yr*
	Advanced ethanol	2,016	0.32	1.10	11.22	28.92	72		0.001%	650
	ATJ	3,711	0.10	1.10	0.17	0.43	72		0.001%	381
	Gasification + methanol	2,905	0.21	0.60	0.16	0.86	85		0.001%	624
	Gasification + SNG	2,992	0.03	1.04	0.04	0.10	74		0.000%	89
	Gasification + FT	3,711	0.05	0.36	0.03	0.28	91		0.000%	195
	Pyrolysis	3,066	0.18	1.03	0.23	0.66	74		0.001%	560
	HTL	2,414	0.03	1.20	0.03	0.07	70		0.000%	61
	Transesterification of UCO and AF (animal fats)	2,180	2.21	0.71	1.92	8.75	82		0.008%	4,817
	Hydrotreatment of UCO and AF (animal fats)	2,715	1.58	0.74	1.51	6.56	81		0.007%	4,280
	TOTAL - w/o Imports	-	**27.43**	**-**	-	**-**	**-**		**0.102%**	**60,385**
	Import - HVO	2,122	1.77	-	-	-	-		0.002%	3,746
	Import - FAME	2,122	2.52	-	-	-	-		0.003%	5,338
	Import - Advanced ethanol	2,016	9.87	-	-	-	-		0.011%	19,888
	Import - SAF	3,711	0.70	-	-	-	-		0.001%	2,613
	Import - Shipping	3,290	0.50	-	-	-	-		0.001%	1,655
	TOTAL - Including Imports	-	**42.79**	**-**	**42.85**	**125.73**	**-**		**0.121%**	**93,626**
Repower	Transesterification of food/feed crops	2,180	5.13	1.16	4.62	11.13	71	30,078	0.019%	11,174
	Hydrotreatment of food/feed crops	2,122	5.25	1.26	5.10	10.84	68		0.019%	11,149

2030										
Scenario	Value chain	Average fuel selling price	Energy contribution	GHG saving				Socio-economic impacts		
		-	*Overall energy contribution*	*Average Carbon Intensity*	*Total Emissions**	*GHG savings potential**	*Average GHG Savings share*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/yr*	*tCO_{2eq}/Mtoe*	*$MtCO_{2eq}$*	*$MtCO_{2eq}$*	*%*	*FTE Jobs*	*%*	*M€/yr*
	Ethanol fermentation of food/feed crops	2,016	3.74	1.22	4.55	10.18	69		0.013%	7,540
	Biomethane from AD	1,256	1.50	-0.72	-1.07	6.86	118		0.003%	1,884
	Transesterification of e.g. brown grease	2,180	1.50	0.62	0.73	3.89	84		0.006%	3,275
	Transesterification of intermediate crops	2,180	2.83	1.16	2.55	6.14	71		0.010%	6,165
	Hydrotreatment of tall oil	2,715	0.21	0.63	0.12	0.65	84		0.001%	571
	Hydrotreatment of intermediate crops	2,715	2.42	1.04	2.35	6.53	74		0.011%	6,563
	Lignin boost of fatty acids (RENFUEL)	2,904	0.14	0.63	0.09	0.46	84		0.001%	407
	Advanced ethanol	2,016	0.32	1.10	0.35	0.92	72		0.001%	650
	ATJ	3,711	0.10	1.10	0.14	0.36	72		0.001%	381
	Gasification + methanol	2,905	0.21	0.60	0.13	0.70	85		0.001%	624
	Gasification + SNG	2,992	0.03	1.03	0.03	0.09	74		0.000%	89
	Gasification + FT	3,711	0.05	0.36	0.02	0.23	91		0.000%	195
	Pyrolysis	3,066	0.18	1.03	0.20	0.57	74		0.001%	560
	HTL	2,414	0.03	1.20	0.03	0.07	70		0.000%	61
	Transesterification of UCO and AF (animal fats)	2,180	2.21	0.71	1.22	5.57	82		0.008%	4,817

2030											
Scenario	Value chain	Average fuel selling price	Energy contribution	GHG saving				Socio-economic impacts		
		-	*Overall energy contribution*	*Average Carbon Intensity*	*Total Emissions**	*GHG savings potential**	*Average GHG Savings share*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/yr*	*tCO_{2eq}/Mtoe*	*$MtCO_{2eq}$*	*$MtCO_{2eq}$*	*%*	*FTE Jobs*	*%*	*M€/yr*
	Hydrotreatment of UCO and AF (animal fats)	2,715	1.58	0.73	1.08	4.71	81		0.007%	4,280
	TOTAL - w/o Imports*	-	**27.43**	**-**	-	**-**	**-**		**0.102%**	**60,385**
	Import - HVO	2,122	-1.79	-	-	-	-		0.000%	-
	Import - FAME	2,122	-2.55	-	-	-	-		0.000%	-
	Import - Advanced ethanol	2,016	0.00	-	-	-	-		0.000%	-
	Import - SAF	3,711	0.36	-	-	-	-		0.001%	1,336
	Import - Shipping	3,290	-0.07	-	-	-	-		0.000%	-
	TOTAL - Including Imports*	-	**23.39**	**-**	**22.25**	**69.90**	**-**		**0.103%**	**61,721**

*N.B., the total emissions and the GHG savings potential reported for each pathway take into consideration also the demand for biofuels satisfied by imports. The import demand was subdivided among compatible value chains (e.g., HVO) as explained in the methodology section on GHG analysis.
** Compared to 2020 values
*** Negative Imports values related to Energy Contribution refers to potential Exports

Table 5-12 Summary of the results for the main KPI indicators in year 2030 for the three Import scenarios, divided among the various production pathways

2050											
Scenario	Value chain	Average fuel selling price	Energy contribution	GHG saving				Socio-economic impacts		
		-	*Overall energy contribution*	*Average Carbon Intensity*	*Total Emissions*	*GHG savings potential*	*Average GHG Savings*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/yr*	*tCO2/Mtoe*	*$MtCO_{2eq}$*	*$MtCO_{2eq}$*	*%*	*FTE Jobs*	*%*	*M€/yr*
FF55 RED	Transesterification of food/feed crops		5,13	1.16	5.93	14.27	71	191,512		
	Hydrotreatment of food/feed crops		5,25	1.26	6.62	14.08	68			
	Ethanol fermentation of food/feed crops		0,00		0.00	0.00				
	Biomethane from AD		4,51	-0.52	-2.33	20.10	113			
	Transesterification of Annex IX-A feedstock		1,50	0.62	0.94	4.98	84			
	Transesterification of intermediate crops		2,83	1.16	3.27	7.87	71			
	Hydrotreatment of tall oil		0,42	0.64	0.27	1.39	84			
	Hydrotreatment of intermediate crops		5,36	1.10	5.88	15.23	72			
	Lignin boost of fatty acids (RENFUEL)		0,70	0.63	0.44	2.32	84			
	Advanced ethanol		0,00		0.00	0.00				
	ATJ		7,70	1.14	8.75	21.59	71			
	Gasification + methanol		2,87	0.61	1.75	9.54	84			
	Gasification + SNG		0,75	1.09	0.81	2.13	72			
	Gasification + FT		5,25	0.38	2.00	18.70	90			
	Pyrolysis		0,81	1.04	0.84	2.36	74			
	HTL		1,67	1.20	2.01	4.57	69			
	Transesterification of UCO and AF (animal fats)		2,21	0.67	1.47	7.23	83			
	Hydrotreatment of UCO and AF (animal fats)		1,58	0.69	1.09	5.12	82			
	TOTAL - w/o Imports	-	**48,54**	-	39.75	151.49	-			

** Compared to 2020 values

Table 5-13 Summary of the results for the main KPI indicators in year 2050 for the FF55 RED scenario, divided among the various production pathways

2030											
Scenario	Value chain	Average fuel selling price	Energy contribution	GHG saving				Socio-economic impacts		
			Overall energy contribution	*Average Carbon Intensity*	*Total Emissions **	*GHG savings potential**	*Average GHG Savings share*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/yr*	*$tCO_{2eq}/Mtoe$*	*$MtCO_{2eq}$*	*$MtCO_{2eq}$*	*%*	*FTE Jobs*	*%*	*M€/yr*
FF55 RED ExtCap	Transesterification of food/feed crops	2,180	5.13	1.16	6.28	15.12	71	52,784	0.019%	11,174
	Hydrotreatment of food/feed crops	2,122	5.25	1.26	7.27	15.47	68		0.019%	11,149
	Ethanol fermentation of food/feed crops	2,016	3.74	1.22	4.55	10.18	69		0.013%	7,540
	Biomethane from AD	1,256	7.85	-0.89	-3.67	19.86	123		0.017%	9,857
	Transesterification of e.g. brown grease	2,180	1.50	0.62	0.99	5.28	84		0.006%	3,275
	Transesterification of intermediate crops	2,180	2.83	1.16	3.47	8.34	71		0.010%	6,165
	Hydrotreatment of tall oil	2,715	0.21	0.64	0.13	0.68	84		0.001%	571
	Hydrotreatment of intermediate crops	2,715	2.42	1.10	2.62	6.77	72		0.011%	6,563
	Lignin boost of fatty acids (RENFUEL)	2,904	0.89	0.63	0.31	1.61	84		0.004%	2,596
	Advanced ethanol	2,016	1.36	1.10	6.22	16.05	72		0.005%	2,750
	ATJ	3,711	0.10	1.10	0.11	0.29	72		0.001%	381
	Gasification + methanol	2,905	1.37	0.60	0.26	1.46	85		0.007%	3,983
	Gasification + SNG	2,992	0.19	0.99	0.09	0.28	75		0.001%	569
	Gasification + FT	3,711	0.34	0.36	0.12	1.18	91		0.002%	1,245
	Pyrolysis	3,066	0.95	1.03	0.74	2.09	74		0.005%	2,906

2030										
Scenario	Value chain	Average fuel selling price	Energy contribution	GHG saving				Socio-economic impacts		
			Overall energy contribution	*Average Carbon Intensity*	*Total Emissions **	*GHG savings potential**	*Average GHG Savings share*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/yr*	*$tCO_{2eq}/Mtoe$*	*$MtCO_{2eq}$*	*$MtCO_{2eq}$*	*%*	*FTE Jobs*	*%*	*M€/yr*
	HTL	2,414	0.15	1.20	0.15	0.35	70		0.001%	371
	Transesterification of UCO and AF (animal fats)	2,180	2.21	0.71	1.66	7.57	82		0.008%	4,817
	Hydrotreatment of UCO and AF (animal fats)	2,715	1.58	0.74	1.15	4.97	81		0.007%	4,280
	TOTAL - w/o Imports	**-**	**38.07**	**-**	-	**-**	**-**		**0.136%**	**80,193**
	Import - HVO	2,122	0.00	-	-	-	-		0.000%	-
	Import - FAME	2,122	0.00	-	-	-	-		0.000%	-
	Import - Advanced ethanol	2,016	0.00	-	-	-	-		0.000%	-
	Import - SAF	3,711	0.00	-	-	-	-		0.000%	-
	Import - Shipping	3,290	0.00	-	-	-	-		0.000%	-
	TOTAL - Including Imports	**-**	**38.07**	**-**	**32.45**	**117.55**	**-**		**0.136%**	**80,193**
FF55 ESR RITA ExtCap	Transesterification of food/feed crops	2,180	5.13	1.16	6.53	15.72	71		0.019%	11,174
	Hydrotreatment of food/feed crops	2,122	5.25	1.26	7.59	16.15	68		0.019%	11,149
	Ethanol fermentation of food/feed crops	2,016	3.74	1.22	4.55	10.18	69	70,344	0.013%	7,540
	Biomethane from AD	1,256	10.66	-0.93	-4.71	24.74	124		0.023%	13,393
	Transesterification of Annex IX-A feedstock	2,180	1.50	0.62	1.03	5.49	84		0.006%	3,275

2030											
Scenario	Value chain	Average fuel selling price	Energy contribution	GHG saving				Socio-economic impacts		
			Overall energy contribution	*Average Carbon Intensity*	*Total Emissions **	*GHG savings potential**	*Average GHG Savings share*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/yr*	*tCO_{2eq}/Mtoe*	*$MtCO_{2eq}$*	*$MtCO_{2eq}$*	*%*	*FTE Jobs*	*%*	*M€/yr*
	Transesterification of intermediate crops	2,180	2.83	1.16	3.60	8.67	71		0.010%	6,165
	Hydrotreatment of tall oil	2,715	0.21	0.65	0.13	0.68	84		0.001%	571
	Hydrotreatment of intermediate crops	2,715	2.42	1.11	2.64	6.73	72		0.011%	6,563
	Lignin boost of fatty acids (RENFUEL)	2,904	1.23	0.63	0.39	2.03	84		0.006%	3,568
	Advanced ethanol	2,016	1.83	1.10	9.03	23.29	72		0.006%	3,682
	ATJ	3,711	0.10	1.10	0.10	0.26	72		0.001%	381
	Gasification + methanol	2,905	1.88	0.60	0.29	1.59	85		0.009%	5,472
	Gasification + SNG	2,992	0.26	0.98	0.11	0.34	75		0.001%	782
	Gasification + FT	3,711	0.46	0.36	0.15	1.49	91		0.003%	1,711
	Pyrolysis	3,066	1.29	1.03	0.93	2.64	74		0.007%	3,947
	HTL	2,414	0.21	1.20	0.21	0.47	70		0.001%	509
	Transesterification of UCO and AF (animal fats)	2,180	2.21	0.71	1.72	7.87	82		0.008%	4,817
	Hydrotreatment of UCO and AF (animal fats)	2,715	1.58	0.74	1.15	4.97	81		0.007%	4,280
	TOTAL - w/o Imports	**-**	**42.79**	**-**	-	**-**	**-**		**0.150%**	**88,979**
	Import - HVO	2,122	0.00	-	-	-	-		0.000%	-
	Import - FAME	2,122	0.00	-	-	-	-		0.000%	-
	Import - Advanced ethanol	2,016	0.00	-	-	-	-		0.000%	-

2030											
Scenario	Value chain	Average fuel selling price	Energy contribution	GHG saving				Socio-economic impacts		
			Overall energy contribution	*Average Carbon Intensity*	*Total Emissions **	*GHG savings potential**	*Average GHG Savings share*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/yr*	*tCO_{2eq}/Mtoe*	*$MtCO_{2eq}$*	*$MtCO_{2eq}$*	*%*	*FTE Jobs*	*%*	*M€/yr*
	Import - SAF	3,711	0.00	-	-	-	-		0.000%	-
	Import - Shipping	3,290	0.00	-	-	-	-		0.000%	-
	TOTAL - Including Imports	**-**	**42.79**	**-**	**35.44**	**133.34**	**-**		**0.150%**	**88,979**
	Import - SAF	3,711	0.00	-	-	-	-		0.000%	-
	Import - Shipping	3,290	0.00	-	-	-	-		0.000%	-
	TOTAL - Including Imports	**-**	**27.43**	**-**	**22.25**	**69.90**	**-**		**0.102%**	**60,385**

*N.B., the total emissions and the GHG savings potential reported for each pathway also take into consideration the demand for biofuels satisfied by imports. The import demand was subdivided among compatible value chains (e.g., HVO) as explained in the methodology section on GHG analysis.
** Compared to 2020 values. The impact of GA scenarios on employment will certainly lead to an increase in FTE jobs, due to an increase in EU production capacity.

Table 5-14 Summary of the results for the main KPI indicators in year 2030 for the two Extended Capacity scenarios, divided into production pathways

6. Organization of consultation workshop (Task 6)

6.1. Aim of Task 6

Task 6 centered on conducting the final consultation workshop in Brussels, on the 26th of September. The aim of the workshop was to discuss the Interim Progress Report Part I and the draft Interim Progress Report Part II, and to validate the results and conclusions of the work completed during the project implementation. Feedback received during the workshop was considered by the project team and incorporated into the final report of the project.

6.2. Organization approach

The workshop primarily targeted key industrial and research stakeholders within the EU's advanced drop-in biofuels value chain and market. Participants engaged with the project team to examine and corroborate the findings generated over the course of the project, specifically those concerning current industrial capacities and the industry's requirements to meet the volumes prescribed by EU policy frameworks.

In an effort to enhance the credibility and robustness of the approach and the results of the project, five renowned Thematic Experts were invited to participate in the workshop as 'external reviewers' for each of the five project tasks.

A workshop agenda and concept note were developed early in the project and distributed among the project Consortium and the Commission. It was decided that the workshop would have a hybrid format to also engage interested stakeholders who were not available to participate physically.

The workshop agenda and the concept note were prepared by the project team and agreed upon with the Commission before they were distributed to the targeted audience. Both documents can be found in Annex 6 (Report on Task 6), in Appendix 1.

The agenda was structured to allow sufficient time to comment on and discuss the results from each task and to answer potential questions from the audience. Thus, a 40-minute time period was given after the presentation of each task for discussion. To have a comprehensive view of the core analysis of the study, Tasks 1, 2, and 3 were discussed first, followed by an overall discussion on the resonance of these tasks by the workshop moderator. Tasks 4 and 5 were presented afterward, followed by a roundtable discussion of approximately an hour long between the Thematic Experts and the Industry officials to validate the conclusions of the study.

During the workshop, the project team presented the findings of the analysis via PowerPoint presentations, including the assumptions and final outcomes. To enhance the audience's participation in the workshop, the project team had prepared a project synopsis in advance, which was shared before the workshop. As a result, they were informed about the purpose and targets of the project, and the results and findings of the study through the five different Tasks, which concluded with their engagement and active participation.

Their involvement was of high importance as they commented on the work achieved and provided meaningful feedback based on their experience and knowledge. The highlights of the workshop, namely key messages, conclusions, a brief description of the tasks, and main comments and recommendations from the Thematic Experts, were captured by the workshop rapporteur in a report.

Finally, a separate report including the responses by the Task Leaders to the comments of the Thematic Experts made during the workshop was also prepared (see Appendix 2 of Task 6 report).

6.3. Stakeholders' engagement

The study projected the industrial capacity development for drop-in advanced biofuels in 2030 and in the longer term, to 2050. Therefore, the engagement of different players in the biofuels industry and various companies/associations was essential and necessary to collect insights and possible future projections. During the implementation of Task 3 (Analysis of capacity potential for the industrial supply of drop-in advanced biofuels), a survey was developed and distributed among a wide range of European and international identified stakeholders, including the industry, companies, associations, and universities. This wide range of stakeholders to whom the Task 3 survey was distributed constituted the basis of the pool of experts to be invited to the study's final workshop. The target was to attract representatives from the key value chains of advanced biofuels, focusing on the relevant EU industry associations, key technology developers, renowned universities, and academic institutions.

Multiple attempts were made to reach out to the identified stakeholders through emails and phone calls, striving to convene a critical mass for an exchange of views, knowledge, and information at the EU level. Such an assembly was intended to enrich the project, confirm the study's results, and solicit any pertinent feedback for the study's culmination. To facilitate efficient and timely attendance tracking, a registration form was also implemented.

Furthermore, a project synopsis document was compiled, encapsulating summaries and central themes from each task, coupled with pertinent questions for the audience. This synopsis was circulated exclusively among confirmed workshop participants. The objective was to equip them with a comprehensive overview of the project's achievements and to present specific questions for each task to ponder beforehand. This preparation aimed to stimulate their contributions and foster dialogue during the workshop.

The complete roster of attendees is documented in Appendix 4 (Annex 6, Report on Task 6). The Slido platform was employed during the workshop as an interactive tool to maximize engagement and feedback collection. Slido, an online platform, enables meeting organizers to generate assorted polls and surveys for live sharing. Accordingly, a series of task-specific questions were prepared for polling. Following each task presentation and discussion, these questions were released online for both virtual and in-person participants to respond by entering a distinct code into the platform. The comprehensive Slido report is included in Appendix 6 (Annex 6, Report on Task 6).

6.4. Key points of the discussion

The following outlines the core questions that guided discussions with workshop participants and offers a succinct summary of their responses.

6.4.1. Task 1

Questions

- Do you believe in a delayed deployment (until 2030) of electromobility and e-fuels? (delayed such that would favor biofuels uptake)
- How important is the role of the fast decarbonization of the electricity grid for the timely

market uptake of advanced biofuels?

- How plausible do you think is the transition of demand for advanced biofuels from road transport to maritime and aviation after 2030?

Results

- The majority of the participants concluded that electromobility and e-fuels deployment will be delayed, favoring although, the uptake of advanced biofuels.
- The role of fast decarbonization of the electricity grid is positively important only for RFNBOs, not for all types of biofuels.
- The transition of demand for advanced biofuels from road transport to maritime and aviation after 2030 it is very likely.

6.4.2. Task 2

Questions

- Do you find it useful and logical to work with three mobilisation scenarios that range in relation to both mobilisation factors and competing use levels?
- Did you expect higher or lower biomass availability for bioenergy from this study?
- Which scenario do you expect to become the most realistic in 2030?
- Which scenario do you expect to become the most realistic in 2050?
- Do you believe it will be realistic that more biomasses will become available over next 30 years from unused, degraded lands in the EU?
- Do you think it is realistic to mobilize new drop-in biofuels through technology development that can convert unused gaseous biomass resources, manure, and organic fractions in sewage sludge, to drop in fuels?
- Do you think it would be good (in terms of biomass mobilization) for the sustainable performance of biofuels if less emphasis is placed on preventing ILUC and more on stimulating overall sustainable land management (e.g., through win wins with carbon farming)?

Results

- All of the responders found useful the idea of working with three mobilization scenarios
- Half of the participants expect higher biomass availability while the rest of them expect lower biomass availability
- Low and medium mobilization scenarios were the ones voted to be more realistic in 2030, while in 2050, the medium mobilization scenario was the dominant one
- Indeed, all participants vote positively that more biomasses will become available over

the next 30 years from unused, degraded lands

- It is very possible and realistic to mobilize new drop-in biofuels through technology development that can convert unused gaseous biomass resources, manure, and organic fractions in sewage sludge, to drop in fuels

- All of the participants voted that it would be good to give less emphasis to prevent ILUC and more to stimulate the overall sustainable land management.

6.4.3. Task 3

Questions

- What would be your merit order of investments?

- Where do you think cover crops would be used for?

- Which percentage of biomethane from AD would you expect to be available to the transport sector in 2030?

- Which percentage of biomethane from AD would you expect to be available to the transport sector in 2050?

- Do you think the resulting 2030 capacities of pathways are reasonable (in general)?

- Do you think the resulting 2050 capacities of pathways are reasonable (in general)?

- Do you think that the overall advanced biofuels and biogas capacity expansion in 2030 is reasonable?

- Do you think that the overall advanced biofuels and biogas capacity expansion in 2050 is reasonable?

Results

- Participants would invest probably in ATJ, gasification for the production of FT-SPK, and HTL, and 2G ethanol, gasification for the production of biomethane, biomethane/DME/ammonia, ad pyrolysis

- Participants voted that cover crops will be used for HVO production and not FAME production

- 5-10% of biomethane production from anaerobic digestion will mostly be available to the transport sector in 2030, while 10-15% will be available in 2050

- The resulting 2030 capacities of pathways are voted to be overestimated, while the opinions differ for 2050 capacities with half of the participants stating that they are reasonable and the rest that the capacities are overestimated

- The overall advanced biofuels and biogas capacity expansion for 2030 is believed to be overestimated, while the one for 2050 is reasonable.

6.4.4. Task 4

Questions

- The gap analysis of the present work suggests that there will be no gap for 2050. Such a situation would directly enhance the security of supply in Europe. Do you believe that the importance of this aspect (i.e., the direct contribution of biofuels to the security of supply) has been appropriately acknowledged?

- There is an impressive list of announced and planned projects for hydrogen production and various e-fuels. However, the installed capacities are still very low. Do you believe these projects will eventually materialize (all factors, e.g., regulatory frame, financing, etc., considered with the current level of knowledge)

- Availability of hydrogen produced from eligible renewable electricity sources is an important barrier to RFNBO capacity development. On the long run availability of CO2 will be more critical. Do you agree with this statement?

Results

- The gap analysis of the present work, suggests that there will be no gap for 2050 and this is believed, by half of the participants, to be acknowledged by the policy makers, while the rest of the participants voted that this is not acknowledged by neither the industry nor the policy makers

- Participants do not believe that hydrogen production and e-fuels projects will materialize in all factors

- Half of the participants agreed that the availability of CO2 will be more critical.

6.4.5. Task 5

Questions

- Do you think that the EU policies and strategies will have an important impact on the extra-EU biofuels market?

- Do you expect that EU-produced biofuel volumes could be exported to extra-EU regions? Or it is more likely that EU production will be sized to EU internal market?

- Further deployment of biofuels will entail a positive effect on the employment of the sector. Do you believe that this critical aspect has been appropriately communicated to all actors?

Results

- It is believed that the EU policies and strategies will have a minor impact on extra-EU biofuels market

- It is believed that production will be sized to EU internal market

- It is not believed that it has been communicated to all actors that further deployment of biofuels will entail a positive effect on the employment of the sector.

A more detailed presentation of the work carried out in Task 6 is provided in Annex 6 of this Final Report.

7. Conclusions and messages

The final conclusions of the project underscore the **critical role of biofuels in reducing emissions in the transport sector,** aligning with the objectives of the Fit for 55 package and climate neutrality goals. This role is expected to escalate as advanced biofuels become increasingly available, bolstered by the full-scale commercialization of technologies, processes, and value chains driven by ambitious policies and sectoral targets.

Demand

Model-based scenarios suggest a significant increase in biofuels demand in transport if advancements in electric vehicle battery technology, alternative fuels infrastructure, electrolyzers, and direct air capture technologies lag behind expectations by 2030. In such cases, **biofuel demand could rise by up to 2.5 times compared to 2021 levels** (reaching up to 42.8 Mtoe in 2030 compared to 16.5 Mtoe in 2021).

Projections indicate **advanced biofuels will constitute about half of all biofuel demand**, **translating to over one-third of all renewable energy consumed in transport by 2030**. Under certain conditions, demand for advanced biofuels might even surpass these estimates, highlighting the strategic importance of the biofuel industry for the EU in achieving timely emissions reductions.

Feedstock potential

The project estimates that total biomass potential available for energy markets in the EU-27 and accession countries ranges from **310 to 836 million dry tonnes (132 - 353 Mtoe/yr) for 2030,** and **294 - 892 million tonnes (128 - 382 Mtoe/yr) for 2050**.

The most significant biomass types, with largest potential to be further mobilized are primary residues from arable crops, manure and stemwood and primary forestry residues. Towards **2050** the **dedicated lignocellulosic crops** and **oil crops produced on unused degraded lands and as cover & intercrop** in combination with food production also become more important. Therefore, one of the **few options to mobilize more biomass**, is significantly increasing the biomass production on unused, degraded lands and from inter- and cover crops.

To effectively increase biomass production, significant R&I support is needed. This includes enhancing the conversion of biomass to biofuels, improving resource efficiency and circularity, and developing novel technologies and biomass resources. Moreover, the implementation of agricultural protocols and practices for biomass mobilization is essential beyond 2030 and crucial in the path to 2050.

Industry assessment

Under current market conditions, industry estimates suggest that **capacity expansion for advanced biofuels and biogas could reach 23.6 Mtoe/yr by 2030** satisfying demand of all other sectors in addition to transport. Biomethane is anticipated to be the most significant contributor, though there is uncertainty regarding its availability for transport and the fleet's readiness for high biomethane usage. Lignocellulosic materials are expected to contribute 1.6 Mtoe/y, while advanced ethanol technology deployment may be limited until 2030.

Technically, capacity expansion could be expedited, with numerous technology providers nearing the commercialization of their technologies and ready to support multiple projects.

With the impending implementation of the revised Renewable Energy Directive, along with ReFuelEU Aviation and FuelEU Maritime, both the aviation and shipping sectors are expected to increasingly demand biofuels, potentially redirecting them from the road sector. This shift creates no-regret investment opportunities in HEFA (Hydrotreated Esters and Fatty Acids) currently and potentially in advanced ethanol (ATJ - Alcohol to Jet) production after 2030, despite a projected decrease in market demand for gasoline substitutes. From this perspective, **the industry has expressed readiness to invest and meet, at least, the relevant EU demand.**

Development challenges

The project highlights the necessity of a substantial effort to enhance the production capacity of advanced biofuels and to mobilize the required sustainable biomass feedstock, particularly lignocellulosic biomass. This escalation is essential to bridge the gap between the anticipated demand for advanced biofuels, crucial for meeting the EU's climate targets for 2030 and 2050, and the current production capacities, as well as those forecasted by experts. The present production capacity for advanced biofuels and biogas, standing at 4.6 Mtoe/yr, is projected to potentially increase sixfold, reaching around 27.4 Mtoe/yr by 2030.

To ramp up advanced biofuels capacity the **EU industry needs:** (1) predictive advanced biofuels targets that remain consistent over an extended period, thereby minimizing regulatory uncertainty and complexity, (2) access to capital for demonstration projects with a higher technological risk profile, and (3) financial support for technological development of advanced biofuels technologies capable of utilizing a wide array of available sustainable feedstocks.

Potential synergies between RFNBOs and advanced biofuels technologies development should be identified and utilized for the benefit of both pathways. For example, both pathways partly use similar technologies, such as methanol and FT synthesis; and biogenic CO_2 emissions of advanced biofuels production could be used as input for RFNBO production.

Socioeconomic impacts

Throughout the various scenarios examined in the project, **the adoption of advanced biofuels is projected to yield considerable GHG savings**, which are directly proportional to the volumes used. A conservative analysis, taking into account the availability of sustainable feedstock, posits that advanced biofuels can make a substantial contribution to meeting environmental targets for transport. Depending on the scenario, emissions avoided by biofuels could range from **70 to 126 MtCO2eq/yr in 2030**. Of this, biofuels from Annex IX Part A feedstock could account for **27 – 65 MtCO2eq/yr**, and biofuels from Annex IX Part B feedstock for **10 – 15 MtCO2eq/yr**. By 2050, the emissions avoidance could exceed **151 MtCO2eq/yr**. Furthermore, the adoption of alternative fuels, including biofuels, e-fuels, and electricity, has the potential to **reduce the carbon intensity (gCO2eq/MJ) of the transport fuel mix by 20% as early as 2030**.

The deployment of advanced biofuels is associated with a significant positive impact, in terms of **direct and indirect employment**. It is estimated that **over 53,000 new jobs could be generated by 2030**, with the potential for this number to increase to **over 190,000 by 2050** in the central scenario, which would represent about **0.1% of the total EU jobs as of 2022**. When compared to other renewable energy technologies, advanced biofuels are found to have a higher employment rate per unit of energy, attributed to the extensive value-chain involved in their production.

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Biofuels are crucial for reducing emissions in the transport sector, contributing significantly to the objectives of the Fit for 55 package and climate neutrality goals. This role is anticipated to grow in the future as advanced biofuels become increasingly accessible. This expansion will be driven by the full commercial-scale development of technologies, processes, and value chains, supported by ambitious policies and sector-specific targets that will encourage their deployment.

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