European Commission

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

Annex 5 Report on Task 5

Research and Innovation

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

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EUROPEAN COMMISSION

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

Annex 5 Report on Task 5

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1. Introduction

Building on the results of Tasks 1 – 4, Task 5 aims at quantifying the expected benefits associated with the modelled scenarios. It considers both the socio-economic and environmental impacts related to the deployment of drop-in advanced biofuels in the EU transport sector. The analysis also includes considerations on the economic dimension of the proposed value-chains. The timeframe for this analysis is the period 2030 - 2050.

As detailed in the specific methodological section, a set of nine KPIs (the KPI "**Imports value**" is evaluated together with other socio-economic indicators) has been defined to properly present the various findings:

- **EU Production Capacity**
- **Biofuels overall energy contribution**
- **Biofuels share of total fuel demand**
- **GHG Savings**
- **Biofuels market price**
- **Annual turnover (including import)**
- **Contribution to GDP (including import)**
- **New Sectorial Employment**

Most of the analysed KPIs have been evaluated in both year 2030 and 2050. **A set of three scenarios** has been defined – as agreed at project-level – in which the expected biofuels demand **for year 2030** is projected to be covered by **a mix of internal production capacity and import.** These three scenarios are globally referred to as the **"Import" scenarios** in the rest of the document; the single scenarios are named and defined as follows:

- **FF55_RED:** it is the Central scenario, reflecting the recent Provisional Agreement on RED III.

- **FF55_ESR_RITA:** it is the High scenario, projecting the highest advanced biofuels demand in 2030, while reflecting the EU policy *Fit-For-55*, combined with equal sectoral ESR (Effort Sharing Regulation) split, and assumption for increased road transport activity.

- **RePower:** it is the Low scenario, derived from the RePower EU context considering the lowest advanced biofuels demand in 2030.

In addition to the three "Import" scenarios, **other three scenarios have been analysed for 2030** in Task 5, based on the results of the **Gap Analysis carried out in Task 4.1**; in this additional set of scenarios, the expected biofuels demand **for year 2030** is projected to be covered only by **an extended mix of internal production capacity.** Thus, these two scenarios are globally referred to as the **"Extended Capacity" scenarios** in the rest of the document; the single scenarios are named as follows:

- **FF55 RED ExtCap**
- **FF55 ESR RITA ExtCap**

The **2050** timeframe is addressed only by the Central scenario, **FF55 RED**, as all the demand scenarios from PRIMES tend to converge to similar biofuels demand values and no significative import contribution are expected.

The economic KPIs (i.e., **market prices**, **annual turnover,** and **contribution to GDP**) have not been quantitatively evaluated in 2050, due to the lack of input data and the significant uncertainty on fuel prices on the long term.

Finally, the deliverable is structured as follow:

- **Chapter 2** presents the scope of the work and methodology used for the evaluation of all the KPIs.
- **Chapter 3** reports the main results and findings for all the KPIs.
- **Chapter 4** presents the main conclusions of this work and a set of summary tables for KPIs values in the various scenarios analysed, both for year 2030 and year 2050
- **Appendix I** presents the main results from the literature review on biofuels demand and supply scenarios for the EU, socio-economic impacts of the deployment of biofuels production capacity and on methodologies for GHG savings calculation
- **Appendix II** presents the development process of the stakeholders matrix, based on the PM2 project management methodology
- **Appendix III** presents the specifically designed tool used in this work to define the GHG saving potential of alternative fuels, for the various transport modes.

2. Scope of the work and Methodology

Based on the results coming from the other Tasks of this project, Task 5 does not only summarize them into a set of KPIs, but also further elaborate on them, in order to gather additional insights from all the projections and estimations related to modelling activities and experts' inputs.

All these activities resulted in nine different KPIs, briefly reported both in Figure 2-1 and in the following part of this section.

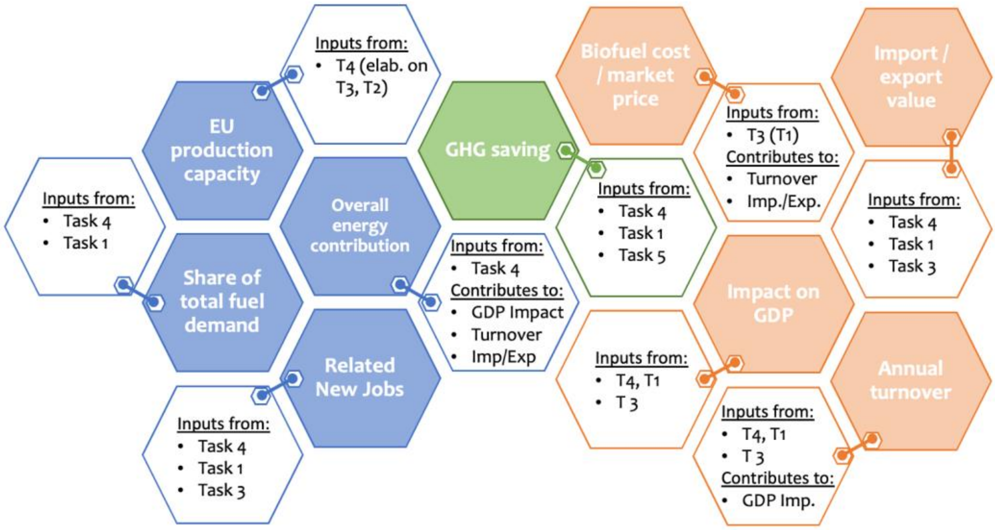

Figure 2-1 Summary of selected KPIs

EU Production Capacity: Data on EU-based biofuels production capacity has been provided by Task 4, as the result of combining experts' opinions gathered by Task 3 with projected feedstock availability as provided by Task 2. Production capacity projections are provided for each considered production pathway, for year 2030 and 2050.

Biofuels overall energy contribution: Biofuels contribution to transport sector energy demand is presented. This KPI aims at highlighting the contribution of biofuels to the total demand, in Mtoe. It is based on the EU Production Capacity KPI (as described above, thus broken down into the various production pathways considered). The projected total production capacity is compared against the expected biofuels demand, as provided by Task 1 results; eventual gaps are highlighted, and plausible import volumes are calculated.

Biofuels share of total fuel demand: The absolute volumes provided in the previous KPI have been converted into contribution shares against total fuel demand in the various transport sector, using Task 1 results.

GHG Savings: This KPI presents the emission savings attained with the replacement of conventional fossil fuels shares with alternative fuels. The demand for each fuel was split among the different value chains according to the European biomass potential estimated in Task 2. To each fuel value chain was attributed a proper emission factor, so to be able to determine the GHG impact of the combination of Task 1 data on transport sector energy demand and Task 4 data on projected EU production capacity, provided the demand for each fuel, for each considered scenario.

Biofuels market price: Market prices of biofuels have been estimated from available experts' opinions for 2030. A range with minimum, maximum, and average values is reported for the different pathways considered in the analysis.

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 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 projection for 2030.

Sectorial Employment: The new jobs in the biofuels sector are evaluated for year 2030 by using an employment factor related to expected biofuels consumption. Then, correction factors are applied; among the others, technology maturity and expected jobs shifts from fossil fuels industry.

This chapter presents the methodologies applied for the evaluation of each KPI, comprising:

- Evaluated scenarios and timeframe of the analysis
- Data sources

2.1. Timeframe of the analysis and scenarios definition

Most of the analysed KPIs have been evaluated in both year 2030 and 2050. **A set of three scenarios** has been defined – as agreed at project-level – in which the expected biofuels demand **for year 2030** is projected to be covered by **a mix of internal production capacity and import.** These three scenarios are globally referred to as the **"Import" scenarios** in the rest of the document; the single scenarios are named and defined as follows:

- **FF55 RED:** it is the Central scenario, reflecting the recent Provisional Agreement on RED III.
- **FF55 ESR RITA:** it is the High scenario, projecting the highest advanced biofuels demand in 2030, while reflecting the EU policy Fit For 55 combined with equal sectoral ESR (Effort Sharing Regulation)[1] split and assumption for increased road transport activity.
- **RePower:** it is the Low scenario, derived from the RePower EU context considering the lowest advanced biofuels demand in 2030.

In all the Import scenarios the EU total expected biofuel production capacity results not totally sufficient to meet the expected decarbonization targets. It has to be noticed that the extent to which the targets are expected not to be met by only using the EU total expected biofuel production capacity varies greatly among the scenarios, as it will be presented in Chapter 3 . In the Import scenarios it is then assumed to fill this gap with biofuels imports, in order to reach the expected demand targets. Thus, for these scenarios, the difference between demand and production is compensated by biofuels imports from other world regions.

In addition to the three Import scenarios, **other two[2] scenarios have been developed for 2030**, based on the results of the **Gap Analysis carried out in Task 4.1**. Objective of Task 4 Gap Analysis activity was to define a hypothetical additional production capacity growth,

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[1] 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.
[2] The RePower EU scenario has not been evaluated by the gap analysis activity, since the overall expected production capacity is higher than the expected biofuels demand.

sufficient to cover the gap between the expected biofuels demand and EU production capacity – that otherwise was considered to be filled with imports. Task 4 results are used as the basis for this additional set of scenarios, which is globally referred to as the **"Extended Capacity" scenarios** in the rest of the document; the single scenarios are named and defined as follows: **FF55 RED ExtCap** and **FF55 ESR RITA ExtCap**.

The year 2050 has been addressed only by the FF55 RED scenario, as all the demand scenarios from PRIMES tend to converge to similar biofuels demand values and no significative import contribution are expected.

The economic KPIs (i.e., market prices, annual turnover, and contribution to GDP) have not been evaluated for 2050, due to the lack of input data and the significant uncertainties on fuel prices, and on the other assumptions.

2.2. EU Production Capacity

The data used for this KPI is provided by Task 3 for the three **Import** scenarios, while is provided by Task 4.1 – where the expected EU production capacity was calculated as part of the Gap Analysis activity – for the two **Extended Capacity** scenarios.

Two different sources have been compared in the other two Tasks, reporting data for each of the conversion pathways considered:

- **Industry outlooks** reporting on production capacity either under construction or planned within year 2030.

- **Experts' opinions and associations interviews** for both year 2030 and 2050 (From Task 3 activity).

Finally, the expected production capacity has been compared with the projected feedstock availability to check for eventual bottlenecks to its projected development.

Both the **Import** set of scenarios and the alternative, **Extended Capacity** one have been considered for the evaluation of this KPI, as reported in Section 2.1 .

2.3. Overall energy contribution

This KPI is based on the output of the previous KPI, **EU production capacity**, and on **Task 1 outputs** for what it concerns the expected biofuels demand in transport (**overall** and sector-related: **Road**, **Aviation**, **Shipping**) for year 2030 and 2050.

The expected biofuel energy contribution to the transport sector from Task 1 was then broken down into two different shares:

- The part covered by the **expected EU production capacity** in year **2030** and year **2050** (divided across the various considered production pathways).

- The remaining part, covered by **imported volumes** from the global market (see Figure 2-2 below).

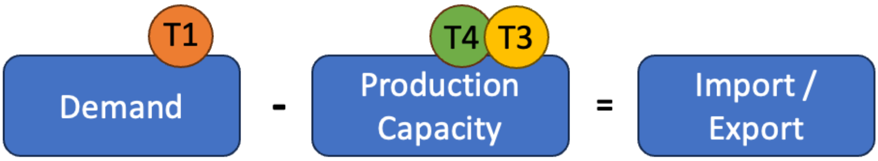

Figure 2-2 Methodology for the calculation of the import / export volumes needed to match EU internal demand for biofuels and EU overall production capacity for biofuels

Since the initial biofuels demand (also biofuels consumption) is provided for each transport sub-sector: Road – Aviation – Shipping, the resulting import volumes present with the same granularity.

In order to **attribute the imports to a specific production pathway** (also with the objective to better define their Emission Factor in the GHG savings calculation), the following two-steps methodology has been applied:

- The ratio between the imported volumes of the various type of fuels (within the same sub sector) has been maintained the same as the one reported by PRIMES for year 2020 (i.e., the ratio between ethanol and biodiesel imported volumes in the road sector); the absolute volumes have been scaled up to reach the total projected import volumes for the considered year.

- When needed, the total projected import volume for a specific macro-category of biofuel has been divided among all the production pathways that can produce it, proportionally to their relative expected capacities (i.e., biodiesel imports for road sector were divided among HVO and FAME pathways).

The results are reported for each production pathway, for the three Import scenarios and the two alternative Extended Capacity scenarios.

2.4. Share of total fuel demand

This KPI builds upon the results from the other KPI **overall energy contribution** and the results from **Task 1 modelling activity**, more specifically the **expected total fuel demand in the transport sector**, further broken down into the three considered sub-sectors. Each of the expected energy contributions from the various production pathways is compared with the expected total fuel demand; the results are reported for each production pathway, in the three Import scenarios and the two alternative Extended Capacity scenarios.

2.5. GHG Savings

The GHG savings express the emissions avoided by replacing shares of conventional fossil fuels with alternative fuels and energy vectors (biofuels, electricity and eFuels[3]). The GHG emissions from transport fuels were derived from the energy consumption provided by Task 1, adjusted by the gap analysis conducted in Task 4, on production capacity. The energy

[3]Within this report, the term eFuels refers to the RFNBO (as per the REDII) and the "Synthetic fuels" (as per the ReFuel EU Aviation).

consumption for each fuel was distributed among the several production pathways, based on Task 2 estimation of European biomass production. Finally, the GHG emissions related to each transport scenario were calculated applying a pertinent emission factor to each fuel production pathway, and the results were compared with a counterfactual scenario in which the energy demand is covered entirely by means of fossil fuels.

2.5.1. Distribution of the estimated fuel demand among the possible production pathways

The biofuels considered in the analysis include different production pathways, based on a range of combinations for feedstocks, production technologies, output fuels and uptake in the final transport segments. The gap analysis carried out in Task 4 aggregated the biofuels according to the classification outlined in Table 2-1. The classification distinguishes biofuels based on the main conversion process and feedstock group.

Biofuel category
Advanced ethanol
Alcohol to Jet (ATJ)
biomethane from anaerobic digestion
Gasification + SNG
Gasification + methanol/DME
HTL
Pyrolysis
Ethanol fermentation of food/feed crops
Hydrotreatment of UCO and AF
Hydrotreatment of food/feed crops
Hydrotreatment of tall oil
Hydrotreatment of intermediate crops
Lignin boost of fatty acids
Transesterification of UCO and AF
Transesterification of intermediate crops
Transesterification of Annex IX-A feedstock
Transesterification of food/feed crops

Table 2-1 Classification of biofuels adopted by Task 4

In spite of this detailed classification, this granularity on the biofuels production pathways was not sufficient for the purpose of properly defining the Emission Factors for the GHG emission analysis, as the emissions associated with the biomass processing stages can significantly vary among different feedstock groups, etc.

With the aim of improving 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 relative projected capacity. The latter information was provided by Task 2 scenarios on the European feedstock production capacity. In detail, the *high mobility* scenario, which guarantees the highest production level was selected.

In the first place, the feedstock-technology matrix provided by Task 4 was used to determine the set of compatible feedstocks, with each conversion process. Then, it was assumed that the uptake of a feedstock type by a certain process would be proportional to the availability (that is, production capacity) of that particular feedstock. The demand for the feedstock-process pathway (e.g., HEFA from UCO) was calculated by multiplying the aggregated biofuel demand (e.g., HVO/HEFA) for the availability of the feedstock, divided for the total feedstock availability for that conversion process. For instance, assuming that the only feedstocks available for the *Biomethane from anaerobic digestion* process were manure and agricultural residues, and that the overall production capacity for these two feedstocks were, respectively, 80 and 20 Mt/y, then the demand for biomethane would be attributed for the 80% to the manure pathway and for the 20% to the agricultural residues pathway.

It was observed that other approaches could have been taken into consideration. One alternative would have been to split the fuel demand across the possible value chains according to the current industrial utilization of the feedstock pool. However, such approach would have been valid only for few pathways, already fully deployed at commercial scale and with sufficient public data, while it would have resulted highly speculative for the others; additionally, data would be scarcely available for emerging feedstock-fuel pathways, and projections to 2030 and 2050 would present major uncertainties. For these reasons, it has been decided to distribute the fuel demand across the possible value chains based on the work carried out in Task 2.

2.5.2. Selection of GHG emission factors for the identified fuel production pathways

The attribution of GHG emission factors to the single value chains was performed using a specifically in-house designed tool (HANDY), described in detail in the Appendix II. The tool consists of two main parts:

- A collection of the most authoritative sources on GHG emission factors of alternative fuels, ranging from EU and international fuel policies (e.g., REDII, FuelEU Maritime and CORSIA) to reliable scientific reports (e.g., the JECv5 WTT study);

- A series of software routines for fuel pathways selection and scenarios evaluation.

As a first step, it was necessary to create a link between the feedstock-process-biofuel classification used in this report and the one implemented in the tool. An example of the mapping exercise is provided in Table 2-2. It has to be noted that, being the two classifications schemes not perfectly overlapping, on some occasions single fuel value chains defined in the report were expanded (e.g., for oil crops) or aggregated (e.g., for the wide variety of secondary residues listed in Task 2).

This Report		Polito's Tool		
Feedstock Category	Process	Feedstock Equivalent	Process Equivalent	Fuel Equivalent
Sec_res_cereal_bran	Anaerobic digestion	Agricultural residues	Anaerobic Digestion	Liquefied biomethane
Organic_waste_sepa	Anaerobic digestion	Municipal organic waste	Anaerobic Digestion	Compressed biomethane
Animal_solid_manure	Anaerobic digestion	Manure	Anaerobic Digestion	Compressed biomethane
Ligno_crops_degraded_land	Gasification + methanol/DME	Farmed wood	Methanol Synthesis	Methanol
Prim_forest_residues	Gasification +FT	Forestry residues	Fischer-Tropsch	Syndiesel
Post_cons_wood_non_hazard	Gasification +FT	Forestry residues	Fischer-Tropsch	Syngasoline
Post_cons_wood_non_hazard	Gasification +FT	Forestry residues	Fischer-Tropsch	Biokerosene

Table 2-2 Example of the mapping of fuel value chains from the classification used in this report to the one available within the tool used for the analysis

The analysed scenarios considered two cases, differing in the assumption about how the missing production capacity would be filled. In the "gap-fill" scenario labelled *Import* the demand is filled by extra-EU imports; in the *Extended Capacity* scenario the demand is covered by an expansion of selected value chains, according to the gap-fill analysis performed in Task 4. For the *Import* strategy, it was assumed that the GHG intensity of imported biofuels would be equal to that of the same biofuel produced in EU. Moreover, the demand for imported biofuels was spread among the compatible value chains proportionally to the foreseen European capacity (e.g., demand for imported HVO was proportionally spread among the value chains based on waste cooking oil, primary oil corps, etc.).

There are two reasons underpinning this choice: the first is that imported biofuels, just like those produced in Europe, must respect the same GHG threshold in order to be eligible in the EU27. Moreover, the stage which usually has the highest impact on upstream GHG emissions of biofuels is the agricultural phase, and a significant share of the internal EU production is supplied by imported feedstock, often from the same regions that were assumed for the import of the final fuels. Therefore, it would be unnecessary to create a specific set of GHG factors, also considering the uncertainties involved, for the imported final product.

Having provided the necessary link among the fuel value chains, it was possible to select the most appropriate GHG emission factors for each of them, choosing them from the available datasets. For the purpose of this report, the GHG emission factors were preferably sourced from official EU policies (e.g., the REDII and FuelEU Maritime Annexes). However, the study dimension required to complement value chains which are not yet considered in these documents (e.g., jet fuels): it was therefore necessary to use other data sources, namely the CORSIA scheme and the JECv5 and RICARDO vehicle LCA reports. When multiple values for the GHG emission factors were available for a value chain, the described hierarchy in the sources was used to select the most appropriate one (i.e., REDI→ CORSIA and JEC v5 → RICARDO, etc.). The in-house designed tool dataset provided a sufficient coverage of the value chains analysed; however, for very specific pathways (e.g., jet fuel from industrial processes residues), an integration from scientific literature[4,5,6,7,8] was needed to fill the gap. The previously described approach allowed to obtain an emission factor for all the value chains considered. Multiplying the emission factor for the demand for each biofuel value chain allows to calculate the emissions and, adding up the emissions across all the value chains, it was finally possible to compute the average emission factor for each biofuel value chain.

An example of the calculation of the emission factor for a value chain is reported below (Table 2-3) for HVO for the road segment, produced from feedstocks in Annex IX part B of the REDII. It has to be noticed that the emission factor of single value chains was weighted on the biomass availability, following the reasoning explained in the previous section.

Feedstock category	Biomass potential - Mtoe/y (share %)	GHG emission factor source	GHG emission factor (gCO2eq/MJ)	Value chain
Sec_res_ani_fats12	1.28 (33.82%)	REDII (default)	21.8	Hydrotreatment of UCO and AF (ROAD)
Waste_UCO	2.50 (66.18%)	REDII (default)	16	
		Weighted average:	17.96	

Table 2-3 Example of calculation of the emission factor of a value chain

For what concerns the other alternative fuels classes, electricity and eFuels, a different approach was followed. It was assumed that eFuels will be solely produced using green electricity, thus yielding an emission factor of zero gCO_{2eq}/MJ (as in the European approach the embedded material cycle emissions are excluded, and additional renewable power production capacity is required for the production on RFNBOs). For electricity, the results of the PRIMES model provided by Task 1 were used for 2030 ($29\ gCO_{2eq}/MJ$) (as it follows the provisions from EEA) whereas for 2050 it was assumed that the power system will be entirely decarbonized, and the emission factor was then set to zero.

With respect to these approaches, for biofuels and eFuels, some caveats are needed. While this approach ensures methodological consistency and comparability, across scenario and with other studies, it must be noted that for advanced biofuels, the Carbon Intensity of the REDII default values represent a conservative figure. Actual values, resulting from the certification of real industrial processes, are significantly lower. This potentially has a direct impact on the quantitative GHG saving resulting from the use of such fuels. Moreover, these

[4] M. Pourbafrani, J. McKechnie, H. L. Maclean, and B. A. Saville, Life cycle greenhouse gas impacts of ethanol, biomethane and limonene production from citrus waste, *Environ. Res. Lett.*, vol. 8, no. 1, **2013**, doi: 10.1088/1748-9326/8/1/015007.
[5] Z. W. Ng *et al.*, Process design and life cycle assessment of furfural and glucose co-production derived from palm oil empty fruit bunches, *Environ. Dev. Sustain.*, no. 0123456789, **2022**, doi: 10.1007/s10668-022-02633-8.
[6] A. Konti, D. Kekos, and D. Mamma, Life cycle analysis of the bioethanol production from food waste—A review, *Energies*, vol. 13, no. 19, pp. 1–14, **2020**, doi: 10.3390/en13195206.
[7] E. F. Pedretti *et al.*, Sustainability of grape-ethanol energy chain, *J. Agric. Eng.*, vol. 45, no. 3, pp. 119–124, **2014**, doi: 10.4081/jae.2014.425.
[8] M. Naqvi, J. Yan, and E. Dahlquist, Synthetic gas production from dry black liquor gasification process using direct causticization with CO2 capture, *Appl. Energy*, vol. 97, pp. 49–55, **2012**, doi: 10.1016/j.apenergy.2011.11.082.

CI values were considered as stable overtime but innovations such as the use of green hydrogen and renewable electricity in the biofuels making are already happening, which would lower the Carbon Intensity of the MJ of finished fuel. For eFuels, instead, the assumption of considering zero emissions is formally correct form an accounting perspective, 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.

Having assessed the GHG emission factors for all the fuels included in the energy mix, it was possible to calculate the emission savings for all the segments, and for the entire transport sector, under each scenario. The emissions savings have been defined by comparing the resulting emissions, against a counterfactual scenario where the mobility services are covered with traditional fossil fuels (with a reference lifecycle value of 94.1 gCO_{2eq}/MJ, as indicated in the REDII).

It is worth noticing that the drop-in biofuels and eFuels are expected to be used in the same propulsion technology as fossil fuels, with minor effects on the efficiency of these engines. It can be assumed that satisfying a demand for transportation would require the same amount of energy, being this in the form of fossil fuel, biofuel or eFuel. However, this does not hold true for electricity, as more efficient battery electric vehicles (BEV) can satisfy the same transportation demand with a lower energy consumption than internal combustion engines (ICE). The emission related to electricity use in transport were thus calculated taking in account the different efficiencies of BEV and ICE. The electricity demand was converted into a fossil equivalent energy, by multiplying it for the ration between typical BEV and ICE fuel economies ($MJ/100km$). The data on projected powertrain efficiencies were sourced from the JEC TTW report[9]. For BEV the fuel economy is 43.8 $MJ/100km$, whereas for ICE engines an average value between diesel (135 $MJ/100km$) and gasoline (159 $MJ/100km$) engines was chosen.

2.5.3. Selected KPIs

The following list of KPIs was used to report the results of the analysis:

- **GHG_S:** Total GHG savings for the whole 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.

[9] Huss, A, Weingerl, P. JEC Tank-To-Wheels report v5: Passenger cars. Maas, H., Herudek, C., Wind, J., Hollweck, B., De Prada, L., Deix, S., Lahaussois, D., Faucon, R., Heurtaux, F., Perrier, B., Vidal, F, Gomes Marques, G., Prussi, M., Lonza, L., Yugo, M. and Hamje, H., editors. EUR 30270 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-19927-4, doi:10.2760/557004, JRC117560.

2.6. Market prices

Market prices of biofuels have been assumed from experts' estimated values[10], as reported in Table 2-4. The experts interviewed in the project provided a minimum and a maximum value, and an additional mean value has been computed and reported. Prices are provided per ton of biofuel, and they have been converted to prices per toe using standard heating values.

Fuel	Min €/t	Max €/t
Advanced biodiesel	1,250	2,500
Advanced bioethanol	1,100	1,500
Bioheavy fuel oil	1,500	4,000
Biokerosene (ATJ, FT, HEFA, SIP)	2,300	5,500
Biomethane	1,200	1,800
Biomethanol/bioDME	775	2,000

Table 2-4 Expected market price evolution in 2030 in €/t (from Task 3)

The market prices for the pathways that were not explicitly mentioned in the experts' estimates were evaluated based on the transport segment distribution of each pathway's output (i.e., road transport, aviation, and shipping).

2.7. Annual turnover including import

The annual turnover of biofuel pathways in 2030 has been estimated by multiplying the annual volume of biofuels with the expected market prices from the industry, described in the previous section. As described above, three levels of turnover have been calculated, based on the minimum, maximum and average market price of the biofuels estimated by the experts.

The turnover has been estimated per each pathway, and it also includes the imported volumes of biofuels, as it is assumed that they are sold in the EU-27 market by the obligated companies.

The impact of biomass feedstock costs on the final market prices of the biofuels (thus on total annual turnover related to biofuels production and sale) could not be evaluated, since no information was available on the expected evolution of feedstock costs in the future.

2.8. Contribution to GDP including import

The contribution to GDP is evaluated by considering the added value, which is obtained by estimating the average gross margin related to the calculated annual turnover.

[10] from the "Report on Task 3", Table 3.3 – Expected market price evolution in 2030.

Average gross margins across industrial sectors in Europe are around 30%[11]. This margin level has been applied to all the pathways considered in the analysis, to estimate a total value added for each pathway and for the biofuels sector as a whole. Biofuels imports are included in the value added, as it is assumed that they are sold in the EU-27 market by the obligated companies. However, the added value related to biofuel imports has been estimated considering a 10% margin level.

The added value is used to assess the contribution to GDP of the biofuel sector. This indicator has been computed as the ratio of the added value against EU's total GDP (as estimated in the 2020 EU Reference Scenario). The 2030 EU's total GDP is estimated at 17.75 trillion $€_{2022}$ (converted from an official value of 14.81 trillion $€_{2015}$). It is important to remember that this GDP estimation does not incorporate the specific assumptions of the different scenarios evaluated in this analysis. However, since no specific assessment of the future GDP has been performed in this study, the latest official forecast available was considered, which still takes into account an estimate of the efforts needed for the decarbonization of the EU economy.

2.9. Additional Employment in the Sector

The socioeconomic impact of the development of drop-in biofuels and use in transport sector encompasses: creation of job opportunities, linking industrial and rural communities, creation of specialized jobs, encouraging the generation of knowledge and technological skills, promotion of local development and mitigation of rural depopulation, support for security of supply and reduction of energy dependence in EU27, thus alleviating effects in citizens' income due to increase of fossil fuels prices.

The positive impact of the third and fourth points is evident and depends on the level of biofuels production in the EU27 and their penetration in the market of transport fuels. In this Section, the employment effect is described, mainly the first point of creation of job opportunities but also the second point and try to indicate the expected impact in the forthcoming period until 2050.

2.9.1. Biofuels relation to employment

A critical issue worth exploring is whether biofuel technologies and the relevant value chain are more labour intensive than fossil fuels in delivering the same amount of energy. When considering jobs in related activities, technology development, manufacturing of equipment, installation, operation & maintenance (O&M), collection/production and transportation of feedstock to various phases of industrial processing are included. The analysis captures both positive (job creation in RES-related sectors) and negative employment impacts (displaced jobs in conventional energy forms) as paving to low-carbon transition by 2030 and particularly by 2040 and 2050.

The expansion of the use of sustainable drop-in biofuels has an important role in reducing GHG emissions, as well as in changing the production and economic system of transport fuels. This transition of the economy to a more sustainable and climate friendly model affects job creation in the relevant sector. From a global point of view of the relevant literature, it is estimated that energy measures to be implemented towards holding the increase in the global average temperature to below 2°C compared with preindustrial times will generate 18 million

[11] As reported by different analyses, including data from January 2023: https://pages.stern.nyu.edu/~adamodar/New_Home_Page/data.html.

net jobs by 2100 (ILO, 2018)[12]. Bioenergy is the main source among renewable energies (INTI-EU, 2015)[13] in increasing related employment, because in most cases the labour needed to generate it, is considerably greater than in the respective production and use of fossil fuels. Bioenergy, and especially the part of biofuels, give rise to agro-industrial and waste collection value chains, which are feeding an emerging industrial sector producing drop-in biofuels and other bio-products directed to transport and other economic sectors.

In its global energy sector employment estimates the International Renewable Energy Agency (IRENA) includes wholly or partly energy demand side activities, including energy efficiency, energy flexibility and grid infrastructure, besides purely energy supply sectors, including biofuels production, (IRENA, 2019)[14]. The sector of liquid biofuels is among the largest renewable energy employers in the world. Total global employment in the sector reached over 2 million jobs in 2018, as shown in Figure 2-3. It is mentioned that renewables may create more jobs than conventional, mostly fossil-based energy, due to their larger labour intensity. Liquid biofuels sector was the third largest renewables employer in the EU-28. In 2018 the sector had over 248 000 jobs in total and particularly in the agriculture/waste collection and industrial sectors. EU Member States leading in biofuels employment include Poland, Romania, France, Spain, Hungary, and Germany. The leading country, Poland, had over 41 000 biofuels jobs in 2018.

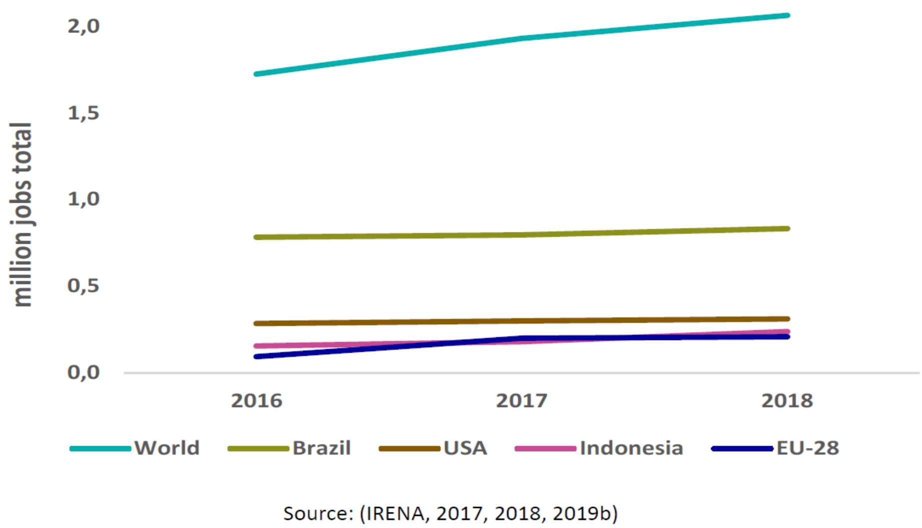

Figure 2-3 Employment in liquid biofuels, world and selected major players, 2016-2018 (Source: IRENA)

In a recent study for EU27, Deloitte[15] argues that bioenergy is a very versatile and flexible solution that can assist the main challenges of achieving climate neutrality by 2050 with job

[12]Greening with Jobs: ILO World Employment Social Outlook 2018, ILO. 2018
[13]Biomass for energy use as a sustainable business, Technological framework N.° 21, INTI-EU, 2015
[14] “Renewable Energy and Jobs Annual Review 2019”, IRENA 2019
https://www.irena.org/publications/2019/Jun/Renewable-Energy-and-Jobs-Annual-Review-2019
[15] “Towards an Integrated Energy System: Assessing Bioenergy’s Socio-Economic and Environmental Impact”, Deloitte, 2022

creation and economic growth. Each additional Mtoe of biomass for energy could lead to an impact of 359 million euros in terms of GDP and an employment creation of 7.376 Full-Time Equivalent (FTE), on average, while preventing 2,4 MtCO2eq emissions due to the replacement of fossil fuels in energy supply. Unlike other forms of renewable energy, biomass is employment intensive as it often needs to be collected, treated, and transported prior to its use. Moreover, biofuels also generate a significant number of jobs in the operation and maintenance of the necessary industrial installations, the manufacture of equipment, as well as the broader development and change of the economy.

However, there is no obvious one-to-one relationship between RES expansion and the net change in energy supply jobs[16]. Net employment effects of switching from fossil fuels to fuels produced by low-carbon energy technologies depend on many factors including the mix of technologies deployed, the domestic content of alternative energy sources, the time period as well as a series of assumptions (Fragkos et al., 2017)[17].

Biofuels are mainly produced utilizing, in principle, local feedstock and its manufacturing value chain is in most cases technologically developed in the European Union. This fact results to the existence of a significant economic opportunity serving as a vehicle for job creation and broader economic development. These jobs cover a wide range of economic sectors: scientific research on innovative processes and technologies, plant construction and operation, transportation of feedstocks and of intermediate/final products, manufacturing of equipment, etc.

2.9.2. The employment assessment methodology

It is broadly acknowledged that the impacts of bioenergy activities on employment can be classified as direct, indirect, and induced, defined as follows:

- **Direct employment impacts:** Direct jobs are derived from biofuel production: equipment supply, onsite installation, O&M, and all activities related to biofuel supply.

- **Indirect employment impacts**: Indirect jobs are related to manufacture of equipment, components and materials used to build biofuel installations and with services and materials used to operate and maintain the biofuel installations.

- **Induced employment impacts:** Induced jobs are those created due to the overall economic impact of biofuel capacity expansion and their estimation requires the macroeconomic analysis simulating both income and price-induced changes in the economic structure made due to biofuels deployment.

In this employment impact assessment, the first two types are considered, i.e., direct, and indirect employment. **Direct and indirect employment** is addressed to a) biomass/waste feedstock production/preparation, b) industrial processing and c) transportation of feedstock and intermediate products.

To calculate the employment effect, two types of jobs are considered:

- permanent jobs that are created and are necessary during the production of biofuels, e.g.,

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[16] "Employment in the Energy Sector, Status Report 2020", JRC
[17] "Employment creation in EU related to renewables expansion" Panagiotis Fragkos, Leonidas Paroussos, Applied Energy, Elsevier, 2018

the O&M of industrial biofuel plants, the feedstock collection and transportation to industries, etc.

- short-term jobs that are created at certain periods of the activity development e.g., construction of installations, when the investment takes place, manufacturing of equipment, and spare materials, etc.

The overall employment effect incorporates both types of jobs under the assumption that the short-term jobs are averaged over the entire lifetime of the production plants and thus, calculating the employment effect in permanent **Full Time Equivalent (FTE)** jobs for each biofuel-related activity. In this impact assessment, as in most relevant studies and analyses, the FTE unit is absolutely used to express the employment quantity.

Two main approaches are used, in literature, for the employment impact assessment:

- The **employment factor** approach (bottom-up analytic process models) estimates the average number of jobs per unit of capacity installed or per unit of biofuel generated (e.g., in ktoe/yr) and combines them with energy data of system evolution to estimate the total number of jobs. Factors are specific to technologies, size of units, implementation maturity, stages/activities in the value chain, thus requiring the necessary relevant corrections.

    – The **supply chain approach** is a bottom-up variant of the employment factor approach; it analyses the supply chain for a technology and estimates labour among other financial parameters in each supply chain link. Labor requirements in each stage are then aggregated to determine employment factors.

This approach is relatively straightforward from a methodological perspective and is commonly more transparent than the approach based on macroeconomic models[18]. In the assessment, the **employment factor and supply chain approaches will be used** to estimate direct and indirect jobs.

- The **use of macro-economic models** which are built based on Input/Output (I-O) tables (top-down analysis) but also include price-induced effects and supply constraints and are thus well-equipped to simulate direct, indirect and induced jobs. A major drawback of previous I-O analyses is that industries producing renewable energy equipment and energy efficient products are not explicitly identified as industrial/manufacturing sectors in national accounts. On the other hand, conventional energy industries (including fossil fuels and electricity) exist in most national accounting systems[7].

The **employment factor approach** will be the basis for the employment assessment of this project. The employment factor is expressed in **FTE jobs per production of biofuels in ktoe/yr**.

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

[18] "ASSET Study on Job creation related to Renewables", EC DG ENER, 2020

(**SBS**) and **EurObservER** annual reports (years 2014 to 2021).

- Data of biofuels consumed in the **transport sector** coming 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.

Especially, it is worth considering that the LFS database is dedicated to the labour market with data originating from private households and covers employment by sector, unemployment, and inactivity. SBS data are derived from enterprises and cover business activities in manufacturing, construction, and services. Due to differences in methodology, figures in LFS statistics are generally higher than in SBS for most sectors. The present assessment uses Eurostat's LFS data according to the Statistical Classification of Economic Activities in the European Community (NACE Rev.2).

As indicated by the literature review of Cameron and van der Zwaan19 on employment opportunities associated with the deployment of renewable energy technology, there is high uncertainty in employment factors, which are related to renewable energies, in available literature, as the range of published job factors stretches roughly over an order of magnitude divergence between minimum and maximum values. **Employment factors are expected to reduce over time** as technologies and production techniques mature and labour productivity increases. Heavner and Churchill20, in their study based on analyses and experience for California transition to renewables, argue that it is a difficult task to quantify employment intensity reduction based on historical precedent and assume an annual intensity decrease of 10% in construction and 5% in O&M for new installations of renewable energy.

There is a large job creation potential in biofuels production after 2030, as advanced conversion technologies mature and are massively developed to decarbonize transport segments that cannot be electrified. Advanced lignocellulose-based biofuels create domestic jobs both in feedstock supply, as woody biomass and waste collection are predominantly produced domestically, in conversion processes, transport but not in the final use, as liquid and gaseous drop-in biofuels in road transport will use the same infrastructure as petroleum and natural gas products.

The estimation of the technological, and thus of the employment factor, evolution makes this employment impact exercise challenging and linked to information on technological assessments coming especially from Tasks 3 and 4.

The value chain of drop-in biofuels, which will be used in the employment impact exercise, is presented in Figure 2-4. The feedstock production and/or collection sector is distinguished from the industrial sector, whereas the necessary transportation activities and the by-

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[19]"Employment factors for wind and solar energy technologies: a literature review" Cameron L, Van der Zwaan, BCC Renew Sustain Energy Rev, 2015

[20] "Renewables work: job growth from renewable energy development in California" Heavner B, Churchill S., Sacramento: CALPIRG Charitable Trust, 2002

products within the value chain are also indicated. The fuel distribution sector remains the same used for fossil fuels and the consequent employment impact is negligible since drop-in biofuels replace similar quantities of fossil fuels.

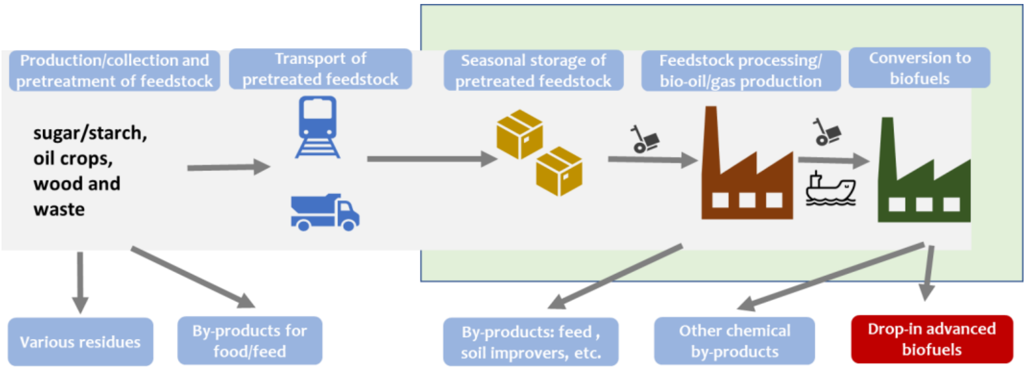

Figure 2-4 Value chain of biofuels production (Source: EXERGIA)

2.9.3. Employment assessment steps

In accordance with the above-mentioned methodology, the calculation steps to be followed towards estimating the employment impact of the drop-in biofuels in the period 2020-2050 and especially for the years 2030, 2040 and 2050, are presented in Figure 2-5. The whole calculation approach concentrates on the estimation of the Employment Factor, as it is defined in Chapter 2.9.5 and might be calculated for the years 2020/2021, which are considered as the base years for the calculations. The existing literature indicates necessary data, based mainly on EUROSTAT and EurObservER, which conclude to a reasonable estimation of the selected Employment Factor for 2020 and 2021, but also for the previous recent years.

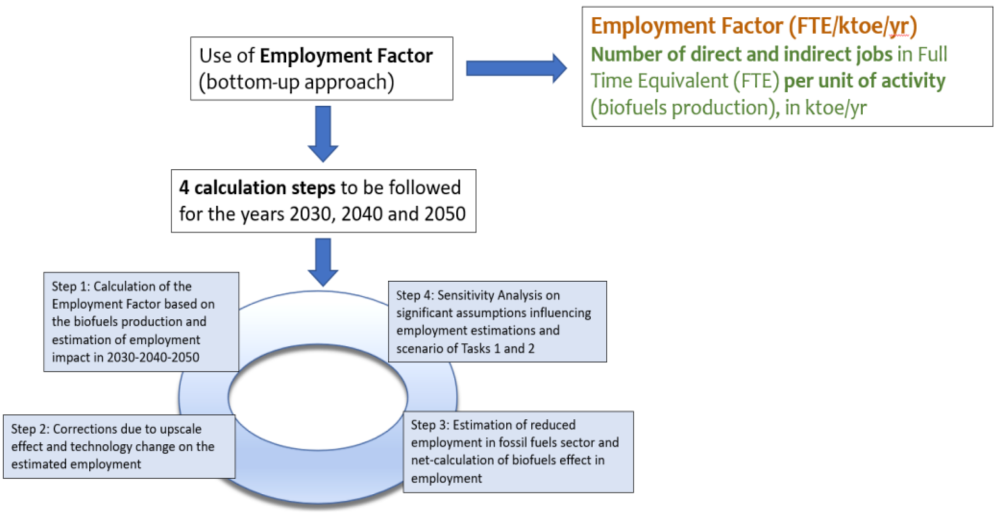

Figure 2-5 Calculation steps of employment assessment

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. This figure is a very draft indication of employment not considering the corrections which are attributed to changing conditions in the period 2020-2030.

- **Step 2**: The first correction 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. Each new industrial, in principle, investment is more efficient and optimized thus leading to lower need of employees per its production activity. This trend has been observed in many relevant activities and is expected to occur in the drop-in biofuels 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. Since the drop-in advanced biofuels replace fossil fuels, the relevant employment reduction is expected to occur in the upstream and especially the midstream pathway of fossil fuels. In this case, the respective reduction in refining due to the substitution of fossil fuels with biofuels is the point of concentration. This substitution is not expected to influence the fuels distribution sector, assuming that the replacement of fossil fuels takes place one by one at quantity level.

- **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. For sure, this sensitivity analysis will focus on significant parameters, like the consumption of biofuels or the policy framework setting restrictions and more or less ambitious targets for the future. The purpose of this exercise is to demonstrate the influence over the employment figures of the basic calculation of Steps 1 to 3.

2.9.4. The EurObserv'ER source

The EurObserv'ER has been compiling data on the European Union's renewable energy sources for over twenty years, to record the state and dynamics of the sectors in thematic barometers. The first part of the last annual report[21] condenses the statistics released in 2022 for the wind power, photovoltaic, solar thermal, CSP, ocean energy, renewable energy in transport and solid biomass sectors. Since the renewable energy consumption in transport is covered by a new legal framework – that of the RED II, most of its provisions came into force on 1 January 2021. The Directive marks a new policy direction that aims to abolish high Indirect Land Use Change (ILUC) risk biofuels by 2030. The presented data in the annual report of EurObserv'ER complied with the requirements of the RED II.

The EurObserv'ER reckons that biodiesel accounted for about 79.9% of total biofuel consumption in 2021 (compliant and non-compliant), ahead of bioethanol (16.6%) and biogas in transport fuel (2.5%). Bioethanol consumption grew (by 13.6% year-on-year, or around 3 Mtoe), outstripping that of biodiesel (2.6%, or 13.7 Mtoe respectively). Biogas fuel consumption in transport also increased (by 30.2%) at 426.9 ktoe, including biomethane injected into the fossil gas grid allocated to the transport sector.

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[21] "THE STATE OF RENEWABLE ENERGIES IN EUROPE", Edition 2022, 21st EurObserv'ER Report

Part of the EurObserv'ER annual report is dedicated to socioeconomic and especially employment conditions related to renewables including biofuels. Since the 2017 Edition, a formalised model developed by the Energy Research Centre of the Netherlands (ECN), currently TNO Energy and Materials Transition, has been used to assess employment and turnover in the EU. The approach applied is based on an evaluation of the economic activity of each renewable sector covered, allowing for a comparison between the EU Member States. The approach has changed in 2015 and in 2019, thus the assessment of direct and indirect employment presents significant leaps in the figures of these years (Table 2-5).

An adjustment to the employment assessment model was adopted in 2019 regarding the calculation of biomass feedstock costs that has led to a decrease in the estimates for biomass feedstock related activities compared to the estimates for 2018. In addition, an update of the biofuels technical data based on the EU Horizon 2020 ADVANCEFUEL[22] project has similarly led to a decrease in the estimates for this category. Most notably, the consultation with stakeholders and the other analyses concluded that a higher efficiency should be assumed for biodiesel production. This leads to a reduced estimate on annual feedstock costs, resulting in lower estimates for turnover and employment.

In this exercise, the EurObserv'ER results are considered based on this last update of approach for the calculation of the employment factor and other parameters. In Table 2-5 the annual consumption (ktoe) of biofuels, categorised in biodiesel, biogasoline and biomethane, and the related direct and indirect employment (FTE) in EU27, as they are compiled by the EurObserv'ER for the years 2013-2021, are presented. A first effort to calculate the employment factor **based on biofuels consumption** is also presented, by which the change of the calculation approach, mentioned above, is evident.

YEAR		2013	2014	2015	2016	2017	2018	2019	2020	2021
Variable	Unit									
Biofuel consumption (TOTAL)	kTOE	12053	12902	13238	13211	14374	15360	16009	16324	17136
Biogasoline	kTOE	2262	2253	2276	2303	2396	2603	2706	2649	3010
Biodiesel	kTOE	9644	10483	10829	10753	11827	12583	13059	13348	13699
Biomethane	kTOE	119	133	128	151	150	173	244	327	427
Other	kTOE	28	32	5	4	1	1	0	0	0
Direct and indirect Employment	FTE	101250	106450	174000	200600	220300	239600	145600	142600	148300
Employment Factor	FTE/kTOE	8,40	8,25	13,14	15,18	15,33	15,60	9,09	8,74	8,65

Table 2-5 Presentation of EurObserv'ER biofuels and employment status for EU27, 2013-2021

In the assessment the considered initial value of Employment Factor for the base year is 8.65 FTE per ktoe/year of biofuels consumption in transport. This table represents better the EU27 recovered economic situation due to the Covid effects and indicates its expected reduction due to maturity in the period 2019-2021.

2.9.5. Specific assumptions and corrections

The following assumptions related to required corrections of the Employment Factor, as mentioned above in the calculation steps, for 2030, 2040 and 2050 are considered.

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[22] "ADVANCEFUEL", EU Horizon 2020, http://www.advancefuel.eu/en/project

Selection of central and min/max scenarios

The calculations of the employment effect for the future years (2030, 2040 and 2050) will be based on the **FF55_RED scenario** (central or basis scenario) results, as it has been presented in Task 1 and has been considered in Task 4, due to assessment of potential feedstock supply (Task 2) and the investment/technology development (Task 3). This scenario incorporates the Provisional Agreement for the new RED and the relevant policy targets and restrictions. The lowest demand – overall and specifically for advanced biofuels Annex IX A and B - is generated in case of the **Repower scenario**, while the highest advanced biofuels demand – thought not the highest overall demand - is generated in the **FF55_ESR_RITA scenario**. These two scenarios indicating the difference between the highest and the lowest advanced biofuels demand scenarios in 2030, will be also considered as min/max cases to illustrate the variance of the employment impact. Therefore, the following three scenarios will be examined:

- Central scenario: FF55_RED, reflecting the recent Provisional Agreement.
- The best advanced biofuels demand in 2030 scenario: **FF55_ESR_RITA** reflecting the EU policy Fit For 55 combined with equal sectoral ESR (Effort Sharing Regulation) [23] split and assumption for Increased road transport activity.
- The lowest advanced biofuels demand in 2030 scenario: **RePower** reflecting the relevant RePowerEU policy.

The forecasts for biofuels demand by type of biofuel and for the years 2030-2050 for the three selected scenarios are presented in Table 2-6. The conventional biofuels or 1G biofuels and two types of advanced biofuels are distinguished, those that conform to Annex IX A of the RED, and those that conform to Annex IX B.

It is evident that for 2040 and 2050, the demand of the three scenarios converges and there is limited variation between them. The conventional biofuels are expected to play a significant role in 2030, on the contrary, they will be nearly phased out in 2040 and actually extinguish in 2050.

2030				
Scenari0	Conventional	RED/Annex 9/A	RED/Annex 9/B	TOTAL
FF55_RED	10.6	18.4	9.0	**38.1**
FF55_ESR_RITA	12.1	20.6	10.1	**42.8**
RePower	10.8	6.2	6.4	**23.4**
2040				
FF55_RED	1.6	32.3	11.4	**45.3**
F55_ESR_RITA	2.6	31.2	11.1	**44.9**
RePower	2.3	27.4	10.1	**39.8**

[23] 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.

2050				
FF55_RED	0.3	39.9	6.5	**46.7**
FF55_ESR_RITA	0.3	39.6	6.5	**46.4**
RePower	0.2	33.5	11.6	**45.3**

Table 2-6 Scenario demand for biofuels in 2030, 2040 and 2050 (Mtoe/year)

Correction by considering local production and imports/exports of biofuels

Starting from the available data for consumption and imports/exports of biofuels, the Employment Factor corrected was calculated, by considering that part of the final biofuels or intermediate industrial inputs of pre-treated feedstock are imported or exported. Thus, the Employment Factor is adjusted to the biofuel quantities produced in the EU27 and consequently the domestic content is considered. Since the EU27 is importer of small quantities of biofuels and intermediate products in the recent years, this adjustment is expected to slightly increase the initial Employment Factor that is based on biofuels consumption in the base year.

In the calculations of the future years (2030, 2040, 2050) this correction might be significant in case there is no feedstock availability (Task 2), and the assessed gap (Task 4) leads to the need of higher imports of pretreated feedstock and biofuels as final products to cover the demand. Since the scenario of Fit-for-55/RED will be the central in the employment assessment, it sounds reasonable that an intensive mobilization for feedstock production, as it is described in Task 2, is required, so the relevant high mobilization scenario for feedstock availability will be considered in compliance also with the Task 4 approach.

Regarding the gap analysis of Task 4 (relevant Figure 4) between demand and capacity production of biofuels in 2030, it is obvious that the existing and planned/under construction capacity cannot meet the anticipated demand in the FF55_RED (central) scenario and the FF55_ESR_RITA scenario. The identified capacity gap of around 11 – 16 Mtoe/year compared to the foreseen capacity of around 25 Mtoe/year is considerable and indicates significant imports of necessary quantities of biofuels. This situation will be reflected in the correction of employment due to expected imports and not EU production of biofuels. On the other hand, the demand indicated in the RePower scenario could be fully covered by the foreseen capacity.

For 2040 and 2050, given that all scenarios essentially converge on a total capacity requirement of 40 to 45 Mtoe/year (2040) and of 45 to 47 Mtoe/year (2050) respectively, which could be met by the additionally foreseen capacity and the respective gaps might happen only due to lack of necessary feedstock. Thus, imports of biofuels as final products should not be considered.

Regarding the availability of feedstock for the foreseen technologies, given the high feedstock mobilisation scenario, and in accordance with the gap analysis of Task 4, the following points should be considered:

- For 2030
- For the biofuels produced from lignocellulosic materials there is enough feedstock even for the maximum scenario.

- For the lipids – FAME and HVO/HEFA – there is even under the high mobilisation scenario not enough biomass for the additional capacity. This will likely be solved by imports of pretreated feedstock (oil) that is in the order of 6 Mtoe/year for the central scenario.

- There is sufficient feedstock for biomethane production as transport fuel.

- For 2040 and 2050

- The forecasted feedstock supply capacity exceeds the total demand in all three scenarios.

Therefore, the employment factor will be corrected for the central Fit-for-55/RED scenario taking into consideration the availability of capacity and the availability of necessary feedstock to meet the foreseen demand. Imports of pretreated feedstock and biofuels will be considered, particularly for 2030, which will negatively affect the expected employment, either in the agriculture/collection sector or in both agriculture/collection and industrial sectors.

Correction by considering technology maturity

Due to learning curve effects, capital costs for advanced biofuels processing plants fall in every new installation. Similar reductions of costs are expected in the O&M activities due to more efficient use of resources and materials. This evolution is experienced in the development of innovative, small scale and immature technologies. The literature is very poor in covering the effect of new installations on employment, however a small number of references[24,9] indicate that employment intensity reduction based on historical precedent is worth considering and assume an annual intensity decrease of 5-10% in construction and in O&M for new installations.

In this employment assessment exercise, it is assumed that a correction factor of 10% used, thus reflecting very conservatively the innovative and developmental nature of biofuels production technologies regarding employment impact. In other words, it was assumed that employment per production activity of a new installation is reduced by 10% compared to the similar installation of the previous year.

Correction due to technology change

As already presented in Tasks 1, 3 and 4, it is expected that a technological change of biofuels industrial processes after 2030 will be observed. Until 2030 industry and the relevant feedstock activity are developed aiming at HVO/HEFA installations. Within the current decade but especially after 2030 the development of industrial units based on advanced ethanol, ATJ (Alcohol to Jet), gasification, pyrolysis, HTL (Hydrothermal Liquefaction), etc. it is expected and will change also the associated feedstocks used. This technological transition could change the employment factors as well.

The international literature on the evolution of employment due to this technological transition in biofuels production is even poorer. Exploiting the supply chain approach, as it has been analysed in the literature[25, 11, 6] the expected changes in employment after the technological transition was assessed. These indicate that, compared to 2030, the employment in

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[24] "U.S. Economic Impact of Advanced Biofuels Production: Perspectives to 2030", BIO Economic Research Associates (bio-era), 2009

[25] "Renewable energy employment effects in the EU and the Member States" Methodology Report, EurObserv'ER, December 2017

feedstock supply in 2040 will decrease by 20% and at the same time the employment of construction activities remains the same and that of the O&M activities is expected to increase by 45%. In total and given the share of each type of activity in the overall employment result, the conclusion is that any significant effect or change due to the expected technological change should not be expected and consequently this correction factor has not been considered in the assessment for 2040 and 2050.

Calculation of net employment

After making the above-mentioned corrections, the net employment assessment considers the relevant reduction of jobs in the fossil fuels sector, the products of which are replaced by the drop-in biofuels. The effect is allocated to the refining sector in principle since the oil distribution sector is not influenced actually by the replacement of fuels. Therefore, the major negative effect is related to the reduction of the refining activity for the replaced fossil fuel quantities by the biofuels.

Based on the EUROSTAT data for the refining activity, the pertinent Employment Factor might be calculated in terms of the ratio of FTE over the production quantity of fossil fuels. It is also assumed that this Employment Factor reflects the result of a strongly mature technology and significant changes are not expected in the study period, thus, the reduction of jobs might be calculated based on the reduction of fossil fuel production because of its replacement by biofuels.

3. Analysis of results and collected data - consolidation by 2030

3.1. EU Production Capacity

Task 3 and Task 4 results show that the overall EU biofuels production capacity is definitely expected to increase in 2030. However, this growth only proves sufficient to match the corresponding growth in total demand as projected in one of the three analysed scenarios – namely the RePower one – which is accounting for a total biofuels demand of 23.4 Mtoe. In the other cases, the gap between the expected demand and the projected capacity (see Figure 3-1), should then be filled by imports from other regions.

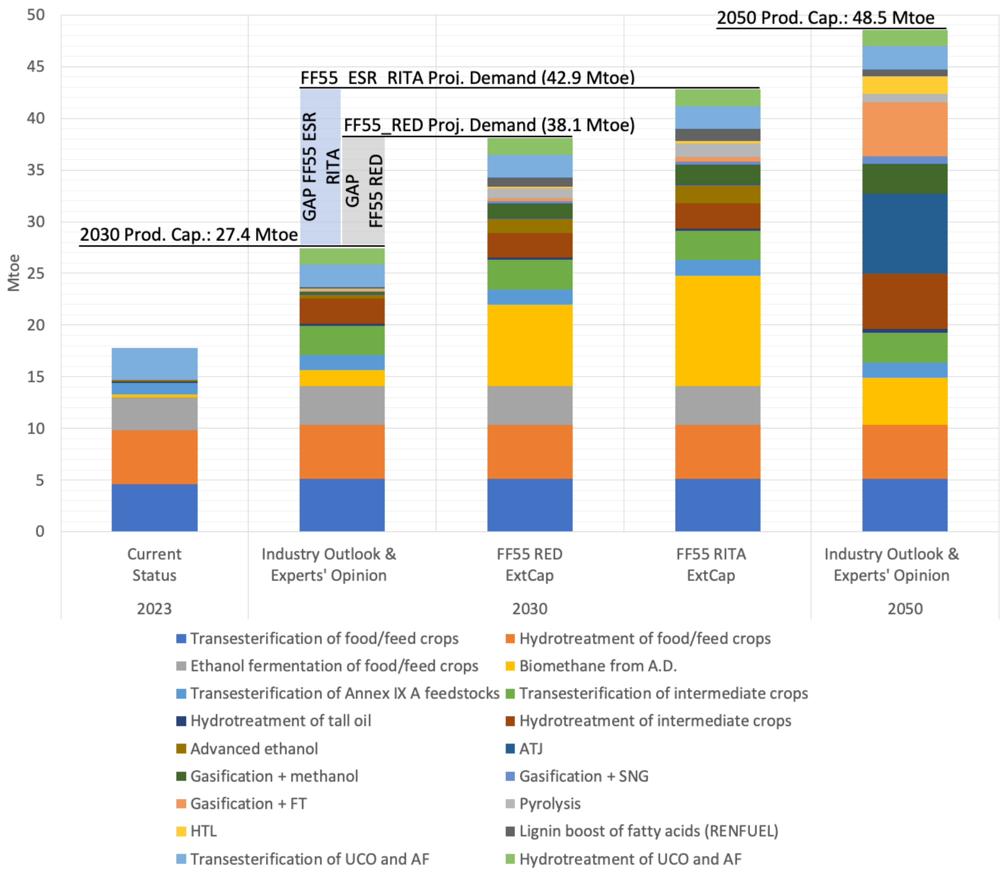


Figure 3-1 Repartition of the expected EU biofuels production capacity among the various pathways, in 2030 and 2050, for the various analysed scenarios

While the demand VS capacity gap is expected to be present in 2030, projections show a sufficient overall EU production capacity in 2050. Focusing on transport segments, the EU aviation could still possibly need to rely on import for 1 Mtoe, to close the total projected demand of 15.9 Mtoe.

Looking at the shares of the EU production capacity among the various pathways, it can be observed that, in 2030, the highest impacts come from FAME pathways, accounting for a total of 11.7 Mtoe and HVO/HEFA with 9.5 Mtoe, followed by conventional ethanol and Biomethane from anaerobic digestion respectively with 3.7 Mtoe and 1.5 Mtoe. The contributions of the remaining pathways are limited at significantly lower values, from the 0.3 Mtoe of the advanced ethanol, down to 0.03 Mtoe in the cases of gasification + SNG and HTL.

The 2050 projections for EU production capacity partially confirm the 2030 situation, with HVO/HEFA and FAME still expected to have the highest capacity, respectively at 12.6 Mtoe and 11.7 Mtoe, with FAME maintaining the 2030 capacity values. Most of the pathways are indeed expected to increase in terms of their relative capacity, with the exception of the conventional and advanced ethanol pathways, which are expected to be phased out (the advanced ethanol pathway only for direct use in transport sector, while still expected to be used as an intermediate and for chemicals production). The steeper increase is expected for Alcohol to Jet, that reaches 7.7 Mtoe, followed by gasification + FT with 5.3 Mtoe, Anaerobic Digestion (biomethane) with 4.5Mtoe and gasification + methanol with 2.9 Mtoe. Almost all the other pathways are above or near the 1 Mtoe of capacity as well, and the total EU production capacity is expected to reach 48.5 Mtoe, oversupplying the total demand target by almost 2 Mtoe.

Task 4 carried out a Gap Analysis, with the objective to propose an additional production capacity growth, able to fulfil the 2030 gap without the need of biofuels imports. One of the main assumptions for this activity was that some of the production pathways – namely FAME, HVO/HEFA, ATJ and Conventional Ethanol – wouldn't be involved in this additional growth, that would instead impact on the remaining pathways, today less developed. This led to a somehow different composition of the overall EU capacity, as summarized in Figure 3-1; the expected increase in production capacity for the various pathways is reported in a more detailed way in Figure 3-2, where FF55 RED scenario results are compared with FF55 RED ExtCap scenario, and in Figure 3-3, where FF55 ESR RITA scenario results are compared with FF55 ESR RITA ExtCap scenario.

Figure 3-2 shows that – in the FF55 RED ExtCap scenario – Biomethane from anaerobic digestion pathway is expected to have by far the highest growth in absolute values, with a more than four times increase when compared to FF55 RED scenario. Advanced ethanol production capacity is expected to grow more than three-fold, while all the other pathways are expected to increase even more than five-fold but reaching much lower absolute values. Looking at the repartition of such projected increases across the sub-sectors, the highest increases could be found in the road one – as expected – since it was the sector with the higher projected gap, when compared to the expected biofuels demand (provided by Task 1). The highest absolute growth in road regards the Biomethane from anaerobic digestion pathway, that concentrates there almost all its additional capacity; the highest growth ratios are instead reported for gasification + SNG, RENFUEL, pyrolysis and HTL. HVO and FAME pathways are expected too to have a little growth in capacity for the road sector, balanced by a similar decrease in the shipping sector (where gasification + methanol has the highest expected increase with more than 1 Mtoe). Aviation experiences only small changes of 0.1-0.3 Mtoe for advanced ethanol, gasification + FT and pyrolysis pathways.

3.2. Overall energy Contribution

For the evaluation of this KPI, it is assumed that the projected EU production capacity is put to use up to the maximum, in order to fulfil the demand for biofuels set by PRIMES model in Task 1 for the three selected scenarios.

Table 3-1 and Table 3-2 below report the overall figures obtained for the three Import scenarios – respectively for year 2030 and year 2050 – divided among the various pathways and among the three sub-sectors of road, aviation, and shipping. Additionally, whenever required, the volumes of imported biofuels are shown as well. The distribution of the biofuels volumes expected to be produced by each pathway among the three transport sub-sectors is based on the information provided by Task 3 and Task 4.

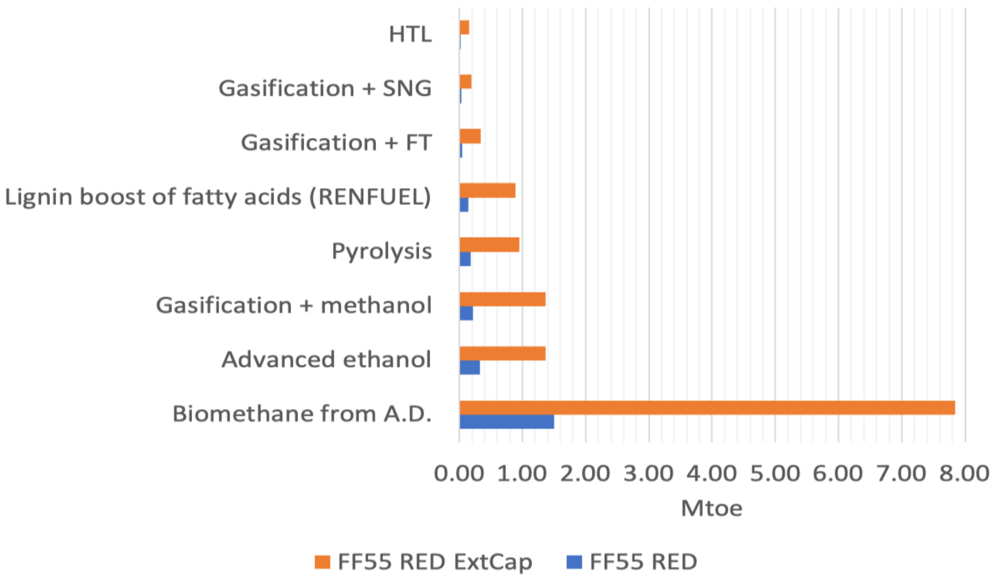


Figure 3-2 Comparison of the main expected production capacity variations between FF55 RED scenario and FF55 RED ExtCap scenario in 2030

Figure 3-3 reports similar results, this time related to FF 55 ESR RITA and FF 55 ESR RITA ExtCap scenarios, for 2030. The overall trends are similar to the ones already reported, regarding the difference between FF55 RED and FF55 RED ExtCap scenarios, only with higher absolute values. This is related to the fact that in the FF55 ESR RITA scenario the gap between expected demand and production capacity is higher than in the FF55 RED one.

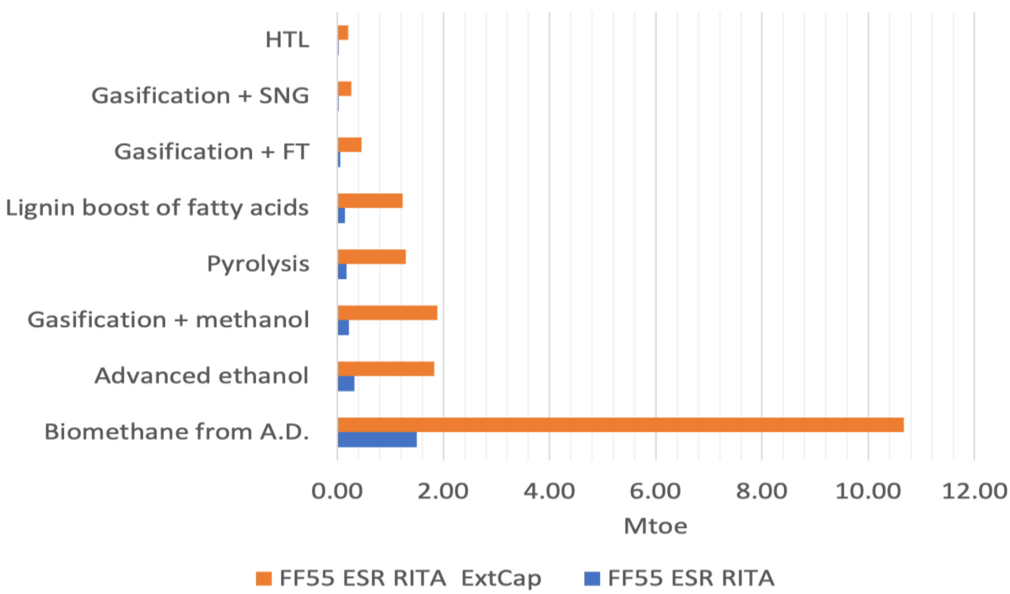


Figure 3-3 Comparison of the main expected production capacity variations between FF55 ESR RITA scenario and FF55 ESR RITA ExtCap scenario in 2030

		FF55 RED - 2030				FF55 ESR RITA - 2030				RePower* - 2030			
		TOT	Road	Aviation	Shipping	TOT	Road	Aviation	Shipping	TOT	Road	Aviation	Shipping
	PRIMES Target Values	*38,1*	*33,0*	*2,2*	*2,9*	*42,8*	*37,6*	*2,2*	*3,0*	*23,4*	*19,1*	*1,9*	*2,4*
Production Pathways	Transesterification of food/feed crops	5,1	4,9	0,0	0,3	5,1	4,9	0,0	0,3	5,1	4,9	0,0	0,3
	Hydrotreatment of food/feed crops	5,3	5,3	0,0	0,0	5,3	5,3	0,0	0,0	5,3	5,3	0,0	0,0
	Ethanol fermentation of food/feed crops	3,7	3,7	0,0	0,0	3,7	3,7	0,0	0,0	3,7	3,7	0,0	0,0
	Biomethane from anaerobic digestion	1,5	0,5	0,0	1,1	1,5	0,5	0,0	1,1	1,5	0,5	0,0	1,1
	Transesterification of Annex IX-A feedstock	1,5	1,4	0,0	0,1	1,5	1,4	0,0	0,1	1,5	1,4	0,0	0,1
	Transesterification of intermediate crops	2,8	2,7	0,0	0,1	2,8	2,7	0,0	0,1	2,8	2,7	0,0	0,1
	Hydrotreatment of tall oil	0,2	0,1	0,1	0,0	0,2	0,1	0,1	0,0	0,2	0,1	0,1	0,0
	Hydrotreatment of intermediate crops	2,4	1,5	0,7	0,2	2,4	1,5	0,7	0,2	2,4	1,5	0,7	0,2
	Lignin boost of fatty acids (RENFUEL)	0,1	0,0	0,0	0,1	0,1	0,0	0,0	0,1	0,1	0,0	0,0	0,1
	Advanced ethanol	0,3	0,3	0,0	0,0	0,3	0,3	0,0	0,0	0,3	0,3	0,0	0,0
	ATJ	0,1	0,0	0,1	0,0	0,1	0,0	0,1	0,0	0,1	0,0	0,1	0,0
	Gasification + methanol	0,2	0,0	0,0	0,2	0,2	0,0	0,0	0,2	0,2	0,0	0,0	0,2
	Gasification + SNG	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Gasification + FT	0,1	0,0	0,1	0,0	0,1	0,0	0,1	0,0	0,1	0,0	0,1	0,0
	Pyrolysis	0,2	0,1	0,1	0,1	0,2	0,1	0,1	0,1	0,2	0,1	0,1	0,1
	HTL	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Transesterification of UCO and AF	2,2	2,1	0,0	0,1	2,2	2,1	0,0	0,1	2,2	2,1	0,0	0,1
	Hydrotreatment of UCO and AF	1,6	0,9	0,5	0,2	1,6	0,9	0,5	0,2	1,6	0,9	0,5	0,2
Import**	HVO	1,2	1,2	0,0	0,0	1,8	1,8	0,0	0,0	-1,8	-1,8	0,0	0,0
	FAME	1,7	1,7	0,0	0,0	2,5	2,5	0,0	0,0	-2,5	-2,5	0,0	0,0
	Advanced ethanol	6,7	6,7	0,0	0,0	9,9	9,9	0,0	0,0	0,0	0,0	0,0	0,0
	SAF	0,7	0,0	0,7	0,0	0,7	0,0	0,7	0,0	0,4	0,0	0,4	0,0
	Shipping	0,4	0,0	0,0	0,4	0,5	0,0	0,0	0,5	-0,1	0,0	0,0	-0,1
TOTAL		**38,1**	**33,0**	**2,2**	**2,9**	**42,8**	**37,6**	**2,2**	**3,0**	**23,4**	**19,1**	**1,9**	**2,4**

* The overall energy contribution in the RePower scenario takes into account also the technical margin (defined as the difference between the production capacity and the expected demand) for eventual exports.

** Negative values of Import figures represent biofuels volumes available for Export

Table 3-1 Projected contribution of the various production pathways (and import) to the expected biofuels demand in 2030 for the three Import scenarios (Mtoe)

		FF55 RED - 2050			
		TOT	Road	Aviation	Shipping
	PRIMES Target Values	*46,8*	*7,1*	*15,9*	*23,8*
Production Pathways	Transesterification of food/feed crops	5,1	0,3	0,0	4,9
	Hydrotreatment of food/feed crops	5,3	5,3	0,0	0,0
	Ethanol fermentation of food/feed crops	0,0	0,0	0,0	0,0
	Biomethane from anaerobic digestion	4,5	0,0	0,0	4,5
	Transesterification of Annex IX-A feedstock	1,5	0,1	0,0	1,4
	Transesterification of intermediate crops	2,8	0,1	0,0	2,7
	Hydrotreatment of tall oil	0,4	0,0	0,1	0,3
	Hydrotreatment of intermediate crops	5,4	0,3	1,6	3,5
	Lignin boost of fatty acids (RENFUEL)	0,7	0,2	0,0	0,5
	Advanced ethanol	0,0	0,0	0,0	0,0
	ATJ	7,7	0,0	7,7	0,0
	Gasification + methanol	2,9	0,0	0,0	2,9
	Gasification + SNG	0,7	0,0	0,0	0,7
	Gasification + FT	5,3	0,0	4,5	0,8
	Pyrolysis	0,8	0,0	0,4	0,4
	HTL	1,7	1,0	0,2	0,5
	Transesterification of UCO and AF	2,2	0,1	0,0	2,1
	Hydrotreatment of UCO and AF	1,6	0,1	0,5	1,0
Import	HVO	0,0	0,0	0,0	0,0
	FAME	0,0	0,0	0,0	0,0
	Advanced ethanol	0,0	0,0	0,0	0,0
	SAF	1,0	0,0	1,0	0,0
	Shipping	0,0	0,0	0,0	0,0
TOTAL		**48,5**	**7,4**	**15,9**	**26,2**

Table 3-2 Projected contribution of the various production pathways (and import) to the expected biofuels demand in 2050 for the F55 RED scenario (Mtoe)

Similarly, Table 3-3 report the overall figures obtained for the two Extended Capacity scenarios for year 2030; there import is not shown since the expected gap between demand and production capacity is projected to be filled by an additional capacity increase.

	FF55 RED ExtCap - 2030				FF55 ESR RITA ExtCap - 2030			
	TOT	Road	Aviation	Shipping	TOT	Road	Aviation	Shipping
PRIMES Target Values	*38,1*	*33,0*	*2,2*	*2,9*	*42,8*	*37,6*	*2,2*	*3,0*
Transesterification of food/feed crops	5,1	5,1	0,0	0,0	5,1	5,1	0,0	0,0
Hydrotreatment of food/feed crops	5,3	5,3	0,0	0,0	5,3	5,3	0,0	0,0
Ethanol fermentation of food/feed crops	3,7	3,7	0,0	0,0	3,7	3,7	0,0	0,0
Biomethane from anaerobic digestion	7,8	6,8	0,0	1,1	10,7	9,9	0,0	0,8
Transesterification of Annex IX-A feedstock	1,5	1,5	0,0	0,0	1,5	1,5	0,0	0,0
Transesterification of intermediate crops	2,8	2,8	0,0	0,0	2,8	2,8	0,0	0,0
Hydrotreatment of tall oil	0,2	0,1	0,1	0,0	0,2	0,1	0,1	0,0
Hydrotreatment of intermediate crops	2,4	1,6	0,7	0,0	2,4	1,9	0,5	0,0
Lignin boost of fatty acids (RENFUEL)	0,9	0,8	0,0	0,1	1,2	1,1	0,0	0,1
Advanced ethanol	1,4	1,2	0,1	0,0	1,8	1,6	0,2	0,0
ATJ	0,1	0,0	0,1	0,0	0,1	0,0	0,1	0,0
Gasification + methanol	1,4	0,0	0,0	1,4	1,9	0,0	0,0	1,9
Gasification + SNG	0,2	0,2	0,0	0,0	0,3	0,2	0,0	0,0
Gasification + FT	0,3	0,0	0,3	0,0	0,5	0,0	0,5	0,0
Pyrolysis	0,9	0,6	0,3	0,1	1,3	0,8	0,5	0,0
HTL	0,2	0,1	0,0	0,0	0,2	0,2	0,0	0,0
Transesterification of UCO and AF	2,2	2,2	0,0	0,0	2,2	2,2	0,0	0,0
Hydrotreatment of UCO and AF	1,6	1,1	0,5	0,0	1,6	1,1	0,5	0,0
TOTAL	**38,1**	**33,0**	**2,2**	**2,9**	**42,8**	**37,6**	**2,2**	**3,0**

Table 3-3 Projected contribution of the various production pathways (and import) to the expected biofuels demand in 2030 for the two Extended Capacity scenarios (Mtoe)

Figure 3-4 highlights the distribution of the biofuels volumes – as produced by the various pathways – among the three subsectors, in year 2030 and for the central FF55 RED scenario.

The first thing to be noticed is that the gap between production capacity and demand – in bright red in the graph – is distributed across the three sub-sectors; the biggest share, around 9.5 Mtoe, is attributed to the road sector, while aviation and shipping are attributed for a gap respectively of 0.7 Mtoe and 0.4 Mtoe

The HVO/HEFA pathway is expected to be the biggest contributor in the aviation sector, and second just to FAME in road. Biomethane from anaerobic digestion pathway is the biggest contributor in the shipping sector followed by FAME and HVO pathways. The other contributors in all the subsectors are far smaller in absolute terms, and the sum of their contributions remain under the 10% share threshold.

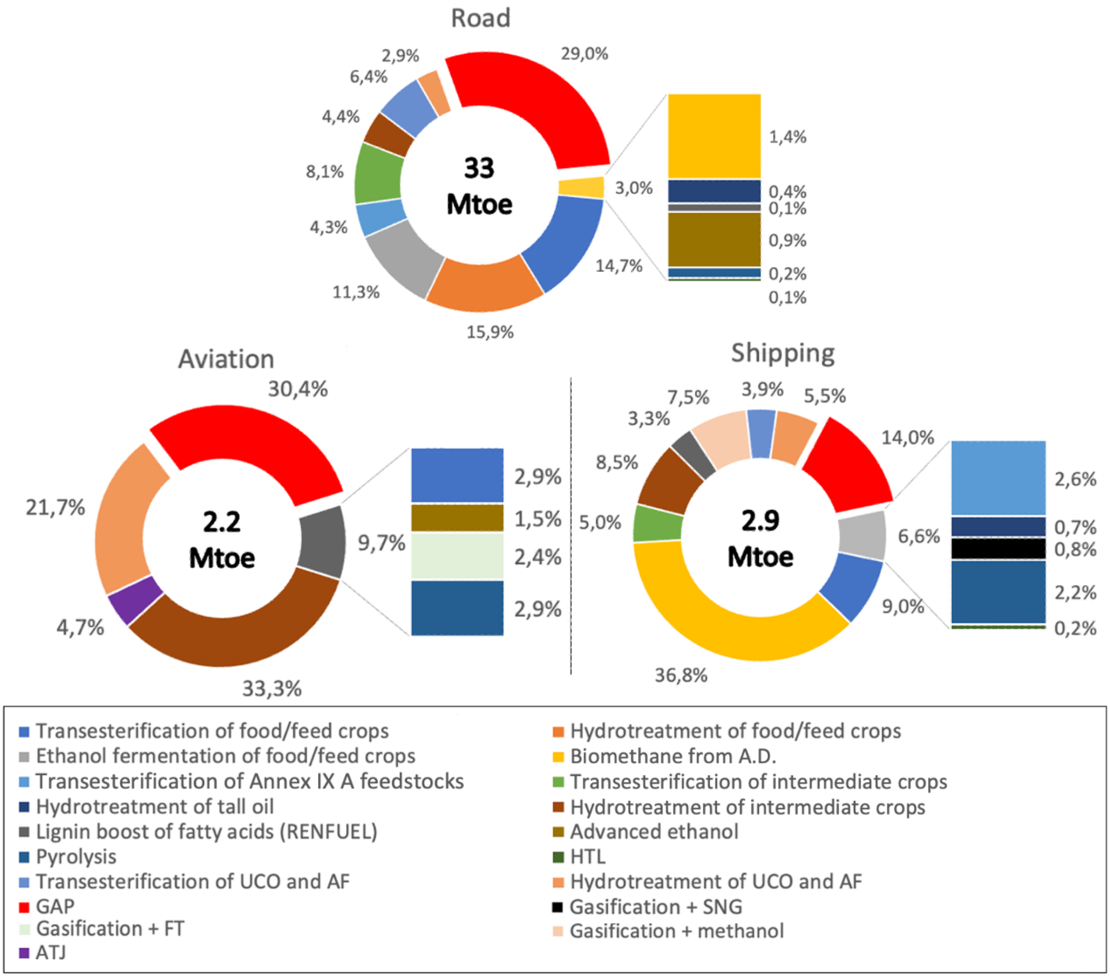


Figure 3-4 Shares of the final use of the projected EU production capacity of the various pathways for the FF55 RED scenario in 2030 (in the centre of each cake graph is reported the projected biofuels demand for the specific subsector)

Similarly, Figure 3-5 shows the distribution of the biofuels volumes as produced by the various pathways among the three subsectors, in year 2050 and for the FF55 RED scenario.

The distribution of the demand across the sectors changes quite importantly, with the total demand from the road sector shrinking and the other two greatly expanding. As already explained before, the projected production capacity is mostly expected to be able to meet the demand for that period; only in the aviation sector a 1 Mtoe gap is projected.

FAME and HVO are still expected to cover most of the road sector biofuels demand, but new pathways such as HTL and RENFUEL will grow as well.

Quite an important change is expected in the composition of the biofuel mix in the aviation sector, with the majority share coming from ATJ pathway, followed by gasification + FT and then HEFA, almost stable on 2030 volumes.

Finally, maritime sector projections show a steep increase in the contribution of FAME, HVO, Biomethane from anaerobic digestion and gasification + Methanol/DME pathways, that together are expected to cover almost 90% of the 2050 sectorial demand.

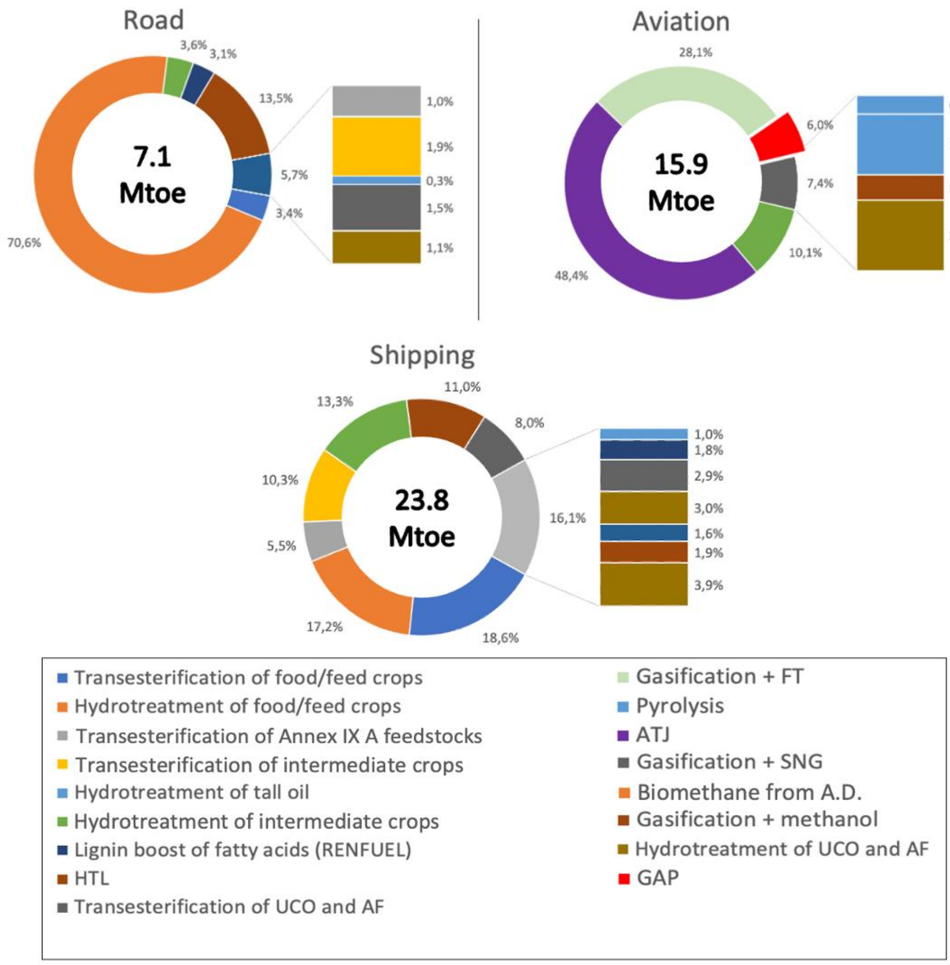


Figure 3-5 Shares of the final use of the projected EU production capacity of the various pathways for the FF55 RED scenario in 2050 (in the centre of each cake graph is reported the projected biofuels demand for the specific subsector)

The expected biofuel mix in the FF55 ESR RITA scenario for 2030 is based on the same projected production capacity mix; the gap increases, due to the higher expected biofuel demand. Similar results are obtained also for the RePower scenario, with the difference that in that case only a small gap is present in the aviation sector, while the other two sectors are expected to be well covered by the projected production capacity.

The distribution of the additional increases in production capacity of the various pathways, as defined by Task 4 Gap Analysis to cover sub-sectorial gaps – and here analysed in the “Extended Capacity” scenarios is described in Figure 3-4, Figure 3-5 and in the related textual descriptions.

3.3. Share of total fuel demand

This KPI normalizes all the information provided by the overall energy contribution KPI against total fuel demand as projected by PRIMES model (from Task 1) in the various scenarios. Total fuel demand can be either at transport level or at sub-sector level, depending on the situation.

The Table 3-4 shows the total and sub-sectorial fuel demand in 2030 and 2050 for the three type of scenarios[26], as provided by Task 1 results.

	2030			2050
	FF55 RED	**FF55 ESR RITA**	**RePower**	**FF55 RED**
Transport - Total Fuel demand	312,7	322,6	301,0	197,4
Road - Total Fuel demand	214,5	223,5	203,1	92,3
Aviation - Total Fuel demand	43,5	44,3	43,5	45,5
Shipping - Total Fuel demand	54,8	54,8	54,8	59,6

Table 3-4 Total and sub-sectorial fuel demand in 2030 and 2050 for the three type of scenarios, as provided by Task 1 results

All the results are reported in the following Table 3-5, related to the three Import scenarios in year 2030, and in Table 3-6, highlighting the Import central scenario FF55 RED for year 2050. Table 3-7 then reports the results for the two Extended Capacity scenarios for year 2030.

[26]In this case the data is the same for both Import and Extended Capacity set of scenarios: what changes is the mix of EU production capacity and eventual import, not the overarching biofuels demand.

	FF55 RED				FF55 ESR RITA				RePower			
	TOT	Road	Aviation	Shipping	TOT	Road	Aviation	Shipping	TOT	Road	Aviation	Shipping
PRIMES Target Values	*12,2%*	*15,4%*	*5,0%*	*5,2%*	*13,3%*	*16,8%*	*5,0%*	*5,4%*	*7,8%*	*9,4%*	*4,3%*	*4,4%*
Transesterification of food/feed crops	1,6%	2,3%	0,0%	0,5%	1,6%	2,2%	0,0%	0,5%	1,7%	2,4%	0,0%	0,5%
Hydrotreatment of food/feed crops	1,7%	2,4%	0,0%	0,0%	1,6%	2,4%	0,0%	0,0%	1,7%	2,6%	0,0%	0,0%
Ethanol fermentation of food/feed crops	1,2%	1,7%	0,0%	0,0%	1,2%	1,7%	0,0%	0,0%	1,2%	1,8%	0,0%	0,0%
Biomethane from anaerobic digestion	0,5%	0,2%	0,0%	1,9%	0,5%	0,2%	0,0%	1,9%	0,5%	0,2%	0,0%	1,9%
Transesterification of Annex IX-A feedstock	0,5%	0,7%	0,0%	0,1%	0,5%	0,6%	0,0%	0,1%	0,5%	0,7%	0,0%	0,1%
Transesterification of intermediate crops	0,9%	1,3%	0,0%	0,3%	0,9%	1,2%	0,0%	0,3%	0,9%	1,3%	0,0%	0,3%
Hydrotreatment of tall oil	0,1%	0,1%	0,1%	0,0%	0,1%	0,1%	0,1%	0,0%	0,1%	0,1%	0,1%	0,0%
Hydrotreatment of intermediate crops	0,8%	0,7%	1,7%	0,4%	0,7%	0,6%	1,6%	0,4%	0,8%	0,7%	1,7%	0,4%
Lignin boost of fatty acids (RENFUEL)	0,0%	0,0%	0,0%	0,2%	0,0%	0,0%	0,0%	0,2%	0,0%	0,0%	0,0%	0,2%
Advanced ethanol	0,1%	0,1%	0,1%	0,0%	0,1%	0,1%	0,1%	0,0%	0,1%	0,1%	0,1%	0,0%
ATJ	0,0%	0,0%	0,2%	0,0%	0,0%	0,0%	0,2%	0,0%	0,0%	0,0%	0,2%	0,0%
Gasification + methanol	0,1%	0,0%	0,0%	0,4%	0,1%	0,0%	0,0%	0,4%	0,1%	0,0%	0,0%	0,4%
Gasification + SNG	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Gasification + FT	0,0%	0,0%	0,1%	0,0%	0,0%	0,0%	0,1%	0,0%	0,0%	0,0%	0,1%	0,0%
Pyrolysis	0,1%	0,0%	0,1%	0,1%	0,1%	0,0%	0,1%	0,1%	0,1%	0,0%	0,1%	0,1%
HTL	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Transesterification of UCO and AF	0,7%	1,0%	0,0%	0,2%	0,7%	0,9%	0,0%	0,2%	0,7%	1,0%	0,0%	0,2%
Hydrotreatment of UCO and AF	0,5%	0,4%	1,1%	0,3%	0,5%	0,4%	1,1%	0,3%	0,5%	0,5%	1,1%	0,3%
IMPORT - HVO	0,4%	0,6%	0,0%	0,0%	0,5%	0,8%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
IMPORT - FAME	0,5%	0,8%	0,0%	0,0%	0,8%	1,1%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
IMPORT - Advanced ethanol	2,1%	3,1%	0,0%	0,0%	3,1%	4,4%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
IMPORT - SAF	0,2%	0,0%	1,5%	0,0%	0,2%	0,0%	1,6%	0,0%	0,1%	0,0%	0,8%	0,0%
IMPORT - Shipping	0,1%	0,0%	0,0%	0,7%	0,2%	0,0%	0,0%	0,9%	0,0%	0,0%	0,0%	0,0%

Table 3-5 Projected share of total fuels demand of the various production pathways (and import) in 2030 for the three Import scenarios

	FF55 RED			
	TOT	Road	Aviation	Shipping
PRIMES Target Values	23,7%	7,7%	34,9%	40,0%
Transesterification of food/feed crops	2,6%	0,3%	0,0%	8,2%
Hydrotreatment of food/feed crops	2,7%	5,7%	0,0%	0,0%
Ethanol fermentation of food/feed crops	0,0%	0,0%	0,0%	0,0%
Biomethane from anaerobic digestion	2,3%	0,0%	0,0%	7,6%
Transesterification of Annex IX-A feedstock	0,8%	0,1%	0,0%	2,4%
Transesterification of intermediate crops	1,4%	0,2%	0,0%	4,5%
Hydrotreatment of tall oil	0,2%	0,0%	0,3%	0,5%
Hydrotreatment of intermediate crops	2,7%	0,3%	3,5%	5,9%
Lignin boost of fatty acids (RENFUEL)	0,4%	0,3%	0,0%	0,8%
Advanced ethanol	0,0%	0,0%	0,0%	0,0%
ATJ	3,9%	0,0%	16,9%	0,0%
Gasification + methanol	1,5%	0,0%	0,0%	4,8%
Gasification + SNG	0,4%	0,0%	0,0%	1,3%
Gasification + FT	2,7%	0,0%	9,8%	1,3%
Pyrolysis	0,4%	0,0%	0,9%	0,7%
HTL	0,8%	1,1%	0,4%	0,8%
Transesterification of UCO and AF	1,1%	0,1%	0,0%	3,5%
Hydrotreatment of UCO and AF	0,8%	0,1%	1,0%	1,7%
TOTAL	24,6%	8,1%	32,9%	43,9%
IMPORT	0,0%	0,0%	2,1%	0,0%

Table 3-6 Projected share of total fuels demand of the various production pathways (and import) for the FF55 RED scenario in 2050

	FF55 RED ExtCap				FF55 ESR RITA ExtCap			
	TOT	Road	Aviation	Shipping	TOT	Road	Aviation	Shipping
PRIMES Target Values	*12.2%*	*15.4%*	*5.0%*	*5.2%*	*13.3%*	*16.8%*	*5.0%*	*5.4%*
Transesterification of food/feed crops	1.6%	2.4%	0.0%	0.1%	1.6%	2.3%	0.0%	0.1%
Hydrotreatment of food/feed crops	1.7%	2.4%	0.0%	0.0%	1.6%	2.4%	0.0%	0.0%
Ethanol fermentation of food/feed crops	1.2%	1.7%	0.0%	0.0%	1.2%	1.7%	0.0%	0.0%
Biomethane from anaerobic digestion	2.5%	3.2%	0.0%	2.0%	3.3%	4.4%	0.0%	1.5%
Transesterification of Annex IX-A feedstock	0.5%	0.7%	0.0%	0.0%	0.5%	0.7%	0.0%	0.0%
Transesterification of intermediate crops	0.9%	1.3%	0.0%	0.1%	0.9%	1.3%	0.0%	0.0%
Hydrotreatment of tall oil	0.1%	0.1%	0.1%	0.0%	0.1%	0.1%	0.1%	0.0%
Hydrotreatment of intermediate crops	0.8%	0.8%	1.7%	0.1%	0.7%	0.9%	1.1%	0.0%
Lignin boost of fatty acids (RENFUEL)	0.3%	0.4%	0.0%	0.2%	0.4%	0.5%	0.0%	0.2%
Advanced ethanol	0.4%	0.6%	0.3%	0.0%	0.6%	0.7%	0.4%	0.0%
ATJ	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.2%	0.0%
Gasification + methanol	0.4%	0.0%	0.0%	2.5%	0.6%	0.0%	0.0%	3.4%
Gasification + SNG	0.1%	0.1%	0.0%	0.1%	0.1%	0.1%	0.0%	0.0%
Gasification + FT	0.1%	0.0%	0.8%	0.0%	0.1%	0.0%	1.0%	0.0%
Pyrolysis	0.3%	0.3%	0.8%	0.1%	0.4%	0.4%	1.0%	0.1%
HTL	0.0%	0.1%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%
Transesterification of UCO and AF	0.7%	1.0%	0.0%	0.0%	0.7%	1.0%	0.0%	0.0%
Hydrotreatment of UCO and AF	0.5%	0.5%	1.1%	0.1%	0.5%	0.5%	1.1%	0.0%

Table 3-7 Projected share of total fuels demand of the various production pathways (and import) in 2030 for the two Extended Capacity scenarios

3.4. GHG savings

With the goal of determining key performance indicators (KPIs) pertaining to greenhouse gases (GHGs), the energy demand scenario from the previous tasks was used (in particular from the task 4).

As described in the methodology section (3.5.1), a meticulous evaluation of the average Carbon Intensity (CI) was conducted across a spectrum of transportation modes, taking into account the pertinent feedstock-to-fuel pathways. The proposed aggregation for the biofuels pathways finally allowed to determine the average carbon intensity (CI) per each transport mode. The results for nearly 500 value chains were gathered in a comprehensive table, of which an extract is shown in Table 3-8.

By defining a hypothetical scenario where the entire energy demand is met by conventional fossil fuels, characterized by a CI of 94.1 gCO2eq/MJ, the GHG mitigation potential that accompanies the adoption of alternative fuels was quantified.

In order to determine the resulting average GHG for the whole transport sector, the energy demand associated with eFuels (RFNBOs), and electricity have been derived from the PRIMES results from Task 1. The assumptions on GHG emission factors for eFuels and electricity are described in the methodology section.

Feedstock_Category	Process	Sector	Emission Factor [gCO2eq/MJ]
Animal_liquid_manure	Biomethane from anaerobic digestion	SHIPPING	-31.3
Animal_liquid_manure	Biomethane from anaerobic digestion	ROAD	-56.6
Animal_solid_manure	Biomethane from anaerobic digestion	SHIPPING	-31.3
Animal_solid_manure	Biomethane from anaerobic digestion	ROAD	-56.6
Cover_crop_ligno	Advanced ethanol	AVIATION	36.1
Cover_crop_ligno	Advanced ethanol	ROAD	32.1
Cover_crop_ligno	Alcohol to Jet (ATJ)	AVIATION	43.4
Cover_crop_ligno	Gasification + SNG	SHIPPING	28.6
Cover_crop_ligno	Gasification + SNG	ROAD	24.3
Cover_crop_ligno	Gasification + methanol/DME	SHIPPING	16.2
	…		
Woody_crops_unused_land	Gasification + methanol/DME	SHIPPING	16.2
Woody_crops_unused_land	Gasification + methanol/DME	ROAD	16.2
Woody_crops_unused_land	Gasification +FT	AVIATION	10.4
Woody_crops_unused_land	Gasification +FT	SHIPPING	14.0
Woody_crops_unused_land	Gasification +FT	ROAD	14.0
Woody_crops_unused_land	HTL	AVIATION	30.1
Woody_crops_unused_land	HTL	SHIPPING	30.1
Woody_crops_unused_land	HTL	ROAD	30.1
Woody_crops_unused_land	Pyrolysis	AVIATION	26.6
Woody_crops_unused_land	Pyrolysis	SHIPPING	26.6
Woody_crops_unused_land	Pyrolysis	ROAD	26.7

Table 3-8 Excerpt of the GHG emission intensity values for the value chains analysed. The original table contains nearly 500 value chains

The GHG saving analysis was performed for the three scenarios provided by the PRIMES model in Task 1 (namely, the *FF55 RED*, *FF55 ESR RITA* and the *Repower* scenarios), reflecting different policy frameworks, and assumptions. 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* 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 a single scenario was studied. Table 3-9 provides a summary of the scenarios investigated.

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
	Extended Capacity	FF55 ESR RITA ExtCap	2030
Repower	(biofuel demand is met internally)	Repower	2030

Table 3-9 Summary of the scenarios investigated in the GHG saving analysis

A summary of the KPIs is reported in Table 3-10 for all scenarios and gap-fill strategies[27]. It can be noticed that, for all the scenarios, the GHG_I_R% shows good agreement with the aggregated results from Task 1. Moreover, the carbon intensity of the transport energy mix in 2030 remains close to the reference fossil fuel values ($94\ gCO_2/MJ$), due to the permanence of high shares of fossil fuels. The projections of emissions change notably for 2050 (shown in the *FF55 RED* scenario), when a large penetration of alternative fuels in all the transport segments leads to a much lower CI factor. Table 3-10 highlights the specific contribution that biofuels can provide, resulting in relevant GHG savings (GHG_S_Bf) across all the scenarios, ranging from 70 to 133 $MtCO_{2eq}$ in 2030.

Scenario	Gap fill strategy	Year	GHG_S	GHG_S_Bf	AVG_CI	GHG_I_R %
FF55 RED	Import	2030	168	112	84	-14%
		2050	923	151	19	-86%
	Expand	2030	174	118	83	-14%
FF55 ESR RITA	Import	2030	255	126	80	-20%
	Expand	2030	262	133	80	-20%
Repower	-	2030	193	70	83	-16%

Table 3-10 Main GHG saving KPIs for the scenarios under study. GHG_S: Total GHG saving for the whole scenario (MtCO2eq) associated with alternative fuels; GHG_S_Bf: Specific contribution of alternative fuels (MtCO2eq); AVG_CI: Average Carbon Intensity of the fuels and energy carrier used for transport sector (gCO2eq/MJ); GHG_I_R%: GHG intensity reduction (%)

[27] For a description of KPIs see the methodology section.

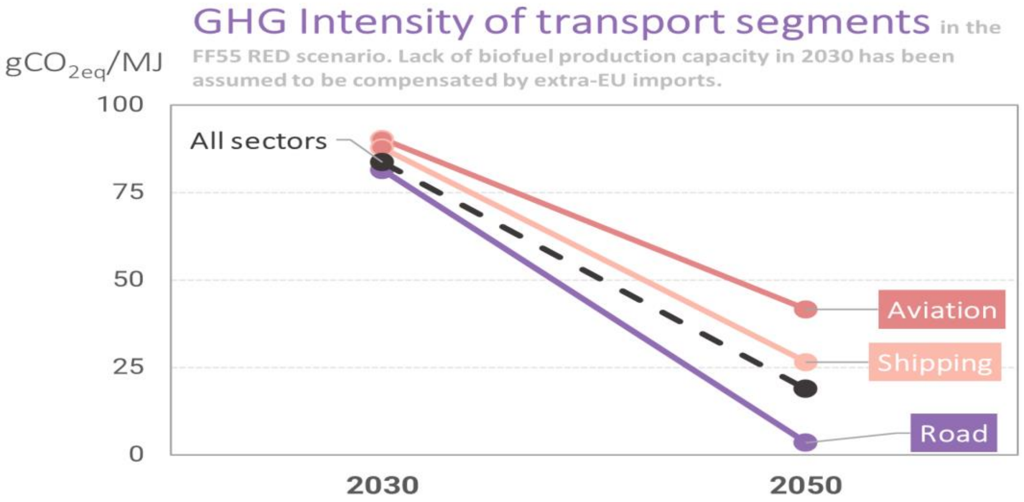


Figure 3-6 GHG intensity of the fuel mix in the transport segment for the FF55 RED ExtCap scenario

A detailed discussion of the results is presented in the following sections for each scenario. For the *FF55 RED* scenario, results are shown for 2030 and 2050, whereas for all the other scenarios results are limited to 2030, in line with the assumptions made for this study.

It must be noticed that negligible differences were observed between the two gap-fill strategies (i.e., *Import* and *Extended Capacity*) for what concern the GHG emissions profiles (see Figure 3-7 for a comparison of the two strategies for the *FF55 RED* scenario). This is also related to the modelling choices made for the *Import* strategy, where it was assumed that the GHG intensity of imported biofuels equal to that of the same biofuel produced in EU production. There are two reasons underpinning this choice: the first is that imported biofuels, just like those produced in Europe, must respect the same GHG threshold in order to be eligible in the EU27. Moreover, the stage which usually has the highest impact on upstream GHG emissions of biofuels is the agricultural phase, and a significant share of the internal EU production is supplied by imported feedstock, often from the same regions that were assumed for the import of the final fuels. Therefore, it would be unnecessary to create a specific set of GHG factors, also considering the uncertainties involved, for the imported final product.

To avoid redundancies, it was chosen to show only the results for the *Import* strategy. The *Extended* Capacity and *Imports* strategies are further compared in section 3.4.4.

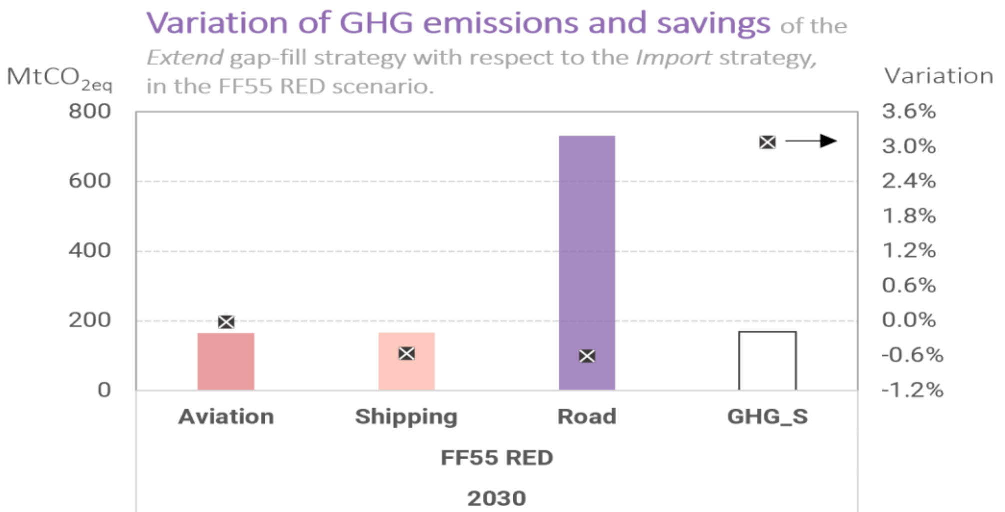
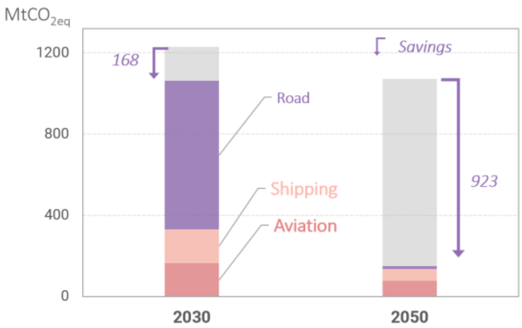


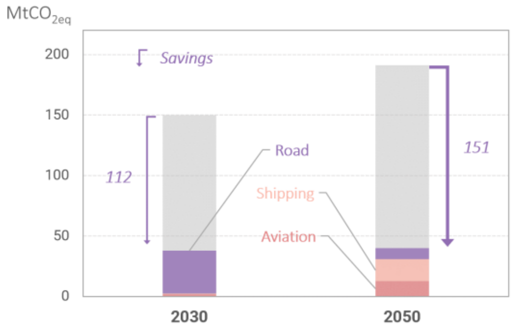
Figure 3-7 Impact of the gap-fill strategy on the GHG emissions results. The calculated savings are roughly 3% higher in the *Extended Capacity* scenario; the difference is therefore negligible

3.4.1. FF55 RED

Figure 3-8 a) shows the GHG emissions of the transport sector in the specific scenario, subdivided per each transport segment. It can be noted that in 2030 the road sector remains the most impactful among the various transport segments, while in 2050 aviation and shipping are expected to be the largest contributors, mainly due to persisting fossil shares and the concurrent expected decarbonisation/electrification of the road segment. In 2030, the GHG emission savings related to the use of the alternative fuels is around 168 $MtCO_{2eq}$, while in 2050 the large deployment of alternative technologies raises this figure up to 923 $MtCO_2eq$.



a)



b)

Figure 3-8 GHG emissions and emission savings in the FF55 RED scenario. a) contribution from all alternative fuels, b) contribution from biofuels

Biofuels represent a significant driver of emissions reduction in 2030 (Figure 3-8 b), accounting for nearly 112 $MtCO_{2eq}$ avoided emissions, while their role is less pronounced in 2050, when they account for 151 of the 923 $MtCO_{2eq}$. In 2030, virtually all the biofuels are fed to the road segment, whereas in 2050 the biofuel demand passes almost entirely to the shipping and aviation segment, while road transport should be almost entirely electrified.

It is worth observing that the higher emissions reduction achieved in 2050 with biofuels is not solely related to a major uptake of these alternative fuels: the demand increases by 23% with respect to 2030, whereas emission savings are 36% higher. The reason underlying this apparent discrepancy depends on the shift towards biofuels mixes to more performant value chains (i.e., higher use of waste-derived alternative fuels, etc.).

In 2030, the biofuels mix for the road sector is dominated by FAME, Advanced ethanol and HVO fuels; the first two being characterized by a higher emission factor, compared to the latter. As the biofuels uptake is shifted towards the aviation and shipping segments, the biofuels mix begins to include “cleaner” production pathways, such as biomethane from anaerobic digestion for shipping and waste based HEFA, ATJ and FT biokerosene for aviation.

The discussion of the scenario is concluded with an overview of the contribution of different alternative fuels to the decarbonisation of the road, shipping, and aviation sector. From Figure 3-9, it is clear that in 2030 biofuels are responsible for the largest share of emission savings for the road and shipping segment, while they represent the totality of the savings in aviation.

The picture notably changes in 2050, when the most part of emission savings in the road segment is delivered by eFuels and, especially, through electrification. As concerns the aviation and shipping segments, GHG savings are almost equally split between biofuels and eFuels, whereas electrification plays a minor role.

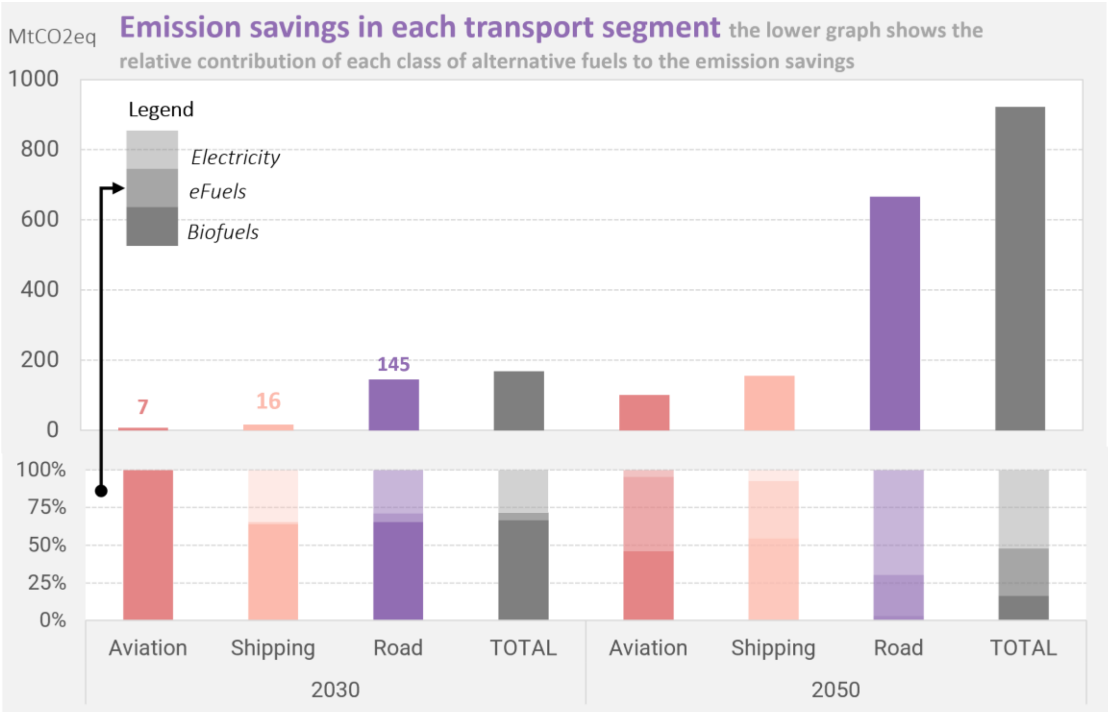


Figure 3-9 Emission savings for each transport segment and contribution of different classes of alternative fuels in the FF55 RED scenario

3.4.2. FF55 ESR RITA

In this scenario, the total emissions saving account for 254 $MtCO_{2eq}$ in 2030, of which 126 $MtCO_{2eq}$ are achieved with the introduction of biofuels (Figure 3-10). Also in this case, the largest part of emission savings is delivered by the deployment of alternative fuels in the road segment.

This scenario foresees a higher deployment of electric vehicles and eFuels in the road segment. The joint contribution of these two classes of alternative fuels is responsible for nearly 50% of the emissions savings, whereas the remaining portion is covered by biofuels (Figure 3-11).

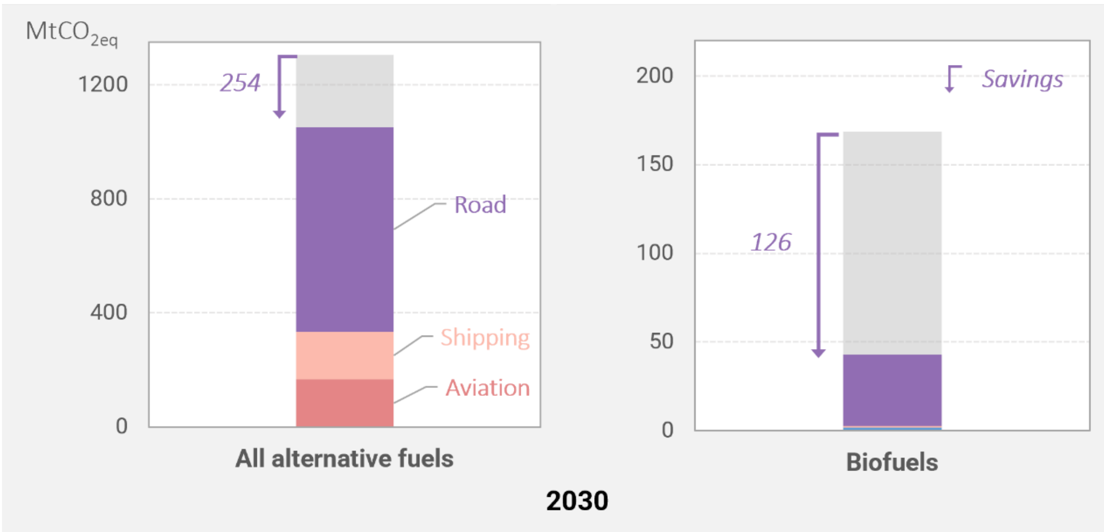


Figure 3-10 GHG emissions and emission savings in the FF5 ESR RITA scenario

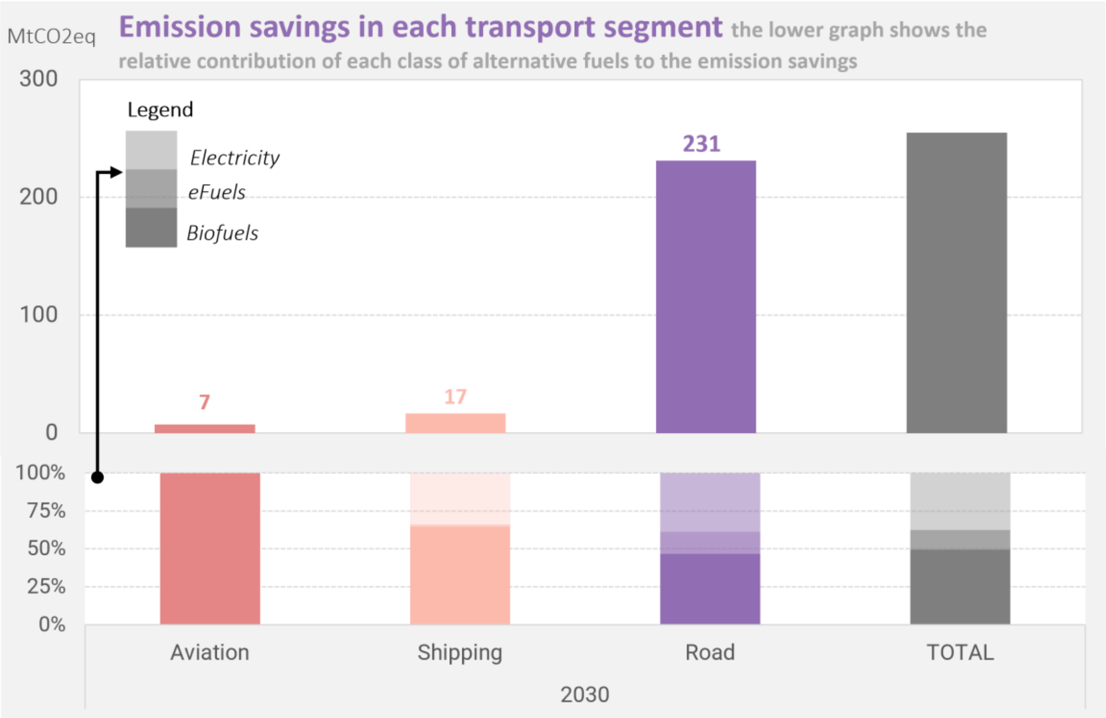


Figure 3-11 Emission savings for each transport segment and contribution of different classes of alternative fuels in the FF55 ESR RITA scenario

3.4.3. Repower

The last scenario analysed is the *Repower* one. In 2030 this scenario shows notable savings related to alternative fuels (193 gCO_{2eq}/MJ), although the contribution of biofuels is significantly lower than the in other ones (70 gCO_{2eq}/MJ) (Figure 3-12). This is due to the lower uptake of biofuels in this scenario, already highlighted in the previous chapters.

Similarly, to what observed in the *FF55 ESR RITA* scenario, more than 70% of the emissions reduction is attained with the introduction of eFuels and electricity in the road sector. As concerns the aviation segment, differently from what observed until now, eFuels are introduced in the energy mix, and contribute to nearly 20% of the emission savings (Figure 3-13).

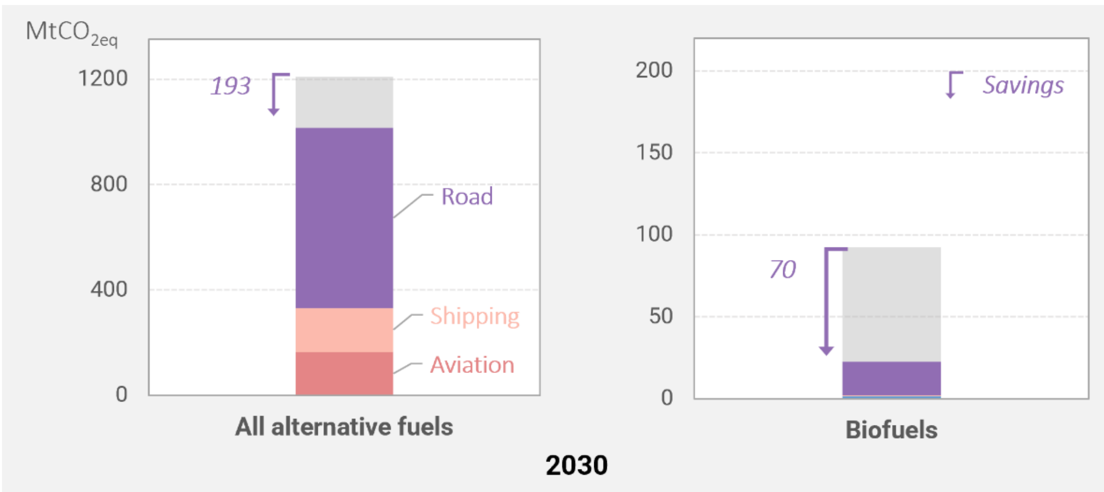


Figure 3-12 GHG emissions and emission savings in the Repower scenario

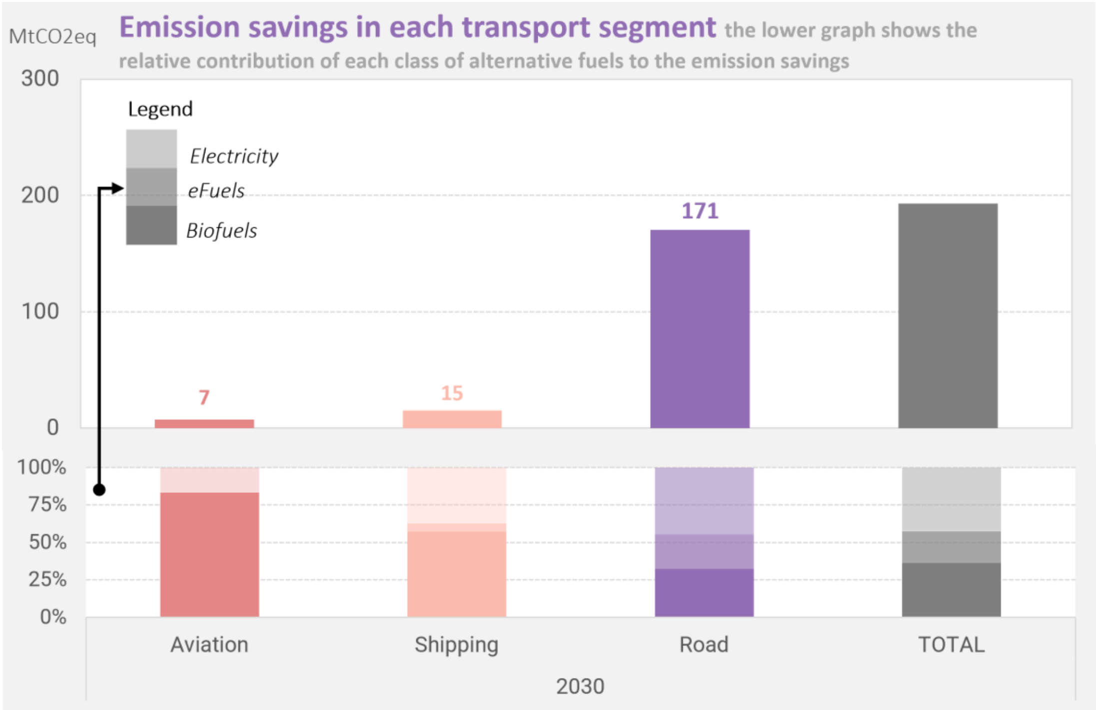


Figure 3-13 Emission savings for each transport segment and contribution of different classes of alternative fuels in the Repower scenario

3.4.4. Comparison of scenarios

The three scenarios analysed are characterized by a significantly different energy demand and mix for the transport sector, resulting in perceptible differences under the GHG emissions profile.

Figure 3-14 reports the KPIs for all the scenarios investigated, including the *Extended Capacity* gap-fill strategies. The difference between the *Import* and *Extended Capacity* scenarios is minimal. The *Extended Capacity* scenarios perform slightly better than the *Import* ones under the GHG savings profile. This is mainly due to the fact that, in the *Extended Capacity* scenario, the missing capacity is mostly filled with value chains presenting a low emission factor, in particular biomethane. For example, in the *FF55 RED* scenario the share of biomethane in the biofuel mix is 4.4%, whereas this figure reaches 10.8% in the *FF55 RED ExtCap* scenario.

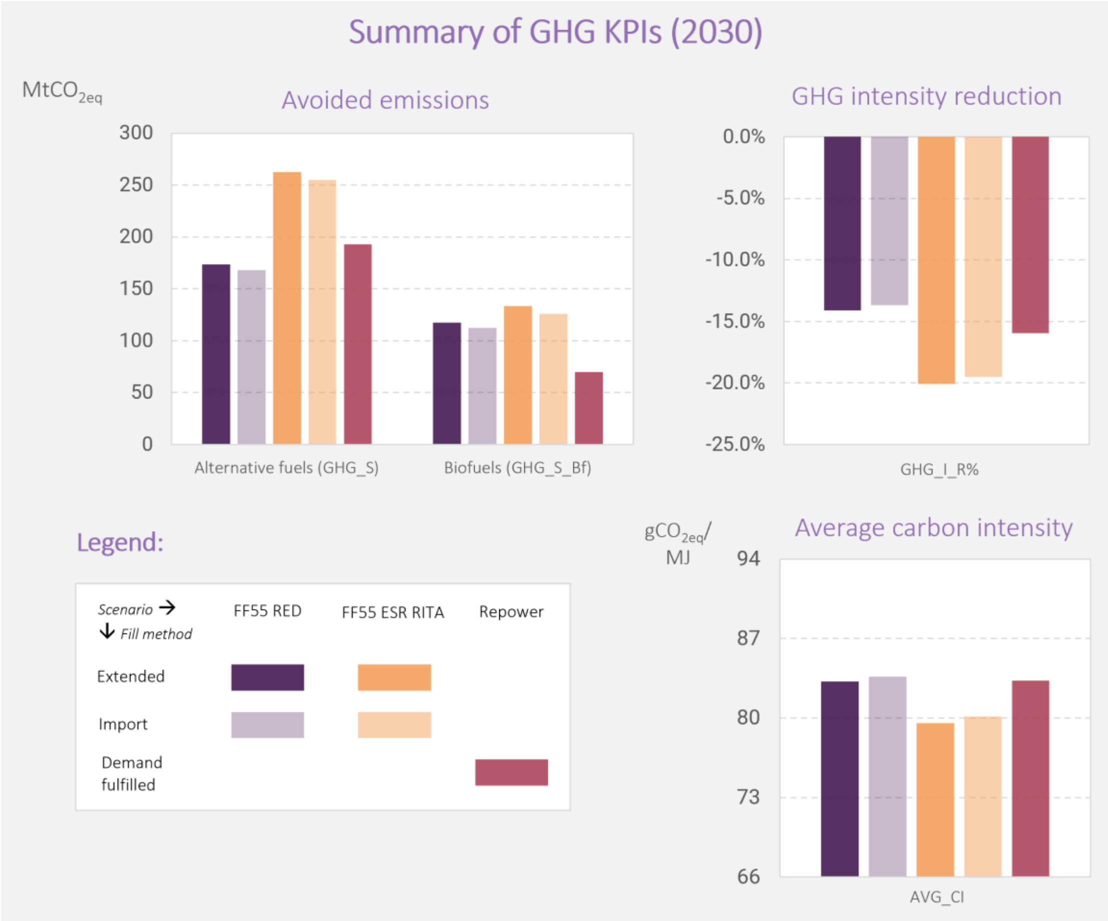


Figure 3-14 Summary of GHG KPIs in the different scenarios

The *FF55 ESR RITA* scenario shows the quantitatively highest avoided emissions, due to large deployment of both electrification and biofuels. However, it has to be highlighted that the overall emission savings from the FF55 ESR RITA scenario are larger in relation to the larger energy demand and qualitatively higher because for eFuels and hydrogen the GHG emissions are set to zero, regardless of the production chain. Clearly, such kind of 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., advance biofuels).

The *FF55 RED* scenario presents comparable savings related to biofuels uptake, although the lower diffusion of electrification leads to smaller avoided emissions overall, with respect to the *FF55 ESR RITA* scenario. The opposite situation is observed for the *Repower* scenario, where the contribution of biofuels to the emission savings is the lowest of the set, but where the remarkable uptake of electricity and eFuels leads to overall emission savings which are higher than in the *FF55 RED* scenario. The different strategies with which the scenarios attain the GHG emissions savings are summarized in Figure 3-15.

The upper-right corner of Figure 3-14 shows the GHG intensity reduction of the various scenarios. This KPI expresses the percentage saving attained with the substitution of fossil fuels with alternative fuels. Coherently with what can be observed for the avoided emissions, the *FF55 ESR RITA* scenario shows the highest reduction (nearly 20%). The *FF55 RED* and *Repower* scenarios settle to 14 and 16%, respectively. It is noted that the results obtained in this GHG saving analysis are fairly aligned with the aggregated values reported by Task 1. It is worth stressing that, the Carbon Intensity of the REDII default values represent a conservative figure. Actual values, resulting from the certification of real industrial processes, are significantly lower. This potentially has a direct impact on the quantitative GHG saving resulting from the use of such fuels. Moreover, these CI values are considered as stable overtime but innovations such as the use of green hydrogen and renewable electricity in the biofuels making are already happening, which would lower the Carbon Intensity of the MJ of finished fuel.

The lower-right corner of Figure 3-14 reports the average carbon intensity of the various scenarios. This KPI is computed considering all the fossil and alternative fuels used in the transport sector. The *FF55 ESR RITA* achieves the lowest carbon intensity (nearly 80 gCO_{2eq}/MJ), due to an energy mix presenting a high penetration of alternative fuels. For the *FF55 RED* and *Repower* scenarios the carbon intensity is slightly higher (84 and 83 gCO_2eq/MJ, respectively).

The high carbon intensity observed for the *Repower* scenario could appear counterintuitive, given the good performance of this scenario in the *GHG_S* KPI. However, Figure 3-15 shows that, despite the reduction of fossil fuel demand in the *Repower* scenario, the overall demands for the road, maritime and aviation sectors decrease even more, leading to a higher fossil fuel share with respect to the*FF55 ESR RITA* scenario. This explains why the average carbon intensity in the *Repower* scenario is comparable to that of the *FF55 RED* scenario.

Looking at Figure 3-16, it can be noted that the *FF55 RED* scenario attains the highest overall emissions of the set. Emissions are lower in the *FF55 ESR RITA* scenario, due to higher avoided emissions. However, the *FF55 ESR RITA* scenario also shows a higher total demand for the transport sector.

On the other hand, the *Repower* scenario shows the lowest overall emissions among the three. This is not only due to the relevant emissions savings attained in this scenario, but also by the combined effect of the lower overall energy demand in the transport sector.

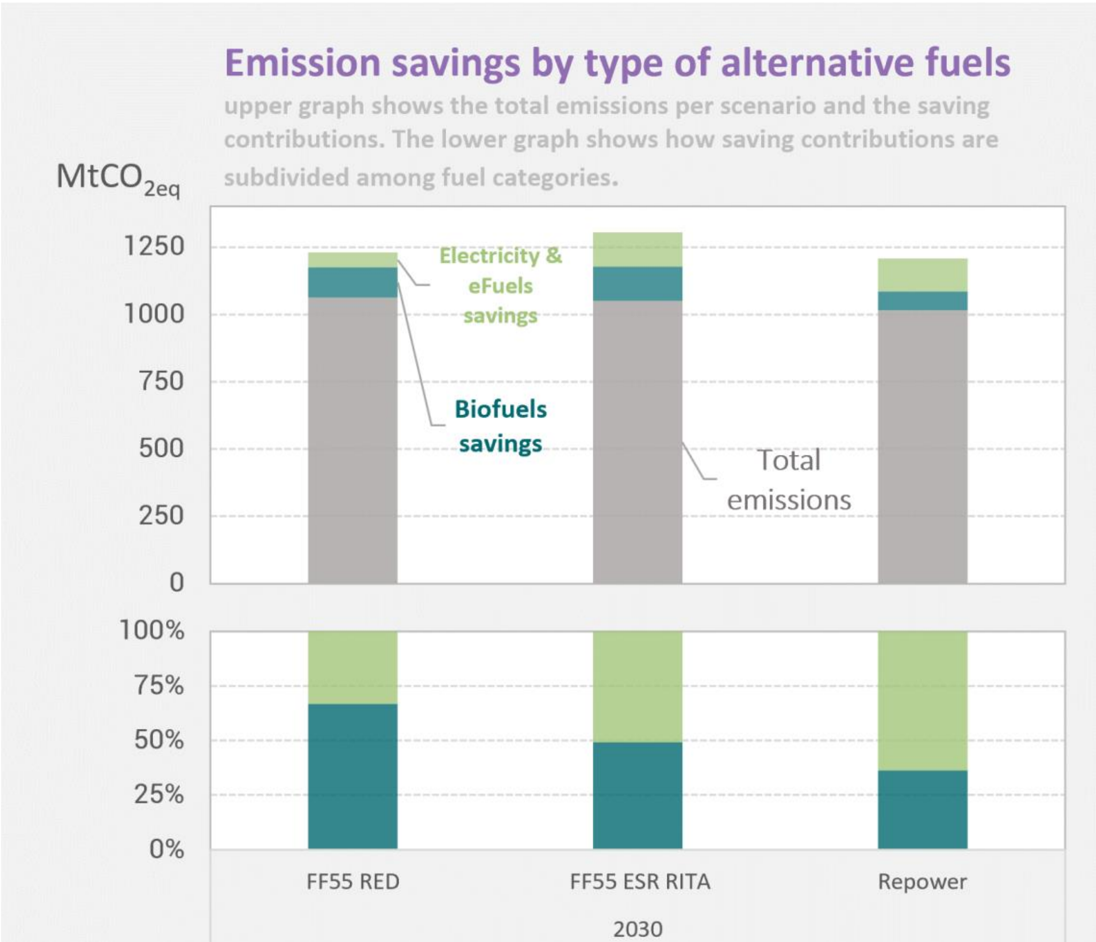


Figure 3-15 Total emissions and relative contribution of bio- and other alternative fuels to GHG savings for all scenarios

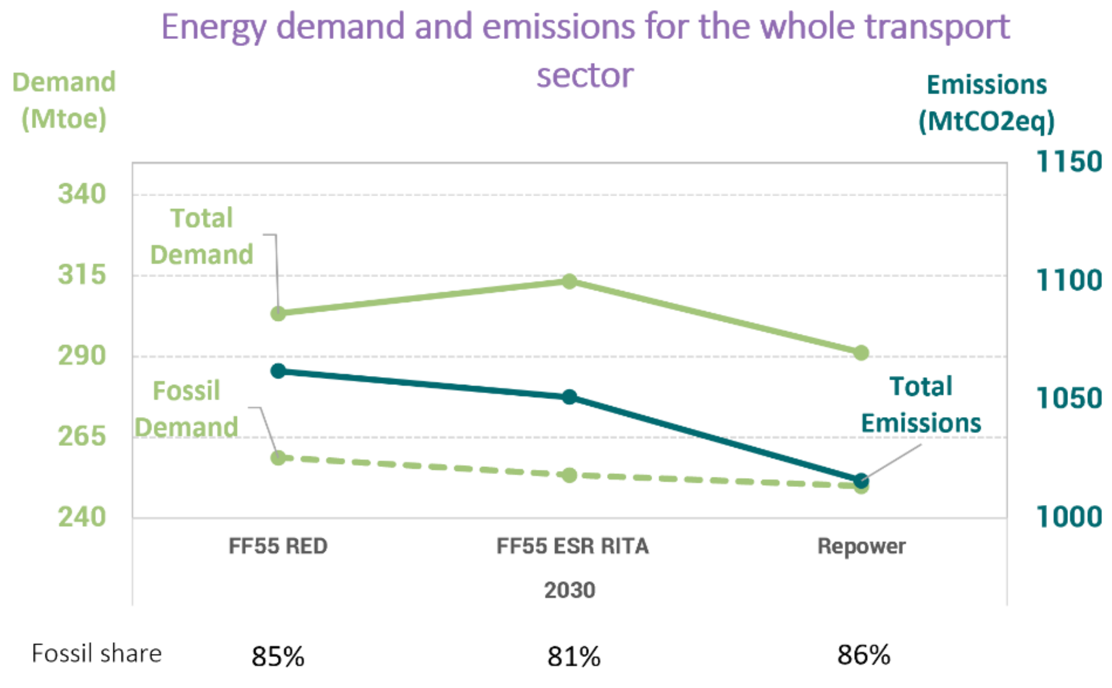


Figure 3-16 Total emissions, fossil fuel demand and total energy demand in the transport sector for all scenarios

3.4.5. Main conclusions for the GHG saving analysis

- **Minor differences** have been noted **between** the ***Import*** and ***Extended*** **gap-fill strategies** under the GHG emissions profile. *Extended* scenarios show slightly higher performance due to a larger share of low-emissions value chains, such as biomethane.

- The three demand scenarios significantly differ in the way emissions are avoided. The *FF55 RED* achieve significant emissions savings primarily thanks to the high uptake of advanced biofuels. The *FF55 ESR RITA* scenario shows a significant uptake of both biofuels and electricity. In the *Repower* 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 eFuels.

- The ***FF55 ESR RITA*** scenario shows the **highest avoided emissions** of the set, as well as the **highest GHG intensity reduction**. However, it has to be highlighted that the overall emission savings from the FF55 ESR RITA scenario are higher due to the higher uptake of alternative fuels (also related to the overall higher energy demand for fuels), and the fact that for eFuels and hydrogen the GHG emissions are set to zero, regardless of the production chain. Clearly, such kind of 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., advance biofuels).

- The **lowest overall emissions** are attained in the ***Repower*** scenario, not only because of the significant emissions avoided through the deployment of electricity, but also because of a lower energy demand.

3.5. Market prices

Figure 3-17 shows a comparison of the price ranges for the biofuel output of each pathway for 2030. Most of the ranges are quite wide, due to the high number of uncertainties that will affect the market price of those fuels (including variability across production pathways and output biofuel types, macroeconomic drivers, the volatility of oil prices, competing technologies, etc.). For this reason, all the economic KPIs have been calculated by considering the minimum, maximum and medium price for each pathway.

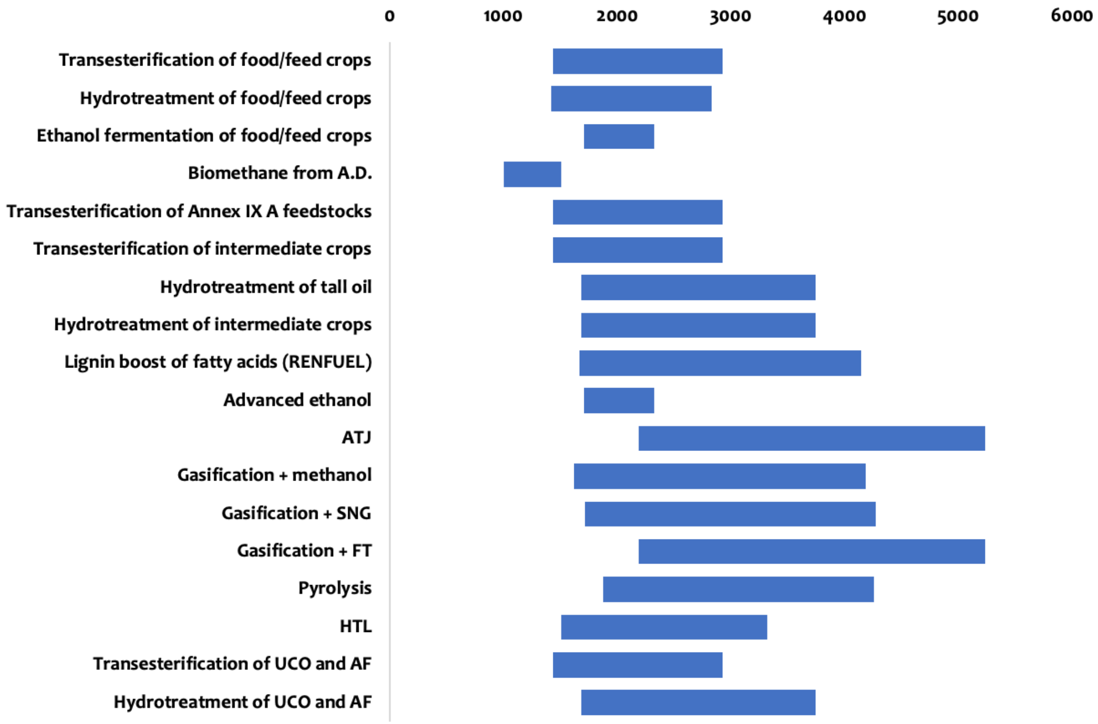


Figure 3-17 Output market price range per pathway (values in EUR/toe)

3.6. Annual turnover including import

The annual turnover for each pathway in 2030 is reported in Figure 3-18 for the Import scenarios of this analysis. The total turnover of biofuels produced in the EU in 2030 is estimated to be between 41 and 80 billion $€_{2022}$, depending on the market prices that are considered. The largest contribution is from transesterification pathways (that account together for 41%-43% of the total), followed by hydrotreatment pathways (35%-38%) and ethanol (12%-17%); such contributions include biofuels produced using RED II Annex IX feedstock. This clearly demonstrates that road transport in 2030 remains the dominant sector for the use of biofuels.

The results also show that the economic value of biofuel imports can be considerable in some scenarios, reaching up to one third of the total turnover of biofuels demand.

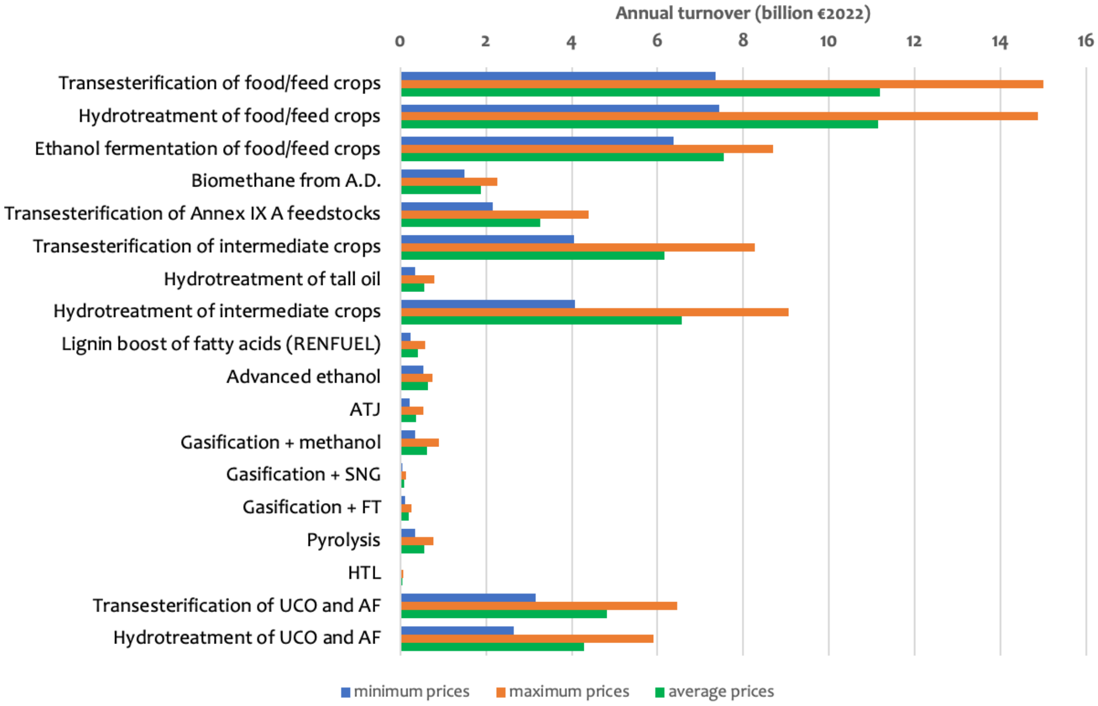


Figure 3-18 Annual turnover per pathway in the Import scenarios, 2030 (values in billion EUR2022)

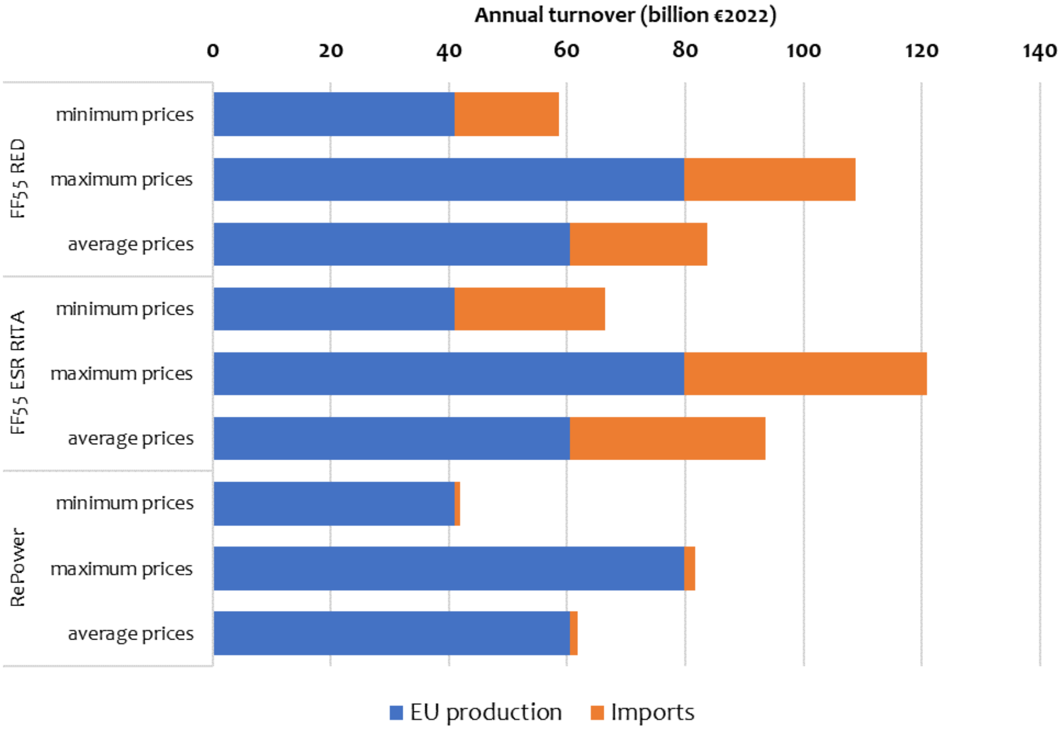


Figure 3-19 Annual turnover in the three Import scenarios with different price levels, 2030 (values in billion EUR2022)

The EU production pathways remain the same in the three Import scenarios that are considered, while the biofuel imports show significant variations. A comparison of the turnover related to imports in the three scenarios is reported in Figure 3-19. The total turnover of imported fuels is estimated in the range 18 – 29 billion €2022 for the FF55 RED scenario, and in the range 25 –41 billion €2022 for the FF55 ESR RITA scenario (thus increasing the total turnover to 59 – 109 billion €2022 and 66

– 121 billion €2022 respectively). The RePower scenario assumes a marginal amount of imported biofuels. Furthermore, in the RePower scenario some pathways show an excess production compared to the actual biofuel demand. As a result, the estimated turnover represents a maximum technical level of productivity, as different market conditions could lead to exports or decreased production.

The total turnover presented in the three Import scenarios can be compared to the results of the Extended Capacity scenarios, where the mismatch between demand and estimated capacity is addressed with additional production capacity within the EU.

The figures for the annual turnover based on average price levels in all the different scenarios are reported in Figure 3-20. The results show that the scenarios based on the Gap Analysis methodology have a lower annual turnover with respect to their corresponding Import scenario. This effect is mostly due to the different biofuels mixes that are considered in the two approaches. The Extended Capacity scenarios show a higher share of biomethane production via anaerobic digestion, which is the biofuel with the lowest average price (per unit of energy content), thus leading to a slight decrease of the total turnover. The Extended Capacity scenarios also rely on important shares of ligno-cellulosic biofuels in substitution of the imported biofuels of the Import scenarios, but in this case the price difference is lower, and so is its impact on the difference between the turnovers. In case a higher share of advanced liquid biofuels would be used to replace fossil fuels as in ESR and RITA, then the turnover figures would have to be revised upward.

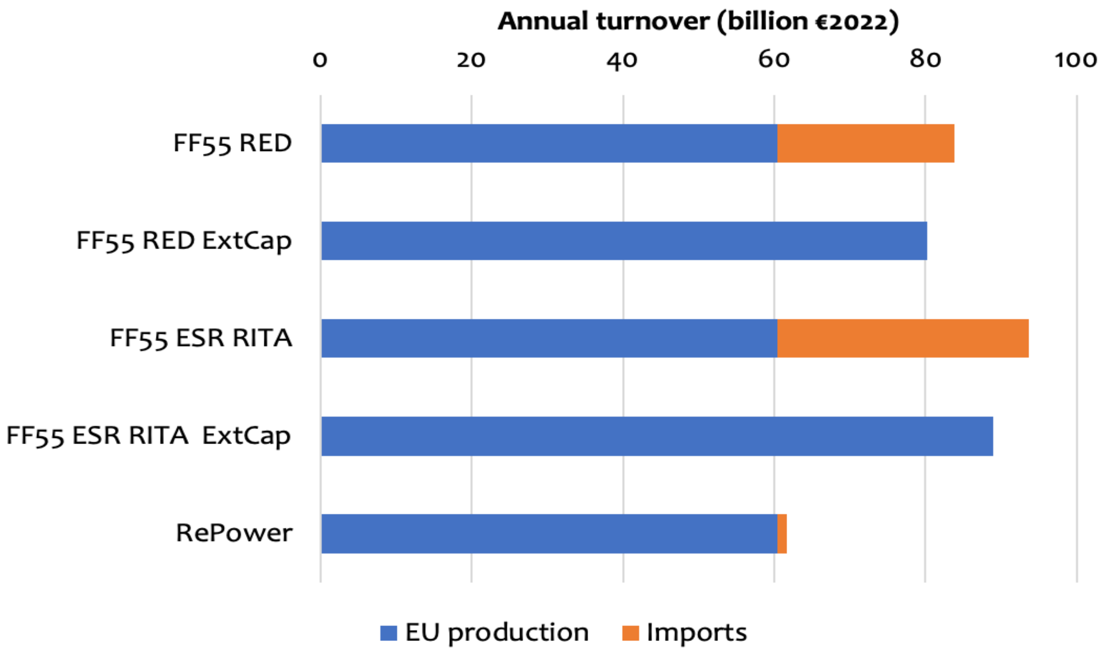


Figure 3-20 Comparison of annual turnover in Import and Extended Capacity scenarios with average prices, 2030 (values in billion EUR2022)

3.7. Contribution to GDP including import

The contribution to GDP is evaluated as the added value of the biofuels sector, as explained in the methodology section (including imported biofuels). The results are reported in Figure 3-21, showing a contribution between 0.07% and 0.20%, depending on the scenario and the price level that is considered. Results show that the Extended Capacity scenarios have on average a higher contribution compared to the corresponding Import scenarios. This is due to the fact that domestic production has a higher added value than imported biofuels. A similar effect could also be expected in case other low-maturity pathways - not considered in Task 4 gap analysis - become commercial as well in the considered timeframe.

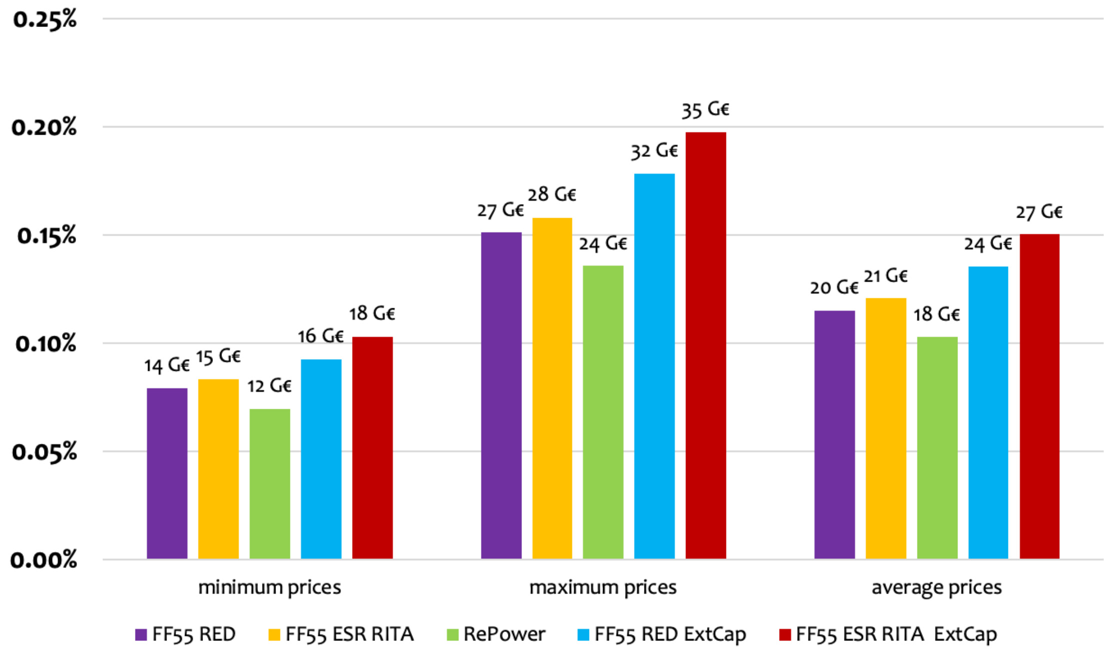


Figure 3-21 Biofuels sector contribution to EU's GDP, 2030

3.8. Additional Employment in the Sector

A number of linked spreadsheets in the form of a specialized calculation tool were created to facilitate the assessment approaching the employment impact, given the above-mentioned assumptions for the correction of the employment in FTE and the evolution of the Employment Factor. The calculation runs were carried out for the years 2030, 3040 and 2050 and for the three selected scenarios; they comprised:

- The employment assessment based on the initial Employment Factor (demand);
- The corrected, based on EU production, employment, considering imports/exports and feedstock availability;
- The correction incorporating the technology maturity;
- The assessment of net employment incorporating the impact to fossil fuels.

It is worth mentioning that, regarding the evolution of employment in the three decades that are examined, a linear evolution of biofuels production and consumption situation for the two decades was assumed, namely 2030-2040 and 2040-2050, whereas the developments within the decade 2020-2030 are expected nearing to 2030, when the EU policies are expected to be fully implemented and most of the new investments on advanced drop-in biofuels will be operational.

All the considered assumptions described in Chapter 2.9.5 are very conservative; therefore, the results of the number of jobs could be characterized as lying on the modest side.

The employment impact expressed in FTE of the central scenario FF55/RED is depicted in Figure 3-22.

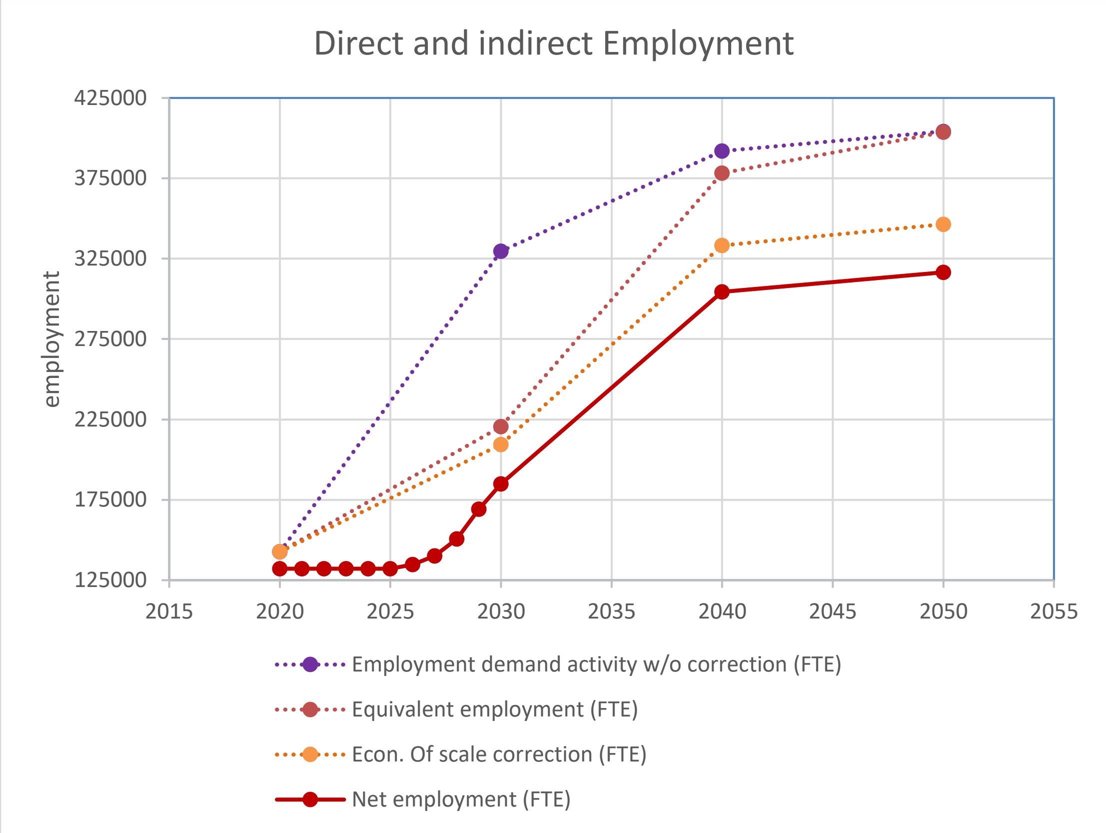


Figure 3-22 Evolution of direct and indirect employment (FTE) due to biofuels activity in scenario FF55/RED

The purple dotted line indicates the impact as it could be assessed by using the Employment Factor calculated in 2020-2021 and referring to biofuels' consumption. The corrected estimation by considering imports/exports and the EU production capacity is indicated by the blue line. It is worth considering that the lack of local production capacity and necessary oil feedstock until 2030 is expected to have significant impact on the pertinent EU employment. A reduction of more than 100,000 FTE in 2030 is expected. The green line indicates the correction due to technology maturity and economies of scale in the new investments. Although the assumed reduction rate sounds high (-10% annual employment reduction on the added new capacity), the expected reduction of employment is rather moderate at around 11,300 FTE in 2030. Following the calculations, it is assumed that there is no need for correction due to technological change, especially after 2030. Finally, the red line presents the net employment impact incorporating the reduction of employment in the fossil fuels sector. The expected **net employment in biofuels for transport is expected to be around 185,000 FTE in 2030 for the central scenario FF55 RED,** that is an increase of around 30% compared to the relevant net employment of 2020. The expected intensification of advanced biofuels investments and production after 2025 is taken into consideration and is shown.

In the forthcoming period of 2040 and 2050 and for the central scenario a certain increase of net employment is expected during the decade 2030-2040 by more than 130,000 FTE and reaching total employment to 304,000 FTE in 2040 that is 2.13 times the relevant employment of 2020. Respectively in the decade 2040-2050 the increase of net employment is estimated to only 12,000 FTE due to the expected small grow of biofuels production and use. In these latter decades the minimization of import/export activities explain the different evolution of the relevant curves in comparison to the first decade 2020-2030.

The evolution of the Employment Factor reflecting the net employment impact is presented in Figure 3-23. The reduction of the Employment Factor from 8.28 FTE/ktoe/year in 2020 to 7.00 FTE/ktoe/year in 2050 is reasonable and is mainly attributed to the higher efficiency of the increasingly mature technologies and to the evolution of the EU production capacity.

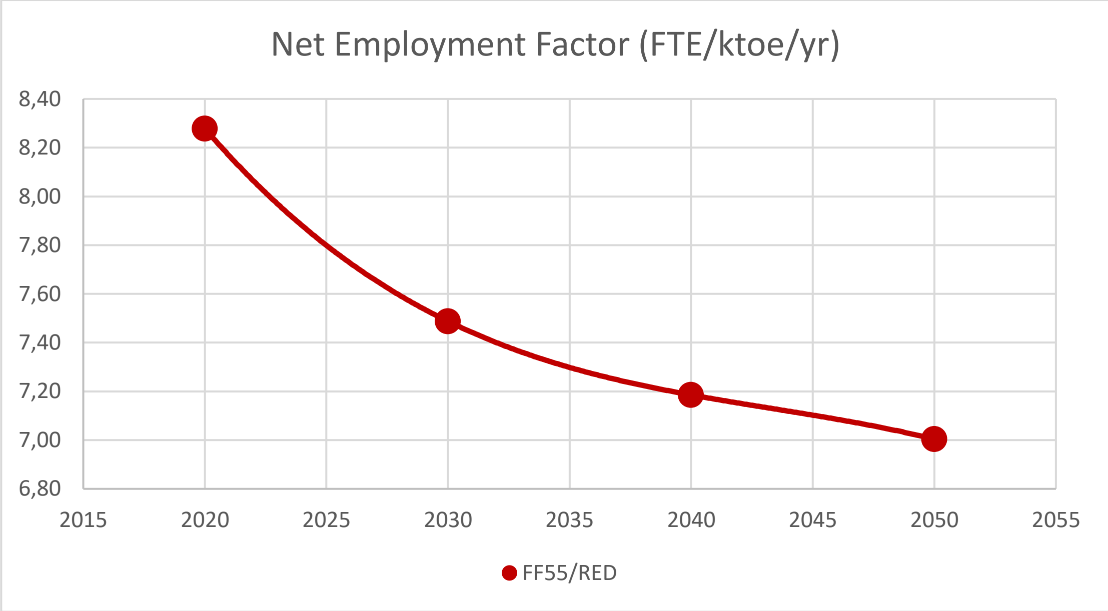


Figure 3-23 Evolution of Employment Factor (FTE/ktoe/year) due to biofuels activity in scenario FF55/RED

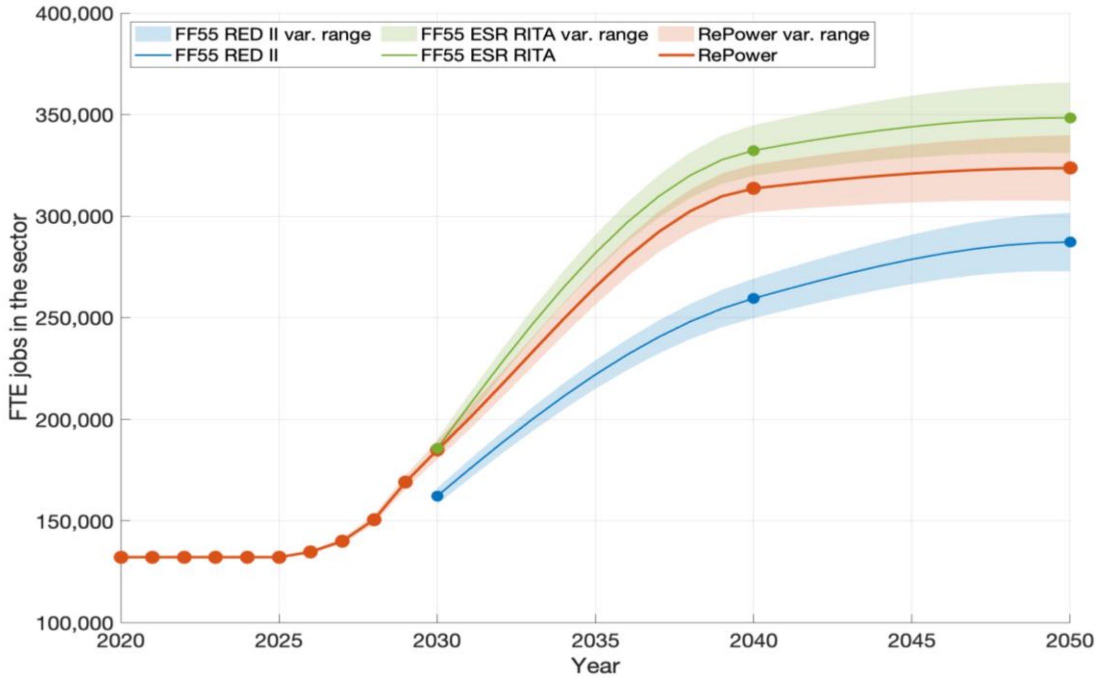


Figure 3-24 Comparative evolution of net employment in FTE for the three selected scenarios

Similar calculations have been done for the selected max/min scenarios, i.e., the FF55_ESR_RITA and the RePower scenarios. The FF55_ESR_RITA (max) scenario has a marginally higher impact in employment calculated to 185,721 jobs (FTE) in 2030 compared to the 184,944 jobs of the FF55/RED (central) scenario and the 162,238 jobs of the RePower (min) scenario in the same year. Following the evolution of biofuels production and the technology maturity, in 2040 the expected net employment is 318,100, 304.311 and 254,789 jobs for the three scenarios respectively. The convergence is higher in 2050 following the relevant convergence of estimations for the biofuels consumption in the three scenarios. This comparative evolution of employment is shown in Figure 3-24. Given the convergence of the differences in the biofuels consumption in the three scenarios in 2040 and 2050, it is worth mentioning that the observed differences of employment are substantially attributed to the different technology and market upscale paths followed in each scenario. Furthermore, the variability range of +/- 5% (shadowed curves) is also depicted in the same Figure, indicating the convergence of the three scenarios in employment effect as getting closer to 2050.

The net Employment Factor, i.e., by incorporating the respective loss of jobs in the fossil fuel industry, in 2020 is calculated to 8,28 FTE/ktoe/year. The relevant evolution of the Employment Factor, calculated on net employment over the production of drop-in biofuels in the EU27 for the three scenarios is presented in Figure 3-25. The range of the Employment Factor is 7.49 – 7.31 – 8.11 FTE/ktoe/year for the central -max -min scenarios in 2030, thus indicating a range 0f less than 10% over the Employment Factor of the central scenario. The relevant range of the max/min scenarios (7.48 – 6,33 FTE/ktoe/year) in 2050 is in the order of 8% compared to the central scenario (7.00 FTE/ktoe/year).

In 2040 and 2050 the estimated Employment Factors follow, more or less, the evolution of employment since the differences in biofuels consumptions are very small among the three scenarios. In 2030 the Employment Factor is, in addition to the biofuels level of consumption, influenced by the necessary imports to cover the demand, due to the expected lack of production capacity and the availability of necessary feedstock in the central and max scenarios. The substantial imports of biofuels or pretreated feedstock reduce the relevant employment, and this is the reason of the calculated lower values of the Employment Factor in comparison to the min scenario, for which the importing requirements are lower.

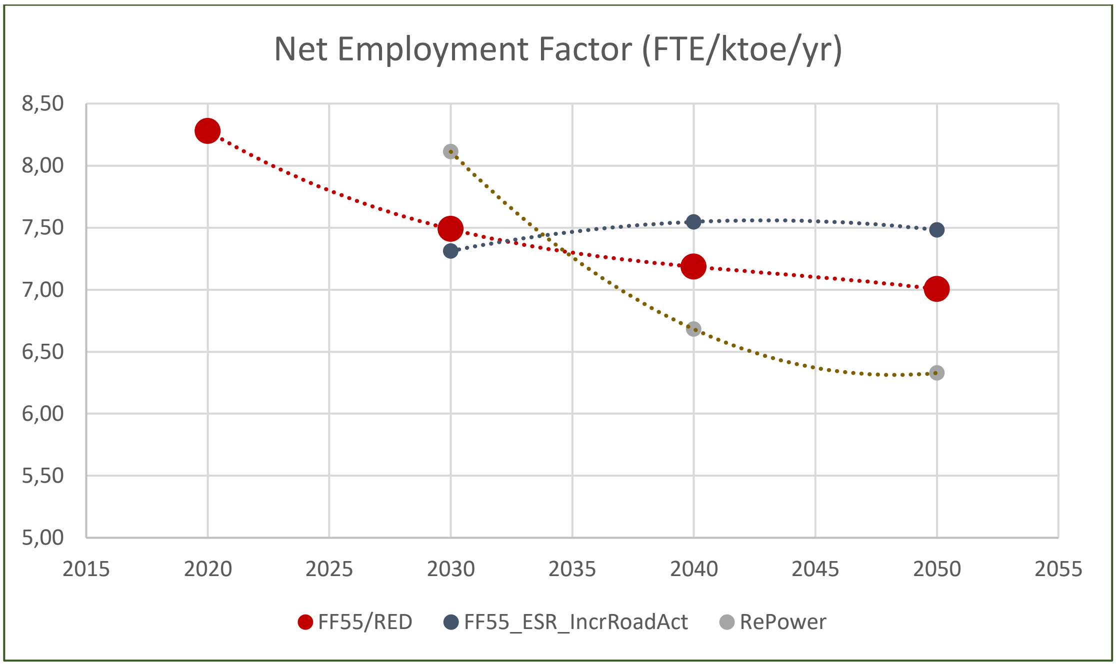


Figure 3-25 Comparative evolution of the net Employment Factor in FTE/ktoe/year for the three selected scenarios

Concluding Remarks

The major conclusion of the employment exercise is that **significant increase of net employment** is expected, under all scenarios considered, as far as the biofuels consumption and particularly production increases 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 significant variance impact on employment. The increase of jobs by 30% or around 53,000 new jobs in the central scenario, albeit assumptions of imports of biofuels and feedstocks have been considered due to lack of required production capacity and domestic sustainable feedstock. The higher increase of employment occurs in the decade 2030-2040, during which 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. Similar results are observed in the other two min/max scenarios. In the period 2040-2050, the same growing trends of employment as in the previous decade are not expected. The main reason is the anticipated low increase rate of biofuels consumption. The estimated net direct and indirect employment in the EU by 2050 is estimated to 287,000 – 348,000 FTE jobs, reflecting an increase of 117% - 164% compared to 2020, depending on the biofuels scenario. It is worth noting that all the new jobs are absolutely related to the development of production of advanced biofuels (RED II) and relevant domestic (EU) feedstock collection/production. This fact implies very positive effects for European rural areas and improvement of security of supply since fossil fuels are replaced.

These findings of significant increase of employment due to replacement of fossil fuels by advanced drop-in biofuels confirm the relevant argument of the international literature on this issue.

It is worth considering, also, that a shift in the **required education levels** of the labour force, especially after 2030 when new production technologies are employed, can have considerable impacts on job creation causing potentially a mismatch between labour supply and demand. A potential shortage of highly skilled labour can undermine the cost-efficient low-carbon transition and might cause intensification of competition between companies for skilled employees[7]. The survey of Task 3 indicated that there will not be significant problem with skilled labour required until 2030, this issue should be rather arisen after 2030. In this context, the analysis of Fragkos and Paroussos[6] indicates that the share of highly qualified workers in energy sectors would grow from 37% in 2015 to 41% in 2050. This increase is modest relative to the underlying trends of the EU economy towards high-skilled jobs[5]. Based on this assessment and the long period for the adaptation of labour supply to new technologies, the employment impact exercise anticipates that the necessary skilled labour 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, only 10.6% of the total, according to the global green job study data of ILO[1] for 2018. These women worked above all in biodiesel and bioethanol plants (11.8% and 9.2%, respectively), whereas their involvement was considerably lower in biogas (3.7%) and in thermal energy (1.7%). The positions they held were mainly administrative, and none had management posts. This situation is expected to improve paving to 2050, especially in the EU where gender discrimination is not realized in the whole value chain of biofuels production.

4. Conclusions

The main results of Task 5 analysis are reported in the Table 4-1 and Table 4-3 for year 2030, respectively related to the three Import scenarios, and to the two Extended Capacity scenarios. The results for the year 2050 are presented in Table 4-2 for the FF55 RED scenario. All the results also present the specific contribution of each production pathway and of the imports, where present.

Considering the **high uncertainties** related to the evaluation of the expected **market prices** for the biofuels in **2050**, this KPI has not been evaluated for this time horizon, as well as the related annual turnover and impact on GDP.

Comparing the results obtained by the **two sets** of **scenarios**, namely the three Import scenarios and the two Extended Capacity scenario, a series of important differences can be noted; these are an effect of both the **different levels** of the **expected production capacity** as well as of its **different distribution** across the **various pathways** (thoroughly described in Chapter 3

Looking at the GHG savings KPIs, **minor differences** have been noted **between** the ***Import*** and ***Extended Capacity*** **scenarios** under the GHG emissions profile. The ***Extended Capacity*** scenarios show slightly higher performance due to a larger share of low-emissions value chains, such as biomethane.

The three demand scenarios significantly differ in the way emissions are avoided. The *FF55 RED* achieves significant emissions savings primarily thanks to biofuels. The *FF55 ESR RITA* scenario shows a significant uptake of both biofuels and electricity. In the *Repower* 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 and eFuels (RFNBOs).

The ***FF55 ESR RITA*** scenario shows the **highest avoided emissions** of the set, as well as the **highest GHG intensity reduction**. However, it has to be highlighted that the overall emission savings from the FF55 ESR RITA scenario are higher due to the higher uptake of alternative fuels (also related to the overall higher energy demand for fuels), and the fact that for eFuels and hydrogen the GHG emissions are set to zero, regardless of the production chain. Clearly, such kind of 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., advance biofuels).

The **lowest overall emissions** are attained in the ***Repower*** scenario, not only because of the significant emissions avoided through the deployment of electricity, but also **because** of a **lower energy demand**.

It is worth stressing that, the Carbon Intensity of the REDII default values represent a conservative figure. Actual values, resulting from the certification of real industrial processes, are significantly lower. This potentially has a direct impact on the quantitative GHG saving resulting from the use of such fuels. Moreover, these CI values are considered as stable overtime but innovations such as the use of green hydrogen and renewable electricity in the biofuels making are already happening, which would lower the Carbon Intensity of the MJ of finished fuel.

The **socio-economic** KPIs present overall better results in the *Extended Capacity* scenarios:

The Impact on **GDP** is **positively impacted** as well: the FF55 RED ExtCap presents an 18% higher value when compared with the FF55 RED scenario, while the FF55 ESR RITA ExtCap has a 25% higher value when compared to the FF55 ESR RITA. This result is mainly related to the fact that margins on imported fuels are considered to be lower than the margins on internally produced fuels and imports are accounted for a share of total turnover ranging between 27% and 35% in these two scenarios.

The impact on **Annual Turnover is** instead **slightly negative**; this KPI reduces by around 4%, when comparing i.e., from FF55 RED ExtCap with FF55 RED scenario. This effect, especially when compared to the positive effect on GDP impact, could seem counterintuitive at first. The explanation has to be searched in the different fuel mix expected in the *Extended Capacity* scenarios, that presents **higher shares of biofuels** from production pathways with **lower market price** of their outputs; above all the others, biomethane from Anaerobic Digestion.

Finally, significant **new net employment, based absolutely on advanced biofuels, is expected to be positively impacted** by a higher EU production capacity, substituting extra-EU fossil imports, fostering very positive effects for European rural areas and security of supply. On the other hand, the adaptation of labour supply to new technologies is possible, since the necessary skilled labour will be available in the period 2030-2050, when the major technology transition in biofuels production will take place.

The current analysis considers the differences in terms of employment, related to the different feedstock production chains. The overall employment effect, for the modelled scenario, may differ over time, as function of the adopted feedstock to fuel mix. It is worth stressing that, when compared with other renewable energy production chains, **biofuels offer significant advantages in terms of employment, as the feedstock production part** has a significant positive impact.

All considered, it emerges that, in the Extended Capacity scenarios, most of the **KPIs presents better performances** when **compared** to the **Import scenarios** (which include a share of biofuels imports). However, it has to be considered that, while the assumptions behind the composition of the Import scenarios (i.e., in terms of production pathways mix – and related growth) were backed up by several interviews to experts, industry and associations, the Extended Capacity scenarios are the result of a more speculative exercise. Therefore, these results should be considered more like an aspirational scenario, where investments in additional new production capacity would substitute imports to match the expected demand. However, several parameters may affect the real distribution across technological pathways, and the real production capacity including learning curves, investment, and operational costs, as well the additional biomass demand in other sectors and in other countries.

The **investigated KPIs** clearly **show** the **potentials** related to **deployment** of **additional EU advanced biofuels production capacity**. However, to make th**is** potential appear, the **EU leadership** in advanced biofuels (both feedstocks and conversion) **must be promoted**, also to **capitalize** the **significant R&D expertise** existing in the region. Support to investment is particularly needed for **achieving** the **2030 results**, and **beyond**.

2030										
Scenario	Value chain	Expected selling price (average)	Energy contribution	GHG saving				Socio-economic impacts		
		-	*Overall energy contribution*	*Average Carbon Intensity*	*Total Emissions**	*GHG savings potential**	*Average GHG Savings share per pathway*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/y*	*tCO2eq/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 anaerobic digestion	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
	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

2030										
Scenario	Value chain	Expected selling price (average)	Energy contribution	GHG saving				Socio-economic impacts		
		-	*Overall energy contribution*	*Average Carbon Intensity*	*Total Emissions**	*GHG savings potential**	*Average GHG Savings share per pathway*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/y*	*tCO2eq/Mtoe*	*MtCO$_{2eq}$*	*MtCO$_{2eq}$*	*%*	*FTE Jobs*	*%*	*M€/yr*
	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**
	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 anaerobic digestion	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		0.006%	3,275
	Transesterification of intermediate crops	2,180	2.83	1.16	4.01	9.65	71		0.010%	6,165
FF55 ESR RITA	Hydrotreatment of tall oil	2,715	0.21	0.64	0.17	0.90	84	53,562	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
	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

2030											
Scenario	Value chain	Expected selling price (average)	Energy contribution	GHG saving				Socio-economic impacts		
		-	*Overall energy contribution*	*Average Carbon Intensity*	*Total Emissions**	*GHG savings potential**	*Average GHG Savings share per pathway*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/y*	*tCO2eq/Mtoe*	*$MtCO_{2eq}$*	*$MtCO_{2eq}$*	*%*	*FTE Jobs*	*%*	*M€/yr*
	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	1.92	8.75	82		0.008%	4,817
	Hydrotreatment of UCO and AF	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
	Ethanol fermentation of food/feed crops	2,016	3.74	1.22	4.55	10.18	69		0.013%	7,540
	Biomethane from anaerobic digestion	1,256	1.50	-0.72	-1.07	6.86	118		0.003%	1,884
	Transesterification of Annex IX-A feedstock	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

2030										
Scenario	Value chain	Expected selling price (average)	Energy contribution	GHG saving				Socio-economic impacts		
		-	*Overall energy contribution*	*Average Carbon Intensity*	*Total Emissions**	*GHG savings potential**	*Average GHG Savings share per pathway*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/y*	*tCO2eq/Mtoe*	*$MtCO_{2eq}$*	*$MtCO_{2eq}$*	*%*	*FTE Jobs*	*%*	*M€/yr*
	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	2,180	2.21	0.71	1.22	5.57	82		0.008%	4,817
	Hydrotreatment of UCO and AF	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 values of Import figures represent biofuels volumes available for Export

Table 4-1 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	Expected selling price (average)	Energy contribution	GHG saving				Socio-economic impacts		
		-	*Overall energy contribution*	*Average Carbon Intensity*	*Total Emissions*	*GHG savings potential*	*Average GHG Savings share per pathway*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/y*	*tCO2eq/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 anaerobic digestion	-	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	-	2,21	0.67	1.47	7.23	83		-	-
	Hydrotreatment of UCO and AF	-	1,58	0.69	1.09	5.12	82		-	-

2050											
Scenario	Value chain	Expected selling price (average)	Energy contribution	GHG saving				Socio-economic impacts		
		-	*Overall energy contribution*	*Average Carbon Intensity*	*Total Emissions*	*GHG savings potential*	*Average GHG Savings share per pathway*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/y*	*tCO2eq/Mtoe*	*$MtCO_{2eq}$*	*$MtCO_{2eq}$*	*%*	*FTE Jobs*	*%*	*M€/yr*
	TOTAL - w/o Imports	-	**48,54**	-	**39.75**	**151.49**	-		-	-

**Compared to 2020 values

Table 4-2 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	Expected selling price (average)	Energy contribution	GHG saving				Socio-economic impacts		
			Overall energy contribution	*Average Carbon Intensity*	*Total Emissions**	*GHG savings potential**	*Average GHG Savings share per pathway*	*New jobs***	*GDP*	*Annual turnover*
		€/toe	*Mtoe/y*	*tCO2eq/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 anaerobic digestion	1,256	7.85	-0.89	-3.67	19.86	123		0.017%	9,857
	Transesterification of Annex IX-A feedstock	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

2030										
Scenario	Value chain	Expected selling price (average)	Energy contribution	GHG saving				Socio-economic impacts		
	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
	HTL	2,414	0.15	1.20	0.15	0.35	70		0.001%	371
	Transesterification of UCO and AF	2,180	2.21	0.71	1.66	7.57	82		0.008%	4,817
	Hydrotreatment of UCO and AF	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		0.013%	7,540
	Biomethane from anaerobic digestion	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	70,344	0.006%	3,275
	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

2030										
Scenario	Value chain	Expected selling price (average)	Energy contribution	GHG saving				Socio-economic impacts		
	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	2,180	2.21	0.71	1.72	7.87	82		0.008%	4,817
	Hydrotreatment of UCO and AF	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%	-
	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**

*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. The impact of GA scenarios on employment will certainly lead to some increase in FTE jobs, due to increase in EU production capacity.

Table 4-3 Summary of the results for the main KPI indicators in year 2030 for the two Extended Capacity scenarios. Divided among the various production pathways

Appendix I - Analysis of literature sources at global and European Level

The first activity of Task 5 is focused on the analysis of the available literature related to social, economic, and environmental indicators for bioenergy pathways, with the aim of highlighting the state of the art on the methods of analysis, as well as presenting some available reports and figures at the global and European level.

The review of the gathered information is performed in a structured manner, and organization of the data according to the goal of the task, as described in the following sections.

4.1. Literature review approach

The objective of the literature review is to gather the available information for the evaluation of the various performance indicators that will be the output of this Task and complement the data that will be provided as outcome of the other Tasks (if needed).

The literature review will cover the following areas:

- Overview of EU-level scenarios regarding biofuels demand/potential, development of technologies/pathways and related MFSP, from available reports.

- Literature on GHG emission reduction (and methodologies for calculation) related to the various pathways.

- Literature on social-economic impacts of biofuels production (especially focused on direct and indirect jobs creation).

- Literature on biofuels production plants (average nameplate capacity, employees, expected evolution between first and n-th plant, eventually CAPEX and OPEX).

The main objective of the review is to provide bases to evaluate the outcomes provided by other tasks and fill eventual data gaps if necessary. Moreover, it provides scientific bases and materials for the development and tailoring of the methodological framework used in the Task.

The following sections will address in detail the different areas that have been analysed in this first activity.

4.2. Relevant studies about EU-level biofuels

This section presents a description of the main scenarios that are currently available in the literature for the European Union, considering the evolution of biofuels and advanced biofuels for the transport sector in 2030 and 2050.

Given the significant impact of the COVID-19 pandemic on EU policies, this section is only considering scenarios published after 2021, since older scenarios are expected to underestimate the decarbonization commitment of recent EU policies. For a comprehensive review of scenarios published before 2021 please refer to Chiaramonti et al., 2021[28].

The institutional scenarios developed by the European Commission that are currently publicly available are the following:

- Reference Scenario 2020,
- 'Fit for 55' REG Scenario,
- 'Fit for 55' MIX Scenario,
- 'Fit for 55' MIX-CP Scenario.

Detailed data of these scenarios are publicly available[29] in specific summary reports for each scenario, including information at the EU level and at country level. This data does not report explicit figures for biofuel demand, but the annual energy consumption can be estimated from the following indicators:

- Biofuels and biomethane in total fuels (excl. hydrogen and electricity) (%),
- Share of Annex IX Part A biofuels and biomethane (based on REDII formula),
- Electricity in road transport (%),
- Final energy consumption in transport (ktoe).

The estimated energy consumption from public data is approximated due to the lacking information about the hydrogen and electricity demand of the transport sector (with exception of electricity for road transport, which can be estimated), and additional data would be required for a precise evaluation.

In addition to official scenarios, a recent report by Concawe, focusing on the industrial sector[30], presents future scenarios that highlight the potential contribution of European refineries to supply biofuels for transport in the continent. Three scenarios are considered in the report:

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[28] Available at: https://doi.org/10.1016/j.rser.2021.110715

[29]Available at: https://energy.ec.europa.eu/data-and-analysis/energy-modelling/policy-scenarios-delivering-european-green-deal_en (Last accessed on 09/05/2023)

[30] Available at: https://www.concawe.eu/wp-content/uploads/Rpt_21-7.pdf (Last accessed on 09/05/2023)

- Scenario 1 (High): Low Carbon Fuels are deployed across the whole transport sector,

- Scenario 2 (Medium): Low Carbon Fuels are used only in the heavy-duty road sector and the aviation and maritime sectors,

- Scenario 3 (Low): Low Carbon Fuels are developed only in the aviation and maritime sectors.

The annual energy supply of total and advanced biofuels for these scenarios are publicly available in the Annex of the report. The resulting data for these scenarios are reported in Figure A1 - 1 and Figure A1 - 2 for total and advanced biofuels respectively, compared with the estimated data from the official EU Scenarios.

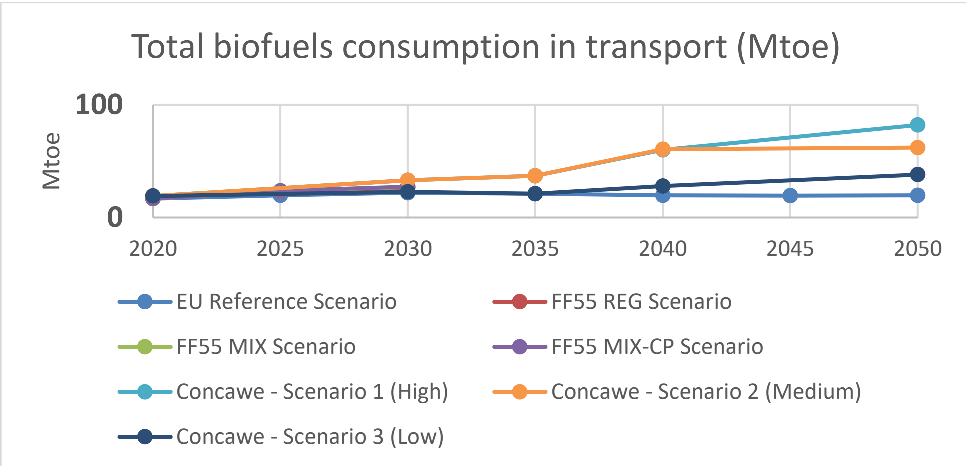

Figure A1 - 1 Estimated biofuels consumption in transport in selected scenarios

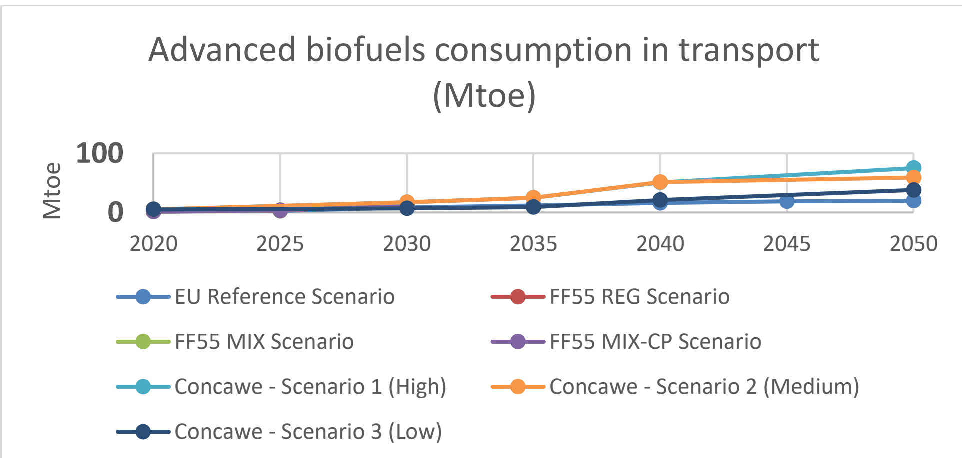

Figure A1 - 2 Estimated advanced biofuels consumption in transport in selected scenarios

Available official data on EU scenarios can be also integrated with the information published in the Impact Assessments of ReFuelEU Aviation and ReFuelEU Maritime, although they provide only information related to these two specific sectors.

Considering aviation, most of the policy options considered in the ReFuelEU Aviation Impact Assessment are based on a SAF demand of 2.3 Mtoe by 2030, increasing to 15 Mtoe by 2040 (32% of the total fuel demand) and 29 Mtoe by 2050. Considering the impact of biofuels demand on available feedstock, in the worst case the kerosene production requires about 11% of the available potential of agricultural residues and wood waste, 3% of the available potential of forestry products and residues, and about 9% of the available potential of energy crops in the EU in 2050. In addition to these resources, kerosene production relies also heavily on used cooking oils (UCO), reaching by 2050 around half of the total available potential of UCO in the EU, compared to about 28% in 2030[31].

Considering biofuels use for shipping, some information is available from the Impact Assessment of the ReFuelEU Maritime. This document presents future scenarios for the maritime sector, where liquid biofuels and bio-LNG demand is expected to increase from around 3 Mtoe in 2030 up to 32 Mtoe in 2050. There are some differences across policy scenarios, but 2050 figures lay in the range 26-32 Mtoe. Most of the required feedstock is expected to be lignocellulosic biomass, around 90% of the total feedstock used for maritime biofuel and bio-LNG production in EU27 by 2030, and almost 99% by 2050, whilst the remainder would mainly be waste lipids such as UCOs. These shares do not consider the feedstock used outside the EU to produce the imported quantities of biofuels. The report also remarks that biofuels production for the maritime sector could be matched domestically with the available biomass. Waste lipids demand for the maritime sector would require about 20% of the feedstock available in the EU by 2030, and around 30% by 2050. Lignocellulosic feedstock demand is expected to require 6 to 20% of the available feedstock potential in the EU by 2050, depending on the type of feedstock and policy option[32].

4.3. Relevant studies about the socio-economic impact

This section presents an analysis of the main studies that address the socio-economic impacts of the biofuel pathways that are of interest for this work. The analysis includes research and review papers from academia, as well as reports from public entities and industrial stakeholders. The evaluation is focused on the most significant elements that are usually addressed when evaluating socio-economic impacts, including:

- Direct, indirect, and induced jobs related to the operation of each biofuel pathway;
- Economic impact in terms of annual turnover and contribution to the GDP;
- Potential of the supply chain in contributing to additional biofuels available for export in other countries or regions.

These indicators are also part of the output of this Deliverable for selected pathways, and therefore a preliminary literature review has been performed to support their estimation.

4.3.1. Reports and public datasets

Public reports and datasets are available about socio-economic benefits of bioenergy, with different levels of detail concerning the type of fuel that is considered, the geographical level

[31] Source: Study supporting the impact assessment of the ReFuelEU Aviation initiative, 2021.
[32] COMMISSION STAFF WORKING DOCUMENT - IMPACT ASSESSMENT Accompanying the Proposal for a Regulation of the European Parliament and of the Council on the use of renewable and low-carbon fuels in maritime transport.

and coverage, and the dimensions and indicators that are analysed. Some studies focus on the entire bio-energy sector, including biofuels, solid biomass, and biogases, while others provide disaggregated figures for liquid biofuels, and in some cases even the detail by kind of fuel.

Public reports and datasets are generally focusing on historical and current figures and statistics, which means that their coverage is mainly on first generation biofuels, i.e., bioethanol and biodiesel. Nevertheless, a literature review on these documents helps understanding the context of the analysis and the main methodologies that can support the estimation of these figures for advanced biofuel pathways.

The European Commission has published a dataset about Jobs and Wealth in the European Union Bioeconomy (Biomass producing and converting sectors), whose results are from a collaboration between the JRC and the nova-Institute[33]. Considering the topic of this report, this dataset includes aggregate information for the sector of liquid biofuels manufacturing, with specific data for biodiesel and bioethanol pathways. The available indicators are the total number of people employed, the turnover and the value added. Those indicators are available for the years 2008-2019, for each EU member state and for the EU-27 as a whole and are expected to be updated annually. They can represent a useful reference to compare the specific pathways indicators that will be obtained in this report. An example of available data is reported in Figure A1 - 3.

Figure A1 - 3 Number of people employed in the EU-27 for biodiesel and bioethanol pathways

The International Renewable Energy Agency (IRENA) publishes an Annual Review on Renewable Energy and Jobs[34]. As part of this publication, detailed data on jobs related to

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[33] Available at: https://datam.jrc.ec.europa.eu/datam/mashup/BIOECONOMICS/index.html#

[34] The 2022 Annual Review is available here: https://www.irena.org/publications/2022/Sep/Renewable-Energy-and-Jobs-Annual-Review-2022

the liquid biofuels technologies are available at national level for around 50 countries over the world, in addition to the global figure. Country-level data for each sector are available in a specific public dataset[35].

The Food and Agriculture Organization of the United Nations (FAO) has published in 2020 a Handbook on a methodology for estimating green jobs in bioenergy[36]. This document is mostly based on specific studies on employment in the bioenergy sector in Santa Fe, Salta, and Misiones provinces. One of the goals of this handbook is to establish conceptual guidelines on bioenergy and green jobs, setting out a methodological basis for the estimation of direct jobs, indirect and induced jobs, as well as an analysis of the quality of the jobs that are created.

The Handbook provides a clear definition of the different job types that are related to the bioenergy sector:

- **Direct jobs:** These are the result of bioenergy plant activities (operation, maintenance, management, among others). In addition, they include activities carried out by bioenergy producing enterprises (for example, soybean production in integrated plants).

- **Indirect jobs:** These are jobs created along the value chain, in other words, in those sectors that supply goods or services to the bioenergy chain (production of agricultural inputs, construction of parts necessary for plant operation, outsourced activities, among others).

- **Induced jobs:** These are jobs created by purchases made by direct and indirect employees of the activity in question with the income received for their work.

Given the complexity of the sector and the multiple value chains that are involved, these jobs include a very wide variety of profiles, that are reported in the Handbook, together with the required skills, the informality, and the employment category.

The Handbook also provides useful recommendations on the potential methods to be used to collect relevant data from enterprises and workers, as well as from secondary sources to evaluate the desired indicators. The number of jobs can then be correlated to the number of manufacturing facilities or the annual biofuel output to compute and compare performance indicators for each specific supply chain and/or region.

Finally, a detailed description of possible methods for calculating the direct and indirect jobs include input-output models and social accounting matrices. The report also presents a case study with some evaluations and simulation at regional level, including multipliers for the value chains of bioethanol and biodiesel.

Other reports highlight the interesting benefits that can be obtained from bioeconomy on other sectors, through the analysis of relevant multipliers[37]. While multipliers allow an estimation of the benefits beyond the bio-economy sector, it is important to acknowledge some limitations of this approach, including the static view of the analysis and the difficulty of having up-to-

[35] Available at: https://www.irena.org/Data/View-data-by-topic/Benefits/Renewable-Energy-Employment-by-Country
[36] Available at: https://www.ilo.org/wcmsp5/groups/public/---ed_emp/documents/publication/wcms_743406.pdf
[37] See for instance: Mainar-Causapé et al. (2017). "Research Brief: Multiplying effects of the bioeconomy". European Commission-Joint Research Centre.

date datasets supporting the calculations.

However, it is important to remark that most of these reports are focused on statistics and figures for existing bioenergy supply chains, and thus provide interesting insights and benchmark references on the current technologies, but few elements to estimate the potential contribution of the advanced value chains that are of interest in this work. For this reason, a specific activity will be carried out to exploit the available information developed in this project as a basis for a better estimation of resulting jobs.

4.3.2. Peer-reviewed papers

Socio-economic benefits of bioenergy have also been widely addressed in the literature, with several research papers dealing with the different methodologies to estimate performance indicators for a range of bioenergy applications. Research works include analyses on specific technologies and pathways, as well as wider evaluations on national or regional scales. Different methodologies and approaches are currently being developed, depending on the goal of the analysis, the available data, and the desired outputs.

A recent review paper by Brinkman et al.[38] illustrates a comprehensive picture of the main methodologies that are used for ex-ante quantification of the socio-economic benefits of bioenergy. The work presents all the main indicators that are used in the literature, together with the different methodologies applied for their quantification. The goal of the paper is to discuss the main limitations that arise, as well as the diffusion of those methods and indicators in the sustainability analyses of different bioenergy pathways.

The main methodologies analysed in the paper are the following:

- Input-Output models: this method consists of a static overview of all economic flows to and from each economic sector in a single geographic area; it links the additional demand proportionally to extra production in all supplying sectors. Some applications have also extended the quantification to energy flows in addition to economic flows

- Computable general equilibrium models: they are a type of macroeconomic models that include a global representation of all sectors of the economy and the economic interactions of supply, demand, and competition between the sectors that lead to a state of equilibrium

- Partial equilibrium models: they are similar to general equilibrium models, but they focus on a limited number of sectors, which are represented with a greater level of detail

- Bottom-up models: this group of models is quite heterogeneous, including a range of different solutions that are generally applied to specific projects or areas, with the aim of evaluating future projections for specific performance indicators.

- Cash flow analyses: they are generally applied at the project level, and their goal is to calculate the economic profitability, by comparing all expected monetary incomes and

[38] Marnix L.J. Brinkman, Birka Wicke, André P.C. Faaij, Floor van der Hilst, Projecting socio-economic impacts of bioenergy: Current status and limitations of ex-ante quantification methods, Renewable and Sustainable Energy Reviews, Volume 115, 2019, 109352, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2019.109352

expenditures, taking opportunity costs and interest rates of capital into account.

- Social life cycle assessments: they aim at evaluating all the social (and in some cases environmental) impacts related to a specific supply chain or process, focusing on all the available data to describe the physical flows of energy and materials. They build on the life cycle assessment (LCA) methodology, which is described by specific international standards to estimate the environmental impacts of products or processes.

These methodologies have been used as a basis to compare their application to bioenergy systems, analysing their geographical scale, the effects that they are able to quantify and their frequency in the literature. The paper also discusses the main limitations of the current approaches, which are mostly related to the inability of properly account for indirect effects, as well as the difficulty of obtaining updated input data to perform reliable predictions.

The methodologies discussed are used in the literature at different geographical scales and focusing on different sectors and/or technologies. Lechón et al.[39] applied input-output model to the biofuels sector in Uruguay to estimate a number of indicators for the sugarcane bioethanol, sorghum bioethanol and biodiesel pathways.

Other studies consider additional indicators to estimate the impact of biofuels, such as the income level of households, both at country level[40] and at global level[41]. Social sustainability indicators have also been included in some studies to support the optimization and design of biofuels pathways, applied to case studies at country level (e.g., in Iran[42] or Canada[43]).

Other recent peer-review papers have addressed the subject in the last years, including:

- Ronzon, T., Iost, S. & Philippidis, G. Has the European Union entered a bioeconomy transition? Combining an output-based approach with a shift-share analysis. Environ Dev Sustain 24, 8195–8217 (2022). https://doi.org/10.1007/s10668-021-01780-8

- Ronzon, T.; M'Barek, R. Socioeconomic Indicators to Monitor the EU's Bioeconomy in Transition. Sustainability 2018, 10, 1745. https://doi.org/10.3390/su10061745

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[39] Y. Lechón, C. de la Rúa, I. Rodríguez, N. Caldés, Socioeconomic implications of biofuels deployment through an Input-Output approach. A case study in Uruguay, Renewable and Sustainable Energy Reviews, Volume 104, 2019, Pages 178-191, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2019.01.029.

[40] S. Mudombi, C. Ochieng, F.X. Johnson, G. von Maltitz, D. Luhanga, E.B. Dompreh, C. Romeu-Dalmau, A. Gasparatos,
Fuelling rural development? The impact of biofuel feedstock production in southern Africa on household income and expenditures, Energy Research & Social Science, Volume 76, 2021, 102053, ISSN 2214-6296, https://doi.org/10.1016/j.erss.2021.102053.

[41] Johanna Choumert Nkolo, Pascale Combes Motel, Charlain Guegang Djimeli, Income-generating Effects of Biofuel Policies: A Meta-analysis of the CGE Literature, Ecological Economics, Volume 147, 2018, Pages 230-242, ISSN 0921-8009, https://doi.org/10.1016/j.ecolecon.2018.01.025.

[42] Zahra Mohtashami, Ali Bozorgi-Amiri, Reza Tavakkoli-Moghaddam, A two-stage multi-objective second generation biodiesel supply chain design considering social sustainability: A case study, Energy, Volume 233, 2021, 121020, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2021.121020.

[43] Claudia Cambero, Taraneh Sowlati, Incorporating social benefits in multi-objective optimization of forest-based bioenergy and biofuel supply chains, Applied Energy, Volume 178, 2016, Pages 721-735, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2016.06.079.

- Ronzon, T.; Piotrowski, S.; Tamosiunas, S.; Dammer, L.; Carus, M.; M'barek, R. Developments of Economic Growth and Employment in Bioeconomy Sectors across the EU. Sustainability 2020, 12, 4507. https://doi.org/10.3390/su12114507

- Ronzon, T., Piotrowski, S., M'Barek, R., & Carus, M. (2017). A systematic approach to understanding and quantifying the EU's bioeconomy. Bio-Based and Applied Economics, 6(1), 1–17. https://doi.org/10.13128/BAE-20567

- Tévécia Ronzon, Susanne Iost, George Philippidis, An output-based measurement of EU bioeconomy services: Marrying statistics with policy insight, Structural Change and Economic Dynamics, Volume 60, 2022, Pages 290-301, ISSN 0954-349X, https://doi.org/10.1016/j.strueco.2021.10.005

- Valeria Ferreira, Laia Pié, Antonio Terceño, Economic impact of the bioeconomy in Spain: Multiplier effects with a bio social accounting matrix, Journal of Cleaner Production, Volume 298, 2021, 126752, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2021.126752

- Markevičius, V. Katinas, E. Perednis, M. Tamašauskienė, Trends and sustainability criteria of the production and use of liquid biofuels, Renewable and Sustainable Energy Reviews, Volume 14, Issue 9, 2010, Pages 3226-3231, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2010.07.015.

- Carol Hunsberger, Laura German, Ariane Goetz, "Unbundling" the biofuel promise: Querying the ability of liquid biofuels to deliver on socio-economic policy expectations, Energy Policy, Volume 108, 2017, Pages 791-805, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2017.04.017.

4.4. Relevant studies about the GHG saving potential

The methodology for GHG assessment can be defined as a mature branch of the wider LCA methodology, as defined in the ISO standards. The ISO 14040/14044 (ISO14040, 2006) (ISO14044, 2006) provide the common basis for all LCA studies. Another relevant resource is the ILCD handbook, prepared by the Institute for Environment and Sustainability in the European Commission Joint Research Centre (JRC). This consists of a general guide on lifecycle assessment, a specific guide on lifecycle inventory and a guideline on lifecycle impact assessment methods. The ILCD handbook addresses many practical considerations for LCA application beyond the general ISO 14040/14044 requirements.

Despite the existence of well-established LCA standards, their application leaves some liberty in the selection of the system boundaries and other methodological aspects. As regards the transport sector, several policies have been developed to regulate the GHG assessment of alternative fuels, especially for the road sector. Among them, the Renewable Energy Directive (RED) and its recast (REDII) set the relevant framework for the application of LCA to the transport sector in Europe. Examples of other similar legislations include the U.S. Renewable Fuel Standard, the California Low Carbon Fuel Standard, and the Brazil RenovaBio.

In the aviation sector, the CORSIA package represents a significant step forward in the implementation of an internationally agreed methodology for the GHG assessment of alternative fuels. Conversely, the maritime sector is slightly lagging behind, although the International Maritime Organization (IMO) is in the process of developing the guidelines for accounting the potential GHG saving offered by alternative marine fuels, while the *FuelEU*

Maritime regulation, which will set the rules for the European maritime sector, is in course of approval.

All the mentioned policies rely on underlying LCA frameworks which presents slightly different boundaries and methodological choices. One typical issue on which different policies diverge is in the handling of ILUC effects. In addition, several studies, and tools available in literature complement and widen the methodologies used in the regulations. One example is the JRC JEC study which, while presenting many common elements with the REDII, presents some key methodological differences.

In the following sections, the relevant policies, studies, and tools developed for the GHG assessment of alternative fuels are reviewed and compared.

4.4.1. REDII (2018/2001/EU) methodology

The recast of the Renewable Energy Directive (REDII) extended the GHG calculation methodology of its predecessor. This methodology allows to calculate the carbon intensity (CI, in gCO2eq/MJfuel) for a specific fuel production pathway.

Default GHG emission values and calculation rules are provided in Annex V (for liquid biofuels) and Annex VI (for solid and gaseous biomass for power and heat production) of the RED II. Annexes V and VI of the REDII also contains default WTT values for the most relevant feedstock-to-fuel pathways.

Economic operators have the option to either use default GHG intensity values provided in RED II or to calculate actual values for their pathway.

The equation for calculating the CI of the fuels is:

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr}$$

E : total emissions from the use of the fuel;
e_{ec} : emissions from the extraction or cultivation of raw materials;
e_l : annualised emissions from carbon stock changes caused by land-use change;
e_p : emissions from processing;
e_{td} : emissions from the fuel in use;
e_{sca} : emission savings from soil carbon accumulation via improved agricultural management
e_{ccs} : emission savings from CO_2 capture and geological storage;
e_{ccr} : emission savings from CO_2 capture and replacement.

The various parameters listed in the equation de facto define the system boundaries for the analysis. No other explanation about system boundaries is contained in the text of the directive. Some of the listed parameters (e.g., e_{sca}) need a specific Delegated Act for clarifying their application in the frame of the methodology.

As specifically indicated in the methodology, “emissions from the manufacture of machinery and equipment shall not be taken into account”. This line is used to justify the assumption that renewable electricity (i.e., PV, wind, etc.) has a carbon intensity of zero when used in a process.

As concerns the consideration of ILUC effects, these are not quantitatively accounted for in the proposed WTT values. This methodological choice was justified in view of the high uncertainty involved in the calculation of indirect GHG emissions related to the ILUC. Although the ILUC is not quantitatively estimated, the REDII requires alternative fuel to satisfy a series of sustainability criteria. Specifically, for ILUC, the regulation sets an upper limit on the amount of fuels considered at high-ILUC risk which Member States can count towards national targets.

4.4.2. JEC v5 Well-To-Tank and Well-To-Wheels reports

The JEC Well-to-Wheels Report v5 consists of two parts: the Well-to-Tank (WTT) and the Tank-to-Wheels (TTW) sections. The WTT part reports the energy demand and the related emissions of producing, transporting, manufacturing, and distributing a range of fuels suitable for road transportation powertrains. The input data used for the JEC WTT analysis provide the reference values for EU legislation on renewable fuels. The TTW section reports the in-vehicle energy consumption and the related emissions of a vehicle concept, using the AVL Cruise™ simulation tool.20.

While the JECv5 shows many similarities with the REDII and shares the same dataset, some methodological differences exist. One key difference is the inclusion of elements of consequential LCA, in opposition to the purely attributional approach of the REDII.

The consequential approach is used in the JECv5 analysis to tackle the problem of allocating emissions among the co-products of a process. As it frequently happens in biofuel pathways, many processes output not only the desired product, but also streams of co-products. A typical example is the production of biodiesel from rapeseed, where large amounts of proteins are made available to the feed sector by biomass processing.

Following a purely attributional approach, the process emissions would be split among the co-products based on their market value, mass or, as in the case of the REDII, energy content. Conversely, in a consequential approach all the process emissions are attributed to the main product, while the co-products generate an emission credit equivalent to the emissions saved by the avoided production of the good which the co-product is most likely to displace.

In order to enable the computation of the emission credits, the boundaries of the system are expanded to include those processes which are conventionally used to produce the good which the co-product is likely to substitute. Through this substitutional approach, the JECv5 analysis allows to capture the incremental emissions induced by a shift of the production from conventional to alternative fuels. As a result of the different approaches used to account for co-products emissions, the WTT values proposed by the JEC study and the REDII shows some differences.

As concerns the DILUC and ILUC effects, none of these is accounted for in the WTT values proposed by the JEC study. As for the REDII, the reason driving this choice lies in the large uncertainties band surrounding the estimation of LUC-related emissions.

4.4.3. GREET and JEC v5

The U.S. Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET®) model is an LCA tool that examines the WTW impacts of vehicle technologies, fuels, and energy systems, as well as the life cycle of vehicle production, use, and recycling/disposal. GREET has been widely used for LCA of transportation fuels and vehicle technologies. Among the programs making use of GREET, the LCFS, the RFS program and the CORSIA package can be mentioned.

In a recent paper published by Cai, et al. (2022)[44] a comparison between GREET and JEC has been carried out. The study compares the methodological approaches of the two models and how these affect the outcome of the modelling exercise.

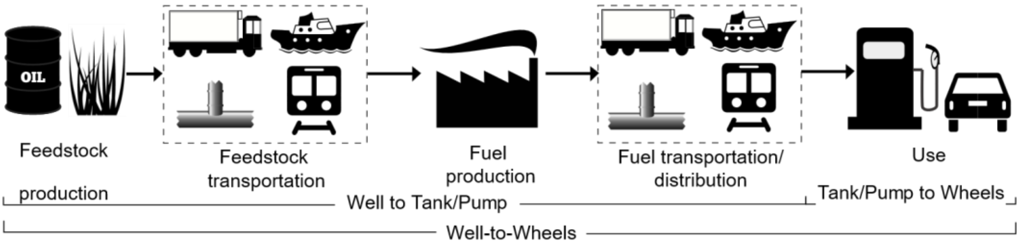
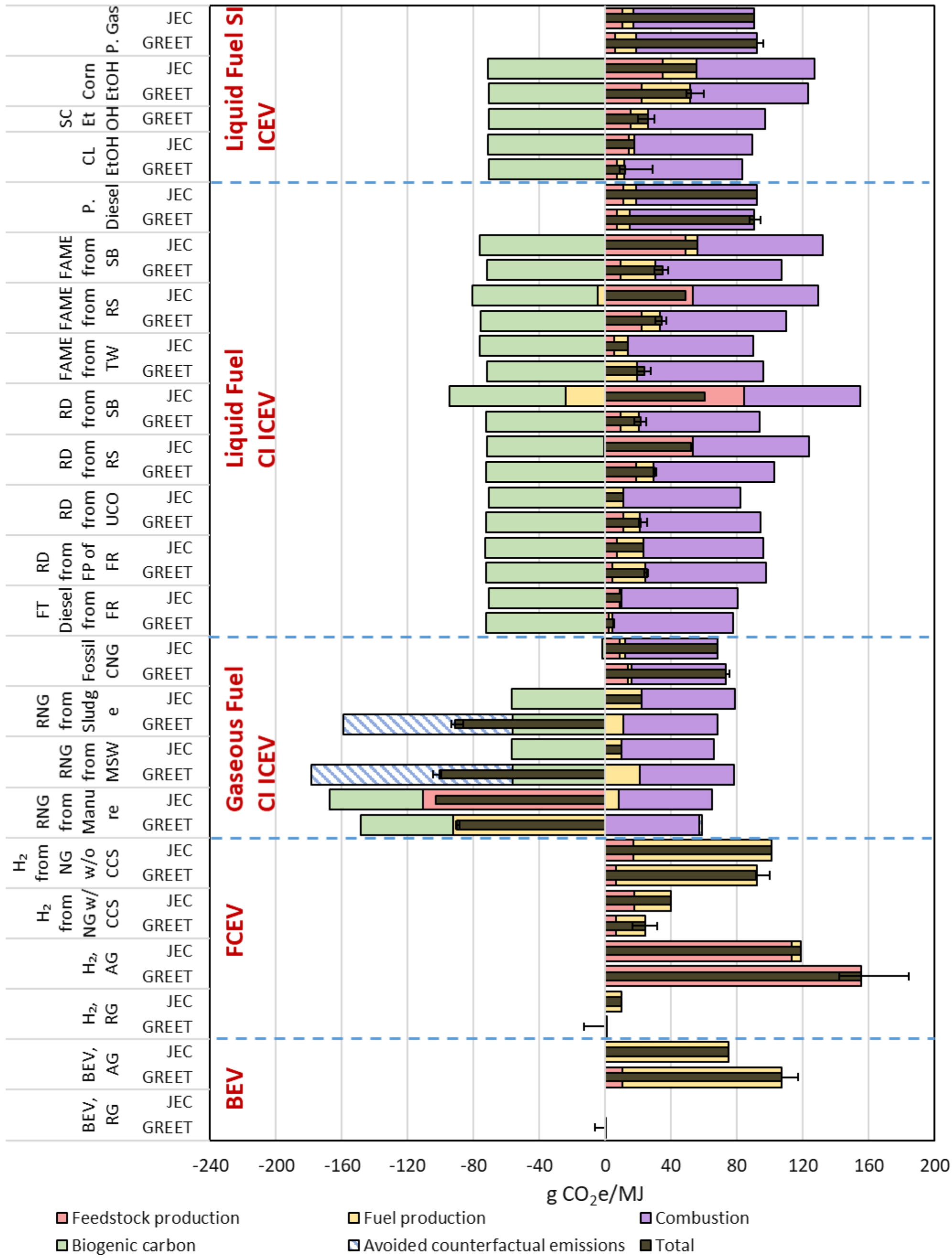


Figure A1 - 4 System boundary of WTW analysis of fuel–vehicle systems in the JEC study and GREET model

Both models are based on an attributional, specifically expanded by a consequential approach to account for indirect emissions. Process efficiencies, energy and material balances across the feedstock-to-fuel supply chain are key modelling inputs, influencing the WTW results.

The study by Cai et al. shows that the WTT and combustion GHG emission results for most fuel production pathways vary between the two models. This is partly due to overarching modelling differences (e.g., concerning the approach used to estimate baseline petroleum values) and partly to the different assumptions made (e.g., concerning the shifting from conventional waste management practices to waste-to-energy practices). However, Cai et al. also highlight that, despite these differences, both the models provide similar results on key issues, such as the importance of waste-to-energy pathways and the opportunity to generate low-carbon fuels from forest and agricultural residues requiring low farming inputs.

[44] Cai, H.; Prussi, M.; Ou, L.; Wang. M.; Yugo, M.; Lonza, L.; Scarlat, N. Supplementary Information for Decarbonization Potentials of On-Road Fuels and Powertrains in the European Union and the United States: A Well-to-Wheels Assessment. Sustainable Energy & Fuels. RCS (2022).



SI: spark ignition; CI: compression ignition; ICEV: internal combustion engine vehicle; FCEV: fuel cell electric vehicle; BEV: battery electric vehicle; P.Gas: petroleum gasoline; CL: cellulosic; FAME: fatty acid methyl ester; FT: Fischer–Tropsch; FP: fast pyrolysis; FR: forest residue; RD: renewable diesel; UCO: used cooking oil; SB: soybean; TW: tallow; RNG: renewable natural gas (biomethane); MSW: municipal solid waste; RG: renewable electricity grid mix, AG: U.S./EU average electricity grid mix; CCS: carbon capture and storage.

Figure A1 - 5 Comparison of WTT and combustion results of various fuel production pathways for light-duty powertrains from GREET and JEC modelling

4.4.4. CORSIA approach to calculate life cycle GHG emissions for aviation fuels

The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) initiative, proposed by ICAO, aims at reducing aviation greenhouse gas emissions in the next decade. In order to evaluate the life cycle GHG emissions of Sustainable Aviation Fuels (SAFs) a specific methodology has been agreed by the 193 ICAO member states. This methodology represents the first internationally adopted approach for the calculation of life cycle GHG emissions of aviation biofuels.

To be considered a CORSIA Eligible Fuel (CEF) the SAF must meet a set of sustainability criteria defined by the ICAO Committee on Aviation Environmental Protection (CAEP). The sustainability themes range from soil and air to social development and food security. Concerning GHG emissions, CEF must guarantee a minimum 10% emission savings, calculated on a WTW basis, with respect to a fossil jet fuel baseline of 89 gCO_{2e}/MJ.

CORSIA methodology for Carbon Intensity assessment

Contrarily to the studies exposed till here, the CORSIA methodology attempts to quantitatively include the ILUC effects in the estimation of life cycle GHG emissions. The WTT values proposed by the CORSIA scheme are the sum a “Core LCA” and a “ILUC” part. Given the significant methodological differences in the estimation of these two values, the work was structured in two technical groups. The Core LCA group developed the LCA methodology for SAFs and endorsed a set of default core LCA emission values for selected pathways. The ILUC working group defined the assumptions and developed results using well-established modelling tools and proposed a set of ILUC values for the selected pathways.

The Core LCA methodology is a process-based purely attributional LCA approach, considering the whole fuel supply chain (Figure A1 - 6). The system boundary includes feedstock cultivation/collection, feedstock transportation, jet fuel production, jet fuel transportation, and jet fuel combustion.

The CORSIA package set clear definitions for the feedstock used for SAF production:

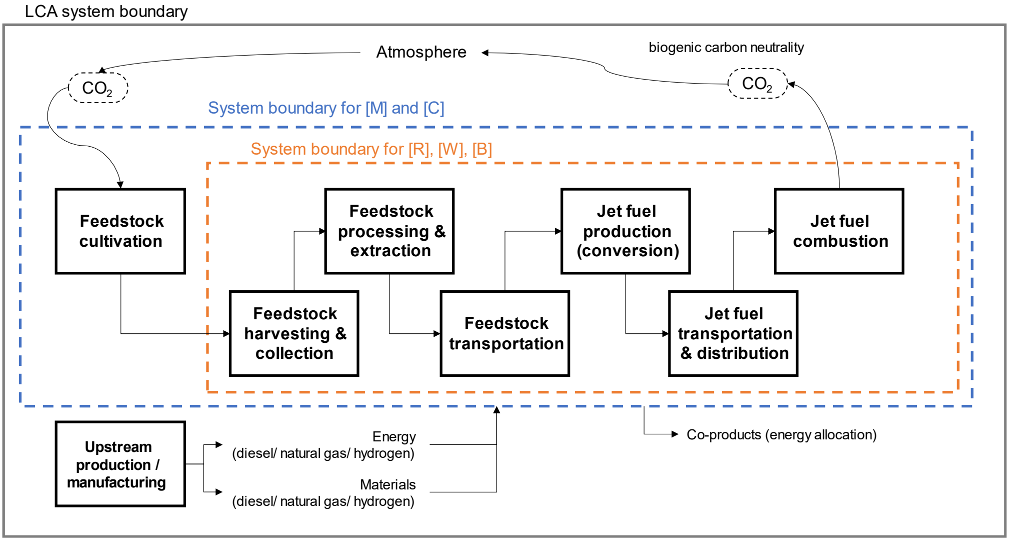
- Primary [M] and co-products [C] are the main products of a production process. These products have significant economic value and elastic supply, (i.e., there is evidence that there is a causal link between feedstock prices and the quantity of feedstock being produced)

- By-products [B] are secondary products with inelastic supply and economic value

- Residues [R] are secondary materials with inelastic supply and little economic value

- Wastes [W] are materials with inelastic supply and no economic value.

For a methodological standpoint, the SAFs produced from main [M] and co-product [C] feedstocks, all GHG emissions resulting from the use of energy and chemicals for cultivation of feedstocks are included in the LCA. For feedstocks categorized as residues,



*Waste, and by-products feedstocks [R, W, B], no upstream emissions burden before collection, recovery, and extraction are included in the LCA of SAFs. Note that the ILUC is only applicable to crops and not to [R, W, B] feedstock classes.

Figure A1 - 6 System boundaries of the Core LCA part of the CORSIA methodology

The feedstock transportation stage includes GHG emissions of transportation of feedstock from farms (or feedstock collection stations) to fuel conversion facilities.

The core LCA methodology can be summarized in the following equation, including terms for:

$$\boldsymbol{Core\ LCA}\ [\boldsymbol{gCO2e/MJ}] = \boldsymbol{efe_c} + \boldsymbol{efe_{hc}} + \boldsymbol{efe_p} + \boldsymbol{efe_t} + \boldsymbol{efefu_p} + \boldsymbol{efu_t} + \boldsymbol{efu_c}$$

efe_c: feedstock cultivation;
efe_{hc}: feedstock harvesting and collection;
efe_p: feedstock processing ;
efe_t: feedstock transportation to processing and fuel production facilities;
$efefu_p$: feedstock-to-fuel conversion processes;
efu_t: fuel transportation and distribution;
efu_c: and fuel combustion in an aircraft engine. For biofuels, this term is set to zero for the fuel fraction produced from biomass.

The functional unit is MJ (lower heating value [LHV]) of fuel produced and combusted, and the results are expressed in grams of CO2 equivalent per MJ of fuel (gCO2e/MJ) combusted in the aircraft engine. GHG emissions from fuel life-cycle stages include CO2, N2O, and CH4 (with the exception of fuel combustion, which only includes CO2), which are expressed in terms of CO2e using their 100-year global warming potentials, according to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC).

The ILUC term is calculated assessing the demand for crop-based biofuels and estimating the potential cropland expansion and the related GHG emissions due to LUC. The available literature on the ILUC effect, mainly related to the road sector, shows important disparities among models in the baseline assumptions, shock size, simulation approach and the input data used to calculate emissions. As a result, the estimation of ILUC emissions are subjected to large uncertainties and are significantly affected by the type of biofuel, feedstock, and production location. Given the remarkable uncertainty inherent to ILUC simulations, in the CORSIA methodology the ILUC emissions were estimated using two well-established economic models: GTAP-BIO and GLOBIOM. The two models have different structures, and use data sets, parameters, and emission factors from different sources.

The values for the currently ASTM certified alternative fuels have been recently published on the ICAO portal[45] and detailed also in Prussi et al, 2021[46].

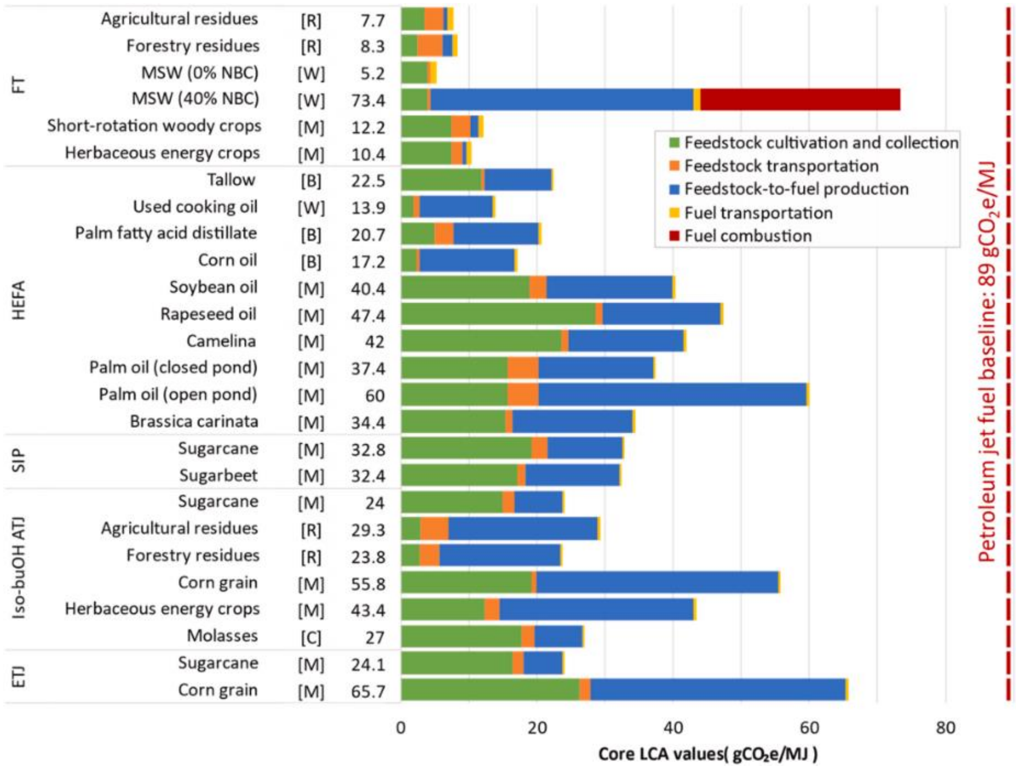


Figure A1 - 7 Carbon intensity (CoreLCA only) for CORSIA SAFs

4.4.5. The FuelEU Maritime

As part of the *Fit For* 55 package, in July 2021 the European Commission adopted the 2021/0210 (COD) regulation, commonly known as *FuelEU Maritime*. The proposal seeks to favour the uptake of low-carbon fuels through the introduction of a limit on the GHG intensity of the energy used on-board ships and imposes the use of on-shore power supply in EU ports.

[45] https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions%20-%20March%202021.pdf
[46] Prussi, M., Lee, U., Wang, M., Malina, R., Valin, H., Taheripour, F., ... & Hileman, J. I. (2021). CORSIA: The first internationally adopted approach to calculate life-cycle GHG emissions for aviation fuels. *Renewable and Sustainable Energy Reviews*, *150*, 111398.

The methodology, set out in Annex I of the proposal, provides the equations for the computation of the yearly average GHG intensity of the energy used on-board, denominated *GHG intensity index*. A full lifecycle approach is applied to determine the GHG intensity index, which is composed of a WTT and a TTW part and expressed in gCO_{2eq}/MJ (see equation below).

$$GHG\ intensity\ index\ [gCO_{2eq}/MJ] =$$

$$\frac{\sum_i^{n\,fuel} M_i \times CO_{2eq\,WtT,i} \times LCV_i + \sum_k^c E_k \times CO_{2eq\,electricity,k}}{\sum_i^{n\,fuel} M_i \times LCV_i + \sum_k^c E_k} + \qquad \text{WTT}$$

$$\frac{\sum_i^{n\,fuel} \sum_j^{n\,fuel} M_{i,j} \times \left[\left(1-\frac{1}{100}C_{engine\,slip,j}\right) \times \left(CO_{2eq,TtW,j}\right) + \left(\frac{1}{100}CO_{2eq\,TtW,slippage,j}\right)\right]}{\sum_i^{n\,fuel} M_i \times LCV_i + \sum_k^l E_k} \qquad \text{TTW}$$

Where the $CO_{2eq,TtW,j}$ and the $CO_{2eq,TtW\,slippage,j}$ terms, representing the TTW emission factors of the fuels, are computed as follows.

$$CO_{2eq,TtW,j} = \left(C_{f\,CO_2,j} \times \mathrm{GWP}_{\mathrm{CO_2}} + C_{f\,CH_4,j} \times \mathrm{GWP}_{\mathrm{CH_4}} + C_{f\,N_2O,j} \times \mathrm{GWP}_{\mathrm{N_2}O}\right)_i$$

$$CO_{2eq,TtW\,slippage,j} = \left(C_{sf\,CO_2,j} \times \mathrm{GWP}_{\mathrm{CO_2}} + C_{sf\,CH_4,j} \times \mathrm{GWP}_{\mathrm{CH_4}} + C_{sf\,N_2O,j} \times \mathrm{GWP}_{\mathrm{N_2}O}\right)_i$$

The numerous symbols and indices used in the equations above are reported in Table A1 - 1.

Term	Explanation	Units
i	Index corresponding to the fuels delivered to the ship in the reference period	
j	Index corresponding to the fuel combustion units on board the ship. For the purpose of this Regulation the units considered are the main engine(s), auxiliary engine(s) and fired oil boilers	
k	Index corresponding to the connection points (*c*) where electricity is supplied per connection point.	
c	Index corresponding to the number of electrical charging points	
m	Index corresponding to the number of energy consumers	
$M_{i,j}$	Mass of the specific fuel *i* oxidised in consumer *j*	g_{fuel}
E_k	Electricity delivered to the ship *per* connection point *k* if more than one	MJ
$CO_{2eq\,WtT,i}$	WtT GHG emission factor of fuel *i*	gCO_{2q}/MJ
$CO_{2eq\,electricity,k}$	WtT GHG emission factor associated to the electricity delivered to the ship at berth *per* connection point *k*	gCO_{2q}/MJ
LCV_i	Lower Calorific Value of fuel *i*	MJ/g_{fuel}

Term	Explanation	Units
$C_{engine\ slip\ j}$	Engine fuel slippage (non-combusted fuel) coefficient as a percentage of the mass of the fuel *i* used by combustion unit *j*	%
$C_{f\ CO_2}, C_{f\ CH_4}, C_{f\ N_2O}$	TtW GHG emission factors by combusted fuel in combustion unit *j*	g_{GHG}/g_{fuel}
$CO_{2eq,TtW,j}$	TtW CO_2 equivalent emissions of combusted fuel *i* in combustion unit *j*	gCO_{2q} $/g_{fuel}$
$C_{sf\ CO_2}, C_{sf\ CH_4}, C_{sf\ N_2O}$	TtW GHG emissions factors by slipped fuel towards combustion unit *j* [gGHG/gFuel]	g_{GHG}/g_{fuel}
$CO_{2eq,TtW\ slippage,j}$	TtW CO_2 equivalent emissions of slipped fuel *i* towards combustion unit *j* [gCO_2eq/gFuel]	gCO_{2q} $/g_{fuel}$
$GWP_{CO_2}, GWP_{CH_4}, GWP_{N_2O}$	CO_2, CH_4, N_2O Global Warming Potential over 100 years	

Table A1 - 1 Explanation of the indices and symbols used in the equations set out by the *FuelEU Maritime* methodology

As concerns the WTT part, two contributions count towards the determination of GHG emissions: the WTT emissions of the fuels used on-board and the WTT emissions associated with the electricity delivered to the ship at berth. The determination of WTT emission factors differs for fossil and non-fossil fuels. For fossil fuels, default values are provided in Annex II of the proposal, whereas the WTT emission factors of non-fossil fuels are established in Annex V of the Directive (EU) 2018/2001 (REDII)[47]. Default values for non-fossil fuels are also provided in Annex II for those pathways which are not covered in the REDII. In case a value different from the default is used, this must have been determined following the REDII methodology and a certificate attesting the fuel production pathways should be presented.

The methodology set out in the *FuelEU Maritime* for the calculation of WTT emissions is thus largely based on the REDII. The main differences concern the range of fuels considered and the addition of a term to account for the WTT emissions of the electricity supplied to the ship at berth.

In addition, the *FuelEU Maritime* lay out a methodology for the determination of TTW emissions from the use of fuels on-board ship. The methodology distinguishes the emissions relating to the combustion of fuel from fugitive emissions. The latter accounts for those emissions caused by the amount of fuel which is not consumed by the combustion unit because incompletely combusted, vented or leaked.

4.4.6. The IMO guidelines

Among the hard-to-abate sectors, the maritime is lagging behind on the journey toward decarbonisation, in comparison with road heavy-duty and aviation. In the recent years, however, the interest of stakeholders and the International Maritime Organisation (IMO) involvement is getting momentum. In particular, IMO adopted in 2018 an initial strategy on the reduction of GHG emissions from ships, setting out a 2050 vision which confirms IMO's commitment to reducing GHG emissions from international shipping. With respect to GHG

[47] It is underlined that the values to be used are those without the combustion term, e_u, which is accounted for in the TTW part of this proposal.

intensity reduction options, the alternative fuels are internationally identified as a short-to medium-term means.

The IMO has been developing an LCA-based methodology, for accounting the potential GHG saving offered by alliterative fuels. These guidelines should be approved by MEPC[48] in the second half of 2023.

4.4.7. ESSF SAPS WTW tool

An interesting tool to estimate the WTW of marine fuels has been produced by the European Sustainable Shipping Forum – by means of its Sustainable Alternative Power for Ships (SAPS) group.

The aim of the workgroup was to provide a comprehensive summary of the existing scientific knowledge on the performance and potential of alternative energy conversion technologies for shipping, including their environmental performance, on a complete WTW approach, complemented, where appropriate, with life cycle considerations.

The approach and methodology are provided on the portal[49] which details every step to determine the emissions and related GWP. The portal does not propose a specific methodology to calculate the WTT and TTW parts. It collects data, that are constantly updated on the basis of the latest research studies. The data collected contains energy carriers' properties but also the coefficients and parameters used to determine emission level, efficiency, slip, etc. For any WTW pathways, emission level is calculated based on the combined emission levels of CO_2, N_2O and CH_4, and provided as Global Warming Potential over 20 and 100 years, in g of CO_{2eq} per effective kWh (used energy). The use of the kWh instead of MJ has been chosen, given the development of electrification and the easiness to compare renewable electric energy output of wind turbines or solar panel with emission per unit energy.

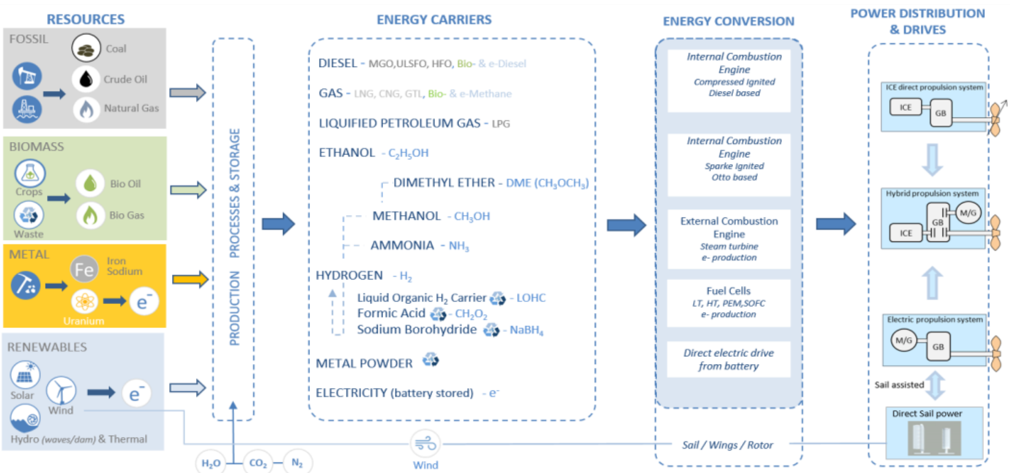


Figure A1 - 8 Scheme explaining the logic of the ESSF SAPS tool

[48] https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC-default.aspx
[49] https://sustainablepower.application.marin.nl\

4.4.8. Summary of the main findings about existing methodologies for GHG emissions assessment of alternative fuels

A summary of the structure and approaches for the above-mentioned studies and methodologies is reported in the following table.

	REDII Annex V and VI	JEC v5	CORSIA
General approach	Purely attributional. Some consequential elements are expected within the Delegated Act for RFNBO.	Attributional with minor consequential thinking related to the co-product allocation criteria.	Purely attributional for CoreLCA, consequential for ILUC.
Feedstock definition	Not clearly defined.	Not clearly defined.	Specific definition provided.
System boundary	Defined for all the stages of the feedstock and fuel production and distribution. Fuel use non-specifically described.	As per the REDII.	Defined for all the stages of the feedstock and fuel production and distribution. Fuel combustion considered for the fossil kerosene. System boundary expansion needed for ILUC part.
Co-product allocation	Energy based: the energy content of the co-product is considered within the process input.	Substitution: a credit is defined in relation to the avoided GHG emission of the market product that the co-produce is going to substitute (e.g. soybean non produced as replaced by the protein cake from rapeseed oil extraction).	Energy based. AS per the REDII.
ILUC	Not calculated. ILUC is managed by specific provisions on the feedstock categories.	Excluded from the study.	Directly calculated and summed up to CoreLCA part, to define the final default value.
GWP	100-years. IPCC AR4	100-years. IPCC AR5	100-years. IPCC AR5
Default values	Proposed for road fuels.	The value proposed in the JEC study are actually default but have not been defined as such.	Proposed for aviation fuels.
Fossil benchmark	Fossil fuel comparator (94 gCO_{2e}/MJ).	Gasoline (90.4 gCO_{2e}/MJ) and Diesel (92.1 gCO_{2e}/MJ) calculated with a marginal approach on an LP model for EU refinery.	Kerosene world average value agreed (89 gCO_{2e}/MJ).

Table A1 - 2 Synopsis of the main WTT methodologies for the assessment pf alternative fuels

Appendix II - Interaction with Stakeholders

The interaction with the stakeholders is a key aspect. In the project, specific moments for the interaction with the stakeholders have been planned at various stages, along various tasks.

In order to support the partners in the identification of the most relevant stakeholder, and to group them so to support their engagement, a stakeholder matrix has been defined. A stakeholder matrix is a tool aiming at supporting the identification of the relevant stakeholders, and their relation to the project.

The proposed structure has been derived from the European Commission PM2[50] project management methodology artifact.

4.5. Matrix structuring and stakeholder identification

The matrix is a tool designed to support the project partners in identifying the best approach to group and interacting with stakeholders. For this project, the matrix has been organized on the basis of the tender structure. The tender has been analysed in order to identify the most relevant groups pf stakeholders, for each task (see Figure A2 - 1).

Additionally, a subdivision per transport segment has been proposed, where relevant.

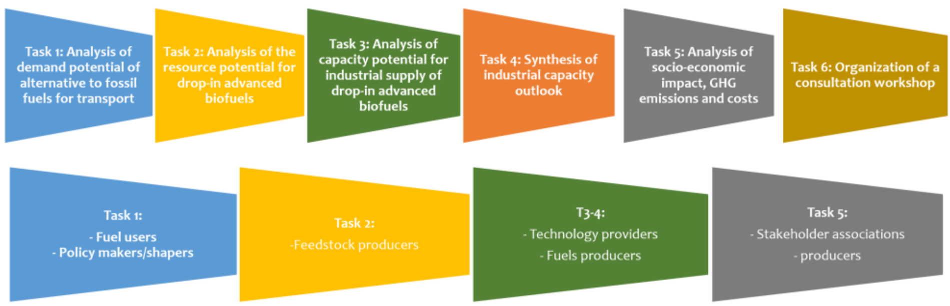


Figure A2 - 1 Analysis of tender structure and related stakeholder identification

The resulting matrix (see Table A2 - 1) allows clustering the stakeholder according to:

- Type of subject (e.g., feedstock producer, technology provider, etc.);
- Transport segment (e.g., maritime, road, etc.) ;
- Involvement in the tender tasks.

[50] https://joinup.ec.europa.eu/interoperable-europe/news/french-translation-pm2-guide-available

			Stakeholder Type						Transport Sector						Involved in Task						Comments	Contact Info (Email - Phone)
Organisation	Name	Impact	Feedstock Producer	Fuel Producer	Technology Provider	Fuel Consumer	Stakeholder Associations	Policy Maker/Shaper	Aviation	Maritime	Road - Heavy Duty	Road - Light Duty	Road - Generic	Intersectorial	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6		

Table A2 - 1 Proposed structure for a stakeholder matrix

The matrix has been made available to the partners, to support the collection of the data, in a structured manner, and the organization of their interaction with the stakeholders.

Appendix III - A specifically designed tool to define the GHG saving potential of alternative fuels, for the various transport modes

In order to collect most relevant data for the GHG of alternative fuels and made them available for calculating the impact of the scenarios proposed, a dedicated tool was developed in the Python programming environment.

The backbone of the tool is a database collecting the most relevant literature dealing with Well-To-Tank assessment of alternative fuels for the transport sector. The data sources include studies for the road transport mode, such as the JEC reports[51],[52] and the RICARDO study[53], as well as for the aviation sector[54]. In its current version, the tool covers 119 different fuel pathways, across 46 feedstock types, 28 conversion processes and 32 fossil and non-fossil fuels (see Figure A3 - 1).

[51] Prussi, M., Yugo, M., de Prada, L., Padella, M., & Edwards, R. (2020). *JEC Well-To-Wheels report v5*. https://doi.org/10.2760/100379
[52] Prussi, M., Yugo, M., de Prada, L., Padella, M., Edwards, R., & Lonza, L. (2020). *JEC Well-to-Tank report v5*. https://doi.org/10.2760/959137
[53] Nikolas, H., Amaral, S., Morgan-Price, S., Bates, J., Helmes, H., Fehrenbach, H., Biemann, K., Abdalla, N., Jorens, J., Cotton, E., German, L., Harris, A., Ziem-Milojevic, S., Haye, S., Sim, C., & Bauen, A. (2020). *Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA*.
[54] Prussi, M., Lee, U., Wang, M., Malina, R., Valin, H., Taheripour, F., Velarde, C., Staples, M. D., Lonza, L., & Hileman, J. I. (2021). CORSIA: The first internationally adopted approach to calculate life-cycle GHG emissions for aviation fuels. In *Renewable and Sustainable Energy Reviews* (Vol. 150). Elsevier Ltd. https://doi.org/10.1016/j.rser.2021.111398

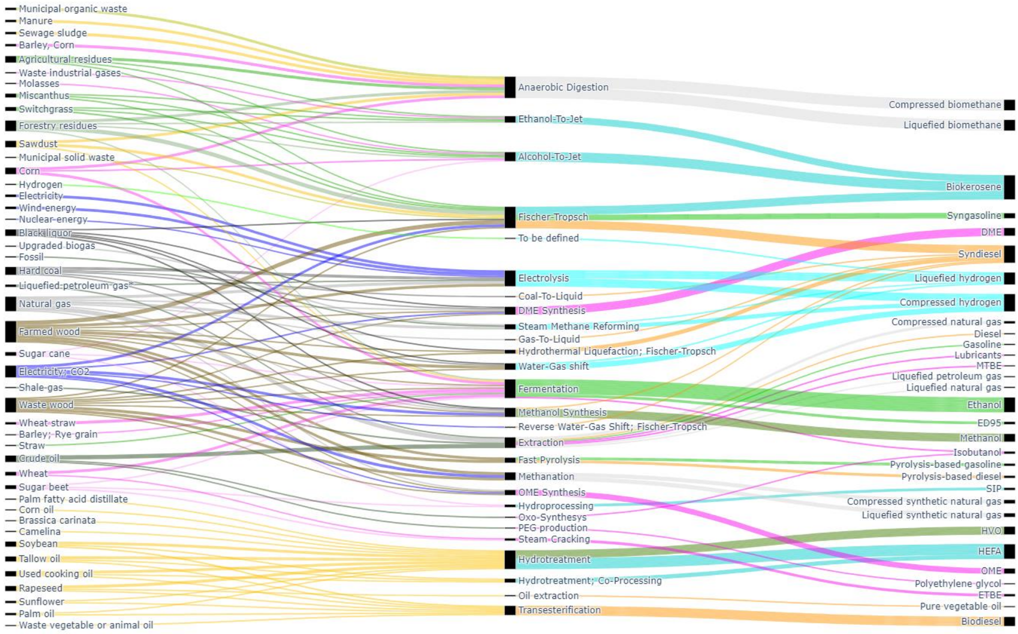


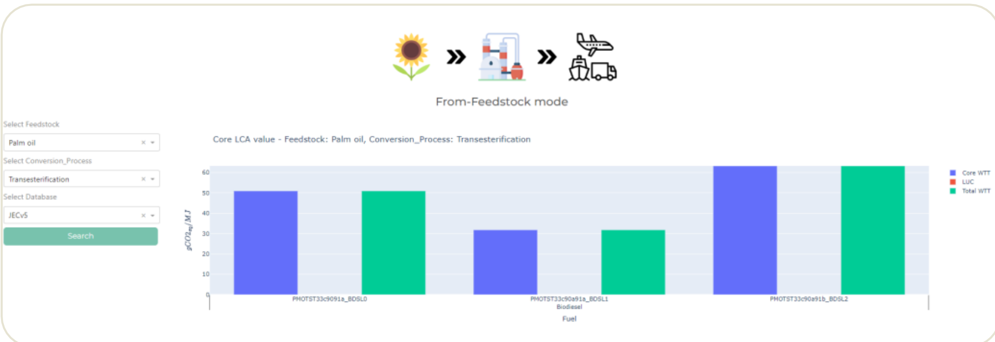
Figure A3 - 1 Fuel pathways covered by the GHG assessment tool

The tool offers two main functions to the user (Figure A3 - 2):

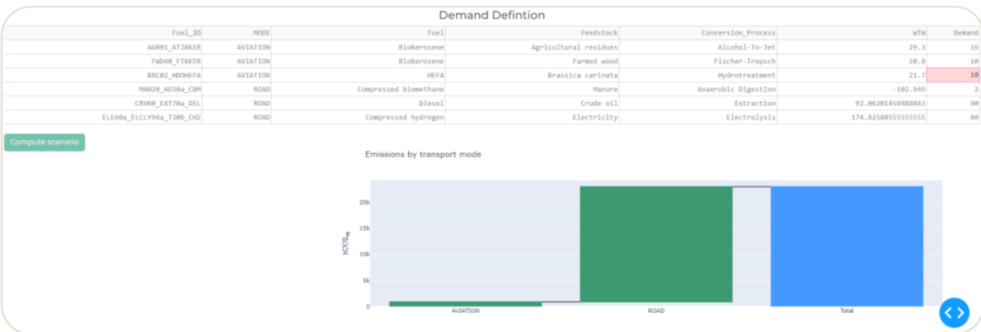
- **Visualisation and comparison** of different fuel supply chains, across different databases. The user is free to select different search modes (e.g., feedstock- vs fuel-based) . Besides providing quick access to WTT data, otherwise fairly dispersed in existing literature, the aim of the tool is to make transparent to the user the methodological assumptions underlying different studies and supply chains.

- **Evaluation of scenarios** for the decarbonisation of the transport sector. The user can select a list of fuel pathways from the database and specify a demand scenario for each of them. The tool retrieves the GHG data from the database and calculates the total GHG emissions in the scenario, for each transport mode. Optionally, the user can compare the scenario with a pre-define baseline. Also in this case, the methodological assumptions characterizing different supply chains and studies are made transparent to the user, so to support an informed selection.

Figure A3 - 2 Structure of the tool for GHG assessment of transport scenarios



a)



b)

Figure A3 - 3 Web-based application of the GHG assessment tool

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The deployment of advanced biofuels is projected to yield considerable GHG savings. Depending on the scenario, emissions avoided by advanced biofuels could account for 27 – 65 MtCO2eq/yr and contribute to reducing the carbon intensity of the transport fuel mix by 20%. By 2050, the emissions avoidance could exceed 151 MtCO2eq/yr. It is also associated with a significant positive impact on direct and indirect employment generating over 53,000 new jobs by 2030 and over190,000 by 2050, which would represent about 0.1% of the total EU jobs as of 2022.

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