Study supporting the impact assessment of the ReFuelEU Aviation initiative

Final report

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Table of Contents

1. Introduction: Background and context of the study

a. Purpose of the study

This study aims to support the European Commission's Impact Assessment of the ReFuelEU Aviation initiative by looking into Policy Options that can be applied to support the large-scale production and use of Sustainable Aviation Fuel of high sustainability[1] potential in the EU at competitive prices.

a. Context

While the overall contribution of the aviation sector to greenhouse gas (GHG) emissions has been relatively small (about 3.6% of the total GHG emissions from the EU), the sector is currently, representing 13.2% of the emissions of the transport sector[2]. This share in transport emissions has been growing since 1990 reflecting the rapid growth in air transport activity that reached over 1,600 billion passenger-km flown in 2018 (i.e. an increase of 60% compared to 2005 levels) (EASA; EEA; EUROCONTROL, 2019). GHG emissions have accompanied this growth in air traffic, albeit at a slower pace (28% increase compared to 2005 levels) due to improvements in aircraft efficiency.

Although the COVID-19 pandemic has significantly depressed air transport activity and in spite of the expected further efficiency improvements (e.g. in the field of Air Traffic Management (ATM), aircraft fuel efficiency etc.), it has long been recognised that the continued growth in demand for air travel would result in aviation becoming one of the largest contributors of GHG emissions if action was not taken to reduce those emissions. With the EU's commitment to achieve the climate objective of limiting global average temperature increase to below 1.5°C above pre-industrial levels as confirmed in the Paris Agreement and reinforced with the announcement of the European Green Deal, the aviation sector will need to take further action to reduce its emissions.

The European Green Deal foresees the achievement of an economy-wide carbon neutrality by 2050, with transport GHG emissions to be reduced by 90% by the same year (compared to 1990 levels) (European Commission , n.d.). The climate target action plans published in September 2020 now aim to achieve GHG emission reductions of 55% by 2030 (European Commission, 2020). Prior to this, the need to reduce both GHG emissions and oil dependency from transport was already supported by other initiatives at the EU level including the 2011 White Paper on Transport, the 2016 European Strategy for Low Emission Mobility and the 2018 "Clean Planet for All" Long Term Strategy. For the aviation sector, initiatives to reduce emissions at the international level are also important given the global nature of the sector. Work is underway at the International Civil Aviation Organisation (ICAO) on a 'basket of measures' for reducing emissions from aviation (ICAO, 2013), including:

- Green aircraft technologies, with more efficient aircraft design and technologies.
- Operational measures, e.g., with improved air traffic management operations.
- Sustainable aviation fuels.
- Market-based measures.

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[1] The Renewable Energy Directive (RED) sets sustainability criteria which include accounting for the potential negative direct impact from the production of biofuels due to indirect land use change (ILUC)

[2] accounting for both intra- and extra-EU flights

The EU is taking action along these lines recognising that a comprehensive approach to reducing GHG emissions from the aviation sector is required. Actions already in place include, support for research and development (R&D) support for “greener” technology, modernisation of ATM systems and market-based measures (such as the EU aviation ETS). This study focusses on promoting Sustainable Aviation Fuels (SAF).

SAFs are defined as advanced biofuels (The European Parliament and the Council of the European Union, 2018) and Renewable Fuel of Non-Biological Origin (RFNBOs), also referred in literature and in this study as (green) synthetic fuels, electrofuels or Power-to-Liquid (PtL) fuels, for aviation that achieve GHG emissions savings as compared to conventional fossil based jet fuel and are compliant with/eligible according to the sustainability framework of the Renewable Energy Directive 2001/2018. The following section provides a more specific understanding of the fuel that could be eligible as SAF.

The use of sustainable, low carbon fuels is one of the pathways available to decarbonise the transport sector. The European Green Deal recognises the importance of increasing the production and deployment of sustainable alternative transport fuels and makes this one of the priority areas for action. For the aviation sector, the use of drop-in alternative fuels[3] to replace fossil fuels is one of the most promising solutions given that the alternatives, such as hydrogen or electrification, which require another generation of aircraft and fuel infrastructure, are not yet mature for commercial deployment, still need significant R&D and are thus more difficult to implement in this sector.

Some of the more closely linked parallel, initiative supporting the goal of decarbonising aviation is the revision of the Renewable Energy Directive (RED II) which currently provides a goal for Member States for achieving a certain level of use of alternative fuels in the transport sector. This directive also provides the sustainability requirements to consider advanced biofuels eligible as SAF. Another initiative, the EU ETS provides a market-based approach to reducing the carbon footprint of the aviation industry instituting a certain level of allowances for GHG emissions. Additionally, the revision of the Energy Taxation Directive also examines whether tax incentives can be used to incentivise the use of more sustainable aviation fuel by taxing conventional fossil fuel.

b. Sustainable aviation fuels

Alternative sustainable fuels can be defined in different ways. In RED II, which asks to establish at Member State level an obligation for fuel suppliers of a renewable energy share of at least 14% in road and rail transport[4], fuels are classified on a feedstock basis. At the same time, the fuels must meet minimum GHG reduction requirements compared to a fossil reference fuel as well as other sustainability requirements in order to be considered sustainable fuels for crediting to the objectives of RED II:

- **Biofuels from food and feed crops (conventional biofuels)** are limited in being eligible towards the RED II targets. Their maximum share is one percentage point higher than the respective national shares in 2020 or 7%. Member States can restrict the eligibility of these biofuels even further in their national implementation of RED II. Additionally, biofuels with high risk of inducing indirect land-use change will have to be completely phased out by 2030.

3 Defined as fuel that are compatible to be used with the existing aircraft technology and fuel storage also blended in with conventional fossil jet fuel.

4 There is the option to include the renewable energy volumes from maritime and aviation sector in the national implementations of the fuel obligations. Renewable electricity used in transport is another possible compliance option which is not listed here.

- **Biofuels from used cooking oil and animal fats (advanced biofuels, Annex IX, part B)** are also limited in being eligible towards the RED II targets due to their limited feedstock availability. Their maximum energetic share in transport is restricted to 1.7%. With the approval of the EU Commission and taking into account the availability of feedstocks, other limits may also be set by the national implementation.
- **Advanced biofuels (using feedstock identified in Annex IX, part A)** for which fuel suppliers have to increase their share over time (2022: 0.2%; 2025: 1%; 2030: 3.5%). The list of possible feedstocks in Annex IX, part A contains different biogenic waste and residue sources.
- **Renewable liquid and gaseous transport fuels of non-biological origin (RFNBO) are another option** to meet the targets of the national implementation of the RED II. They include synthetic fuels (electrofuels) produced with the use of renewable electricity and hydrogen. Intermediate products of conventional fuel production such as the use of hydrogen from electrolysis in refineries are also eligible towards the RED II target. Delegated acts on how to calculate GHG emissions of RFNBOs and on the criteria which have to be met for electricity to be considered renewable electricity are due in 2021.
- **Recycled carbon fuels (RCF)** use fossil waste as a feedstock for fuel production. Member States can choose to make them eligible in their national implementation to meet the required renewable share in road and rail transport in. The methodology to calculate their GHG emissions will be provided by an upcoming delegated act by the end of 2021.

The fuels must also meet eligibility thresholds in terms of GHG emission reduction compared to a fossil comparator to be accounted for under the RED II. Biofuels and RFNBO must have minimum GHG savings of 65% respectively 70%. The definition of the GHG emission threshold for RCF will be defined by January 2021.

Thus, RED II provides the general framework within which the national implementation of the required fuel mandates can be implemented by the Member States. However, multipliers for the crediting of certain fuels and modes of transport, the type of mandate, the level of caps for conventional biofuels and advanced biofuels Annex IX, part B, the crediting of recycled carbon fuels and other design elements are determined at Member State level and can therefore differ.

2. Problem definition

This section presents the problem this intervention is called to address. At first, a higher level overview is presented providing the problem tree diagram that links the specific problem drivers with the problems and the initiative’s objectives. Then the nature and magnitude of the problem is defined before elaborating on the three problem drivers contributing to its development. After that, the expected development of the problem in the absence of any intervention and the expected effects this would have on different stakeholder groups are provided. Finally, the justification is given according to which an EU initiative is required to address the problem.

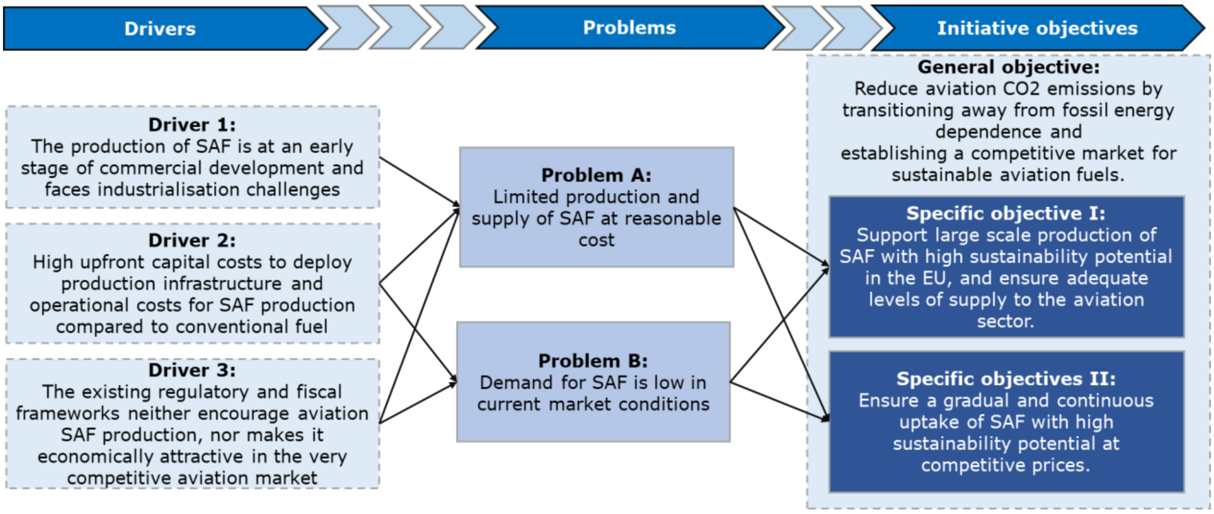
a. Problem tree diagram

The problem analysis that has taken place and is presented in the following sections of the chapter concluded on identifying the following identified problems:

- **Problem A:** There is currently limited production of SAF taking place in the EU, resulting at a lack of supply of these fuels at a reasonable cost;
- **Problem B:** The demand for SAF by airlines is currently low as a result of the current market conditions.

These two problems are linked to a set of specific problem drivers as seen in Figure 1. The problem drivers are elaborated in the following sections also highlighting their expected development in the future. Finally, in this figure the problems are linked to the developed general and specific objectives of the initiative which are elaborated later in Chapter 4.

Figure 1: Problem tree



b. Nature and magnitude of the problem

Problem area A: Limited production and supply of SAF at reasonable costs

In 2018, the transport sector was responsible for 29.7% of the total greenhouse gas emissions in the EU-27, with aviation being responsible for 13.2% of this. Despite efficiency gains, a significant increase in the number of passenger-kilometres flown has led to emissions from international aviation[5] increase by 119% compared to 1990 levels.

The European Green Deal foresees the achievement of economy-wide climate neutrality by 2050, with transport GHG emissions to be reduced by 90% by the same year (compared to 1990 levels). It also aims to boost the production and uptake of sustainable alternative fuels across all transport modes. The EU 2030 Climate Target Plan (European Commission, 2020) sets more ambitious goals for GHG reductions with a 55% reduction target by 2030. The Plan specifically foresees an increase in the share of renewable energy used in transport to 24% of the sector's needs by the same year. Prior to this, the Fuel Quality Directive (FQD) already mandates for 2020 a reduction of GHG intensity by 6% compared to 2010 levels (assuming a baseline of 94.1gCO_{2eq}/MJ). Additionally, the need to reduce both GHG emissions and oil dependency from transport was already supported by other initiatives at the EU level including the 2011 White Paper on Transport, the 2016 European Strategy for Low Emission Mobility and the 2018 "Clean Planet for All" Long Term Strategy.

[5] both domestic and international flights

At an international level, the International Civil Aviation Organisation (ICAO) "basket of measures for reducing aviation emissions" (ICAO, 2013) identifies SAF as one of the four measures to be adopted for the reduction of aviation GHG emissions.

According to the International Energy Agency's (IEA) Sustainable Development Scenario, 10% and 20% of aviation energy demand in 2030 and 2040 respectively, would have to be met by biofuels in order to reach a 50% reduction in emissions by 2050, compared to 2005 levels (IEA, 2019).

Moreover, a significant increase in the use of SAF by 2050 would be required to achieve the temperature goals for the Paris Agreement: in this scenario advanced biofuels (The European Parliament and the Council of the European Union, 2018) and electrofuels would represent almost 23% and 34%, respectively, of the energy mix in the aviation sector by 2050 (European Commission, 2018).

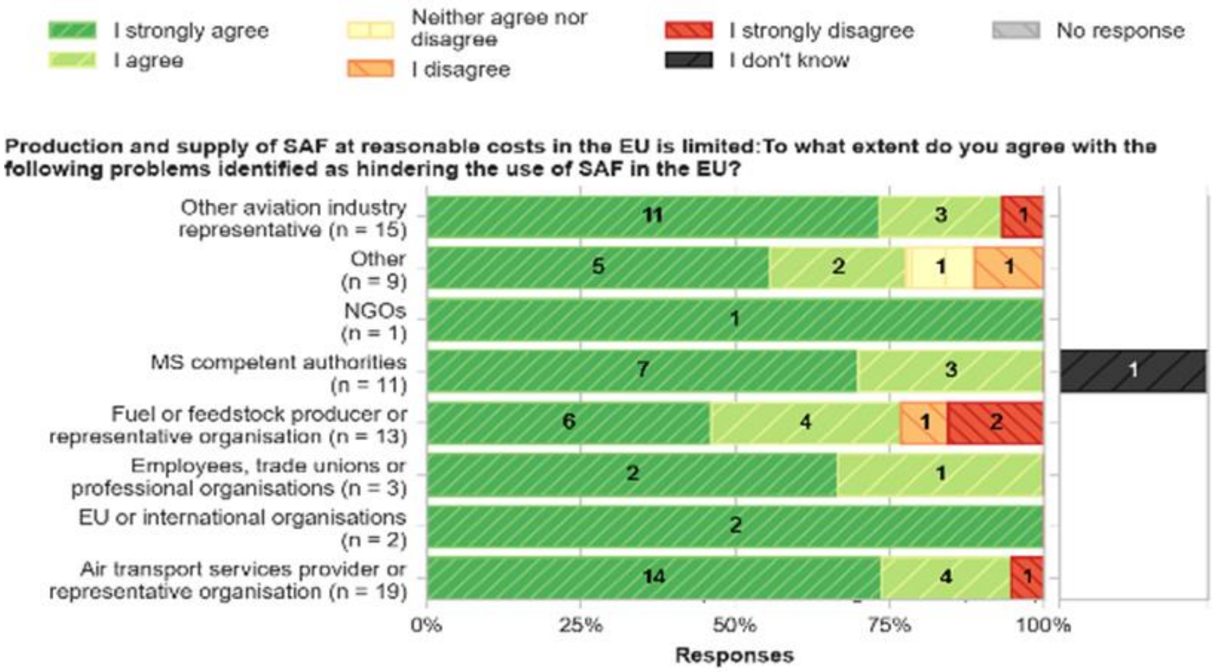
Although the increased use of SAF is considered a critical element of the sector's climate response, their uptake for 2020, prior to assessing the impacts of the travel decline related to COVID-19, has been forecasted to be as little as 0.05 million tonnes (Mt)_(European Commission, 2018). The current uptake of SAF to date has been marginal despite commitments from policy makers and industry to take action to support their uptake dating to nearly a decade ago. Indeed, the European Advanced Biofuels Flightpath[6], aiming to achieve 2 Mt of SAF usage in the EU by 2020 (European Commission, 2011), this voluntary partnership has fallen short of meeting this target. This goal is far from being reached despite the theoretical SAF capacity currently deployed in the EU being able to produce 2.3 Mt per year (equivalent to 4% of the total EU conventional aviation fuel demand), there is currently negligible capacity dedicated to SAF, proving the sectors heavy reliance on fossil fuel to meet its needs.

Further, the low competitiveness of SAF prevents the refineries from maximising their production of biomass derived SAF (EASA; EEA; EUROCONTROL, n.d.). Achieving a considerable uptake of SAF requires not only maximising the use of existing production capacity, but also the deployment of significant volumes of additional SAF production capacity. The majority of stakeholders that responded to the survey[7] (65 out of 72 respondents) either agree or strongly agree that there is currently limited production and supply of SAF at reasonable costs in the EU as can be seen in Figure 2 below. From all stakeholder groups, fuel suppliers seem to be the more reluctant to support this statement, although they (Strongly) agree with this in their majority (10 out of 13 respondents.

[6] a partnership, launched in 2011 and comprised of the European Commission, Eurocontrol and representatives of the aviation and biofuels industry

[7] Responses received by 9 September 2020

Figure 2: Stakeholders opinion on Problem A: Production and supply of SAF at reasonable costs in the EU is limited



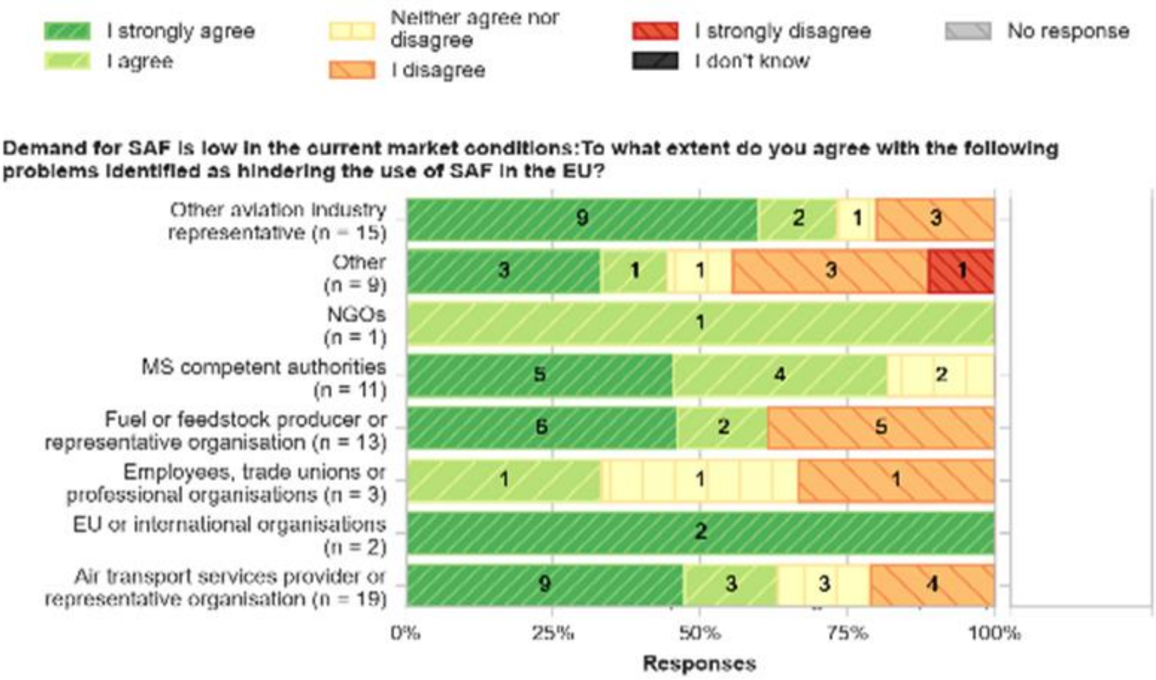
Source: Targeted stakeholder survey

Problem area B: Demand for SAF is low in the current market conditions

As elaborated also under Problem area A, meeting the EU's climate goals requires a significant increase in the uptake for SAF in the coming years. Despite the fact that the currently deployed production is not sufficient to meet the SAF production necessary in future years, the production facilities already in place (predominantly for the HEFA-SPK production route), are far from maximising potential SAF production. The main reason for this is the lack of sufficient demand for SAF by aviation service providers. Although a number of airlines have experience with using SAF as part of their fuel blend, the overall consumption of SAF remains extremely low. SAF was forecasted to contribute in 2020 only a small fraction of the approximately 57 Mt of fuel used per year in the EU. The Clean Planet for all strategy (European Commission, 2018) indicates that aviation needs to turn to the use of advanced biofuels and electrofuels produced with renewable energy in order to achieve the requirements of the Paris Climate Agreement for the EU; more than 50% of the fuel volume in the aviation sector needs to come from advanced biofuels and electrofuels by 2050. It is obvious that a very significant increase in SAF uptake by airlines is required to take place in future years.

Roughly two thirds of stakeholders that responded to the survey (48 out of 73 respondents) either agree or strongly agree that there is currently low demand for SAF in the EU as can be seen in Figure 3 below. Similar to Problem A, from all stakeholder groups, fuel suppliers seem to disagree with this statement the most although the majority of this group still (strongly) agrees (8 out of 13 respondents).

Figure 3: Stakeholders opinion on Problem B: Demand for SAF is low in the current market conditions



Source: Targeted stakeholder survey

c. Drivers and root causes of the problems

Driver 1: The production of SAF is at an early stage of commercial development and faces industrialisation challenges.

Advanced biofuels

Currently a total of 8 production routes for advanced aviation biofuels have been certified by the American Society for Testing and Material (ASTM) which is the only certification body accepted worldwide. These are shown in Table 1:

Table 1: SAF production routes

	SAF Production Route	Feedstock	Referenced in RED II
1	Hydroprocessed Esters and Fatty Acids (HEFA)	Used cooking oil, Animal fats classified as categories 1 and 2 in accordance with Regulation (EC) No 1069/2009 (European Parliament and the Council of the European Union, 2009)	Annex IX, Part B
2	Co-processing oils/fats		Annex IX, Part B
3	Direct Sugars to Hydrocarbons (DSHC)	Straw, Grape marcs and wine lees, Other non-food cellulosic material Other ligno-cellulosic material except	Annex IX, part A
4	Alcohols to Jet (AtJ)		Annex IX, part A

	SAF Production Route	Feedstock	Referenced in RED II
		saw logs and veneer logs	
5	Biomass Gasification + Fischer-Tropsch (Gas+FT)	Biomass fraction of municipal or industrial waste and biowaste,	Annex IX, part A
6	Biomass Gasification + FT with Aromatics	Biomass fraction of wastes and residues from forestry and forest-based industries, Tall oil pitch, Bagasse, Nut shells, Husks, Cobs cleaned of kernels of corn Other non-food cellulosic material Other ligno-cellulosic material except saw logs and veneer logs	Annex IX, part A
7	Catalytic Hydrothermolysis (CHJ)	Used cooking oil, Animal fats classified as categories 1 and 2 in accordance with Regulation (EC) No 1069/2009	Annex IX, part A
8	HEFA from algae	Algae if cultivated on land in ponds or photobioreactors	Annex IX, part A

For a number of these production routes, supplying the production with sufficient feedstock that meets the requirements of the Renewable Energy Directive – Recast to 2030 (RED II) - Annex IX provisions for sustainable biofuels, is a challenge. The RED II distinguishes advanced biofuels depending on the feedstock used for their production. These are distinguished into biofuels produced by advanced technologies" (Annex IX - Part A) and those in Annex IX - Part B, with the latter derived from feedstock considered of limited availability. The Directive is providing a specific minimum sub-quota for the production of Part A biofuels while capping the contribution of overall production of Part B biofuels[8] to the general target on renewable energy share in transport.

HEFA-SPK is the most commercially advanced SAF production route and is currently applied at an industrial scale. Although the fuel produced through this production routes is not cost competitive to conventional fuel yet, the technological maturity of this technology indicates that production of SAF through this route is the most promising for being delivered at a large scale in the near future. Nevertheless, the production capacity through this route is constrained by the availability of waste oils as a feedstock. Using virgin oils, produced exclusively for their conversion into biofuels can potentially create high land-use change emissions and are thus not eligible under the RED II Annex IX provisions. Estimates regarding the feedstock availability to produce SAF via this production route bring the global SAF production capacity using used cooking oils (UCO) to between 7.8 and 10.1 Mt/year and

8 Allowing however for exceptions

for the EU to between 2.3 and 3 Mt/year. The World Economic Forum (WEF) suggests that additional feedstocks for HEFA such as animal fats (tallow) and oils from paper production, and residue streams from corn and palm oil production, could also contribute to HEFA providing an additional 11-15 Mt of HEFA globally. Overall, the WEF expects that approximately, 5-10% of the global aviation fuel needs could be covered from SAF produced via the HEFA route (World Economic Forum, 2020). The same feedstock limitations are the case for the CHJ or the co-processing production routes which use similar feedstock sources. Overall, feedstock used in these production pathways is estimated to cover up to approximately 10% of the EU aviation needs. We should note though that these estimates need to be considered with caution, as they may not take full account of the needs of other sectors of the economy for the same feedstock.

Feedstock availability is also a challenge for other production routes. ATJ-SPK relies on agricultural and forestry residues which are classified as Annex IX, Part A feedstock in the REDII, however, the supply and availability of these raw materials is not unlimited, also taking into account their current use in other economic sectors, and the need for collection systems. Similarly, optimal GHG emission reductions from the Gas+FT production route (and that of Gas+FT with aromatics) are achieved when agricultural and forestry residues are used as feedstock. This represents similar challenges regarding their availability and collection. In the future, purpose-grown ligno-cellulosic energy crops could also be used if the agricultural sector took up cultivation of these crops, as they require low levels of agricultural inputs, and so have low associated GHG emissions. The organic fraction of municipal solid waste can also be used as a feedstock and is e.g. being considered for some gasification routes.

It is estimated that between 34 and 93 Mt/year[9] of SAF can be produced in the EU from production routes using these feedstocks. To set this in context, current aviation fuel consumption in the EU reached about 48 Mt in 2020.[10] This means that these feedstocks can potentially cover at least 60% of the EU aviation fuel needs in the future thus contributing considerably to covering the needs of the sector. Nevertheless, the future availability of these feedstocks for aviation vis-à-vis the needs of other sectors needs careful consideration.

Scaling up to this level of SAF production would require a number of barriers to be overcome, in particular residues and wastes may occur in scattered locations and have limited transportability so plants need to be located in regions where there is a high concentration of the feedstock and their logistics to the locations were fuels are needed will need to be further elaborated. While decentralised production might bring regional economic benefits, it may also present a challenge to reform the existing fuel distribution system structure. The costs of purchasing feedstock and their logistics can actually become the dominant cost driver in some cases. This is due to the work intensity of collecting and preparing the material streams for the production of SAF.

Less production capacity can be expected from less developed advanced biofuel production routes, which can however prove useful and cost-competitive when applied locally and exploiting more available local feedstock and thus contribute to the overall SAF production.

Another important input for SAF production is the availability of hydrogen, the availability of which in the market from non-fossil origin is still limited, while other sectors are also

[9] more elaborate feedstock availability estimations provided in Annex 3

[10] Based on Eurostat dataset (nrg_cb_oil)

competing for its use. The main constrain for this is the availability of sufficient and renewable energy at a price making the production of hydrogen through electrolysis sufficiently cost competitive.

An additional factor that affects the production of SAF is the fact that during their refining process, other chemical products are also developed, such as HVO (Hydrotreated Vegetable Oil) which is used for the production of biodiesel (ICCT, 2019). The production ratios for the different refined products can, within specific limits, be calibrated in favour of producing specific products. Currently, in the case of HEFA-SPK/HVO it is estimated that only about 10% to 15% of the current production process output is aviation fuel, with the rest being converted to other refinery products. Nevertheless, it is technically feasible to convert up to as much as 50% to 60% of the total output to aviation fuel (Prussi, et al., 2019). This is similar for FT synthesis which produces the largest fraction of road biofuel with only a smaller component of aviation fuel.

This is in part because the production of aviation fuel is often more demanding in terms of technical requirements and is more costly than that of road biofuels (estimates suggest that maximising jet fuel output increases costs by 7-8% (Seber, et al., 2014)). There is also a more established demand for road transport biofuels, as obligatory mandates for the use of renewable energy (including biofuels) in road and rail transport are already in existing since the RED requirements have come in place[11]. Therefore, bio-fuel producers often calibrate the production process to producing less aviation fuel in favour of road-fuel as this is where most of the demand lays and where profit can be made[12].

An exception to this might be the ATJ-SPK process, which is mainly dedicated to producing jet fuels that represent 74% of the overall product mass, meaning that production facilities are mainly dedicated to jet fuel production. Regardless, installed production capacity for this production route is very limited and in theory could account for about 0.03 Mt of aviation fuel per year[13]. Moreover, it’s intermediate products (ethanol, butanol and other) command a higher value in the chemicals and materials market, than as a precursor for jet fuel. For this reason, companies are focusing on the production of bioplastics and other biomaterials to the detriment of sustainable aviation fuels. For example, Amyris, who spearheaded the Direct Sugars to Hydrocarbons (DSHC) conversion route based on farnesene, has now scaled down production of biofuels and is focusing on the cosmetics market instead, where their product commands a higher value (Bullis, 2012).

This information is in accordance with the views of the majority of stakeholders that responded to the survey. More than two thirds either agree or strongly agree that the availability of suitable feedstock (50 out of 72 respondents) and the competition with others sectors[14] for their use (48 out of 72 respondents), is a contributor to the limited production and uptake of SAF in the EU.

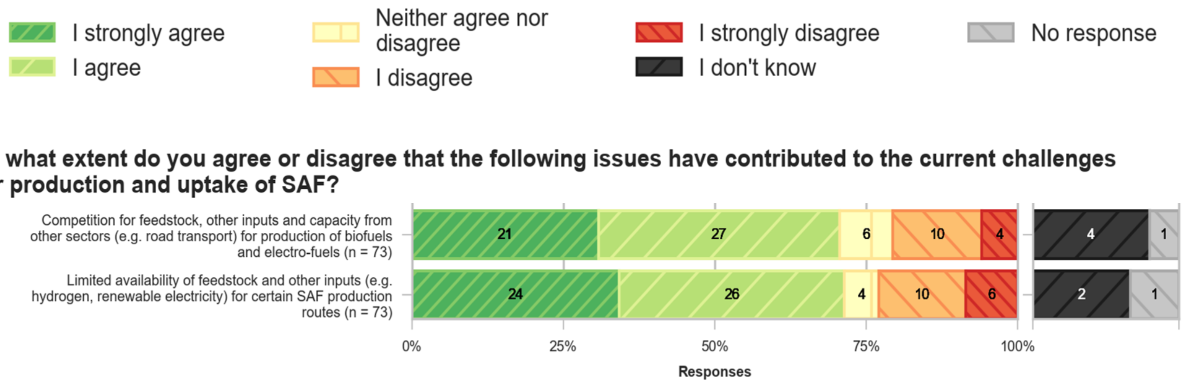
11 The REDII provides that bio-kerosene can also be counted towards Member State goals for biofuels, even receiving a multiplier of 1.2. However, Member States can decide whether aviation bio-fuel is eventually considered in achieving their renewable energy targets, which is not obligatory.

12 a view shared in the interviews with SkyNRG, KLM and ACI

13 Equivalent to approximately 0.05% of EU aviation fuel demand

14 also mentioned in the interview with airline association EBAA and the Dutch Ministry of Infrastructure and Water management,

Figure 4: Stakeholders views on the availability and competition for feedstock as an issue for SAF production and uptake



Source: Targeted stakeholder survey

Some SAF suppliers[15] highlight that avoiding a simplistic approach in setting criteria to define the feedstock and technologies eligible for SAF would increase the exploitable feedstock and help reduce the price of SAF. An example brought in this context is the cap set by REDII in the use of HEFA-SPK SAF production due to the limitations in the availability of pure waste streams such as UCO. However, feedstock can be also derived from non-waste and residues streams with the defining sustainability factor being the specific land use and crops growing methods used.

To summarise the above, the limited availability of feedstock and the competition for its usage with the production of more commercially mature products (especially for HEFA), such as biodiesel, lead to a limited production capacity of SAF from the existing production routes.

For all certified production routes, there are specific maximum limits set to the blending of SAF that can be used safely in the fuel mix as specified in the fuel certifications by ASTM due to technical constraints. These limits are in a range of 5%-50% depending on the production route (ATAG, n.d.). The current limitations to blending of SAF in the fuel mix means that under the current certified processes, a maximum of 50% blending of SAF in the fuel production mix can be achieved. For some of the production routes though, this can be significantly lower. In Annex 3 the current level of maturity and deployment of the various advanced aviation biofuels production routes is presented.

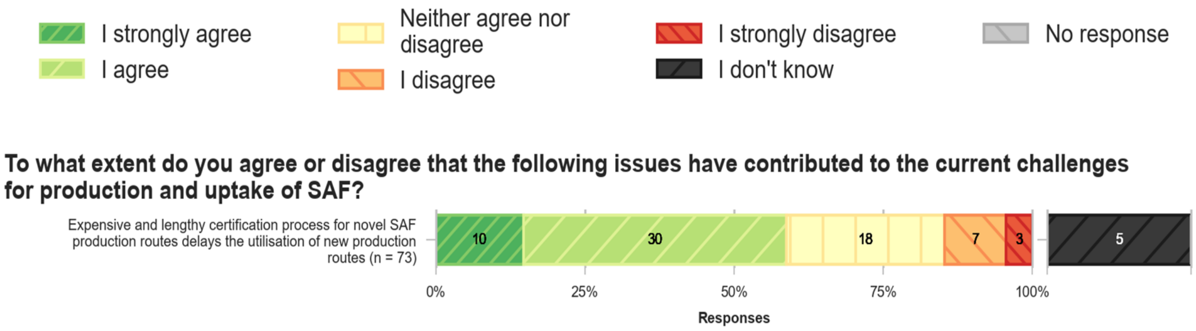
These limitations to SAF production are aggravated by the low industrial maturity of most of the currently certified production routes. With the exception of HEFA-SPK, most of the other certified production routes are further away from achieving full industrial maturity and demonstrating the potential for commercial use and scaled up production. Additional support is needed to develop these technologies and move from the pilot and demonstration phase to producing substantial SAF volumes before the feedstock potential becomes fully exploitable. In the very short term, only HEFA-SPK production seems to be mature enough to be applied at a large industrial scale to cover part of the fuel needs of the aviation industry although, as discussed earlier, this production route faces also limits in terms of feedstock availability.

[15] Interviews with Neste and SkyNRG

With the maturity of more production routes developing, additional production capacity could be made available in time through the exploitation of more feedstock types such as municipal solid waste, ligno-cellulosic sugars and agricultural and forestry residues. The speed of making additional feedstock available for SAF depends heavily on the speed of developing new production routes and certifying the advanced biofuels produced through these routes, although a number of stakeholders still consider that the feedstock available through the currently certified production routes would suffice to fuel SAF production for the following years.

Aviation fuel certification is currently performed by the American Society for Testing and Materials (ASTM). Given the great safety considerations related to aviation, SAF need to pass a stringent multi-tier certification process which can last long (4-6 years) and cost a significant amount of money (approx. €5 million) before obtaining the final approval to use SAF as drop-in fuel (Rumizen, 2019). The time, costs and volumes of fuels needed for the process can be critical deterrents for SAF producers that aim to introduce new production routes to the market (EASA, 2020). Although some stakeholders believe that currently sufficient SAF production pathways are certified to allow for covering future SAF needs[16], EASA clarifies that the existence of the currently certified pathways does not mean that production from all relevant feedstock is also the case. More than half of all stakeholders participating to the survey (40 out of 73 respondents) either agree or strongly agree that the costs and time needed for the fuel certification processes are part of the reason for the limited production and uptake of SAF in the EU with only a small minority (10 out of 73 respondents) disagreeing with this statement.

Figure 5: Stakeholders views on the SAF certification process as a challenge to SAF production and uptake



Source: Targeted stakeholder survey

Electrofuels

Electrofuels are seen as a long-term solution for decarbonising EU aviation as the current expectation is that upon industrial maturity, its resources can be made available at the volumes necessary for decarbonising EU aviation[17].

The production of electrofuels requires the use of renewable electricity, carbon dioxide and water as main resources. Hydrogen is produced from renewable electricity and water as an intermediate product which can be synthesized into hydrocarbon fuels via different production routes. The synthesis of these resources into synthetic aviation fuels is currently certified only through the Fischer-Tropsch method. Another potential synthesis method,

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16 interviews with Neste and ICCT

17 Input from interviews with the French competent authority, the World Economic Forum and Neste

which requires the intermediate synthesis of methanol is not yet approved for the production of aviation fuel.

Producing electrofuels with significant GHG emissions reduction means supplying the production process with renewable electricity and carbon dioxide from sustainable sources. Eventually, new, additional renewable electricity production capacity needs to be deployed to cater for the needs of transport and aviation in particular.

Hydrogen, produced by electrolysis, is currently available in limited volumes, thus upscaling the production of electrofuels requires the deployment of relevant electrolysis and renewable electricity production capacities[18]. When it comes to the supply of hydrogen, only about 4% of today's global and European hydrogen demand are produced by electrolysis[19] (IRENA, 2018) (European Commission, 2020). New water electrolysis capacities globally correspond to around 100 MW per year (NOW GmbH, 2018)[20] which has to be increased by some order of magnitude for sustainable aviation fuel production.

Carbon dioxide sources that allow a carbon cycle with the atmosphere are the direct capture of carbon dioxide from the atmosphere (DAC) or capture from industrial and combustion processes in which sustainable biogenic materials are used as feedstock[21]. Biomass is currently not used as a main input in large combustion and industrial processes and can therefore only be captured from rather small and decentralised industry process. Additionally, the technical maturity of the carbon dioxide capturing units from industrial point sources depends on the respective combustion or industrial process (**T**echnology **R**eadiness **L**evel 5-9, depending on the source)[22] (Skov & Mathiesen, 2017). The level of maturity is much lower for the DAC technology, as it has only been shown to date at demonstration scale level (TRL 3-6). This means that sustainable carbon dioxide is currently not available at large quantities and would have to be produced at a sufficient scale to support the large-scale production of SAF.

To add to the above, the production of aviation electrofuels requires 90-120 GJ of electricity inputs per tonne[23] aviation fuel if standard low temperature electrolysis technology is used[24]. Higher efficiency of high temperature electrolysis may reduce the electricity requirement to 68 GJ of electricity per tonne[25] aviation fuel. The high demand for electricity also means that a climate protection effect only occurs if the electricity used has a very high share of additional renewable electricity generation. When fossil fuels are used to generate electricity, electrofuels can have several times higher GHG emissions than fossil fuels (see Figure 31). This means that the sustainable production of electrofuels in Europe is basically constrained by the availability of renewable electricity in Europe. Electrofuel production also competes with existing hydrogen demand from other industry processes, which is expected to increase with increasing climate protection efforts in the industry sector and possibly in other sectors and transport modes.

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18 Using fossil-fuel origin hydrogen would lead to electrofuels not being in line with the REDII framework.

19 Almost all of it is produced as by-product of chlor-alkali electrolysis.

20 The electrolysis capacity of 100 MW corresponds to approx. 1 PJ (0.04 kg) of fuel production.

21 see Appendix 3 for more detailed discussion

22 TRL is a system for estimating the maturity level of technologies.: It ranges from 1 (basic principles observed) to 9 (proven and commercialized technology in operational environment)

23 This translates into 90-120 GJ of electricity input compared to 43 GJ of aviation fuel output.

24 Overall efficiency of electrofuel production of 36-48% (see Appendix 3 for sources)

25 This translates into 68 GJ of electricity input compared to 43 GJ of aviation fuel output.

Together with the limited availability of resources, the current competition means that insufficient inputs are currently available for the production of SAF from electrofuels. A reversal of this situation would require significant investments in electrolysers and carbon capturing infrastructure in the future.

Most importantly however, the main obstacle to producing electrofuels currently is the industrial maturity of some elements of the production routes, as either research is needed to achieve the necessary efficiency levels to render the technologies competitive, or to manage the upscaling of the current production capacities to a commercial level. The obstacles to achieving industrial maturity and process efficiencies for electrofuels are presented analytically in Annex 3. One of the important issues is that the more energy efficient hydrogen production processes via electrolysis are technologically less mature and need further research and development to become realistic technical options for fuel production. Also, the Fischer-Tropsch synthesis (FT synthesis) is a well-established synthesis process (TRL 9), however the production of the main resource input for this process, syngas which is produced from hydrogen and carbon dioxide is at a lower stage of development and is currently "only" shown in demonstration plants (TRL 5-6). The first small industrial-scale electrofuel production site with syngas production has been announced to start production in the early to mid-2020s (Holen, 2019). The alternative production route via methanol synthesis is missing the final conversion step from methanol to jet fuel and is therefore not certified for use in aviation. With no additional EU level intervention, it is thus expected, that electrofuels will not be produced at a large scale until 2050. With support at an early stage, first large-scale industrial production plants (approx. 100,000 kt per year of production capacity) could be available by the year 2030.

Driver 2: High upfront capital costs to deploy production infrastructure and operational costs for SAF production

SAF production currently, still fails to be competitive with conventional aviation fossil fuels on a cost basis. A usual distinction as to the maturity of SAF identifies three (3) broad generations based on the commercial maturity of each production route and the time estimated to become cost competitive to fossil fuel.

- 1st generation (short term available) – HEFA and co-processing oils/fats[26]
- 2nd generation (midterm available) – AtJ, FT+Gas and other advanced bio-fuels
- 3rd generation (long term available) – electrofuels (using renewable energy and air carbon capture)

Whereas, conventional aviation jet fuel currently costs roughly €600 per tonne (EASA; EEA; EUROCONTROL, n.d.), the production cost of a tonne of SAF via the HEFA-SPK production route is estimated to range from €950 (EASA; EEA; EUROCONTROL, n.d.) to as high as approximately €1,500[27] per tonne[28].The WEF expects the price of HEFA produced SAF to drop from approximately €1,050 currently to around €850 per tonne by the late 2030's provided that the technology uptake peaks up over time. The scaling up of production capacity is also expected to lead to cost reductions.

[26] as long as the feedstock production does not cause negative indirect effects e.g. ILUC

[27] Lufthansa estimations

[28] Detailed cost assessments can be found in Annex 3 for all production routes

For less mature (2nd generation) technologies, production costs can be higher. The high costs for the production of advanced biofuel SAF are a result of the high capital investment costs for the production routes that rely on novel conversion technologies. These are for instance the gasification unit for FT and the pre-treatment, hydrolysis and fermentation units for ATJ. The high discrepancy in investment costs needed and the difference in technology maturity means that there will be little incentive for fuel suppliers to invest in production technologies beyond that of the more mature HEAF-SPK route. Although SAF producers consider that supporting the first-of-a-kind projects will drive more capital in SAF production investments that could lower costs in the future[29]. Figure 6 provides cost breakdowns for a number of production routes with fuel costs (depending on the feedstock) for the AtJ route estimated between €1,680 and €2,430 per tonne and for the FT route between €1,340 and €1,780 per tonne. Estimations provided by Lufthansa and Sunfire are lower with AtJ priced at 1,200-1,500 and FT at 1,000-1,300 without clarifying though the feedstock used. WEF expects these to drop over time but not to get competitive to fossil fuel prices anytime in the foreseeable future. The Energy Transition Commission iterated this point in an interview noting that scaling up production capacity will be necessary to achieve further cost reductions.

Other production routes can lead to significant higher costs. For instance, the HC-HEFA-SPK production route leads to approximately 250% higher costs than conventional fuel (estimated at €2,100 per tonne), while the HFS-SIP route leads to costs in excess of €4,000 per tonne of SAF (more than 6 times the cost of conventional jet fuel) as a result of the high feedstock and energy costs (Bauen & Bitossi, 2020).

For electrofuels, the high energy requirements for the operation of the production process leads to high operational costs for these fuels as renewable energy represents the majority of their costs. Cost estimates are heavily dependent on electricity procurement costs, the investment cost development of electrolysers and of carbon capture units, financing costs as well as on the capacity factor of fuel production and the maintenance costs. Depending on assumptions, they range from around €1,400 to €6,000 (today), €1,150 to €5,000 (2030) and €750 to €4,000 (2050) per tonne of fuel supplied[30]. If investments in electrolysers and renewable energy are accounted for, Transport and Environment estimated that under the current fuel production costs, a €9.4 billion capital investment for deploying the capacity needed to achieve a 1% participation of electrofuels in the aviation fuel mix by 2030 (Transport & Environment, 2020). However, with increasing electrolyser capacities, the necessary investment costs per unit would be considerably lower in the period after 2030 as currently these are tailored-made increasing so the CAPEX of this production pathway[31].

From this evidence, it can be derived that SAF prices can be significantly higher than those of conventional jet fuel for the most mature production processes, many times more expensive for the ones that are earlier at their development phase.

A relevant comparison figure has been produced by the International Council on Clean Transportation (ICCT, 2019) as presented in Figure 6 below. We note that the below chart includes references to feedstock which are not considered relevant under the present initiative, e.g. palm oil, soy oil. However, the acknowledgement that SAF can be multiple

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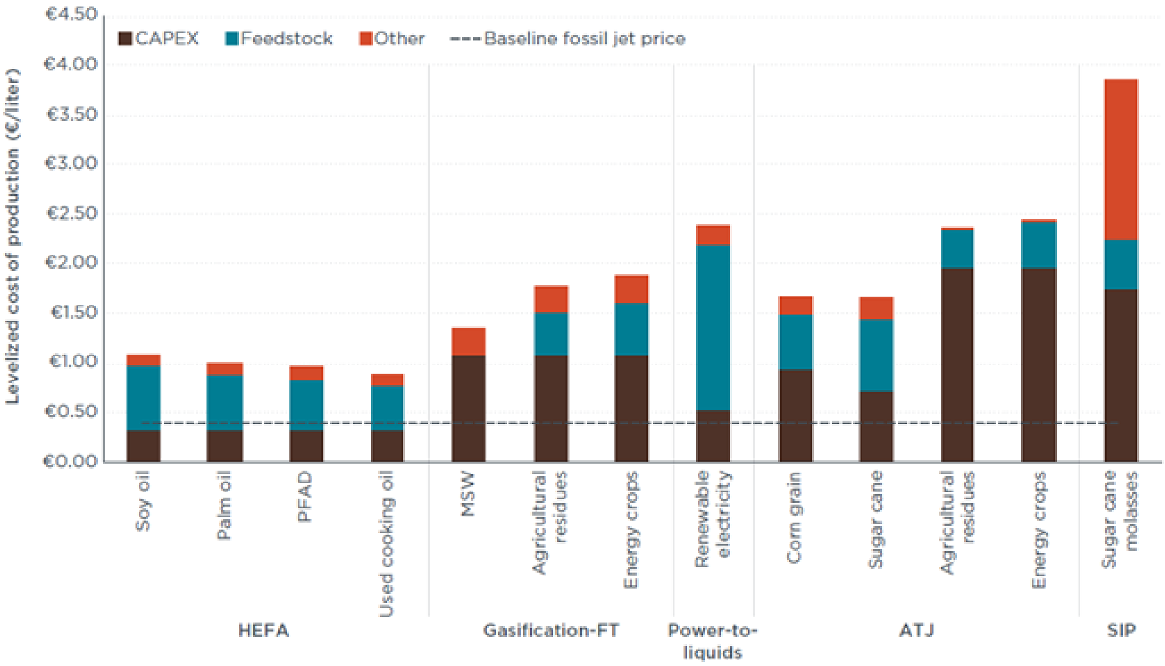
[29] According to IIA feedback from Velocys

30 See Figure 32

[31] Interview with VDMA

times more expensive and thus unable to viably compete with fossil fuels is also supported by the aviation and SAF industry[32].

Figure 6: Current cost breakdown for SAF technologies



Source: (ICCT, 2019)

In addition to high investment and operational costs, the competitiveness of SAF for some of the production routes is affected in particular by the cost of feedstock[33] that can be a significant share of the total production cost (European Commission, 2020). Given the aforementioned limited availability of such feedstocks, and competition for them, prices can be relatively high and easily oscillate according to market demand which makes investments in an un-established market more precarious than on the oil market. This is for instance the case for the HEFA-SPK production, where increased demand for waste oils has had a significant impact on prices. In the case of electrofuels, the electricity prices of additional renewable capacities have a large effect on the overall cost of production of these fuels (ICCT, 2019).

The competitive cost disadvantage of SAF compared to conventional fossil fuels is according to SkyNRG (SAF supplier) aggravated by the fact that fossil fuel production relies on already well-established infrastructure subsidies over the previous decades contributing to their development and a steady demand.

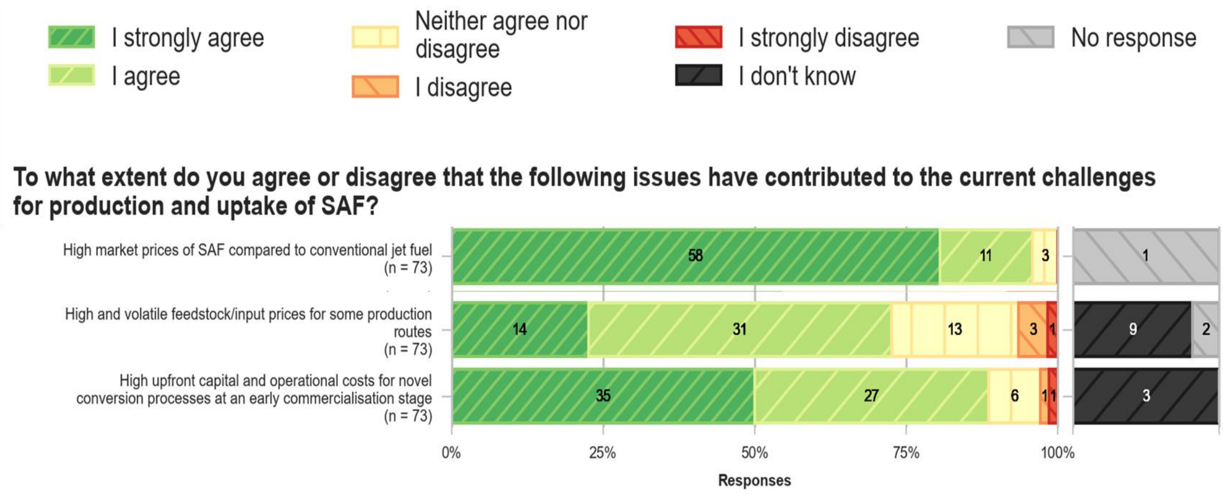
The challenges posed by the high capital and operational costs and the high and volatile feedstock costs is also recognised by the survey respondents who in majority either agree or strongly agree with these as contributors to the low SAF production and uptake. High capital

[32] IIA feedback

[33] typically, an operational cost, but here singled out because of its significant contribution

and operational costs are considered a more important contributor[34] (62 out of 73 survey respondents either agree or strongly agree with the statement) than that of the feedstock high prices and volatility (45 out of 71 respondents agree with the statement). The resulting high market prices of SAF are seen as a very strong challenge to the production and uptake of SAF by virtually all stakeholders participating in the survey (69 out of 73 respondents)[35] as seen in Figure 7.

Figure 7: Stakeholders views on the contribution of cost elements as a challenge to SAF production and uptake



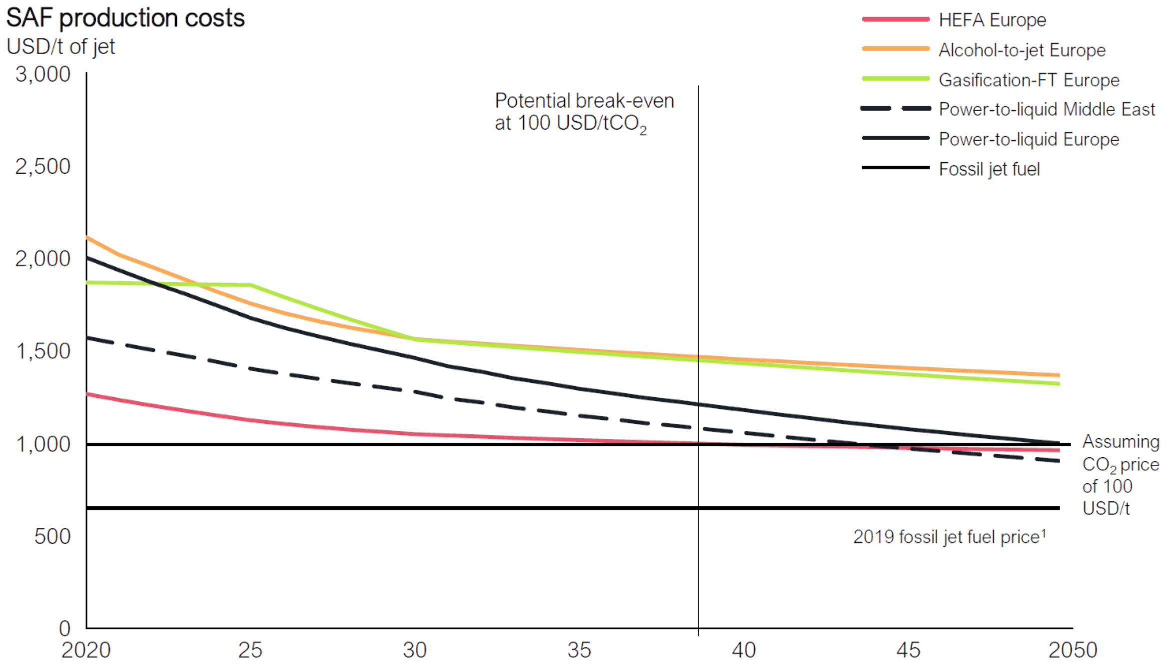
Source: Targeted stakeholder survey

SAF production is therefore characterised by high uncertainty and risks associated with unproven technology, high capital costs and feedstock/input prices while its price remains too high to be competitive against conventional jet fuel and road biodiesel. WEF expects these costs to gradually drop over time, as seen in Figure 8, but not to really become competitive with fossil fuel prices at their current levels.

[34] Interviews with SAF producer SkyNRG, fuel suppliers association FuelsEurope, and the Polish Civil Aviation Authority

[35] Interviews with SAF producers SkyNRG and Sunfire, fuel suppliers association FuelsEurope, airline association EBAA, Dutch Ministry of Environment and Water management and the Polish Civil Aviation Authority

Figure 8: SAF production costs development - WEF (2020)



1. Indicative price at 2019 level, assuming full recovery to pre-Covid level in the long run

Source: McKinsey analysis

At the same time, there is no clear indication of which technologies will be required to meet future demand and which feedstock will be considered acceptable with regard to their sustainability performance. The lack of long-term investment security is discouraging some of the larger fuel industry stakeholders to invest significantly into the production of SAF[36]. A long-term regulatory framework is needed to support SAF production investments[37] which are currently insufficient to result in a considerable production capacity deployment.

Additionally, as elaborated earlier, a combination of high investment and operational costs and the dependence on limited availability feedstock for which competition with more mature uses takes place, leads to high prices for SAF compared to conventional jet fuel. Currently, for HEFA-SPK which is the most commercialised SAF production route, SAF prices are about 60% higher than that of conventional jet fuel. With even higher prices, less mature SAF production routes find it even more difficult to compete with conventional jet fuel. At the same time, the prices for conventional fuel (namely fossil-based kerosene) are heavily determined by the price of crude oil which is known to be relatively low and oscillate in times of crisis. The current situation of a global pandemic and the related heavy reduction in international travel has further depressed oil prices. Under these market conditions, the price gap between SAF and conventional fuel might develop even less favourably for the uptake of SAF in the future.

What makes demand for aviation fuel particularly sensitive to prices is the very competitive nature of air passenger transport services to ticket prices, one of the largest cost components of which is the cost of fuel (representing over one third of airlines' operating costs). Adding to this, is the fact that EU air carriers operate under very limited profit margins, can explain why air carriers may be hesitant to procure significant volumes of SAF as long as

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36 Input from interview with the World Economic Forum and Fuels Europe

37 IIA feedback

this could have a major impact on their costs structure and jeopardise their overall competitiveness.

Driver 3: The existing regulatory and fiscal frameworks neither encourage aviation SAF production nor makes it economically attractive

Some of the potentially relevant EU regulatory frameworks concerning the use of cleaner transport fuels often focus on transport without promoting the use of alternative fuels in aviation. In the case of the Alternative Fuels Infrastructure Directive (Directive 2014/94/EU), which aims to support the harmonised uptake of alternative fuels and relevant infrastructure, there is limited action towards the use of SAF. Member States are only required to consider the need for renewable jet fuel refuelling points in airports across the Core Trans-European Network for Transport (TEN-T), rather than establishing minimum infrastructure targets (as is the case for other transport modes). Similarly, the Fuel Quality Directive (Directive 2009/30/EC) addresses road transport, non-road mobile machinery (including inland waterway vessels), tractors and recreational craft only. Aviation is included only via a voluntary opt in for Member States.

The current existing incentives for the use of SAF in aviation are limited. The Energy Taxation Directive (Directive 2003/96/EC) recommends Member States impose taxes on energy products. The Directive introduces the possibility for Member States to introduce taxes on fuel used in intra-EU flights based on bilateral agreements. Such agreements though, are subject to the provisions of existing Air Services Agreements with non-EU countries which may foresee a tax exemption (Pache, 2019). As a result EU Member States refrain from imposing taxation on aviation fuel through bilateral agreements as these could not be possibly extended to non-EU carriers leading to a competitive disadvantage of domestic carriers The taxation of fuels under this Directive does not account for energy content, rather it is volume-based, thereby failing to account for the lower energy content of renewable fuels. Given that aviation fuel is not taxed, it is not possible to reward the use of SAF through differential fuel taxing or exemption from fuel tax for low carbon fuels. Should a tax on fossil-based fuel be allowed, and should EU Member States opt to apply it for fuel uplifted from their airports, this would bridge part of the price gap between SAF and fossil jet fuel (currently amounting to a minimum of €350/tonne of fuel). However, there is an implicit (carbon) tax for flights within and between EU Member States via the existing EU's Emission Trading System (ETS) and the forthcoming application of ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA):

The EU ETS is a 'cap and trade' system, which limits total emissions covered to a certain amount (the 'cap'). The cap is set to 95% of the average annual emissions between 2004 and 2006 for intra-EU flights. From 2021 to 2030 the cap is going to be reduced by 2.2% per year. Allowances are allocated to airlines as follows:

- 82% are allocated for free to operators based on a benchmark in line with their activity levels in 2010,
- 15% can be purchased through auctions.
- A special reserve with the remaining 3% of allowances ensures that new aircraft operators have access to the market and assists aircraft operators with high rates of growth in the number of tonne-kilometres that they perform.

Operators are required to surrender allowances (EU aviation allowances (EUAAs) and EU allowances (EUAs)) or a limited percentage of international credits for emissions on flights. In the year prior to the COVID pandemic, the price of the EUAAs fluctuated between €18 and €29 per tonne of CO_2 produced leading to a price tag of between €56.7 and €91.4 per tonne of kerosene. The Climate Target Plan impact assessment projects the EU ETS allowances to reach in 2030 the level of €44 per tonne of CO_2[38] leading to a cost of €138.6 per tonne of kerosene. This price tag is significantly smaller than the price gap between fossil-based fuel and SAF which before the COVID-19 impact on aviation fuel prices was already expected to be higher than €350 per tonne. The airline operators receive free allocation amounting to 82% of total aviation allowances, but due to the growth of emissions since establishing the benchmark, this covers about 50% of actual emissions in 2019. Operators need to purchase the remaining allowances from the market. They can use EUAAs or EUAs (general allowances), which contributes to the stringency of the economy-wide EU-ETS.

While the EU aviation ETS scheme applies to intra-EU flights, CORSIA will start applying to international flights between participating ICAO Member States from 2021 onwards. Operators are required to purchase offsets to cover the growth in emissions over 2019 levels.

EU ETS allows zero-rating of aviation fuels (i.e. SAF are attributed zero emissions under the scheme) as long as they meet the sustainability criteria defined in the RED (in the case of ETS). CORSIA offers the possibility to report the used SAF in order to claim offsetting requirement reductions, on a life-cycle assessment (LCA) basis, provided that the sustainability criteria for eligible fuels under CORSIA are respected. However, at this point, the CORSIA fuels framework is not transposed in EU law.

Therefore, operators could via these instruments be incentivised to use SAF to reduce emissions and thereby reduce the number of ETS allowances or CORSIA offsets that they need to purchase. However, previous analyses (European Commission, 2016) have indicated that neither scheme has/will have a significant impact on the demand for SAF due to the clear economic incentive to purchase allowances/offsets rather than use SAF as seen by the price difference between the prices for EU ETS allowances and the price difference between SAF and conventional fossil jet fuel.

The Renewable Energy Directive (RED), somewhat provides incentives for the production and use of SAF by setting targets for the supply and uptake of energy from renewable sources in the EU. The recently adopted revision of RED (RED II), currently under implementation by Member States, sets an overall target for the contribution of renewable energy in transport of 14% by 2030. It is also making it clear that the production of advanced biofuels (defined as using a range of non-food crop feedstocks including wastes and residues but excluding used cooking oil and tallow) should make a contribution to the overall target of a minimum of 0.2% of transport energy in 2022, 1% in 2025 and increasing to at least 3.5% by 2030. Advanced biofuels (defined in Annex IX Part A) can be considered to be twice their energy content in contribution to these targets. Conversely, RED II discourages additional production of crop-based biofuels, setting a cap on them that varies by Member State, but cannot exceed 7%. The contribution that biofuels based on waste oils and tallows can make to the target is also capped, at 1.7%. While the RED targets do not apply to aviation fuel, the RED recognises the possibility of a so-called 'voluntary aviation opt-in' to implement in national legislation putting forward a multiplier of 1.2 for the use of biofuels in aviation which means that biofuels used in aviation are counted by an additional 20% towards the targets and caps mentioned above. Although the existence of the multiplier is seen as a positive step, stakeholders interviewed consider a review of its effectiveness to be

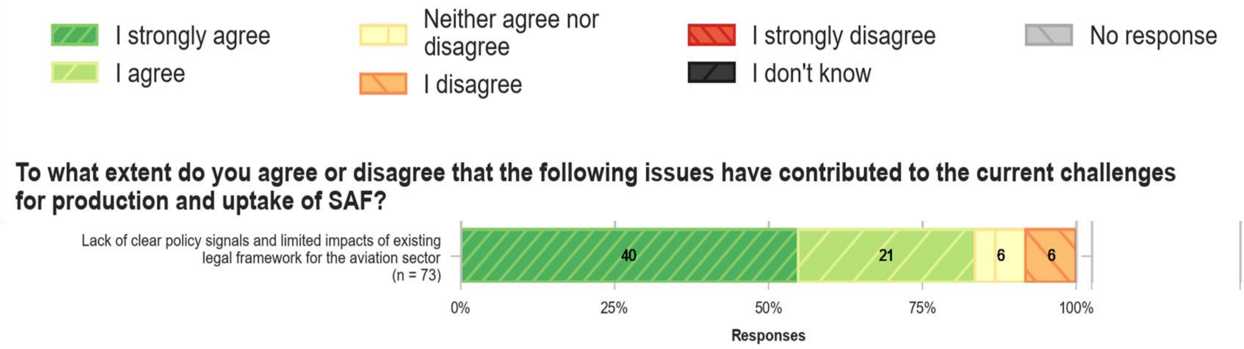
[38] according to the MIX scenario

necessary as Member States are required to translate the REDII obligation into an incentives framework for aviation, an action that has not taken place in most Member States[39].

The lack of coherent commitment to increase the use of SAF is also showcased by the reluctance of the NATO operated Central European Pipeline System (CEPS) to accept SAF. Reportedly, in order to allow new types of fuels to be transferred by this pipeline system, a unanimous approval is needed by all Member States through which the pipeline network runs.[40] Such an approval is not obtained to this date for SAF to be used in the pipeline system[41]. This pipeline system is used to supply fuel to a number of major EU airport hubs and lack of such an approval would mean that alternative, potentially more expensive, means of fuel delivery (such as using road transport) would be needed for SAF be supplied to a number of major EU hubs.

The aviation and fuel stakeholders that took part to the survey to a large extend (61 out of 73 respondents) either agreed or strongly agreed that a lack of a clear policy signal and the limited impact of the current legal framework are responsible for the low production and uptake of SAF[42] as seen in Figure 9. This statement was supported strongly by both fuel suppliers (11 out of 13 respondents) and air transport services providers (16 out of 19 respondents). Stakeholders responding to the survey also mentioned the need for a clear long-term EU policy on SAF and the need for a scheme to support scaling up production as a means of de-risking investments in SAF to develop investors' confidence.

Figure 9: Stakeholders views on the contribution of the current legal framework to SAF production and uptake



Source: Targeted stakeholder survey

This lack of clear, coherent or sufficiently strong policy signals and the limited impacts of the existing legal framework means that higher SAF costs deter investments in SAF production facilities. At the same time, the absence of sufficient incentives to use SAF, leads to a very low demand for SAF by air transport providers.

39 Input from interviews with the French competent authority and Neste

40 The reluctance to allow SAF to flow through the pipeline is reportedly linked to the use of the jet fuel running through the pipeline for military aircrafts, for a small number of which SAF has not been approved as appropriate fuel (as reported by fuel suppliers consulted for this study)

41 as expressed by stakeholders interviewed

42 this was mentioned also in the interviews with the French Ministry of the Environment, Energy and Sea, Dutch Ministry of Environment and Water management, SAF producers SkyNRG and Sunfire, fuel suppliers association FuelsEurope and other IIA feedback

d. How will the problem evolve?

Problem area A: Limited production and supply of SAF at reasonable costs

In the near future, further investments are expected by a number of industry players targeting the deployment especially of the most mature HEFA-SPK technology.[43] Neste[44] alone intends to expand their SAF production capacity from this route to about 2 Mt by 2025.[45] However, there are only limited other known investments plans for the less mature production routes, with HFS-SIP, ATJ and Gas+FT planned production capacity expansion amounting to about 0.6 Mt per year. Even though, as seen earlier, the deployment of production capacity doesn't necessarily mean its usage for SAF production, these investment plans might in turn also be susceptible to being curtailed in the aftermath of the COVID-19 crisis and its impact on the transport and fuel industry. Additionally, the HEFA-SPK production route should not be the sole route relied on for achieving SAF production as the capacity of this production route is constrained by the availability of suitable[46] feedstock.

Considering the long-term security needed to support investments to develop the less mature production routes, there is no signal that actual SAF production will grow rapidly enough to meaningfully support the decarbonisation effort of the aviation industry in lack of EU level intervention. Notably, the EU Reference Scenario foresees the uptake of SAF to remain limited to 0.1 Mtoe in 2030, increasing gradually to 1.4 Mtoe in 2050, will represent 2.7% of total fuel consumption in aviation. Specifically, the update of PtL in this scenario is expected to be close to 0% due to the persisting large price gap[47].

Problem area B: Demand for SAF is low in the current market conditions

We can expect SAF prices to lower over time as the advanced biofuels production technologies become more mature. For example, capital costs can be lowered through technology learning. A report prepared for the JRC (E4tech, 2017) indicates the significant cost reductions that can be achieved when moving from a first-of-a-kind plant to a mature plant for a number of technologies. That said, this reduction can be expected to happen at a slow pace and might potentially be insufficient in order to make SAF (especially SAF from the less mature production routes) competitive with conventional fossil jet fuel in the short-term future. For electrofuels, the process of technology costs reduction can be expected to be even longer and the result, in terms of price competitiveness, even less encouraging. On the other hand, the cost of renewable energy for the production of electrofuels is expected to continue decreasing over time. Still, this development is not expected to be sufficient to render electrofuels competitive to conventional aviation fuels. In the absence of a support framework it seems it is not expected that SAF will become an economically viable substitute for fossil aviation fuel[48].

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[43] A full list of the available production pathways is presented in section 2c

[44] One of the largest biofuel producers currently

[45] Input from interview with Neste

[46] As per the REDII Annex II Parts A and B definitions

[47] A majority of stakeholders responding to the survey do not expect SAF use under the current outlook to increase to more than 1% of total aviation fuel usage by 2025, 3% by 2030 and 5% by 2040 although some stakeholders adopt a more positive view.

[48] IIA feedback supported by both aviation service providers (e.g. IATA, ERA, A4A, GE Aviation, Ryanair) and SAF producers (e.g. Gevo and Fulcrum)

A number of EEA countries have announced their intentions to mandate the use of alternative fuels in their aviation sectors, by applying a mandate to all fuel uplifted in that Member State (so including both domestic and international aviation). Member States which are considering their own aviation mandates include Sweden, France[49], Spain, Finland, the Netherlands and Germany. These proposals are at various stages of development, although none of them is in force to date. Norway introduced a 0.5% mandate from January 2020, limited to advanced fuels as defined by Annex IX of RED II with an intention to increase that percentage to 30% by 2030, though it is yet to legislate for this increase. Should a number of the initiatives mentioned earlier conclude, they may provide a boost to the production and usage of SAF in specific Member States. However, it is unlikely that these actions alone will enable development of SAF at a competitive price and their usage across the EU in sufficient volumes to lead to significant GHG reduction from the aviation sector. Moreover, a patchwork of regulations in Member States may lead to market distortions. Finally, there is no certainty that the combined targets would put aviation on the necessary trajectory to contribute to the EU's climate targets by 2030 and 2050.

Additionally, the European Green Deal roadmap provides for the opportunity to revise the EU ETS, the Energy Taxation Directive (ETD) and the RED framework through which stronger incentives could be provided to promote the demand for SAF. These measures could potentially contribute to bridging part of the price gap between SAF and conventional aviation fuel by reducing the free allocation of ETS allowances, by increasing the taxation on aviation fuel or by incentivising more strongly investments in SAF through an increased multiplier. Currently, the projected uptake of SAF according to the Baseline Scenario is limited to 0.1 Mt in 2030, increasing gradually to 1.4 Mt by 2050 (European Commission, 2020), which is just 2.7% of the total EU aviation fuel consumption.

e. Affected stakeholders

Problem area A: Limited production and supply of SAF at reasonable costs.

This problem affects entities responsible for the reduction of GHG emissions from aviation like Member States, and the air transport services providers (air carriers) who currently cannot purchase SAF at reasonable costs in order to reduce the GHG emissions of their operations. Eventually, non-compliance with the GHG emissions reduction affects the success of the European Green Deal and compliance with the EU's commitments as per the Paris Agreement. It further hinders international progress towards achieving GHG emission reductions since also international carriers using EU airports are affected. Eventually, society as a whole is impacted by climate change to which the GHG emissions of conventional jet fuel are contributing. To resolve the problem, a clear and steady regulatory framework is needed. The lack of such a framework and the support needed leads to a lack of incentive for fuel suppliers to invest into production infrastructure in order to increase SAF production. A pre-requisite to this is the support needed to bring SAF production processes and their feedstock supply chains to commercial maturity.

Problem area B: Demand for SAF is low in the current market conditions.

This problem affects entities responsible for reducing GHG emissions, like Member State authorities. Eventually, non-compliance with the GHG emissions reduction affects the success of the European Green Deal and compliance with the EU's commitments as per the Paris Agreement. Moreover, the lack of sufficient SAF demand prevents SAF fuel producers

[49] Input from the interview with the French competent authority points to the intention of establishing a blending mandate for SAF of 2% in 2025 and 5% in 2030 considering the production capacity potential in the country.

from fully exploiting their SAF production capacity and from seeking to make funds available for additional capacity deployment and research and development of the currently less mature production routes. The existing price gap between SAF and conventional jet fuels needs to be bridged before SAF comprises a significant share of the fuel used in aviation. The persistence of such a price gap is expected to hinder aviation fuel users from purchasing and using SAF and thus greening their operations.

f. The EU dimension of the problems

Combating climate change is an EU level ambition, but actions in that direction can be focused at a European, national or local level. However, the international (and even global) nature of the aviation sector requires an EU level response. There is an increasing social pressure to curb the carbon footprint of aviation, a commitment to tackling this has also been made in the context of the European Green Deal. Discrepancies between Member States in delivering measures to support the production of SAF could lead to market distortions and an unlevel playing field for SAF producers and between air transport service providers. Different incentive structures to boost demand for SAF between Member States may lead to an unlevel playing field in the aviation fuels market.

Climate action for transport overall and aviation in particular is already coordinated at EU level with a number of existing and relevant EU-level instruments such as the EU ETS and REDII and their foreseen revisions. These instruments intend to lower the GHG emission levels of fuels used in aviation and indirectly promote the use of SAF. Thus, an EU-level initiative aiming to promote the use of SAF seems coherent to the existing policy framework. Most importantly, an EU level commitment also produces a stronger political signal reinforcing the aviation industry's certainty to pursue the further use of SAF. Stakeholders approached during the exploratory interviews agree that a common and shared European level objective is needed to provide the investment certainty for upscaling SAF production technologies.[50] An EU level commitment also produces a stronger political signal reinforcing the industry's investment certainty to develop SAF capacity.

50 Input from interviews with the French competent authority, the World Economic Forum and Neste

3. EU right to act

The EU right to act in the field of aviation is supported by the Treaty on the Functioning of the European Union which confers to the European institutions the competence to lay down appropriate provisions in the air transport sector (Article 100(2) and/or Article 192(1) and/or Article 194(1) TFEU).

The need for EU action is supported by the problem definition elaborated earlier. In short, the problem of increasing aviation GHG emissions threatens the achievement of the EU climate goals as defined in the Climate Target Plan. The Plan identifies an increase in the use of SAF as one of the important contributors to the goal of reducing GHG emissions by 55% by 2030 and achieve a climate-neutral economy by 2050. To achieve this, SAF will need to correspond to 63% of the volume of all jet fuel used in the EU (both intra- and extra-EU flights), however current projections suggest a significantly lower expectation with SAF comprising merely 2.7% of all aviation fuel by that time.

The problem drivers described above have proven to persist voluntary industry action over the last decade and are expected to resist the impact of other existing EU policies aiming to increase the use of alternative fuels (such as the RED II or the FQD), or even an anticipated increase in the price of EU ETS allowances prices and the CORSIA offset scheme. National initiatives to incentivise the supply and use of SAF in the Netherlands (by an aviation opt-in to the RED II targets) and Nordic countries (with the emergence of SAF usage mandates) seem to have only incremental impact on the usage of SAF and may not be expected to achieve the speed of SAF production capacity deployment necessary.

Stakeholders consulted from across the EU agree that the supply and uptake of SAF will remain relatively low across the EU and the price gap with conventional jet fuel will persist in the absence of an EU-wide approach to incentivise the production and usage of SAF at competitive prices.

Further, the current setting of emerging national initiatives threatens to create a patchwork of different obligations for the aviation and fuel supply industry. Different obligations for the use of SAF could potentially lead to differences in fuel prices and distortions to the market incentivising adverse stakeholder practices such as airlines tankering in Member States with less strict obligations to save on fuel costs. Such approaches could even lead to opposite-than-intended results as they have the potential of introducing inefficiencies in the aviation industry (in matters of trajectories or column of fuel lifted) that could lead to further fuel consumption and resulting GHG emissions. Moreover, a fragmented Member State approach could lead to multiplication of reporting requirements to meet different obligations.

Accounting for the international nature of the aviation and fuel supply industry, and the inefficiencies of potential national approaches, EU-wide action would be needed to overcome the twin problems of lagging supply and demand. Industry stakeholders sight the lack of a common and long-term regulatory framework as one of the main problem drivers causing uncertainty whereas benefits are expected also from deriving more clarity regarding the set of sustainability criteria to be used for SAF so as to avoid negative indirect impacts. A fragmented approach is unlikely to deal with these issues efficiently calling therefore an EU initiative to deal with the two problem areas.

4. Policy Objectives

a. General policy objectives

According to the EU's contribution to the Paris Agreement the EU aims to reduce emissions by at least 40% by 2030 compared to 1990 (European Commission, 2020). The Clean Planet for All Communication (European Commission, 2018) produces a vision for implementing the EU's commitments according to the Paris Agreement and achieving net-zero greenhouse gas emissions by 2050. The transport sector is expected to also play a role in achieving these goals. For aviation, where electrification is challenging, a shift to advanced biofuels and electrofuels is targeted.

The Climate Target Plan (European Commission, 2020) raised this target to 55%. The Climate Target Plan also identifies the need for aviation to contribute to achieving this target by, amongst other measures, increasing the use of SAF. Regarding aviation, the Commission committed to consider legislative options to boost the production and uptake of sustainable alternative fuels for the different transport modes and for aviation in specific. It also indicated its intention to revise the Energy Taxation Directive, looking amongst other areas at the current tax exemptions for aviation fuels.

In light of the above, the general policy objective is set to: **Reduce aviation CO_{2eq} emissions by transitioning away from fossil energy dependence and establishing a competitive market for sustainable aviation fuels (in the EU).**

b. Specific objectives

To ensure that the specific objectives reflect the definition of the problem and the underlying causes and that there is a clear logical link between the two, we present the objectives in a table mapping the relevant problems to each of them. As can be seen, in Table 2, the general and specific problem objectives proposed correspond to the consequences that the policy measures should aim to mitigate. Specific objective 1 is aiming to support large scale production of SAF in the EU to counter problem area A. Similarly, the second specific objective on increasing the uptake of SAF while maintaining competitive prices, aims to address problem area B.

Table 2: Initiative objectives

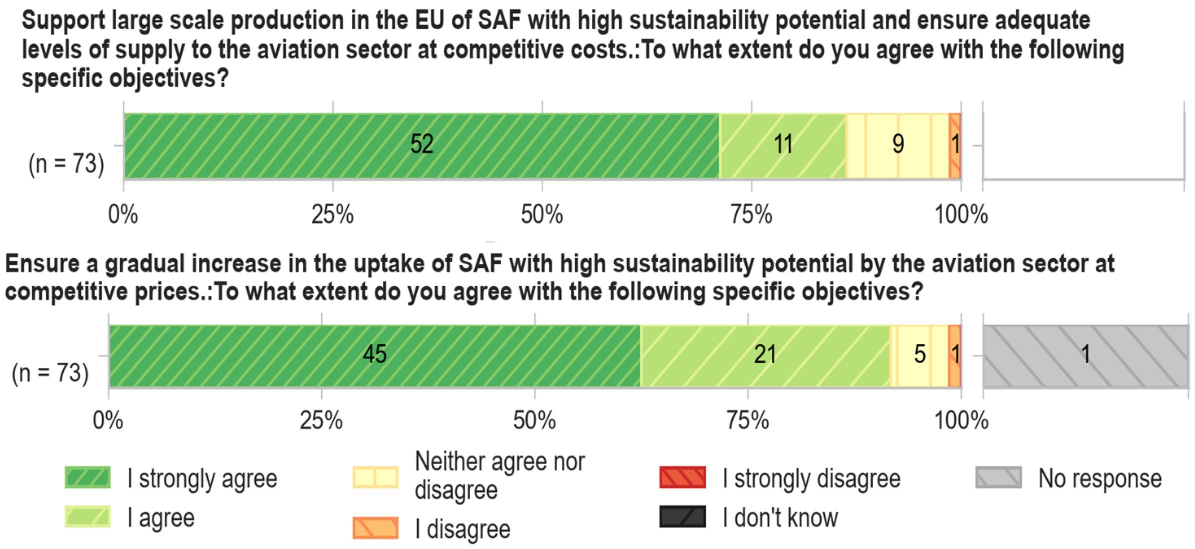
Problem definition	Proposed initiative objectives
Overall problem The uptake of SAF in aviation is hindered by lagging production and supply as well as by low demand.	**Reduce aviation CO_2 emissions by transitioning away from fossil energy dependence and establishing a competitive market for sustainable aviation fuels (in the EU).**
Problem area A Limited production and supply of SAF at reasonable cost	**Specific objective 1** Support large scale production of SAF in the EU with high sustainability potential and ensure adequate levels of supply to the aviation sector at competitive costs[51].
Problem area B	**Specific objective 2**

[51] compared to the cost of fossil jet fuels

Demand for SAF is low in the current market conditions	Ensure a gradual increase in the uptake of SAF with high sustainability potential by the aviation sector at competitive prices.

The two specific objectives present a high level of synergy. Although they focus on the two different sides of the SAF supply-demand relation, the pursuit of one will definitely support the pursuit of the other. Achieving one of the specific objectives will contribute to also resolving the other problem driver to a certain extend and vice-versa. That is to say that an increased SAF production at a competitive price will facilitate the uptake of SAF demand since the price gap seems to be currently one of the most important barriers to this. Similarly, increasing the demand and uptake of SAF by the aviation industry is expected to accelerate the attraction of investments in order to deploy further production capacity. However, the majority of stakeholders consulted have pointed to the need for a combined effort on both sides of the problem in order to achieve the General objective. As seen in Figure 10 a significant majority of stakeholders participating in the survey agree with both specific objectives for the initiative. In specific, 63 out of 73 respondents either agree or strongly agree with the objective of supporting large scale production of SAF in the EU while 66 out of 72 are in favour of ensuring a gradual uptake of SAF.

Figure 10: Stakeholder views of the policy objectives



Source: Targeted stakeholder survey

The initiative, under its newest set of objectives functions in synergy with the vision set in the Climate Target Plan to support the uptake of advanced biofuels and electrofuels by the aviation sector. The inclusion of the aim to do so targeting SAF with high sustainability potential (low Life Cycle CO2eq emissions), aligns with the REDII provisions that discourage the production of crop-based aviation fuel.

Assessing the potential of Policy Options to achieve the specific objectives of the initiative, a set of criteria and indicators are considered as presented in Table 3.

Table 3: Assessment criteria and indicators

Specific objectives	Assessment criteria	Indicators
Specific objective 1 Support large scale production in the EU of SAF with high sustainability potential, and ensure adequate levels of supply to the aviation sector at competitive costs	Large scale production of SAF in the EU	Volume of SAF production capacity (per production route)
	Availability of SAF to the aviation sector	Sufficiency of feedstock available for SAF production (per production route) compared to overall needs for SAF as defined per the Climate Target Plan
		Sufficiency of renewable electricity available for SAF production compared to overall needs of renewable electricity as defined per the Climate Target Plan
		Ensure that airlines have access to SAF at airports
	Production of SAF with high sustainability potential	Development of sustainable and cost-effective SAF pathways, taking a technology-neutral approach
	Reduction of EU's energy dependence on oil imports	Reduction in oil products used by air transport
Specific objective 2 Ensure a gradual and continuous uptake of SAF with high sustainability potential by the aviation sector at competitive prices	Achievement of SAF uptake targets as set by the Climate Target Plan	Uptake of SAF in line with the analysis underpinning the impact assessment accompanying the 2030 Climate Target Plan
	Reduction in the external costs of transport	Reduction of well to wing CO2 emissions from air transport
		Avoid carbon leakage resulting from fuel tankering
		Reduction of external costs of CO2 emissions relative to the baseline, expressed as present value over 2021-2050
		Reduction of external costs of air pollution
	Ensure the competitiveness of the EU aviation sector	Ensure a level playing field between airlines

5. Options to achieve the objectives

a. Baseline scenario

In order to assess the impact of the Policy Options proposed in the impact assessment support study of the ReFuelEU Aviation initiative, they need to be compared to a Baseline scenario. This section defines the Baseline scenario which reflects future developments under current trends and policies as described in the problem definition section.

The Baseline scenario is identified as a "no policy change" scenario. Such a scenario includes most relevant socio-economic developments such as population growth and GDP growth, as well as impacts of endogenous and exogenous factors. The endogenous factors include all relevant announced existing and upcoming EU-level and national policies and measures identified in the problem definition section which are expected to come in force over the course of the evaluation timeline (until 2050). The exogenous factors relate with technological developments and the expected evolution, for instance of oil prices.

The Policy Option scenarios include the same assumptions with the Baseline on socio-economic developments, endogenous and exogenous factors, varying only as per the specific Policy Options considered for the aviation sector. By comparing the Baseline scenario with the Policy Option scenarios, the impact of the latter can be assessed quantitatively or qualitatively. Our approach for defining the Baseline scenario and the Policy Option scenarios combines a model-based analysis using the PRIMES-TREMOVE and the PRIMES-Aviation models. This approach and the quantification of the Baseline scenario and the Policy Options are presented in more detail in the following sections and in Annex 5: Model results of this report together with the model outputs for each of the Policy Options.

The modelling suite computes the impact on air transport activity, the shift to other transport modes, energy use, CO_{2eq} emissions (tank to wing and well to wheel) and costs for each scenario, at an EU27 level and by Member State.

Quantification of the Baseline scenario

The Baseline scenario builds upon the modelling work underpinning the Climate Target Plan Impact Assessment. It includes policies and measures adopted at an EU level by the end of 2019. Among others, key policies included are the CO_2 standards for new light duty and heavy goods vehicles, the Clean Vehicle Directive, the Alternative Fuels Infrastructure Directive, Renewables Energy Directive and the Fuel Quality Directive, TEN-T Regulation supported by CEF funding, etc. For aviation, it takes account of the implementation of the EU Emission Trading Scheme, the Single European Sky, the deployment of SESAR technologies, the research and development of cleaner aircraft technologies lead by Clean Sky and aeroplane CO_2 emissions standards, as part of the so-called "basket of measures" that aim to reduce emissions from the sector. The Baseline scenario is quantified until 2050.

In line with the update of the Better Regulation Guidelines with respect to the COVID-19 crisis, the Baseline scenario as well as the Policy Options should consider the COVID-19 effects if the crisis has a significant bearing on the sector or policy area. Given that the aviation sector is one of the sectors greatly affected by the global pandemic, the Baseline scenario (and the Policy Options) includes the effects of the COVID-19 crisis on transport activity and macro-economic trends.

The Baseline scenario builds on the Commission's Spring Economic Forecast that estimates that real GDP could be about 2.3% lower compared to pre-COVID projections by 2030 (European Commission, 2020). As large part of the world went into lockdown, fossil fuel prices collapsed with crude oil spot prices halved compared to last year levels. The oil price is projected to gradually recover over time, reaching 80$/bbl in 2030 and 118$/bbl in 2050. It is however projected to remain below the projected pre-COVID levels which could potentially affect the demand for SAF. The situation is still evolving, and it is currently not possible to understand the full impact of the unfolding pandemic. These estimates do not include the possibility of more negative outcomes (e.g. due to the second wave of the epidemic outbreak).

Capturing the impact of COVID-19 on the EU transport activity

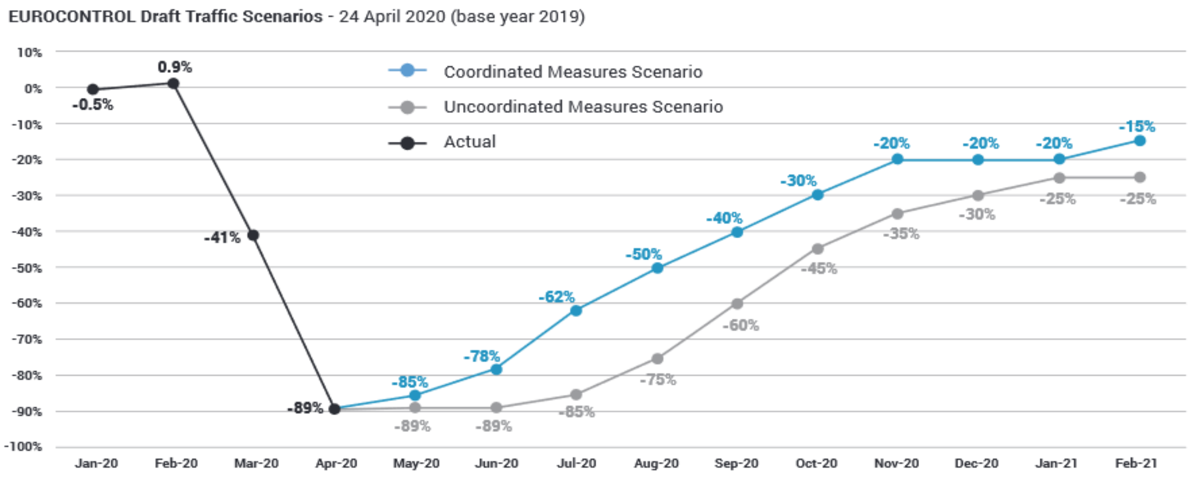
Since the COVID-19 outbreak, several governments took drastic measures to contain its wider expansion to the population. As a result, the activity in several economic sectors has slowed down. Particularly, the transport sector has been greatly affected due to international travel bans, confinement measures, stay-at-home requirements, and restricted access to public transport. In addition, global trade between countries and consequently freight transport, decreased to some extent due to lower economic activity and reduction in manufacturing output.

In this section we present the evidence that we used to assess the impact of COVID-19 on the transport activity in aviation, in order to estimate the demand for transport activity in the Baseline scenario. It should be noted that the situation with COVID-19 unfolds dynamically, and its impact on the transport sector activity has not yet stabilised (e.g. due to travel restriction updates between EU countries on a bi-weekly basis, second wave, local lock-downs). Incorporating such dynamic developments as part of the Baseline would entail a constantly evolving scenario, challenging the comparison with the Policy Options. In order to quantify the demand for transport activity in the Baseline scenario we take stock of the developments up to and including May 2020 as a cut-off date, with assumptions on the evolution of the impact of the pandemic in transport activity in the subsequent period. More specifically:

- International travel restrictions led to a steep decline of domestic, intra- and extra-EU air traffic, through February, March and April (up to almost 90% less than 2019 levels, the lowest throughout the year). From June onwards, a gradual recovery of flight activity is assumed first from domestic and intra-EU flights, as a result of increased international intra-EU mobility. Moving towards the last quarter of 2020, and assuming that the COVID-19 outbreak becomes more manageable, extra-EU flights are also assumed to recover, but to lower levels than 2019 (Figure 11).[52]

[52] Unfortunately, latest developments seem not to justify an optimistic outlook

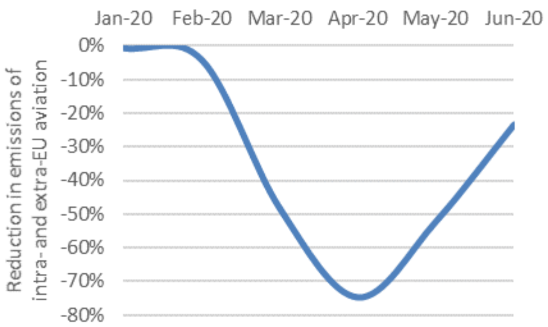
Figure 11: Development of intra- and extra-EU flight activity in 2020 compared to 2019



Source: EUROCONTROL

- The activity of the sector can also be determined by looking at the emissions of the sector that indicate a steep reduction in aviation CO_2 emissions in the months of March and April and to some extent May. Data for June were indicating a recovery of the CO_2 emissions and the activity of the sector (Figure 12);

Figure 12: Estimated reduction in CO_2 emissions from aviation compared to 2019



Note: Estimates based on total number of departing flights by aircraft on ground until 11 June 2020. Source: E3-Modelling based on ICOS data

The impact of COVID-19 on transport activity becomes evident in the results that are presented in Annex 1c.

Key modelling results in the Baseline scenario

- Transport activity in aviation increases annually at a rate of about 2% between 2010 and 2050 (from 1,360 Gpkm to 3,000 Gpkm).
- In the projection horizon, the demand for jet fuel increases by 30%, from 38 Mtoe in 2010 to almost 50 Mtoe in 2050.
- Intra- and extra-EU aviation is the only segment in passenger transport that sees a steep increase in its CO_2 emissions, by more than 30 Mtons CO_2 - or 27% - between 2010 and 2050.

- The projected uptake of SAF is limited to about 0.1 Mtoe in 2030, increasing gradually to 1.5 Mtoe in 2050, which is 3% of total fuel consumption in aviation. From this total, about half (approx. 0.7 Mtoe) is produced within the EU with the rest being imported. Out of the biofuel produced in the EU, 0.58 Mtoe are expected to come out of the HEFA production route while the AtJ route is expected to contribute the remainder (0.14 Mtoe)
- The average jet fuel price increases from around 1,030 €/toe in 2030 to 1,250 €/toe in 2050. The development of the jet fuel price follows the price development of international oil prices used in the CTP impact assessment.

b. Policy measures

The long-list of policy measures is needed to address both the supply-side (Problem area A) and demand-side (Problem area B) issues that need to be addressed. It is unlikely that a single policy measure will be able to solve alone both of the identified problems. This may point to the need for co-ordinated policy action to deal with the two problem drivers in a joined-up manner, potentially reflecting a need for packages of measures that work together.

In the following section we examine the initial list of measures considered. We also shortly discuss possible design variations for each of these policy measures.

c. SAF blending mandate design

Most stakeholders agree that a SAF blending mandate can be an effective measure to achieve the policy objectives. Regardless, important points have been expressed by various stakeholders as to the design, timing and level of the mandate. Most importantly, stakeholders across the board participating at all stakeholder engagement activities highlighted the need to safeguard that the mandate is not introduced faster than the SAF production sector's capacity to source feedstock and deploy the relevant production capacity as this might compromise the industry's ability to meet the requirement and supply the necessary level of SAF. Considerations were also raised regarding the expected impact on fuel prices and the consequent need to address the price gap between fossil fuels and SAF in the process.

Blending mandates could take different forms and be calibrated on a number of important parameters including the:

- Obliged party;
- Measurement unit for the mandate calculation (i.e. volume of SAF or GHG reductions achieved);
- Eligible fuels;
- Flexibility of administering the mandate (i.e. blending all fuel or a book & claim system)
- Existence of sub-mandates for specific production pathways.

Penalties are also an important parameter in designing and effectively enforcing a mandate. Considerations on the appropriate functioning of penalties for non-compliance are also presented.

In the following, we elaborate on the possible design options for these parameters before discussing other possible measures.

Obliged entity

For the implementation of a SAF mandate one entity in the supply chain needs to be responsible that the mandated share of SAF fuel is actually achieved. Entities involved in the aviation fuel supply chain are:

- Fuel producers: refineries or companies which produce fossil jet fuel and/or SAF;
- Fuel suppliers: sell the fuel to air transport service providers; some of the fuel producers have their own production branch but some fuel suppliers do not have any production capacities and only trade aviation fuel;
- Fuel handlers: manage the refuelling infrastructure at airports but do not buy or sell fuel;
- Airports: aviation fuel is handled and traded on their territory, but they are not directly involved in buying or selling aviation fuel;
- Air transport service providers (airlines): buy the aviation fuel usually from fuel suppliers.

Since fuel handlers and airports are not directly involved in the commercial trade of aviation fuel, obliging them would require establishing additional financial incentives in the supply chain. Since that would result in comparatively high additional administrative burden, both options are excluded from further considerations below.

Table 4: Pros and Cons of different policy design options (obliged entity)

Options for the policy design		Pros	Cons
1	**Fuel producer**	• Directly encourages conventional fuel producers' investments in SAF production • Small number of entities currently, to which this is applicable, facilitates implementation, monitoring and enforcement; but number of entities expected to grow with the increasing commercial maturity of SAF production routes	• Uncertainty on how the producer environment will develop as the SAF industry is in its very early phases of development • Administrative burden to handle the mandate (monitoring, certification) for new stakeholder group increases the cost of SAF production; especially relevant for new fuel producers (start-ups) • Would be advantageous for established large-scale fuel producers/refinery operators (e.g. BP, Shell) which are also fuel suppliers since they already have implemented the required administrative processes of a fuel mandate • Risk of airlines (and potentially also suppliers) to supply fuel from outside the EU in countries with no/less demanding mandates (tankering)
2	**Fuel supplier**	• Compatibility with existing reporting frameworks, particularly RED II • Small number of entities to which this is applicable, facilitates implementation, monitoring and enforcement • Fuel obligations in road/rail transport show the effectiveness of setting a mandate for fuel suppliers as obliged bodies Incentive to existing fuel suppliers to invest in SAF production capacity and deployment or to progressively	• Lower influence of aviation service providers on the SAF production process and sustainability criteria may result in the choice of SAF production routes and feedstock driven more strongly by production costs rather than the sustainability criteria set by public-facing airlines • Risk of fuel tankering

Options for the policy design		Pros	Cons
		reduce CO_2eq intensity of the output over time (when already involved in fuel production)	
3	**Air transport service provider**	• Existing monitoring of fuel consumption under the EU ETS and CORSIA can be slightly adjusted to report on SAF usage • Airlines in control of sustainability performance facilitates more sustainably oriented firms pursuing more environmentally friendly fuel use	• Larger number of entities that need to be regulated • Precise monitoring of aviation fuel used per flight can be complicated, requires extensive mass-balancing calculations due to the common refuelling infrastructure for airlines provided in airports unless book & claim system is applied • Could lead to issues with enforcing the mandate to non-EU airlines (see EU-ETS)

Respondents to the targeted survey supported a supplier obligation to a larger extend (45 out of 67 respondents) compared to an obligation on the producers (30 out of 67) or the fuel users (36 out of 67 respondents)

Most of the fuel producer/suppliers consulted viewed the application of a mandate on the suppliers positively. That was provided that air transport service providers were also obliged or incentivised somehow to use the produced SAF. Overall, air transport providers viewed the imposition of a mandate more sceptically[53], although some of the largest operators are in favour of a mandate[54]. Member State competent authorities preferred a mandate on the suppliers[55] which they see as easier to enforce and more compatible with existing reporting obligations, or both the suppliers and the users in order to distribute responsibility across the value chain[56].

In making a design decision for this policy measure the following need to be considered:

- **Environmental integrity:** Provided that the fuel obligation is adequately monitored and enforced, the type of the regulated entity does not influence the environmental integrity.
- **Compatibility with existing regulations:**
    - The RED II Directive (EU) 2018/2001 (The European Parliament and the Council of the European Union, 2018) establishes a common framework for the promotion of energy from renewable sources. Liquid bio-based or synthetic e-fuels, i.e. SAF, which comply with the Directive's eligibility requirements and which are used for aviation could generally be accounted to comply with the requirements of the directive. The entities responsible for monitoring the use of these fuels are fuel suppliers, which are defined in Article 2 (38) as "an entity supplying fuel to the market that is responsible for

[53] IATA, A4E and ERA expressed concerns on a user mandate, A4A, IAG and Ryanair expressed concerns with a mandate overall while EBAA recommended motivating the whole SAF value chain.

[54] Interviews with KLM (user mandate) and Lufthansa (supplier mandate)

[55] Interviews with France, Sweden, and the Netherlands

[56] Interview with Poland.

passing fuel through an excise duty point". In this context, fuel suppliers are also involved with the monitoring of SAF blending aviation fuel.

- The ETS Directive (EU) 2018/410 (European Commission, 2012) requires airlines to report on the GHG emissions. The emission factor to be applied to biofuels eligibly according to RED is zero so that their use reduces the airlines' requirements to surrender allowances. This obligation is in principle compatible with reporting on the GHG emission reduction achieved by using SAF. However, since the ETS Directive refers to biofuels only, which are defined in the corresponding MRV regulation (The European Parliament and the Council of the European Union, 2018), it implicitly excludes similar incentives for synthetic e-fuels. To put biofuels and synthetic e-fuels at a level play field, the EU ETS Directive might need to be amended accordingly.
- Considerations have also been presented at the timing of introduction of the EU aviation ETS regarding the capacity to impose charges to non-EEA operators for the fuel they use. Similar considerations might lead to a choice to exclude non-EEA flights from the scope of the initiative should the obligation be placed on the air service providers. The alternative of maintaining the charge only for EEA operators would distort competition in extra-EEA flights.
- The Fuel Quality Directive (2009/30/EC) (European Parliament and of the Council of the European Union, 2009) aims to reduce air pollutant emissions from diesel and petrol fuels and sets a binding target to reduce the GHG life cycle emissions of these fuels. However, it focusses on road transport and provides only a voluntary opt-in option for aviation.

- **Number of entities:** the number of entities involved is particularly relevant in the context of monitoring, reporting and enforcement of the policy and determines the transactions costs of the regulators and the regulated. Generally, it can be assumed that the smaller the amount of regulated entities, the lower the transactions costs potential failures or discrepancies are.
  - **Fuel producers:** Fossil fuel producers are mainly refineries. By the end of 2018, 75 refineries were operating in the EU according to Fuels Europe (Transport & Environment, 2018). In addition, there are 224 biorefineries by the end of 2017 (Nova Institute, 2017). The number of refineries affected will be smaller, since not all of the fossil or biorefineries produce aviation fuel. The number of e-fuel producers is not known. It can be assumed that the number will develop dynamically due to the SAF fuel obligation. In the initial years, many new start-ups can be expected so that the number may grow quickly. However, with the growing production capacity it is likely that the market consolidates again through mergers and acquisitions so that the number of fuel producers may decline again in the mid-term. However, since not all existing refineries supply aviation fuel we assume that number of fuel producers is likely to be lower than 100 entities.
  - **Fuel suppliers:** There are no publicly available statistics or overviews of aviation fuel suppliers at European airports. However, we assessed that the top 25 of the almost 900 EU airports are serving more than 50% of the passengers in 2018 (Eurostat, n.d.). These 25 airports are supplied by 16 fuel suppliers. Two of the suppliers (BP, Shell) supply more than 20 of them, while five others supply 10 or more of these airports (CAPA, n.d.). We therefore estimate that the total number of aviation fuel suppliers in the EU is likely to be lower than 30.
  - **Air transport service providers:** Aircraft operators need to report their emissions under the EU ETS. Each operator serving one of the EU airports is

allocated to one of the Member States, which are then responsible for the compliance control of all covered flights of this operator. In 2018, 511 aircraft operators were covered by the EU ETS (Eionet, 2019).

- **Incentives for evasion:** The incentives for evasion, mainly through fuel tankering outside the EU, are predominantly induced through the increased fuel price due to the SAF blending. This incentive becomes higher for larger price gaps between SAF and conventional jet fuel, but remains relevant only for a small number of short- (and perhaps medium-) range flights that operate between the EU and non-EU Member States with less stringent regulation where more than needed fuel can be procured outside the EU to cover operational needs within the EU. With the distance of a flight increasing so does the fuel consumption related to carrying additional fuel making long-haul tankering more costly. Eurocontrol estimated that CO2 emissions induced by tankering amounted to 901.000 t in 2018 (EUROCONTROL, 2019). This is equivalent to 1.4% of the aviation sector's verified CO2 emission under the EU ETS in the same year (EEA, 2020). Even though this share could increase due to additional fuel related cost after the implementation of a fuel mandate, the increase is likely to be small or even not distinguishable since in the initial years of the mandate the price increase is likely to be much smaller than the historical price volatility of fossil kerosene. Brexit may also increase the opportunities for tankering, unless UK would implement an equivalent policy (Lord Deben, 2019). Case studies are performed in the impact assessment section (chapter 6 of this report) for a number of frequently flown indicative Origin-Destination pairs between EEA and non-EEA country pairs to assess the impacts of tankering on fuel prices.

Eligible fuels to meet the SAF obligation

The set of potential fuels that are examined within this initiative are presented in section 1b earlier. In brief these consist of:

- **Conventional biofuels** are currently the main sources to meet the Member State fuel obligation in road and rail transport. Due to sustainability concerns the quantity which can be credited for meeting the RED II targets is limited at Member State level. Thus, the level of the cap for this fuel type will differ considerably between Member States.
- **Advanced biofuels (Annex IX, part B)** are commercially available at relatively low cost and have been used in road/rail transport to meet the national fuel obligations. Their production costs are lower than the costs of advanced biofuels (Annex IX, part A). However, they are more expensive in production than conventional jet fuel (see Figure 8).

  Their use is capped to 1.7% under the RED II due to the rigid supply of the feedstocks and potential fraud if the additional use is incentivized. This cap considers the quantity of jet fuel used. Therefore, no changes are needed as long as the jet fuel quantities of the mandate for the aviation sector fall under the cap. The national maximum shares of this fuel type can slightly differ from 1.7% since the caps can be adjusted by the Member States[57].
- **Advanced biofuels (Annex IX, part A**) are not commercially available today. However, they may become available by 2025 and more widespread by 2030. While there is a wide range of low-cost feedstock available for these, their supply chain is not yet fully developed, and the high capital costs needed for their production will potentially have a significant impact on SAF prices.

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[57] A deviation from 1.7% must be approved by the EU Commission.

- **RFNBOs** are not available at commercial level today. However, they may become available by 2030. RFNBOs have the highest cost in the mid-term and the lowest conversion efficiency and would only be used for compliance if the production of other fuel types is limited and quantities would not be sufficient to meet the target of the mandate.
    - **RFNBO phase in:** Since there is currently a significant price difference between RFNBO and other more technologically mature SAF production pathways, ensuring their initial take-up would require further incentives. A sub quota or an accounting multiplier for RFNBO may be used to stimulate first production and to achieve strong cost degression in the short-term (up to 2030) before assessing if this is still needed in the long-term [58]. Consideration is required on how this sub-quota can be a technology-neutral application to avoid distorting the market.
- **RCF** are not commercially available today. However, they may be available by 2030. Their feedstock (fossil waste) is rather limited if sustainability requirements are met. There might be synergies with the development of advanced biofuel (Annex IX, part A) since the underlying processes of the fuel production are similar.

In making a design decision for this policy measure the points of Table 5 below need to be considered:

Table 5: Pros and Cons of different policy design options (eligibility of different fuel types)

Options for the policy design		Pros	Cons
1	**Conventional biofuels**	• Commercially available; lowest production cost compared to other SAF	• Their share for road and rail transport is capped in RED II due to risk of indirect land use change • The level of the cap for these fuels differs between Member States. • Sustainability concerns exist where such biofuels can lead to undesirable indirect land use change emissions
2	**Advanced biofuels (Annex IX, part B)**	• Commercially available; rather low production cost compared to other SAF	• Sustainable feedstock (in EU) is limited • Their share for road and rail transport is capped in RED II due to rigid supply and potential fraud. • The level of the cap for these fuels may differ between Member States (changing the 1.7% cap requires approval of the EU COM)
3	**Advanced biofuels (Annex IX, part A)**	• Could become commercially available by 2025 • Synergies (technology development) with RED II (minimum share of these fuels required for road and rail transport)	• Have higher costs than other biofuels • Less mature production routes and feedstock supply chains
4	**RFNBO**	• RFNBO could become commercially available around 2030 • Rather large feedstock availability (at	• They have highest cost in a mid-term perspective • RFNBO intermediates (such as green

[58] This concept was mentioned by Sunfire in the stakeholder interviews.

Options for the policy design		Pros	Cons
		global scale) • RFNBO have high potential for cost degression	hydrogen in refineries) creates competition with investments in more innovative fuel technologies
5	RCF	• RCF could become commercially available by 2030 • There might be synergies with advanced biofuel technology development since the same processes are used	• May conflict with more appropriate use of fossil waste (e.g. recycling) • The feedstock is very limited

All stakeholders consulted support the incentivisation of the REDII Annex IX - Part A and RFNBO SAF. REDII Annex IX – Part B SAF are considered by many a necessary addition to the SAF feedstock mix and very important to get the SAF market started, however a number of stakeholders' express concerns regarding the availability of sufficient sustainable feedstock for this production route. Finally, a number of fuel producers[59] consider the current list of feedstocks presented in REDII Annex IX – Parts A&B too limiting and argue that a review of the two lists would possibly make more feedstock available for SAF.

SAF fuel producers have criticized the feedstock-based approach of the REDII stating that the use of a specific feedstock does not necessarily make the produced fuel sustainable regardless of the specifics of its production.

RED II defines various fuels and sets minimum criteria for GHG reduction to be taken into account in the objectives of RED II (see chapter 1b). The scope of this initiative is set to be in line with the sustainability framework presented in the RED II and thus includes advanced biofuels (Annex IX, Parts A&B and RFNBOs).

Measurement unit for the mandate calculation

To determine and monitor the supply or demand mandate basically two different options can be considered: The mandate could be quantified in terms of fuel volume, or in terms of the GHG emission reductions achieved by the fuel.

In the first case the SAF would need to comply with minimum criteria for being eligible. Once the fuels would be certified as being compliant with the SAF requirements they would account according to their physical amount, even if some of the fuels would contribute more to GHG reduction than others.

Quantifying the mandate in terms of GHG emissions would require a minimum GHG reduction of the total amount of fuel used compared to a reference fuel. The emission factor of the reference fuel should be conservative to reflect uncertainties in determining the value. For this purpose the emission factor applied under RED II (94 g CO_2eq/MJ) (The European Parliament and the Council of the European Union, 2018, p. 155) might need to be aligned to the more conservative factor applied under CORSIA for jet fuel (89 g CO_2eq/MJ) (ICAO, 2018, p. 33). GHG reduction values need to be established based on the well-to-wing approach for each type of SAF.

[59] Interviews with Neste, SkyNRG, LanzaTech, Galp, FuelsEurope and Ethanol Europe.

Table 6: Pros and Cons of different policy design options (measurement unit for the mandate calculation)

Options for the policy design		Pros	Cons
1	**Volume (litre/tonnes)**	• Easy to measure, limiting "translation" mistakes	• Least accurate in terms of GHG emissions since differences in GHG reduction are not considered • Does not provide incentives to further reduce the GHG reduction performance of a fuel once it is qualified as SAF
3	**Emissions (CO_2eq)**	• Provide incentives to further reduce the GHG reduction performance of a fuel once it is qualified as SAF • Fairer and most accurate in terms of GHG reduction • Incentivises an LCA approach to reducing GHG limiting carbon leakage	• More complex to implement and monitor; especially sub quotas • Need to establish clear guidelines calculating GHG for all SAF and conventional jet fuel (LCA basis).

With respect to their preference for a mandate calculation unit, stakeholders have been positive to both a GHG- and a volume-based mandate. However, it seems that they are slightly more strongly in support of the GHG-based mandate calculation (47 out of 73 survey respondents) compared to the support for a volume-based calculation (40 out of 73 respondents). It is also acknowledged that a GHG oriented target would incentivise the production of the best performing SAF type and would be an approach consistent with the target of the initiative, although this is not the most straightforward approach. The relative simplicity of a volume-based approach is also widely identified but only a small number of stakeholders clearly favour this option provided that a minimum GHG emission reduction is considered and that upstream fuel emissions are also included.[60]

In making a design decision for this policy measure the following need to be considered:

- The GHG emission-based approach would result in different incentives compared to the volume-based approach. While the volume approach would only provide incentives to achieve the volume requirement, the GHG emission-based approach would provide additional incentives for SAF, which enablable a stronger reduction of GHG beyond the eligibility requirements. This is on the one hand more accurate and thus fairer for competing producers. On the other hand, it also ensures stronger incentives towards full de-fossilization of the fuels. The emissions-based approach may be more complex because it would involve determining reduction rates rather than a yes-no decision regarding compliance with the SAF requirements. However, the GHG emission calculation methodology of RED II and the underlying certification processes could be applied.

The EU ETS and CORSIA apply different approaches in accounting for the use of SAF. Under the EU ETS airlines can apply an emissions factor of zero (European Parliament and the Council of the European Union, 2008, p. 18) for the fuel certified as of biogenic origin pursuant to RED. Under CORSIA aeroplane operators must compute the emission reduction achieved using SAF based on life cycle emission factors compared to the reference emission factor for jet fuel of 89 g CO_2eq/MJ (ICAO, 2018, p. 33). In both cases the reductions

[60] Survey response from the Center for Solar Energy and Hydrogen Research Baden-Wuerttemberg and UPM Biofuels.

determined can be deduced from the requirements to surrender allowances or offsets, respectively. In other words, under the EU ETS a volume-based approach is applied to account for the use of SAF while under CORSIA an emissions-based approach is applied.

Level of administering the mandate

Determining the level of administering the mandate is very important in designing the relevant reporting mechanisms. The efficient administration of the obligation for all involved stakeholders is dependent on this choice. Choices available for this design option include the obligation to blend every drop of fuel, implement an obligation to blend on average for all obliged parties or develop a SAF certificate market place where obliged bodies would not need to physically supply/use SAF, but rather buy the rights for the relevant SAF volumes or GHG credits/certificates.

Blending every drop of aviation fuel with SAF would mean that SAF would need to be blended in all aviation fuel supplied across the EU. To this an exception could be considered for remote airfields.

The average blending requirement (mass-balancing) can be applied at the level of each obliged body and cover a period of time (possible less than a year) within which the mandate would need to be met on average across the actors' operations without having to blend all fuel supplies. This could be implemented at an airport level or additional flexibility could be added with the mandate met on average at a Member State or EU level.

Installing a SAF certificate trading system would mean that SAF certificates (volume GHG reductions based) could be issued . This option allows for SAF being used near to where it is more efficiently produced preventing inefficient supply chains.

Table 7: Pros and Cons of different policy design options (level of administration of the mandate)

Options for the policy design		Pros	Cons
1	**Every drop of fuel blended**	• Incentivises the production of SAF locally • Requires all suppliers/users to develop a SAF value chain approach • Simple enforcement	• Inefficient logistics to supply all airports especially in the short term • Requires a constant and steady SAF production and distribution stream • Leads to higher SAF costs •
2	**Average supply/use of all entities blended**	• Potential flexibility at the level of application (airport, Member State, EU) can be gradually adjusted to account for and incentivise increasing SAF availability locally • Most efficient reporting requirements • Logistically flexible approach • Can incentivise supply where it is more efficient • Requires all suppliers/users to develop a SAF value chain approach •	• Not strongly incentivising local SAF production • Average enforcement complexity
3	**SAF certificates trading system**	• Incentivisation of most efficient SAF production and supply chain • Flexibility in fuel logistics • Allows higher than required SAF usage (if mandate is on the air	• Additional administration and enforcement mechanism needed • May not create engagement of all relevant stakeholders in developing a SAF supply chain

Options for the policy design		Pros	Cons
		transport service providers)	• Reduced incentives for widespread deployment of SAF production capacity in the long-term

A number of stakeholders favour the development of a SAF certificate trading system as they consider it more efficient in delivering SAF while reducing logistical costs[61]. Less of the stakeholders responding to the survey disagree or strongly disagree with having a SAF certificates trading system (14 out of 73 respondents) than with the use of a system requiring every drop being blended (25 out of 73 respondents).

Part of the support to this policy design comes from the flexibility it provides to the production locations and the supply chain operations which are also partially addressed by the "on average" blending requirement[62]. Other fuel stakeholders[63] regard that a universal blending obligation would better stimulate the market incentivising localised production. This could in turn achieve better LCA GHG reduction. The Swedish Ministry of Infrastructure pointed that experience with mass-balancing from the RED and FQD proves that this approach works and a limited certificates trading mechanism (within Member State) could be a useful add-on.[64]

Penalties for non-compliance

Penalties for non-compliance

[61] Feedback received from SAF producer Sunfire, Galp, Shell, FuelsEurope, EBAA, the International Transport Forum, KLM, Lufthansa, the Polish Civil Aviation Authority and the Dutch Ministry of Infrastructure and Water Management

[62] Also, SAF producer Neste is in favour the "on average" blending approach

[63] survey responses from LanzaTech, Total and UPM Biofuels, interview response from ICCT

[64] compared to what they consider a more complicated cross-border trading

The enforcement of the mandate should foresee penalties in cases of non-compliance. This means that in case either fuel suppliers, or air transport service providers, are caught not meeting their obligation when either selling or supplying a volume of fuel, penalties would be imposed on them by the authority charged with enforcing the mandate. As there is already long experience with Member States with enforcing fuel regulation, it would make sense if they would be the stakeholders responsible for such enforcement actions.

In order to have preventive effect, the penalties ought to be (considerably) higher than the potential benefit one could expect to achieve by not complying with the given obligation. This means that penalties could be defined as fines larger than the said potential financial benefit. That financial benefit would be calculated on the basis of the price difference between conventional fuel blends multiplied with the volume of fuel to be found in breach of the obligation. To ensure the fine is larger than the potential benefit, and thus make non-compliance financially un-attractive, a multiplier could be applied to the expected financial benefit. This multiplier will need to be defined during the legislative proposal and would be expected to be larger than 1. Having too high a penalty multiplier though, could lead to exaggerated fines that could jeopardize the financial survival of the operators at breach of obligation. Thus, setting an appropriate fines level would require due consideration.

The formula below briefly describes the logic of defining penalty levels.

Penalty (€) = Cost differential (SAF blend -Fossil fuel cost) * Volume of fuel in breach * penalty multiplier

The penalty scheme could replicated the non-compliance penalty system of the EASA Basic Regulation (Regulation 2018/1139), where (art 131) "Member States shall lay down the rules on penalties applicable to infringement of this Regulation and of the delegated and implementing acts adopted on the basis thereof and shall take all measures necessary to ensure that they are implemented. The penalties provided for shall be effective, proportionate and dissuasive."

d. Flanking measures

Funding mechanism: Funding can play an important role in upscaling production of SAF and bridging the price gap between SAF and conventional aviation fuel prices. This can support the competitiveness of SAF and help boost their supply and help at a second stage to increase their demand. Depending on the exact targeting within each of the problem areas, this funding can take different forms and lead to different effects. For example, funding for R&D, pilot and demonstration projects can speed the path to maturity for certain technologies needed to commercialise certain production routes. This can prove helpful for developing less mature technologies like the electrofuels and certain production routes for advanced biofuels. Another target of funding could be towards bridging the price gap between SAF and jet fuels by supporting capital investments needed to deploy production capacity (CAPEX) or operational costs (OPEX) of new industrial-scale SAF production sites or their SAF-dedicated feedstock production and logistics.

The origin of the funding is also very important in that respect as funding derived from aviation fossil fuel can put an additional pressure for transition as their effect on closing the price gap is in this fashion catalysed. Examples of such, aviation specific, funding sources can be the EU aviation ETS, an aviation fuel tax applicable for conventional jet fuel or differentiated air traffic charges dependent on the GHG performance of aircrafts.

Irrespective of the funding source, a number of potential funding instruments are presented in Table 8 after an initial screening and their suitability in supporting SAF production deployment and uptake is briefly discussed. the origin of the funding is not examined in this table.

Table 8: Potential of existing funding instruments to be used for supporting SAF production

Funding instruments		Brief description	Relevance to supporting SAF uptake
1	EU Emissions Trading System	This fund is to identify low-carbon technologies in energy intensive	The goal of the instrument to support low-cost technologies is highly relevant for supporting

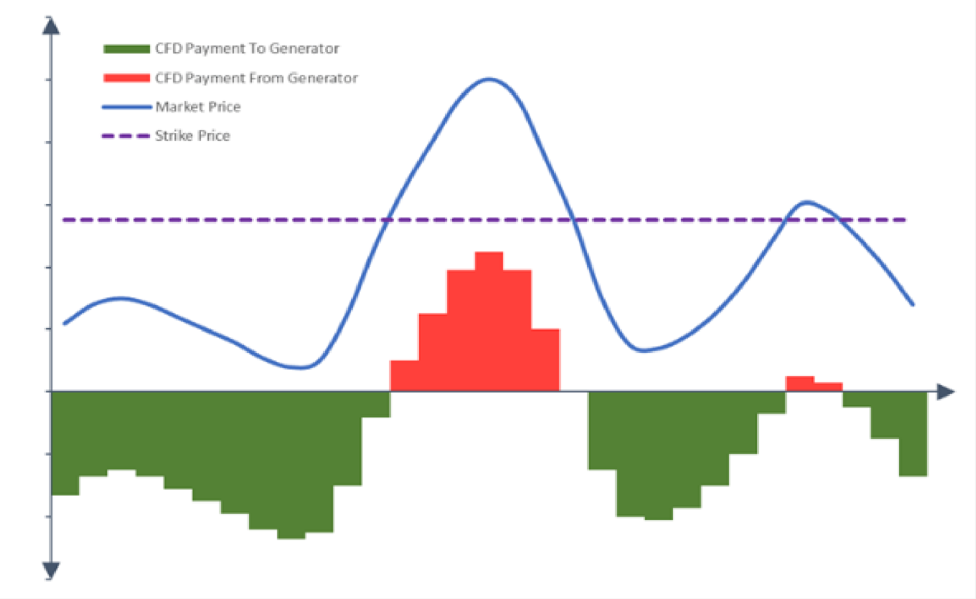
Funding instruments		Brief description	Relevance to supporting SAF uptake
	Innovation Fund	industries as well as Carbon Capture and utilisation or storage (CCU, CCS) renewable energy generation and energy storage. Funding of around €10 billion will be made available from the EU ETS auctioning of 450 million allowances between 2020-2030. The fund will support up to 60% of the additional capital and operational costs. This will target highly innovative technologies and big flagship projects across all sectors.	SAF uptake. Instrument suitable for funding first-of-a-kind production facilities and upscaling of technologies to achieve commercial maturity. Relevant for supporting the faster development of production capacity of the less advanced production routes as these targeting the REDII Annex IX – Part A feedstock or synthetic fuels. This funding tool will need to be probably supplemented by other instruments to cover large-scale and wide-spread deployment of SAF production.
2	**Horizon Europe**	This fund is for research and innovation to strengthen scientific and technological bases. Funding of €100 billion is available between 2021-2027. They will invest in projects focusing on adaption to climate change, including societal transformation, cancer, climate-neutral and smart cities, healthy oceans, seas, coastal and inland waters, soil health and food.	The goal of the instrument to support innovation in the field of climate neutral technologies is highly relevant for supporting SAF uptake. Instrument suitable for funding research and innovation project that can help improve the technological maturity of less advanced SAF production routes or innovations in their current process that will further improve their effectiveness/efficiency. Relevant for accelerating the time to the market of these technologies. The instrument volume, accounting for the very broad spectrum of application will probably not suffice for wide-spread industrial support to SAF production but would rather focus on R&D support
3	**Connecting Europe Facility (CEF)**	This fund supports the development of high performing, sustainable and efficiently interconnected trans-European networks in the fields of transport, energy and digital services in order to improve the use of infrastructure, reduce the environmental impact of transport, enhance energy efficiency and increase safety. It has a budget of €24.05 billion for Transport and €5.35 billion for Energy (2014-2020). CEF supports projects with high economic and EU value that require grant funding to become financially viable and attract market-based financing. CEF supports projects from TRL 7-8 levels, it continues into operational deployment. In addition to grants, CEF offers financial support to projects. Through blending (a combination of grants with financial instruments such as guarantees and project bonds) it acts as a catalyst to attract further funding from the private sector and other public sector actors.	The goal of the instrument to reduce the environmental impact of transport and enhance energy efficiency is highly relevant for supporting SAF uptake. Instrument suitable for funding the large-scale deployment of mature technology SAF production capacity. Through the blending function it can support the financially viability of SAF projects. The instrument volume might be sufficient to support large-scale SAF production installations, but further analysis will be needed to establish if this can be done to a sufficient level given the volumes of investments needed.
4	**Just Transition Fund**	This fund aims to strengthen economic and social cohesion in the European Union by correcting imbalances between its regions. €40	The goal of the instrument to support SMEs in the field of clean energy is highly relevant for supporting SAF uptake. The limitation to fund SMEs can be a restricting

Funding instruments		Brief description	Relevance to supporting SAF uptake
		billion is available between 2021-2024. The instrument is targeting research and innovation in SMEs looking to improve the digital agenda and low-carbon economy. This includes the creation of new firms, environmental rehabilitation, clean energy, upskilling workers and job search assistance.	factor to supporting some of the core SAF production functions. The instrument could be suitable for funding businesses involved in the SAF value chain and can for example support research in and production capacity of localised supply chains for SAF feedstock. The instrument volume seems sufficient to support the deployment of localised SAF production capacity and value chains in EU regions.
5	**InvestEU**	This fund will bring together the European Fund for Strategic Investments and 13 EU financial instruments currently available. This will provide an EU budget guarantee of €75 billion that will back the investment projects of implementing partners such as the European Investment Bank (EIB) Group and others, the guarantee will be provisioned at 45%, meaning that €34 billion of the EU budget is set aside. This fund is focusing on four main policy areas: sustainable infrastructure; research, innovation and digitisation; small and medium businesses; and social investment and skills.	The goal of the instrument to support SMEs and sustainable infrastructure is relevant for supporting SAF uptake. The type of support may be effective in de-risking SAF investments. However, the guarantee provided might need to be supplemented by contributions from other instruments to render SAF investments viable. The instrument volume could be used at the later stage of SAF production maturity or to supplement other instruments in supporting SAF investments.
6	**Next GenerationEU**	This fund will support Member State efforts to recover from the crisis, boost private investment, support ailing companies and accelerate the green and digital transitions. €750 billion is available between 2021-2024. The bulk of the funding from Next Generation EU (more than 80%) will be used to support public investment and key structural reforms in the Member States	It is unclear how exactly the instrument will function and whether the funding will be relevant for SAF production support and what type of projects will be exactly targeted. The instrument volume seems adequate to support the large-scale unrolling of SAF production capacity.
7	**Important Project of Common European Interest (IPCEI)**	The instrument aims to support the battery sectors of raw and advanced materials, cells and modules, battery systems, and repurposing, recycling and refining. This fund will support research and innovation in the common European priority area of batteries. €3.2 billion is available between 2020-2031.	A purpose-made instrument to support the uptake of SAF could prove useful. Setting up a funding instrument with the participation of Member States and relevant industrial actors can be a relevant approach to support SAF R&D or production capacity scale up

Central auctioning mechanism: Auction schemes have been used in the renewable power sector over the last few years because they potentially enable the deployment of renewable energy technologies in an organised, cost-effective and transparent manner. Auctions also ensure that there are commitments between users and suppliers – key for new technologies where a lack of commitment can be a major barrier to commercial production. The producer who offers the product at the lowest price per GHG reduction performance would win the auction and secure a commitment from a fuel purchaser for a contract for a set amount of SAF. In this line of thinking, the bonus/subsidy can be auctioned on the basis of carbon

contracts for difference (Richstein, 2017)**,** where the producers receive the difference to their offered strike price if the market price for fossil fuel is below but need to refund the difference if the market price is above their strike prices. The next table briefly explains some of the key characteristics of this scheme.

Table 9: Functioning of Contracts for Difference

	Contracts for difference (CfD)
Purpose	Provide public subsidies to investors of GHG reducing technologies in a way which ensures efficient use of the subsidies while eliminating windfall profits and mitigating price risks for investors at the same time
Functioning	The government (or a mandated company) calls for the delivery of climate friendly product to the market and provides subsidies for those providers/investors who can offer the product at lowest subsidy Typical products are (renewable) electricity or climate friendly steel/cement/chemicals; the production e-fuels would be another potential application; if the product is an emission reduction through a certain technology/product, they are usually called Carbon Contracts for Difference (CCfD) At an auction, investors provide sealed bids, in which they commit to provide a certain production capacity or producing a certain amount of the product at a price, the so-called strike price, which covers total CAPEX and OPEX over the contract period Once that bid was successful, the investor receives on delivery of the product the difference between the contracted strike price and the price of the reference product, which typically is determined at a public exchange; if the price of the reference product exceeds the strike price, contractors have to pay the difference to the government. Contract periods typically range from 15 (DBEIS, 2020) to 20 (DIW Berlin, 2019) years
Illustrative example for the mechanics of a CfD and resulting payments (Low Carbon Contracts Company, n.d.)	
Auctioning design	Bid capacities/amounts could be limited to ensure that more than 2 e-fuel producers compete for the most efficient production technology Auctions for CfD should be held frequently Preferably the auctioned product volume should be synchronized with the projected increasing demand, e.g. due to a fuel mandate

	Producers which received a CfD in earlier auctions can use subsequent auction rounds to expand their production Due to learning by doing and economies of scale the average strike price is likely to decline over time; competition between different e-fuel producer facilitates innovation similar to the promotion of renewable electricity through feed-in tariffs
Application examples	UK applies CfD since 2015 for auctioning offshore wind and nuclear power subsidies (DBEIS, 2020); France, Denmark and Poland follow UK's example (S. Hanke, 2020)
Advantages	Provides long-term demand and price certainty for investors (similar to for example feed-in tariffs, though without potential windfall profits) Provides access to long-term finance at lower cost also for SME or start-ups, which usually have higher finance cost than larger, incumbent companies; this way CfD provide a broader spectrum of providers and is likely to accelerate innovation similar to feed-in tariffs for renewable energy Payment on delivery ensures fewer investment ruins financed by public subsidies in comparison to pure investment subsidies; if an investor goes bust, the subsidy would have only been paid for the amount of product actually delivered Payment on delivery provides incentives to run and constantly improve the installations
Disadvantages	No incentives to adapt production to market signals which are transmitted via the market price Requires the definition of a reference product and transparency and independency on its price formation
Legal aspects	OPEX subsidies are in principle incompatible with EU state aid rules (Art 107); however, in a decision in the context of UK's support for electricity generation from the nuclear power plant Hinkley Point C, the EU Commission made clear that OPEX subsidies in cases of CfD are equivalent to CAPEX subsidies and thus eligible (European Commission, 2014, pp. 344-347 & 394-397). The Guidelines on State aid for environmental protection and energy make clear that the subsidy may be granted for 100% of the eligible cost (instead of usual threshold of 40% or 70%), if the subsidy is allocated in a competitive and non-discriminatory bidding process (European Commission, 2014, pp. 43, 54, 80 and Annex 1).

Voluntary agreements: Such agreements between airlines and fuel suppliers could be facilitated at EU-level in order to (a) encourage airlines to purchase SAF on a regular basis and (b) encourage fuel producers to produce and sell SAF on a regular basis.

SAF Technical support facility: The objective of this initiative would be to accompany SAF producers along the SAF approval process, by providing the necessary technical support and facilitate the certification of new SAF production routes.

Monitoring: Establishing a monitoring system with a specified data stream will be necessary to follow the implementation of any blending mandate in place. This will depend on the obliged body choice for a potential mandate as elaborated earlier with the potential administrative burden varying based on this information as well as the scope of the chosen level for administering the mandate. Combining this information obligation with the data streams set up for the EU aviation ETS, CORSIA and RED II will help avoid duplication of effort.

Revision of the multiplier pursuant to RED II Drop-in SAF can be currently counted toward national targets under RED II with a multiplier of 1.2. Currently only the Netherlands has opted for including aviation GHG reductions towards its REDII targets. An upwards revision of this multiplier is expected to potentially lead to an increased incentive for Member States to pursue the use of SAF as suggested also by stakeholders approached in the exploratory interview phase[65], but will also possibly results in a comparatively lower uptake of physical quantities of SAF.

e. Measures subject to other Commission initiatives

The following measures are identified as meaningful contributors to the promotion of the usage of SAF. They are the subject of other Commission initiatives and as such their detailed impact assessment is not part of this study. It is acknowledged nevertheless that these could produce significant synergies with this initiative and are thus briefly elaborated.

Taxation: Unlike the case of road transport, aviation fuel is currently not directly taxed meaning that a differentiation in taxation levels between conventional jet fuels and SAF is not possible. A revision of the aviation taxation approach of the EU could help in bridging the price gap for air transport providers between SAF and conventional jet fuel. This price gap depends on the production pathways used (lower for HEFA than other SAF fuel) and is expected to decline over time as the technologies at stake mature. Potentially leading to increased SAF demand, in combination with other measures described above. It should be noted that such a change to the current aviation taxation approach would be incorporated into the revision of the Energy Taxation Directive, rather than being included in this initiative.

Alternative origins of tax revenue that could help to bridge the price gap could be the restructuring of the air traffic control charges (although this would probably require a significant increase of the current level of charges), or the expansion of the current EU aviation ETS auctioning allowances revenue by phasing out the current free allowances. Nonetheless, it is important discuss here to have a complete overview of the potential measures incentivising uptake of SAF.

Revision of the Fuel Quality Directive (FQD): The current Directive includes aviation only as a voluntary opt-in. Widening the scope of the Directive would set a target for the reduction of greenhouse gas intensity (calculated on a life-cycle basis) of jet fuel, thereby increasing the use of SAF in Member States. The FQD introduces the voluntary reporting not only of the volumes of fuels, but also their GHG intensity for both fossil-based fuel and biofuels. It also requires the reporting of additional information such as the place of purchase and the country of origin of the fuel.[66] These information are relevant to estimate the Life Cycle Analysis (LCA) of the GHG emissions, though, due to the voluntary reporting, these information are reported at a relatively low rate.[67]

65 French competent authority and Neste

[66] for biofuels this refers to the feedstock place of origin

[67] The level of reporting is considerably lower for fossil fuels (reporting the place of purchase of fossil fuels for 11.3 % and the country of origin for 10.5 %of total fuel quantities). than for biofuels,(33.1 % for the place of purchase and 55.3 % for the country of origin of the feedstock).

The measures described above are presented in Table 10. The multiple design parameters and the alternative available choices there can be used to extensively tweak the design of the specific policy measure with a number of variations possible. In the following table two variations are developed one for a supply-side mandate and a second for a demand-side mandate. In each of these a specific choice is made regarding the mandate basis of measurement and its administration level so that the measure design would be as coherent as possible to the obliged body at stake. The choice of eligible fuels is considered constant for both Policy measures designs.

Table 10: Description of policy measures

#	Policy measure	What is required	What it will achieve	Drivers
1	**Supply mandate**	Aviation fuel suppliers are required to deliver a minimum percentage of SAF as part of their delivery of aviation fuel to air transport service providers. This requirement will steadily increase over time providing long term security to the market and accounting for ongoing performance of the measure. It will apply to all aviation fuel deliveries taking place in the EU. In the short term not all fuel needs to be blended but the overall deliveries of each supplier within a certain period of time (balancing period) in each EU Member State will need to account for the specified percentage of SAF. As SAF production reaches more significant volumes, compliance with the mandate percentage can be considered at an airport supply basis and/or move to prescribing all SAF being blended. The measurement unit in this measure is can be either a SAF volumes supplied or a GHG-reduction target. Within this mandate RED II Annex IX – Part A&B fuel are eligible as well as electrofuels. Penalties are foreseen for suppliers not achieving the specific goal. A sub-target will be set for the supply of electrofuels. This will be very low in the short term to mirror the lack of technological maturity and limited production capacity currently available.	This measure develops a specific market for SAF distinguishing demand for the commodity from that of conventional jet fuel. It aims to increase the supply for SAF by requiring the deployment of additional SAF production capacity. Since all fuel suppliers are required to supply SAF, they are incentivised to invest in SAF production or seek to procure SAF quantities from SAF producers. Where distributors are not fuel producers, they will seek to purchase SAF from their suppliers creating demand. Distributors would be willing to pay an increased cost for fuels containing SAF to avoid the penalties which would at least partially justify the higher prices required for SAF purchases. Penalties need to be well considered to avoid the negative impacts from setting them too high This higher market price for SAF would eventually support investments in SAF in a two-step approach which in turn may lead to increased investments in SAF technology maturity and some eventual reduction of SAF prices as a result of this maturity. SAF technology mainstreaming will also lead to increased investments in SAF technology maturity and some eventual reduction of SAF prices as a result of this maturity. Depending on the mandate delivery flexibility, a requirement per supplier at EU level would mean that logistics can be simplified and SAF can be delivered where it is most efficiently produced, rather than aiming to supply every single EU airport at least at the initial phase of SAF production where volumes will be limited and distributing the relatively small production from a limited number of SAF production sites across the whole of Europe, would not be economically optimal. The volume-based targeting brings the advantage of reporting simplicity. On the flip side, this may not incentivise the production and use of the most sustainable fuels with the higher GHG reduction capacity, nor allows for a full incorporation of an LCA approach.	1, (2) and 3

#	Policy measure	What is required	What it will achieve	Drivers
			This strong and long-term policy signal produces market security for long-term investments in SAF. Reporting requirements on the number of obliged body and flexibility of delivering the mandate will minimise the administrative burden and costs to establish the relevant data streams and enforce the measure.	
2	**Demand mandate**	Air transport service providers are required to purchase fuel blended with SAF. This requirement will steadily increase over time providing long term security to the market. Every air transport service provider must provide proof of certain level of SAF contained in the fuel mix used over the course of a reporting period. With some alignment in the reporting requirements, this aligns data streams with those of the EU aviation ETS. This measure could be complemented with a SAF certificate trading system where airlines do not have physical access to SAF at airports and to give them the opportunity to surpass quotas if desired. Within this mandate RED II Annex IX – Part A&B fuel are eligible as well as electrofuels. A sub-target will be set for the supply of electrofuels. This will be very low in the short term to mirror the lack of technological maturity and limited production capacity currently available. Penalties are foreseen for air service providers not achieving the specific goal. These penalties could be charges proportional to the SAF volumes lacking from the suppliers' deliveries and account for the price difference between SAF and conventional jet fuel to avoid economic behaviour.	This measure develops a specific market for SAF distinguishing demand for the commodity from that of conventional jet fuel. It aims to develop the demand for SAF. Airlines would then be willing to pay an increased cost for fuels containing SAF to avoid the penalties which would at least partially justify the higher prices required for SAF purchases. This higher market price for SAF would eventually support investments in SAF in a two-step approach which in turn may lead to increased investments in SAF technology maturity and some eventual reduction of SAF prices as a result of this maturity. A SAF certificate trading system could support a more system-oriented production of fuels as the production can be located where it is most efficient and supply chains and scales can be freely optimised. This will be especially important for the initial years of SAF production when distributing the relatively small SAF production volumes from a limited number of SAF production sites across the whole of the EU, would not be economically optimal. This strong and long-term policy signal produces market security for long-term investments in SAF. If adopting the variant excluding extra-EEA flights, this will significantly curtail the efficiency of the mandate as they produce the majority of CO_2 emissions.	(1), 2 and 3
2.1	**Demand mandate for all flights (intra- and**	In this variant, operators flying to or from EEA airports are obliged to use SAF over their total consumption for intra- and extra-EEA	This option would achieve a similar impact as the supply side mandate but has also the capacity of preventing tankering of fuel as operators would be obliged to use SFA regardless of the location they purchase	

#	Policy measure	What is required	What it will achieve	Drivers
	extra-EEA)	non-EEA flights.	fuel. This would also avoid a market distortion with intra-EEA flights being more expensive than extra-EEA flights which could lead to a change in transport patterns.	
2.2	**Demand mandate for intra-EEA flights**	This measure would mandate the use of SAF only in intra-EE flights similar to the scope applied by the EU aviation ETS. This choice is due to legal concerns regarding the possibility to oblige non-EEA operators to use SAF. Additionally, obliging EEA operators to use SAF also on non-EE flights would be possible but would result in a market distortion and with their competitive disadvantage vis-à-vis their non-EEA competitors.	This measure avoids legal uncertainty regarding its application, it has however a significantly reduced potential compared to the option of obliging all flights to use SAF as the majority of aviation emissions comes from non-EEA flights. It further produces a certain market distortion making transfer flights outside the EEA area more competitive.	
2.3	**Fuel uplifting obligation**	All air transport service providers that use EEA airports will be obliged, when departing from an EEA airport, to uplift at least the exact amount of fuel they need for their next flight. In this measure, air transport service providers would be required to uplift and report on this requirement for all their flights departing from EEA airports. Applying this measure universally to all departing flights (intra- and extra-EEA) would prevent market distortions.	This is a measure aiming to prevent carbon leakage in the form of tankering. It intends to stop air transport service providers from supplying fuel with no/less than the required SAF content or GHG emission reduction potential prior to entering the EEA area in volumes such that would reduce allow them to use it also for flights departing from EEA airports. This is meant to safeguard that the fuel supplied in EEA airports and meeting the SAF obligation, would still be bought by air transport service providers.	
3	**RFNBO sub-mandate**	In case of a volume-based mandate (either supply or demand), a sub-target will be set for the supply of synthetic fuels. This will be very low in the short term to mirror the lack of technological maturity and limited production capacity currently available.	This will boost the mainstreaming of SAF technologies that are further away from commercial maturity, which are however not facing feedstock limitations and can potentially achieve a higher GHG reduction performance. This might enable the earlier introduction of these production pathways.	
4	**RFNBO multiplier**	In case of a GHG-based mandate (supply-side), a multiplier will be needed to stimulate the use of RFNBO fuels. The setting of the multiplier will account for the GHG reduction achieved per fuel volume unit of each SAF type. It should also account for the price premium associated to achieving this GHG emission reduction for each SAF type so that the, currently, less	Similarly, to the above, this will boost the mainstreaming of SAF technologies that are further away from commercial maturity. It does so by eliminating reducing the price premium needed to deliver the GHG emissions mandate via the use of RFNBOs	

#	Policy measure	What is required	What it will achieve	Drivers
		price efficient RFNBOs can be brought on an equal footing with more mature SAF production routes. Over time, the multiplier will need to be revaluated accounting for production cost developments.	This might result though in lower overall emissions reduction as the reductions from the use of RFNBOs will be double counted.	
5	**SAF certificates trading system**	This measure foresees the development of a system of producing and trading certificates for the supply or use of SAF by obliged entities. These certificates could refer either to SAF volumes or GHG emissions reductions achieved depending on the selected unit used for measuring compliance with the mandate. In the latter case a standardised methodology to calculate the LCA emissions of fuel will be needed. A mechanism to administer and enforce the functioning of the system will also need to be developed to reduce the risk of fraudulent practices. The RED II would need to be revised to allow for such as system as this is currently not the case.	This system will enable obliged entities to trade to obtain the certificates they would need to fulfil the mandate in place. This would mean that they would not necessarily supply/use the SAF needed but would be able to demonstrate compliance by presenting the certificates they produced or obtained via trade. The absence of a physical requirement to supply/use SAF would lead to the optimisation of the deployment and logistics of SAF production. The produced flexibility in fuel logistics would prevent inefficiencies developing in the feedstock and fuel supply chain leading to lower overall costs than in a system where all fuel needs to be blended. Cost savings are also expected at the reporting side as this can with this system be made at an aggregate level.	
6	**Funding SAF R&D**	EU funding could be made available in the form of R&D grants supporting the research and development, demonstration (Horizon Europe) and initial deployment of less mature SAF production technologies (EU ETS Innovation Fund). This funding will also support other novel technologies related to the production and logistics of the inputs to SAF production aiming to yield efficiencies across the whole supply chain. This funding can be sourced through existing EU R&D funding instruments such as Horizon Europe, the ETS Innovation Fund or other.	By funding the initial stages of technology development, the path of the targeted technologies to maturity is accelerated and their commercialisation will bring the deployment of SAF production capacity forward in time. Accelerating the reduction of SAF prices due to technology maturity. Supporting the commercialisation of additional production routes, the feedstock pool on which SAF production is based is widened creating a larger potential for SAF uptake	1 and (2)
7	**Funding in support of SAF production deployment**	EU funding is made available to support the deployment of SAF production capacity through some of the existing or future EU funding instruments. Instrument like the CEF can be used to fund large scale production capacity deployment for SAF technologies that are in their commercialisation phase. The EU Just Transition Fund could be utilised to supplement this funding with its targeting of SMEs and innovation technologies it can be utilised to support the SAF value chain development and especially for their supply	By participating in the production and/or operational costs of SAF capacity deployment, this measure first of all secures the increased deployment of SAF production capacity. The subsidised production costs and the improved maturity of the production routes will indirectly lead to lower SAF prices, while also ensuring a certain level of reduction in the prices that SAF is made available on the market. Further, the use of aviation fossil fuel taxation sources to fund these	1 and (2)

#	Policy measure	What is required	What it will achieve	Drivers
		chain development. These existing instruments already have established funding sources. Increasing their volumes with funds originating from aviation fossil fuel sources such as an aviation fossil fuel tax[68], an increase in the EU aviation ETS revenues or differentiated Single Sky ATC charges depending on the fuel used could be considered. Through the co-funding of projects, CAPEX or OPEX costs for new production facilities or for the adaptation of existing installations, the deployment and upscaling of additional SAF capacity will be facilitated. Specific calls can be used to incentivise certain SAF production routes depending on their maturity level and sustainability potential. To secure that SAF production will be held in the long term, this funding will be made available requiring the producer's obligation of a certain level of SAF production over time.	investments brings an additional reduction to the price gap between SAF and conventional fuel as they are expected to increase the cost of using conventional fuel. These reduces the competitive disadvantage of SAF compared to conventional jet fuel and thus encourages SAF demand.	
8	**Central auctioning mechanism – Contract for difference**	The contract for difference scheme is a specific form of how policy 4 (supporting SAF production deployment) could be implemented. It involves an invitation by a central auctioning authority to SAF producers to bid at the lowest price to supply SAF of a certain GHG emission reduction potential to the aviation market over a certain period. The scheme may guarantee that any difference between the market and the strike price is covered through subsidies by Member State or EU funding. In case the strike price is higher than the market price, the suppliers need to refund the difference.[69] The invitation to auction should be held relatively frequently with the view that technological learning is reflected in declining unit prices for SAF and to ensure continuous upscaling of SAF production capacities.	This measure provides greater certainty for users in the price of the final product while guaranteeing a certain price for SAF producers. The provided subsidies can serve to bridge the gap between SAF and conventional fuel prices and thus increase the competitiveness of SAF. This in turn is expected to increase the demand for SAF by aviation service providers. The commitment between suppliers and users provides a certain level of certainty for the duration of the contract and reduces investment risks for SAF production.	2 and (3)

68 Potential Energy Taxation Directive (ETD) revision

69 Alternatively, the price might be defined by the auctioning itself instead of being guaranteed but this would not result in an equally strong signal and the result on de-risking investments would be weaker

#	Policy measure	What is required	What it will achieve	Drivers
9	**Technical facilitation and support facilities**	An advisory facility is set up to support the SAF producers in obtaining certification of novel SAF production routes. This platform assists SAF producers in navigating the certification process and in obtaining faster pre-approvals of their innovation. The objective of this facility would be to accompany SAF producers along the approval process, by providing the necessary technical support and faster facilitate the certification of new SAF production routes. Additionally, an EU coordination platform could be set up with the participation of SAF producers, air transport service providers and Member State regulatory authorities. This platform convenes regularly with the intention to identify, promote and implement actions that support the common objective of developing the SAF market.	Commercialisation of less mature SAF production routes is accelerated resulting in the earlier entry of this SAF production capacity to the market. This measure couples well with the R&D funding mechanism so as new facilities / process are developed and scaled up, the fuels can be certified to ensure their future scalability and demand. The coordination platform develops actions aiming at the development of the SAF market and to overcome barriers to SAF deployment and demand development.	1
10	**Monitoring SAF production/ use**	A robust data stream is designed and developed to monitor the implementation of SAF mandates. Depending on the obliged body the reporting framework is developed to capture the relevant information. Attention is placed in aligning reporting requirements with those of the EU ETS, CORSIA and REDII in order to avoid double counting of GHG reduction achievements and duplication of data reporting efforts while accounting for the different sustainability criteria in place. A volume-based mandate on the supply side would align best with the REDII reporting requirements while a GHG-based mandate could identify synergies with the EU aviation ETS reporting structure. The implementation of the mandates is closely monitored by an EU body which is mandated to evaluate periodically the progress towards the goals and to develop recommends and corrective actions when necessary to further support the achievement of the set targets.	The availability of reliable information regarding the implementation of the SAF mandates allows for the close monitoring of the situation and the timely development of corrective action when targets are threatened. The close monitoring of the deployment or uptake of SAF in the EU by a European body and the commitment to achieving the given set of goals creates a strong political commitment reducing the market uncertainty for SAF producers to invest in novel technologies.	3
11	**Voluntary**	This option corresponds to a “laisser-faire” approach, whereby the market is let free to organise itself towards SAF ramp up, without	This measure may lead to some degree of SAF ramp up over time but this is expected to be negligible with respect to the necessary scale up	(3)

#	Policy measure	What is required	What it will achieve	Drivers
	agreements	further specific regulatory intervention at EU level.	of the SAF uptake needed to reach EU climate objectives	

In Table 11 the long list of measures is mapped against the identified problem drivers. This mapping will allow the formulation of Policy Options that intend to address all the identified Problem Drivers.

Table 11: Mapping of policy measures against problems and drivers

No	Policy measure	Problem driver(s) targeted		
		D1 – Resources for SAF production	**D2 – High capital and operational costs**	**D3 – Regulatory and fiscal certainty**
1.	SAF supply mandate	**X**	**X**	**X**
2.	SAF demand mandate			
2.1	Demand mandate all flights -	(**X**)	**X**	**X**
2.2	Demand mandate for intra-EEA flights only	(**X**)	**X**	**X**
2.3	Fuel uplifting obligation		**X**	
3.	RFNBO sub-mandate	**X**	**X**)	**X**
4.	RFNBO multiplier	**X**	**(X)**	**X**
5.	SAF certificates trading system	**(X)**	(**X**)	(**X**)
6.	Funding SAF R&D	**X**	(**X**)	
7.	Funding in support of SAF production deployment	**X**	**X**	
8.	Contracts for difference		**X**	(**X**)
9.	Technical facilitation and support facilities	**X**		
10.	Monitoring mechanism			**X**
11.	Voluntary agreements		(**X**)	(**X**)

X: Driver targeted

(**X**): Driver partially/indirectly targeted

f. Initial screening of measures

In this section an initial screening of the long list of measures identified earlier is performed based on the criteria outlined in Table 12. The objective of this exercise is to narrow down the long list in a sensible manner so that less preferable measures are discarded.

Table 12: Suggested screening criteria

Criteria	Description
Legal feasibility	Extent that options respect the principle of conferral and whether they may conflict with other EU legislation
Technical feasibility	The presence of any technical barriers to the adoption and enforcement of a measure. This is particularly important for measures that would require the development of legislation in other areas.
Effectiveness and efficiency	The contribution of the measure to addressing the specific problem and/or meeting the objectives that it is targeted to and the (qualitative) cost burden or savings that could be achieved with the adoption of the measure. Quantitative assessment will be conducted

Criteria	Description
	in the detailed impact assessment.
Political feasibility	Check whether specific options are expected not to garner the necessary support for adoption of legislation and implementation
Subsidiarity and proportionality	To ensure that the principles of subsidiarity and proportionality are respected

The assessment as seen in Annex 4 is at this stage qualitative (detailed quantitative assessment will be performed for the packages of measures comprising the Policy Options) and based on the findings from the literature, stakeholder inputs and judgement from the experts in our team.

Based on the screening above, the voluntary agreements measure presents a low expected effectiveness in dealing with the problem drivers. This assessment is based on the fact that voluntary cooperation between users and suppliers of SAF has been taking place in various frameworks[70] already for a number of years but has failed to yield very concrete results. The stakeholders participating in these initiatives have called for a coordinated EU-wide action according to the feedback provided to the Inception Impact Assessment (Commission, 2020).

g. Policy Options

Presentation of selected Policy Options

In building the Policy Options, a selection of policy measures is made in each, such as to ensure that all problem drivers are addressed by policy measures as per the mapping presented in Table 11. The development of the Policy Options aims to create combinations of measures to explore different measure configurations to deliver on the policy objectives. In line with the categorisation of the policy measures presented in the previous section, the Policy Options comprise of alternative mandate designs measures. All mandates are also accompanied with a relevant monitoring mechanism to track progress towards the set of targets.

The flanking measures aiming to support the mandate implementation, whilst not part of this initiative, would be needed across all Policy Options to support the commercialisation and upscaling of novel technologies. These include making available funding for SAF production capacity deployment. Supporting CAPEX and OPEX costs at least for the early entrants to the market and the commercialisation and upscaling of novel technologies. Dedicated R&D funding is to be made available to develop, pilot and demonstrate technologies at earlier maturity levels. To further support SAF suppliers, a technical facilitation platform can be set up to support the certification of new technologies and provide a forum for stakeholders to coordinate on overcoming further barriers to meeting the initiative’s objectives. Finally, all Policy Options are considered in a context where other Commission initiatives are being carried out, which could have a positive impact on the SAF market uptake. This is notably the case of the ongoing revision of the ETD and REDII and EU ETS.

The different Policy Options are meant to address the range of design options presented for the delivery of the mandate design in appropriate combinations. Eventually, different approaches are addressed regarding the mandate design parameters as presented along the measure descriptions:

70 Such as in the European Advanced Biofuels Flightpath initiative of 2011 or the Clean Sky Coalition more recently established.

- Obliged party (fuel suppliers or air transport service providers)
- Scope of flights addressed (all flights or intra-EEA flights only)
- Measurement unit for mandate calculation (volume-based or GHG-based)
- Level of mandate administration (and flexibility)

As the choice of the obliged party has the potential to impact all other mandate design parameters, this is going to be different between the main Policy Options with their variants aiming to explore combinations of the other parameters including different levels of ambition.

There is no intention to differentiate the mandate design in relation to the time horizon and ambition of achieving the GHG reductions[71] and the scope of eligible SAF[72] as these are considered given for purposes of coherence with other EC initiatives. The level of ambition of SAF in the fuel mix is given by the MIX scenario used in the 2030 Climate Target Plan and is presented in Table 13 below.

Table 13: 2030 Climate Target Plan target for SAF participation in the fuel mix

Shares in the fuel mix (in %)	2025	2030	2035	2040	2045	2050
SAF ramp up	**2**	**5**	**20**	**32**	**38**	**63**
Sub-mandate – green synthetic fuels	-	0.7	5	8	11	28

Based on these targets, the following Policy Options have been defined:

Policy Option A1:

- **Supply-side obligation:** Fuel suppliers are obliged to supply all jet fuel in EU airports blended with at least a minimum SAF share. The obligation will foresee a, gradually increasing over time, level of SAF suppliers should include in the fuel mix they deliver to air transport providers. A sub-mandate will be targeting the supply of green synthetic fuels. The share of SAF prescribed by the mandate is presented in Table 13.
- **Intra- and extra-EEA**: The obligation will concern all fuel uplifted from EEA airports. Exemptions may be established for remote, insular and airports with low traffic levels. The exemptions should be of scale that would not jeopardise the overall effectiveness of the initiative in meeting the targeted GHG emissions reduction.
- **Volume-based**: The obligation for fuel suppliers will be measured in the amount of SAF volumes introduced in their fuel mix.
- **Every drop blended**: SAF will be required to be blended at all EU airports so that all fuel uplifted from EU airports will contain at least the same minimum level of SAF

Policy Option A2:

- Same as Policy Option A1 with difference regarding the chosen mandate measurement approach.

71 These are linked to the GHG reduction goals derived from the 2030 Climate Target Plan.

72 Which is following the sustainability framework of the Renewable Energy Directive

- **GHG reduction-based**: The obligation for fuel suppliers will be measured in the amount of GHG emissions reduction achieved. Synthetic fuels production will be further incentivised via the use of a multiplier in the calculation of the achieved GHG reductions. Hence, unlike Policy option A1, the relative contribution of biokerosene and synthetic kerosene is an endogenous outcome in Policy option A2. The application of the multiplier in the modelling aims to support the uptake of synthetic kerosene, by improving its cost efficiency (i.e. in terms of Euro/tonCO2) when compared to that biokerosene. The multiplier is relevant for the decade 2030-2040, in which the price gap between the synthetic kerosene and biokerosene, is projected to be high (i.e. more pronounced in 2030). A multiplier of 1.6 and 1.2 was considered for 2030 and 2040, respectively. From 2045 onwards, a multiplier of 1 applies.

Policy Option B1:

- **Demand-side obligation:** Air transport service providers are obliged to use a minimum share of SAF in the flights to/from EEA airports. The obligation will foresee a, gradually increasing over time, level of SAF to be use in their jet fuel mix. A sub-mandate will be targeting the use of green synthetic fuels. The share of SAF prescribed by the mandate is (similarly to Policy Option A1) presented in Table 13.
- **Intra- and extra-EEA**: The obligation will concern all flights departing from EEA airports. This will include both intra- and extra-EEA flights.
- **Volume-based**: The obligation for fuel suppliers will be measured in the amount of SAF volumes introduced in their fuel mix.
- **SAF certificates trading system**: Air transport service providers may not have physical access to SAF at their destination airports. Via the use of the trading system, they can purchase SAF certificates to meet their obligation (even if the volumes at stake are used by other airlines) in a flexible way over their whole operations. This will lead to more efficient distribution of SAF across their EEA-wide fuel supply chain operations.

Policy Option B2:

- Same as Policy Option B1 with difference regarding the chosen scope of flights addressed.
- **Only intra-EEA flights**: This option considers the potential legal conflict of imposing the obligation to non-EEA air transport service providers. Thus, instead of obliging only EEA-operators, which would have distorted competition in the extra-EEA transport market, the obligation applies only to intra-EEA flights departing from EEA airports. This means that intra-EEA flights departing from EEA airports will be required to use a minimum level of SAF as presented in Table 13. The reduced scope of the Policy Option is expected to have a significant impact on its performance regarding meeting the GHG emissions reduction target of the 2030 CTP.

Policy Option C1:

- **Supply-side obligation:** Fuel suppliers are obliged to supply all jet fuel in EU airports blended with a minimum SAF share. The obligation will foresee the, gradually increasing over time, level of SAF suppliers should include in the fuel mix they deliver to air transport providers. An additional sub-mandate will be targeting the supply of green synthetic fuels. The share of SAF prescribed by the mandate is presented in Table 13.
    - **Intra- and extra-EEA**: The obligation will concern all fuel supplied to EEA airports. Exemptions may be established for remote, insular and airports with

low traffic levels. The exemptions should be of scale that would not jeopardise the overall effectiveness of the initiative in meeting the targeted GHG emissions reduction.

- **Volume-based**: The obligation for fuel suppliers will be measured in the amount of SAF volumes introduced in their fuel mix.
- **Every drop blended**: After the expiration of the transition period (see below),SAF will be required to be blended in a uniform way across all EU airports so that all fuel uplifted from EU airports will contain the same minimum level of SAF
- **Transition period:**
    - Over the **first 5 years** (2025-2029) of the mandate application, suppliers can meet their obligation flexibly across their operations with no need to supply a minimum amount of SAF in every airport
    - In the **next 5 years** (2030-2034), suppliers can still meet their obligation flexibly across their operations however they will need to supply a minimum amount of SAF in every airport. The minimum SAF supply is defined at 2% for overall SAF content, of which at least 0.3% would come from green synthetic fuels.
    - A SAF certificate **trading system** for fuel suppliers will be set up and operated temporarily during the transition period to enable fuel suppliers to trade certificates to demonstrate meeting their obligation. This will also allow airlines to purchase SAF where not physically available at their destination airports.
- **Fuel uplifting obligation:** Air transport service providers will be obliged, when departing from an EEA airport, to uplift the amount of fuel they need for their next flight.

Policy Option C2:

- Same as Policy Option C1 with difference regarding the chosen mandate measurement approach.
- **GHG reduction-based**: The obligation for fuel suppliers will be measured in the amount of GHG emissions reduction achieved. Synthetic fuels production will be further incentivised via the use of a multiplier in the calculation of the achieved GHG reductions. The same logic applies here as in Policy Option A2.

As seen in Table 14, all Policy Options will put forward recommendations for funding R&D activities for novel SAF technologies, support for SAF production capacity deployment and further market mechanisms that can potentially support the uptake of SAF and provide long-term investment security

Table 14: Policy Option packaging

No	Policy measure	Policy Options					
		PO A – Supply side obligation		PO C – Demand side obligation		PO C – Supply & demand obligation	
		PO A1 – volume	PO A2 - GHG	PO B1 – all flights	PO B2 – intra-EEA flights	PO C1 – all flights	PO C2 – intra-EEA flights
1.	SAF supply mandate	X	X			X	X
2.1	Demand mandate – all flights			X			
2.2	Demand mandate – intra-EEA flights				X		

No	Policy measure	Policy Options					
2.3	Fuel uplifting obligation					X	X
3.	RFNBO sub-mandate	X		X	X	X	
4.	RFNBO multiplier		X				X
5.	SAF certificates trading system			X	X	(X)	(X)
6.	Funding SAF R&D	X	X	X	X	X	X
7.	Funding in support of SAF production deployment	X	X	X	X	X	X
8.	Technical facilitation for SAF approval	X	X	X	X	X	X
9.	Monitoring mechanism	X	X	X	X	X	X

6. Analysis of impacts of Policy Options

This section presents the impacts as assessed for each Policy Option is expected to achieve in comparison with the Baseline scenario. The impacts presentation that follows addresses first the modelling results regarding expected SAF production and deployment across the different Policy Options. Detailed modelling results are presented in Annex 5. Then the presentation of impacts is structured along the lines of economic, social and environmental impact categories.

a. Model results on SAF production and deployment for the Policy Options

SAF production costs

The current costs of SAF production based on literature review[73], and the trajectory of biokerosene and synthetic kerosene price are calculated over time and used in the modelling framework for each Policy Option as presented in Figure 13 SAF price in the Policy Options in a high bioenergy demand context and Figure 14. The trajectory of biokerosene prices per pathway is estimated by the PRIMES Biomass supply model. The cost includes capital investments, fixed costs and variable costs (feedstock, energy, and other) and the price is formed including a profit margin[74]. In these figures, the projected prices of the different SAF types are presented only for the years in the modelling in which the respective fuels are expected to be commercially available (compared to pilot or small scale applications), as in the model logic prices derive from the equilibrium of demand and supply. The two scenarios presented (high and low bioenergy demand) correspond to the two broadly levels of SAF demand derived according to the requirements of the Policy Options. In specific, the high bioenergy demand scenario addresses the expected SAF demand in Policy Options A1, A2, B1, C1 and C2 where the obligation for using SAF/reducing GHG emissions is applied to all aviation fuel used. In contrast, the low bioenergy demand scenario corresponds to the situation developed under Policy Option B2, where the obligation is only addressing fuel used in intra-EEA flights.

With the exception of biokerosene produced via the HEFA route, the current cost estimates for biokerosene produced via Gasification and Fischer-Tropsch (FT), and ATJ are uncertain as these are not yet commercially available. The broad ranges of current costs presented in Figure 13 SAF price in the Policy Options in a high bioenergy demand context and Figure 14 reflect this uncertainty. The analysis presupposes the improvement and implementation of measures across various actors that enables the uptake of advanced technologies at scale that are not yet commercially available. The climate and policy context of the analysis considers the EU GHG emission reduction target for 2030 and also the long-term climate neutrality objective. These imply structural changes in all sectors of the economy and their

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[73] Including (ICCT, 2019), (World Economic Forum, 2020) and nth plant estimates in de Jong (2015) are assumed as current costs. A range is estimated based on the prices reported in these sources. Note that the range of current costs is also a result of different assumptions on feedstock costs.

[74] Biokerosene prices are presented for a high bioenergy and a low bioenergy demand scenario in order to capture the increase in feedstock price driven by the increase in feedstock consumption which results from increase in bioenergy demand from aviation but also the energy sector and other transport sectors. Prices for synthetic kerosene are the same in these scenarios. For a more detailed description see Annex 1.

successful coordination. Coordinated decisions presuppose implementation of measures by numerous actors, including energy consumers, energy producers and distributors, infrastructure investors and regulators and technology developers. For the biomass system, the above are reflected in the form of large-scale improvements in advanced biofuel production, also supported by biomass related innovation and agriculture policies, initially targeting the supply of biofuels in the aviation and other sectors by 2030. Given this context, the policy content of this exercise (i.e. blending mandates) is considered as the strongest signal (compared to other policy actions such as pricing, incentives, etc.) to the related market actors (e.g. as regards regulatory certainty to fuel suppliers about the demand for SAF in the aviation sector for 2030 and beyond) and can justify an accelerated technological progress which helps to reduce SAF prices by 2030 relative to the current levels reported in the recent literature.

Literature notes that the potential for the reduction in production costs is driven by operational expenditure and technology capital costs, depending on the technology (World Economic Forum, 2020). The analysis of the costs of plants for fully commercialised technologies (Nth plant analysis) also expects capital investments and related costs (e.g. maintenance) to be a driver of cost reduction compared to pioneer plants. The present analysis shows that, depending on the pathway, the reduction of biokerosene price ranges between 12% and 35% in 2030 compared to the average of current costs (including a profit margin to the costs found in literature). The reduction may be even higher if projected prices are compared with the upper end of current cost range. Hence, it can be asserted that the regulatory context of blending mandates in the aviation sector by 2030 can help decrease the more expensive costs of SAF (as found in the literature). The gap of the SAF prices against fossil-based kerosene is projected to still remain throughout the projection period for reasons which are explained below. A contribution from other policy instruments (e.g. ETS, taxation) will be required to help further reduce the aforementioned gap and this is described in the following sections.

The trajectory between 2030 and 2050 shows a relatively stable biokerosene price produced by the Gasification and FT, and the ATJ route at around € 2,000 per tonne. This relatively stable trend, close to the level of biokerosene price in 2030, is supported by literature (see Figure 8). Regarding the short term developments, such reductions are evident when comparing the SAF prices against the theoretical current prices. The results of the present analysis show that the uptake of SAF contributes to the reduction of scalable components such as capital and variable costs. Such reduction is expected to take place in particular in the short term (until 2025/2030) and in the medium/long term (2030-2040). Such cost reduction drivers are also expected by literature. In the present analysis, this is particularly noticeable in the capital and variable costs reduction of the ATJ route by 9% and 5%, respectively, between 2025 and 2035, and in the reduction of capital and variable costs of the Gasification and FT route between 2035 and 2040, that reaches 30% and 5%, respectively (see Figure 13 and Figure 14). The reduction on capital costs occurs earlier in time in the ATJ route, due to the maturity of this technology, particularly for the conversion of lignocellulose to ethanol step, compared to, for example, other advanced pathways such as the Gasification and FT route; this explains why ATJ emerges in 2025, while Gasification and FT only emerges in 2035. As such, scaling up biokerosene demand favours cost and price reduction through technological learning and economies of scale.

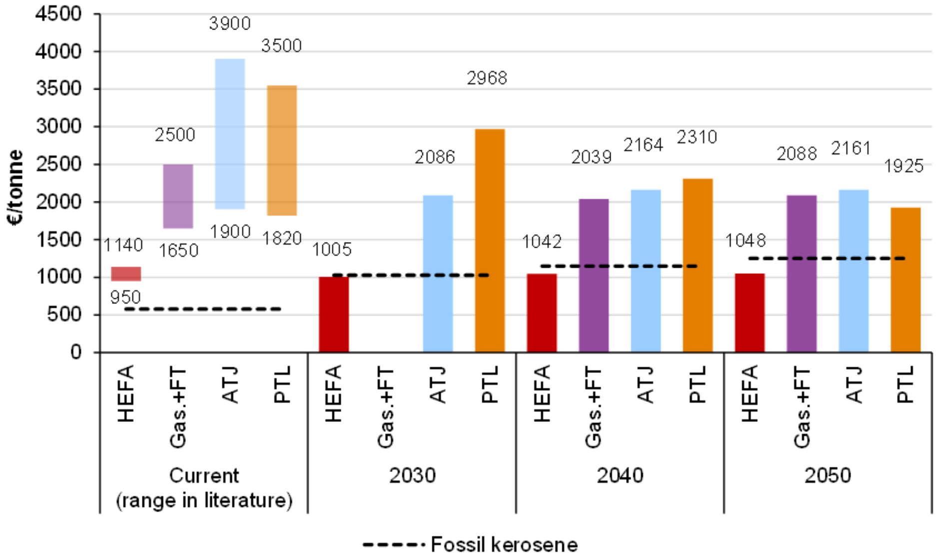
On the other hand, the decrease of biokerosene price due to lower capital and variable costs (compared to current levels), is counterbalanced by the increase of feedstock costs that are driven by the demand of biomass for biokerosene but primarily also for the demand for bioenergy from other sectors. Increase in bioenergy demand stimulates additional supply, moderating to some extent the price increase of biomass feedstock. We note that the policy context of the scenarios is established within the Climate Target Plan ambition, which means that significant quantities of bioenergy are demanded by other transport (including international maritime) and energy sectors. This entails that the biomass system is pushed towards more expensive feedstocks. This may contrast other sources from literature that focus only on the developments in a specific sector and neglect the impacts with the rest of the energy and transport system or the overall climate ambition effort. Nonetheless, literature notes the wide range of biokerosene costs driven by feedstock; WEF remarks that the choice of feedstock can change the production cost of SAF via the ATJ route by 45-70%, and via the Gasification and FT route by 20-30%. In addition, the biokerosene price trajectory in Figure 13 and Figure 14, includes a profit margin of about 10% in addition to production costs that are typically reported in literature. Under these considerations, the price estimates of the present analysis are considered to be in line with literature.

Biokerosene production from the HEFA route has the lowest costs across all other sustainable aviation fuels over the time horizon. Its price is around €1,000 /tonne across the time horizon. This is a mature technology/pathway commercially available today that has benefited from cost reduction due to the surge of demand for HVO biodiesel used in road transport. However, the HEFA route can only contribute to a small part of the overall energy needs of the aviation sector as it depends on feedstock with relatively limited potential (i.e. Annex IX part B). The price of biokerosene produced from the ATJ is between €2,100 and €2,150 per tonne in 2030-2050, and from the FT route between €2,050 and €2,100 per tonne in 2035-2050. In contrast to the HEFA production pathways, the production technologies of advanced biokerosene from ATJ and/or Gasification & Fischer Tropsch routes are not yet available at scale and require investments on first-of-a-kind plants and their scale-up to benefit from learning effects and as a result lower costs. Production cost ranges found in literature reflect this uncertainty for advanced biofuels while showing more certainty for Part B biofuels (i.e. a narrower margin on the prices; see e.g. Figure 13), and in addition show the cost difference between the two categories of biofuels. Besides capital costs, looking into other cost components provides additional insights in the differences between Part B and advanced biofuels. Firstly, the use of expensive enzymes or catalysts increase the variable costs of advanced biofuel production relative to the Part B pathway. As a result, in absolute terms, the variable cost of Part B production is significantly lower than that of advanced biofuels (see also Figure 15 in the report that presents a sensitivity analysis on variable costs for the advanced biofuel routes). Secondly, advanced biofuels require substantially more quantities of biomass feedstock input compared to Part B biofuels produced from used cooking oil. This leads to overall higher feedstock costs of advanced biofuels compared to Part B.

The converging trend of biokerosene prices from these two routes is also in line with literature (WEF 2020; Figure 8). The slight price increase that is projected post 2030 in the present analysis, results from the surge in biokerosene demand, that requires increasing quantities of feedstock, as explained above. In addition, in the period 2040-2050, there is a partial shift from lower cost feedstocks (e.g. agricultural residues) used by biokerosene production pathways to higher cost feedstocks (e.g. annual energy crops), as the former are used to satisfy increasing bioenergy demand in other sectors.

The gradual price increase of fossil kerosene, that is in line with the development of international oil prices, and the reduction of biokerosene price compared to current levels lead to a reduction of the price gap between the fossil kerosene and biokerosene over time. The price difference of fossil kerosene with the other two biokerosene routes reduces from about 60% currently, to about 40% in the years leading to 2050.

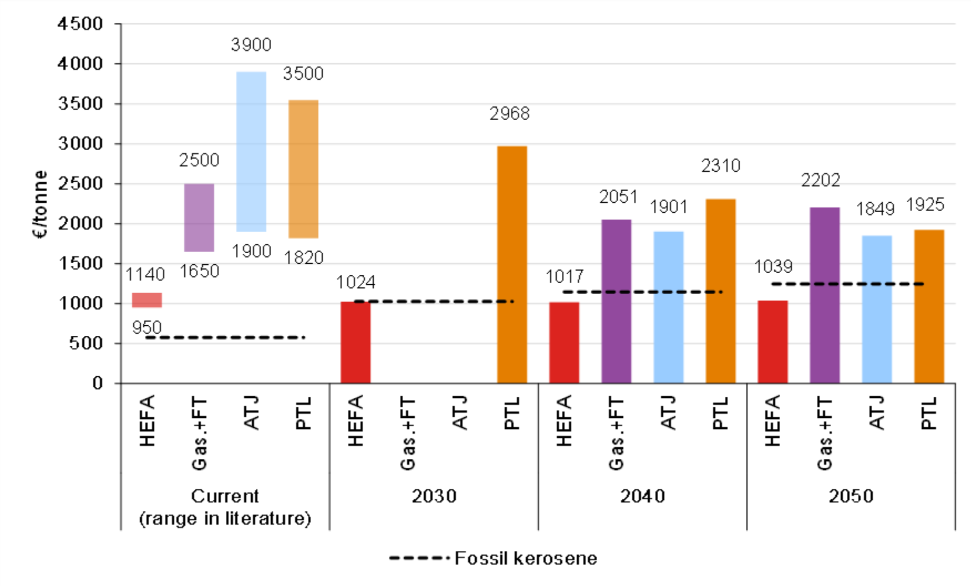
Figure 13 SAF price in the Policy Options in a high bioenergy demand context [75]



Note: Current cost range based on literature review and do not include a profit margin. The projected SAF prices for 2030-2050 also include a profit margin. Source: PRIMES Biomass and PRIMES-TREMOVE

[75] applicable to Policy Options A1, A2, B1, C1 and C2

Figure 14 SAF price in the Policy Options in a low bioenergy demand context[76]

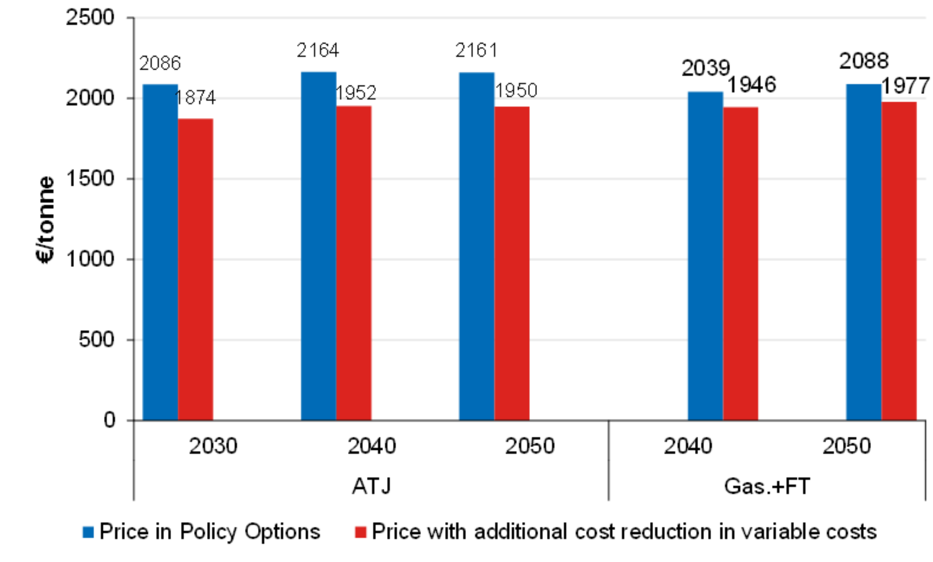


Note: Current cost range based on literature review and do not include a profit margin. The projected SAF prices for 2030-2050 also include a profit margin. Source: PRIMES Biomass and PRIMES-TREMOVE

The contribution of variable costs in the cost of biokerosene such as those of energy, catalysts, enzymes, other utilities and waste management is between 35% and 47% depending on the year and the technology (see section 6b). Such contribution levels are in line with literature (Baker et al., 2017; de Jong 2015, IRENA 2016, WEF2020). Additional reduction may be achieved due to technology developments or economies of scale reducing further variable costs than what estimated in the present analysis. To assess the sensitivity of the price of biokerosene, we use the reduction trajectory denoted by WEF (2020) on variable costs: by 2050, variable costs in WEF decrease by 30% in the ATJ process and by 14% in Gasification and Fischer-Tropsch, relative to 2020. Based on these trajectories, we estimate the effect on the biokerosene price, as shown in Figure 15. The price trajectories on biokerosene presented in Figure 13 are lower by about 10% for ATJ and by about 5% for Gasification and FT, and the price of biokerosene is less than €2,000/tonne, across the time horizon. It should be noted that the reduction indicated in WEF occurs primarily early in the time horizon (by around 2030), and thereafter a slower improvement rate is shown. This is similar with the findings of the present analysis, that shows a drop of current theoretical costs by 2030, and a rather constant price trajectory thereafter.

[76] applicable to Policy Option B2

Figure 15 Sensitivity of biokerosene price on variable costs



Note: Own calculations based on input from PRIMES-Biomass and literature review

The price of synthetic kerosene is broadly in line with the relevant literature and estimations from the PRIMES energy systems model on scenarios reaching the 55% GHG emission reduction in 2030 and carbon neutrality in 2050. Synthetic kerosene is produced from hydrogen which is based on renewable electricity. The price of synthetic kerosene in 2030 is about 40% more expensive than the ATJ biokerosene price. Modelling results using the PRIMES-Biomass model shows that the price of synthetic kerosene converges to the price of biokerosene towards 2050. Similar to advanced biokerosene routes, the demand for synthetic kerosene drives an increase in hydrogen demand and eventually to large-scale deployment of hydrogen generation technologies. The modelling considers learning-by-doing effects, reducing the costs of electrolysers, which is a critical cost component. The reduction in the synthetic fuel price is mainly driven by a reduction in the costs of electrolysers needed for the production of hydrogen.

SAF participation in the jet fuel mix

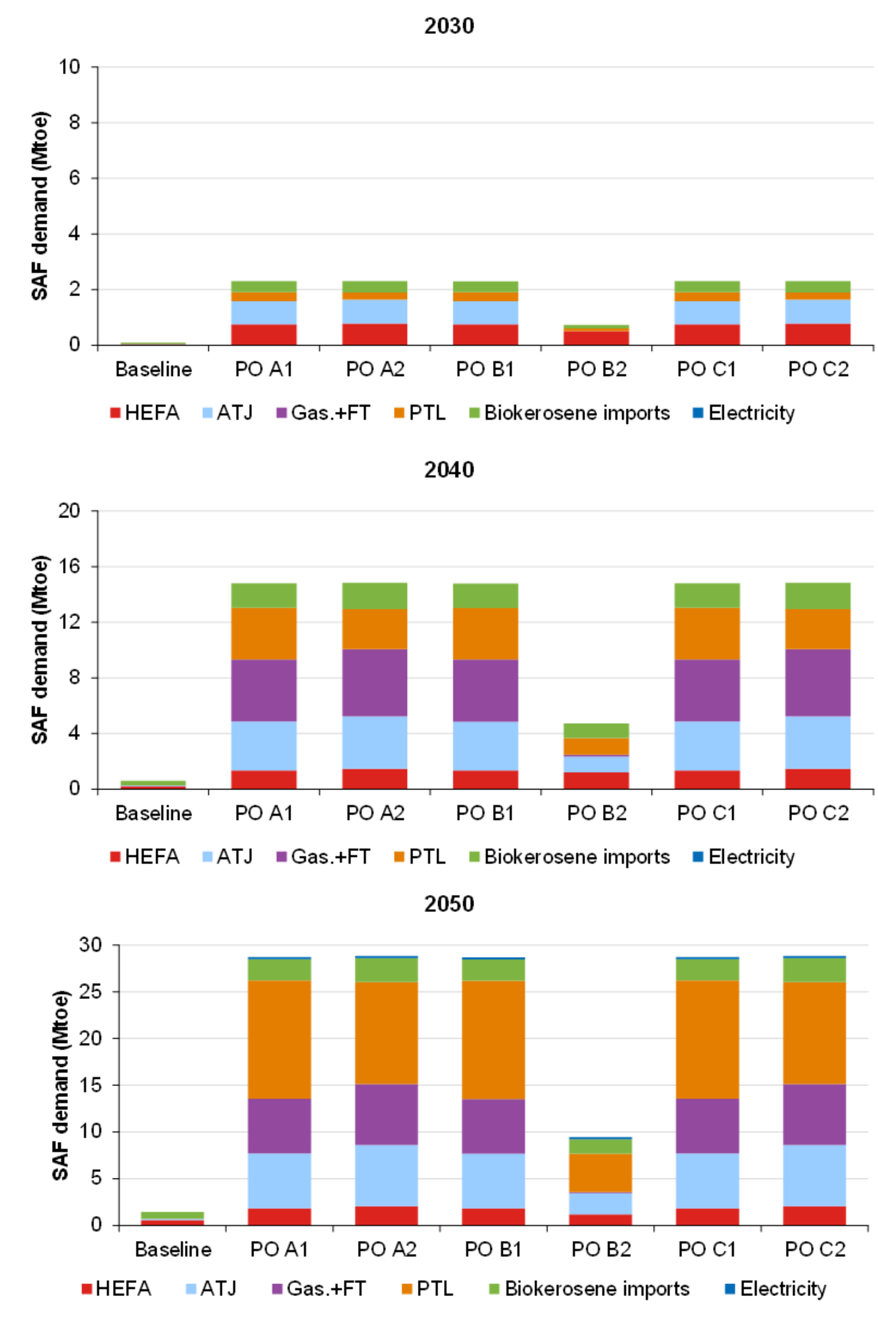
This section presents the expected fuel mix used in the aviation sector in the various policy scenarios. The section also presents the various types of biokerosene which are expected to be utilised in each policy scenario as a result of the modelling. The demand for jet fuel in the EU, is presented per production pathway in the Baseline and the Policy Options for 2030, 2040 and 2050 (Figure 16). The fuel shares per pathway are presented for 2030, 2040 and 2050 in Table 15.

In 2030, the demand for SAF is around 2.3 Mtoe in all Policy Options except from Policy Option B2 in which 0.7 Mtoe of SAF is consumed, as the blending mandate is applied only to intra-EU flights. Biokerosene is the main SAF deployed due to the higher blending mandates and the lower production costs. Its share in the jet fuel blend is around 4.3%; the HEFA route supplies 1.6-1.7%, the ATJ route supplies 1.8-1.9%, and imports account for 0.9% in all Policy Options, apart from Policy Option B2, where shares are lower. PtL blends range between 0.5% and 0.7%.

In 2040, SAF blends are expected to increase to 32%; biokerosene produced by the Gasification and FT route supplies the highest share (around 10%), followed by ATJ (around 8%) and PTL (between 6% and 8% depending on the scenario). Biokerosene imports and domestic production from the HEFA route account for the remainder of the supply, in roughly equal shares. Notably, the Gasification and FT route emerges in 2035. While the production costs of ATJ and Gasification and FT are rather similar, the earlier deployment of the ATJ route is due to its technology maturity and availability that is enabled earlier in time by developments in ethanol production from lignocellulosic feedstocks, as opposed to biomass gasification and conversion of syngas to fuels.

By 2050, with increasing SAF demand due to the ramp up of the blending mandates and technological development, biokerosene demand increases to between 16-18 Mtoe, three-quarters of which are produced in the EU. The ATJ and the FT routes supply equal volumes of SAF; each pathway supplies between 13% and 14% of the total jet fuel demand. About 4-5% is produced by the HEFA pathway, and the remainder of biokerosene is imported (or roughly 5-6% of jet fuel demand). Consumption of synthetic kerosene reaches 11-13 Mtoe in all scenarios (except for Policy Option B2) and accounts for 24% to 28% of jet fuel consumption. The ranges depend on whether the mandate of biokerosene and synthetic kerosene is prescribed or determined on the basis of GHG emission intensity of the jet fuel blend. The lower biokerosene demand in Policy Option B2 is found not to be enough to trigger a significant uptake of ATJ and the Gasification and FT pathways; modelling results indicate a persistence in the use of HEFA and imported biokerosene.

Figure 16 SAF demand per production pathway in the Baseline and the Policy Options in 2030, 2040 and 2050 in the EU27



Source: PRIMES-TREMOVE and PRIMES Biomass

Table 15 Jet fuel blends in the Baseline and the Policy Options in the EU27

Air transport energy mix (in %)	Baseline			PO A1			PO A2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Air transport energy use	100%	100%	100%	100%	100%	100%	100%	100%	100%
Kerosene	99.8%	98.8%	97.1%	95.0%	68.0%	36.8%	95.0%	68.0%	36.8%
Biokerosene	0.2%	1.2%	2.9%	4.3%	24.0%	34.8%	4.5%	25.8%	38.7%
HVO/HEFA	0.1%	0.4%	1.2%	1.6%	2.9%	4.0%	1.7%	3.1%	4.5%
Gasification and Fischer Tropsch	0.0%	0.0%	0.0%	0.0%	9.7%	12.9%	0.0%	10.4%	14.4%
Alcohol to Jet	0.0%	0.1%	0.3%	1.8%	7.6%	12.9%	1.9%	8.2%	14.3%
Imports biokerosene	0.1%	0.7%	1.5%	0.9%	3.8%	5.0%	0.9%	4.1%	5.6%
Synthetic fuels	0.0%	0.0%	0.0%	0.7%	8.0%	27.9%	0.5%	6.2%	23.9%
Electricity	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.5%
Air transport energy mix (in %)	**Baseline**			**PO B1**			**PO B2**		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Air transport energy use	100%	100%	100%	100%	100%	100%	100%	100%	100%
Kerosene	99.8%	98.8%	97.1%	95.0%	68.0%	36.8%	98.4%	89.9%	79.9%
Biokerosene	0.2%	1.2%	2.9%	4.3%	24.0%	34.8%	1.4%	7.6%	10.9%
HVO/HEFA	0.1%	0.4%	1.2%	1.6%	2.9%	4.0%	1.1%	2.6%	2.5%
Gasification and Fischer Tropsch	0.0%	0.0%	0.0%	0.0%	9.7%	12.9%	0.0%	0.3%	0.3%
Alcohol to Jet	0.0%	0.1%	0.3%	1.8%	7.6%	12.9%	0.0%	2.4%	4.8%
Imports biokerosene	0.1%	0.7%	1.5%	0.9%	3.8%	5.0%	0.3%	2.3%	3.3%
Synthetic fuels	0.0%	0.0%	0.0%	0.7%	8.0%	27.9%	0.2%	2.5%	8.7%
Electricity	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.5%
Air transport energy mix (in %)	**Baseline**			**PO C1**			**PO C2**		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Air transport energy use	100%	100%	100%	100%	100%	100%	100%	100%	100%
Kerosene	99.8%	98.8%	97.1%	95.0%	68.0%	36.8%	95.0%	68.0%	36.8%
Biokerosene	0.2%	1.2%	2.9%	4.3%	24.0%	34.8%	4.5%	25.8%	38.7%
HVO/HEFA	0.1%	0.4%	1.2%	1.6%	2.9%	4.0%	1.7%	3.1%	4.5%
Gasification and Fischer Tropsch	0.0%	0.0%	0.0%	0.0%	9.7%	12.9%	0.0%	10.4%	14.4%
Alcohol to Jet	0.0%	0.1%	0.3%	1.8%	7.6%	12.9%	1.9%	8.2%	14.3%
Imports biokerosene	0.1%	0.7%	1.5%	0.9%	3.8%	5.0%	0.9%	4.1%	5.6%
Synthetic fuels	0.0%	0.0%	0.0%	0.7%	8.0%	27.9%	0.6%	6.2%	23.9%
Electricity	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.5%

Source: PRIMES-TREMOVE

Cost of average jet fuel mix

Accounting for the prices and participation of the respective SAF types in the fuel mix, the following table estimates the average price of the aviation fuel mix for 2030, 2040 and 2050.

Table 16 Average jet fuel blend prices in the Baseline and the Policy Options in the EU27 in 2030

	2030 (€/toe)	Increase on baseline	2040 (€/toe)	Increase on baseline	2050 (€/toe)	Increase on baseline
Baseline	1051		1172		1274	
Policy Option A1	1086	3.3%	1433	22.2%	1690	32.7%
Policy Option A2	1084	3.1%	1423	21.5%	1688	32.5%
Policy Option B1	1086	3.3%	1433	22.2%	1690	32.7%
Policy Option B2	1057	0.5%	1222	4.2%	1362	6.9%
Policy Option C1	1086	3.3%	1433	22.3%	1690	32.7%
Policy Option C2	1084	3.1%	1424	21.5%	1688	32.5%

Source: PRIMES-TREMOVE

In all Policy Options the average jet fuel price increases as a result of the participation of more expensive fuels in the mix. Policy Options A1, A2, B1, C1 and C2, which foresee a similar and significant participation of SAF in the average fuel mix, result in minor differentiations mainly caused by the different composition of biofuel and synthetic fuels resulting from the use of volume and GHG target setting. On the contrary, Policy Option B2 which foresees lower SAF participation results in a lower overall price.

Feedstock requirements for biofuels

The volume of biomass feedstock used for biokerosene production in the Baseline and the Policy Option scenarios in the EU in 2030 and 2050 is presented in Table 17. Solid biomass includes feedstocks such as agricultural and forestry residues, wood waste, forestry products (e.g. harvested wood), annual and perennial energy crops. Average prices of biomass feedstocks are presented in the next sections. The consumption of solid biomass feedstock increases by about a factor 10 between 2030 and 2050, although starting from a low base, driven by the increase of biokerosene demand which is met by production from the ATJ and the Gasification and FT routes. Notably, the increase of solid biomass feedstock in Policy Option B2 is smaller, as in this scenario the demand for biokerosene is met by increasing imports and HEFA jet fuel.

Table 17 Biomass feedstock consumption for biokerosene production in the Baseline and the Policy Options in the EU27 in 2030 and 2050

Mtonnes	2030		2050	
	UCO	Solid biomass	UCO	Solid biomass
Baseline	0.05	0.02	0.69	0.43
Policy Option A1	1.10	5.52	2.8	62.5
Policy Option A2	1.14	5.72	3.1	69.8
Policy Option B1	1.10	5.52	2.8	62.4
Policy Option B2	0.59	0.00	1.4	7.6
Policy Option C1	1.10	5.53	2.8	62.5
Policy Option C2	1.14	5.72	3.1	69.8

Source: PRIMES-Biomass

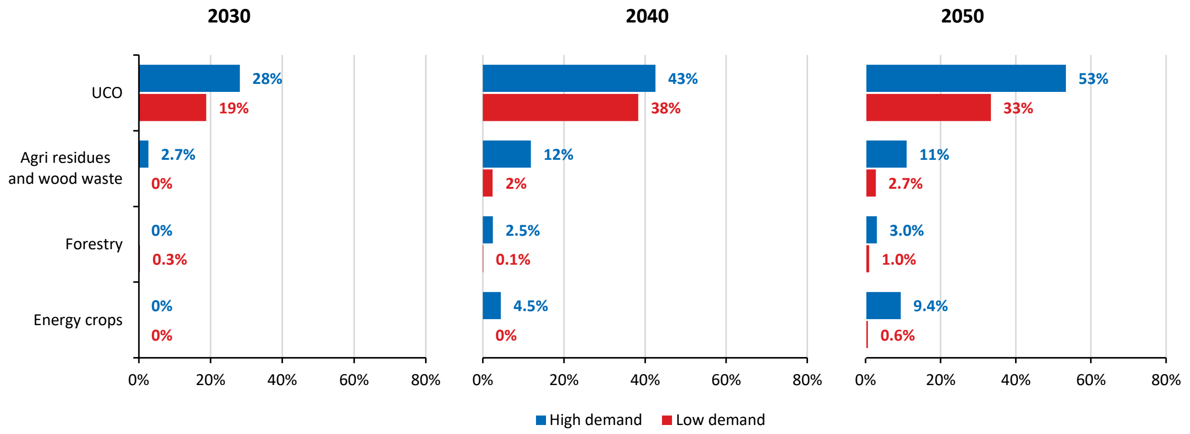
In order to assess the sufficiency of biomass availability in the EU and technological availability (biomass conversion pathways) to meet a certain demand for bioenergy we use the PRIMES Biomass supply model. As such, the assessment of the bioenergy supply system of the Policy Options is developed within a context of climate neutrality with high bioenergy demand from all sectors of the energy system (incl. other transport sectors and the rest of the energy system, drawing results from the entire PRIMES modelling suite) in the transition to zero emissions by 2050 (i.e. the MIX scenario of CTP). The results show that the total demand for bioenergy increases by roughly 82% between 2015 and 2050 (from about 140 Mtoe to 255 Mtoe). This projected increase of bioenergy is primarily due to demand coming from sectors other than aviation.

On the supply side, the results show that there is abundance of domestically available biomass to meet the demand increase; biokerosene production in the EU requires less than 10% of all biomass feedstock used to meet bioenergy demand in a climate neutral context by 2050. More specifically, in 2030, in the high bioenergy demand context (relevant for Policy Options A1, A2, B1, C1 and C2), HEFA, as one of the main pathways producing biokerosene, is a key consumer of UCO requiring less than one-third of total available potential in the EU (see Figure 17). The majority of the additional feedstock required for SAF production is expected to be derived from projected moderate feedstock collection increases. The majority of collectable UCO is expected to still be consumed in other transport segments such as road transport and maritime that will see some minor restrictions in feedstock availability compared to the current situation which can be potentially overcome by feedstock imports. The context in which the demand for biokerosene is comparably lower (relevant for Policy Option B2), shows that the HEFA route requires about one-fifth of the UCO potential in the EU in 2030. The deployment of the ATJ route in 2030, leads to the consumption mainly of agricultural residues, and about 3% of the available potential in the EU is used for biokerosene production.

Towards 2050, the increase of biokerosene demand and the significant ramp up of other advanced biokerosene production technologies lead to an increase in the volumes of lignocellulosic feedstocks and of the share of the available potential in the EU used for biokerosene. These feedstocks are primarily agricultural residues, wood waste, and new energy crops. In the high biokerosene demand context, the ATJ and the Gasification and FT routes consume 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. The gradual increase of production from the HEFA route in the high biokerosene demand context, leads to an increase in the use of UCO for biokerosene. In 2050, biokerosene consumes around half of the total available potential of UCO in the EU, compared to about 28% that it requires in 2030. The majority of the additional feedstock required is expected to come from feedstock collection increase. The other half of the domestically collected feedstock will be available to other transport segments marking a certain restriction in their overall availability in the long-term that may need to be tackled with feedstock imports. Nonetheless, looking into total feedstock volumes, UCO represents about 4% of the total feedstock consumed in aviation in 2050 (Table 17).

In the low biokerosene demand context, the production from the HEFA chain also increases post-2030 and so does its consumption share of UCO that is available in the EU. From about 20% in 2030, the HEFA route consumes 33% of the EU's UCO potential in 2050. There is also an increase of lignocellulosic feedstock consumption, yet at less than 3% of the available lignocellulosic feedstocks for bioenergy in the EU in 2050.

Figure 17 Share of the available biomass feedstock in the EU used for biokerosene production in the high and low bioenergy demand context



Note: The high bioenergy demand context is relevant for PO A1, A2, B1, C1 and PO C2, and the low bioenergy demand context is relevant for PO B2). Source: PRIMES Biomass

In the production of biofuels, biomass feedstock requires most of the energy demand to produce bioenergy commodities. In addition, bioenergy production requires energy inputs in several steps in the production process, from biomass cultivation or collection, to transport, and conversion of biomass to bioenergy. PRIMES Biomass takes the energy requirements across the production chain into account. Based on PRIMES Biomass, the production of all bioenergy commodities projected in the context of climate neutrality, requires about 36 Mtoe of electricity, liquid fuels and gas in 2050. This corresponds to less than 3% of the overall energy supply (of electricity, liquid fuel and gas) for the same year; the respective share of energy inputs for biokerosene production is less than 0.2% of the energy supply in 2050.

Electricity demand for synthetic fuels

The production of synthetic fuels drives an increase in the demand for renewable electricity, which is used to produced hydrogen as an intermediate product, before the production of synthetic kerosene. The electricity required to produce synthetic kerosene for each policy scenario is presented in Table 18. The electricity needs are lowest in Policy Option B2 which, by design, only applies SAF mandates on intra-EU aviation.

Table 18 Renewable electricity consumption for synthetic kerosene production (TWh)

	2030	2050
Policy Option A1	7.1	267.6
Policy Option A2	5.5	230.7
Policy Option B1	7.1	267.3
Policy Option B2	2.2	86.4
Policy Option C1	7.1	267.3
Policy Option C2	5.6	230.4

Source: Own calculations using input from PRIMES-TREMOVE and PRIMES energy model

The electricity demand for synthetic kerosene production represents between 0.04% to 0.13% of gross electricity generation or between 0.1% and 0.4% of renewable electricity generation in the EU in 2030. The shares increase to between 0.7% and 2.2% of gross and 1.8% and 5.5% of renewable electricity generation in the EU in 2050 (Table 19, Table 20). The relative shares are built on the MIX scenario of the CTP IA which was quantified with the PRIMES energy systems model.

Table 19 Share of gross electricity generation used for the production of synthetic kerosene

	2030	2050
Policy Option A1	0.13%	2.2%
Policy Option A2	0.10%	1.9%
Policy Option B1	0.13%	2.2%
Policy Option B2	0.04%	0.7%
Policy Option C1	0.13%	2.2%
Policy Option C2	0.10%	1.9%

Source: Own calculations using input from PRIMES-TREMOVE and PRIMES energy model

Table 20 Share of renewable electricity generation used for the production of synthetic kerosene

	2030	2050
Policy Option A1	0.4%	5.5%
Policy Option A2	0.3%	4.7%
Policy Option B1	0.4%	5.5%
Policy Option B2	0.1%	1.8%
Policy Option C1	0.4%	5.5%
Policy Option C2	0.3%	4.7%

Source: Own calculations using input from PRIMES-TREMOVE and PRIMES energy model

b. Analysis of economic impacts

This section presents the expected impacts in the following categories:

- Cost for businesses (cost of fuel, cost of additional fuel logistics and administrative costs);
- Cost for authorities (enforcement and administrative costs);
- SAF cost structure;
- Investment costs (for deploying SAF production capacity);
- Energy dependence of the EU;
- Functioning of the internal market (fuel price differences and tankering potential);
- Innovation
- Industry and sectoral competitiveness (aviation and fuel industry);
- Regional competitiveness

Costs for businesses

The cost for businesses comprises of the costs needed to comply with the provisions of the initiative. These include the additional cost fuel suppliers will need to incur to purchase SAF-blended fuel and the additional cost of fuel logistics as a result of the underdeveloped SAF supply chain induced due to the mandate on SAF content. Finally, also the administrative costs generated for the obliged bodies (either suppliers or air transport service providers) in order to report on their obligations.

Cost of fuel

As a result of including increased volumes of SAF content in the fuel mix (see Table 15) and the estimated prices for the respective SAF production pathways (see Figure 13 and Figure 14 earlier) an updated total fuel cost is calculated. The total costs for the fuel blend present only slight changes by 2030 as can be seen in

Table 21 as the price increase is not as steep while it is also counteracted by a small decrease in overall fuel consumption. The increase in fuel costs by 2050 amounts to between 39% and 44% in the Policy Options related to the high bioenergy use scenarios. The exception to the above is in Policy Option B2, in which the fuel cost development is actually slightly negative in 2030 and remains limited to a 5% increase by 2050. The relatively mild cost increase is due to the reduced scope of the initiative combined with the reduction of overall fuel consumption as intra-EEA flights are responsible for only approximately 1/3 of the total jet fuel consumption.

Table 21 Annual cost of SAF fuel blend (in € million)

	2030		2040		2050	
	Fuel cost	*Impact (%)*	*Fuel cost*	*Impact (%)*	*Fuel cost*	*Impact (%)*
Baseline	48.3		55.6		62.7	
Policy Option A1	49.0	1.4%	66.9	20.3%	90.1	43.7%
Policy Option A2	48.9	1.2%	65.4	17.6%	87.5	39.6%
Policy Option B1	49.0	1.4%	66.8	20.1%	90.0	43.5%
Policy Option B2	47.9	-0.8%	57.8	4.0%	65.9	5.1%
Policy Option C1	49.0	1.4%	66.9	20.3%	90.1	43.7%

Policy Option C2	48.9	1.2%	65.4	17.6%	87.5	39.6%

Source: PRIMES-TREMOVE and PRIMES Biomass model outputs

As seen in

Table 21, the Policy Options putting forward a GHG-reduction based obligation target (A2 and C2) appear to be more efficient in the mid-term and until 2045 in delivering their target with slightly reduced costs compared to the mandates in which the obligation is set on a SAF volume basis. This is because, in the absence of a synthetic fuel sub-mandate, the obliged bodies are free to choose between using biofuels or synthetic fuels as long as they turn in the required GHG-emissions reduction, in these Policy Options appropriate multipliers are introduced for the synthetic fuels to incentivise their uptake. The result is a more cost-efficient choice. Only in the long-term when PtL costs drop further do the volume-based Policy Options (A1, B1 and C1) gain a price advantage. The overall price advantage of the GHG-based options becomes more obvious when calculating the Present Value of fuel costs over the whole 2020-2050 period as seen in Table 22. Specifically, Policy Options A2 and C2 both result in an approximately 4% smaller overall impact on fuel costs which accounts to about € 2.5 billion of cost savings annually by 2050.

Table 22 Present value of fuel cost impacts 2020-2050 (in € billion)

Present Value	PO A1	PO A2	PO B1	PO B2	PO C1	PO C2
Impact on fuel cost	103.5	88.3	103.0	14.7	103.5	88.2

Source: PRIMES-TREMOVE and PRIMES Biomass model outputs

Fuel costs are taken up by fuel suppliers, who are expected to pass through these costs to airlines via an increase in jet fuel prices. In turn, they will pass them through to consumers via an increase in passenger ticket and air freight prices.

Cost of SAF logistics

SAF are certified as drop-in fuels. This means that they can directly use conventional jet fuel infrastructure. Due to the fact that airports can only accept already certified fuel, SAF cannot be delivered directly to airport facilities. This means that the integration of SAF in the fossil fuel supply chain is optimally taking place upstream, at oil refineries and large terminals. This integration requires the use of blending facilities that are usually available at these locations.

An estimated 500 - 2,000 fuel blending facilities (fuel blenders) have been identified in the EU (CE Delft, 2014) which are used, amongst other activities, also for the purpose of blending biofuel and conventional fuel. The blended fuel can then be delivered to airports via pipelines or other means with no additional cost compared to the usual jet fuel logistical costs as SAF will merely substitute the conventional fossil kerosene. It is unclear whether the current capacity of fuel blending capacity across the EU, which is also used for other fuel blending operations, is fully utilised and so whether it would suffice for the additional blending activities needed due to SAF. It could be however expected that in the early years of a mandate operation when SAF volumes remain relatively low, and especially under a flexible SAF allocation scenario (such as in Policy Options C1 and C2 for the transition period) there would be a lesser immediate need for investments in SAF blending facilities.

It is expected that the introduction of SAF would in principle incur no additional logistical costs since from the moment it enters the fuel supply chain at the blending facilities, the logistical costs would be the exact same as for the fossil fuel it displaces. Regardless, especially in the early years of mandate introduction, it is expected that SAF production sites will be rather limited at least compared to the current supply points of kerosene. Thus, fulfilling the horizontal SAF supply/usage obligation to supply all airports under the different Policy Options may lead to longer than usual fuel supply chains to serve the relatively small volumes of SAF need. This horizontal obligation applies to Policy Options A1 and A2, already from 2025 while also kicks in for Policy Options C1 and C2 in year 2030.[77] This would lead to additional transport costs related to delivering the needed SAF volumes to all airports that are not exempt from the obligations.

For PO B1, in which airlines are allowed to meet their obligation in a flexible way across their operations, we still estimate that SAF distribution across Member States will be fairly even (similar to Policy Options A1 and A2). Due to the fact that airlines based in each Member State will need to meet their obligation for all their flights (including domestic ones) it is expected that they would use the flexibility within their Member State of establishment to provide concentrated SAF volumes in their operational centres. This means that eventually sufficient SAF supply will need to be developed in each Member State and whereas minor variations cannot be excluded, a more or less evenly distributed across Member States seems like a safe assumption. Therefore, although Policy Options B1 and B2 provide additional flexibility compared to A1 and A2 within each Member State, this is not expected to affect the volume of cross-border logistics although it cannot be excluded that some transactional costs related to further distributing SAF within each country may occur.

Annex 1 describes the methodology used to estimate the volumes of fuel and the transport costs[78] of any needed cross-border deliveries as a proxy for assessing what part of SAF would need to be delivered further than the current fuel supply chains from refineries to airports.

The required distribution of SAF to Member States (as presented in Table 51 in Annex 1) is different from the economically more beneficial distribution presented in Table 40. In the latter, SAF would be used flexibly to fulfil SAF obligations of suppliers across the EU expecting the obligated parties to make the more economically beneficial choices. This means SAF production would be developed in locations that optimise the overall supply lines and their costs so as to supply either airports with large jet fuel demand, efficient fuel supply chains or those in proximity to SAF production (and feedstock) capacity. It is assumed thus that the flexibly allocated SAF usage, closely resembles the SAF production capacity deployment production.

By comparing the optimal and uniform allocation of SAF (as % of jet fuel mix) supply to different EU Member States under the different Policy Options, we can identify the additional logistical effort required to meet the mandate obligations. The calculation of the additional capacity assumes that countries presenting with a larger than obliged SAF usage in the optimal SAF allocation scenario, have a production surplus while countries that have a lower

78 Under the conservative assumption these are performed with trucks

usage have a SAF production deficit. Table 43 presents the estimated SAF surplus and deficit for different Member States. Additional logistical costs may also be introduced within each Member State. However, the working assumption is that within each country, SAF supply is expected to enter the conventional fuel supply chain with a reasonable level of logistic costs as more difficult to reach airports are exempt from the mandate obligation.

The total activity of SAF volumes transported cross-border is presented in Table 23 on an annual basis together with the total additional fuel logistics induced by these logistics. In this table the costs for each reference year are presented. Policy Options A1, A2 and B1 present nearly identical results. Policy Options C1 and C2 contain the transition period provision have no induced logistics for 2030 but start resembling the other high biogenic context policy options soon after the transition period. Finally, Policy Option B2 presents only a fraction of the total additional logistics activity of the other policy options as a result of the overall lower total volume of SAF used.

Table 23 Annual cross-border SAF transport volumes and related costs

Policy Option	2030		2040		2050	
	tonne.km (million)	*€ (million)*	*tonne.km (million)*	*€ (million)*	*tonne.km (million)*	*€ (million)*
Policy Option A1	395	14	740	26	1,099	38
Policy Option A2	394	14	741	26	1,108	38
Policy Option B1	395	14	739	26	1,103	38
Policy Option B2	125	4	236	8	357	12
Policy Option C1	-	-	740	26	1,099	38
Policy Option C2	-	-	741	26	1,108	38

Source: Own calculation based on PRIMES-Biomass model outputs

Similar to fuel costs, the cost of additional SAF logistics, is taken on by fuel suppliers and then passed through to air transport service providers before ending up further to impact consumers.

Administrative costs for businesses

Reporting for fuel suppliers

Under all POs, the reporting of fuel supply can be done via Union Database which is being developed as a requirement of the Renewable Energy Directive recast (Article 28). It should be ensured that the database takes into account the reporting needs as defined by the aviation mandate and is consistent with CORSIA MRV requirements for SAF. Therefore, it is assumed that no additional administrative burden will be caused for businesses via this initiative.

Reporting for air transport service providers

In the Policy Options that include a demand side mandate (Policy Options B1, B2), air transport service providers are the obliged body. They are in this respect required to report on their SAF uptake. For intra-EEA flights, the reporting stream established for the aviation ETS foresees the reporting of SAF uptake. Utilising this data stream means that no additional administrative burden will be required for reporting on this obligation. For extra-EEA flights under Policy Option B1, airlines will report SAF use to their administering state. For EU airlines, his information will be collected by EU States and could be made available with no additional administrative burden for air transport service providers. However, for non-EU airlines, this data will not be sent to EU authorities pursuant to CORSIA rules. It is therefore needed to request non-EU airlines to report directly SAF use to an EU agency (a new data stream will need to be established). This is not expected to incur significant additional costs as the data required are already available.

Additionally, for Policy Options C1 and C2, fuel users will need to report on the amount of fuel they have uplifted before each flight taking off from an EEA airport to showcase that they have uplifted the amount of fuel necessary for their upcoming trip (no more, no less – all safety and operation margins considered). This reporting could be done under the EU ETS reporting system for intra-EEA flights (via an adaptation of the reporting template) and via a new reporting stream for extra-EEA flights, where airlines report directly to an EU agency. It is expected that this reporting process should not take more than a couple of minutes per flight.

We assume a high estimate of 5' needed to report per flight and considering the EU hourly average transport wage (€18.4/hour). These amount to annual costs of a total of €16.8 million for the first year of the mandate application in 2025 and around € 24 million in 2050 for both Policy Options. The calculation of the number of flights considers as a base year the 10.56 million flights counted in 2019 and the projected recovery until 2025 by Eurocontrol. From 2025 onwards, the number of flights is considered to increase proportionally to the projected air transport activity as modelled by the PRIMES-TREMOVE model runs.[79]

Table 24 Annual administrative costs for air transport service providers (in € million)

Policy Option	2025	2050
Baseline	-	-
Policy Option A1	-	-
Policy Option A2	-	-
Policy Option B1	-	-
Policy Option B2	-	-
Policy Option C1	16.8	24.2
Policy Option C2	16.8	23.5

Source: Own calculation based on PRIMES-TREMOVE model outputs

Costs to authorities

SAF supply enforcement and verification at Member State and EU level

The costs to authorities for the options with a supplier mandate (A1, A2, C1 and C2) regard the cost of enforcing the mandate and the cost of monitoring via administering the information collection at an EU level and reporting on its implementation. Enforcing the mandate would be delegated to individual Member State authorities who would need to verify that suppliers meet their obligation on the individual fuel batches supplied by performing inspections to check compliance with the regulation. The FQD evaluation collected information from Member States regarding the costs of inspecting fuel suppliers and examining fuel samples, something that would need to be done by national accreditation bodies. The cost per Member State have been estimated in that respect to be between

[79] https://www.eurocontrol.int/publication/eurocontrol-five-year-forecast-2020-2024

€173,000 and €650,000. For the purposes of this assessment, a central value from this range (€411,500) is applied to all Member States as a conservative estimate. This leads to annual administrative costs of €11.1 million for the whole of the EU27.

The EU-level collection and reporting of the relevant information would be a task best assigned to a European organisation that would compile the information submitted in the Union Database into a reporting at a fuel supplier level. When asking stakeholders about the time they expect such a reporting would require, there has been limited reported experience. France has been the only Member State to estimate the effort they put in monitoring SAF supply to being around 0.5 FTE. A4A has also responded to collect and report on SAF usage by their member airlines. This they reported would not take more than a couple of days a year so we assume that the effort estimation provided by France would include also other relevant tasks. Since the data stream is expected to be digitalised, a level of effort similar to that reported by France (0.5 FTE) would seem reasonable to monitor, verify and report on the implementation for the supply mandate. The labour cost for this administrator category is calculated to be approximately €82,000 per year[80] leading to an overall estimation of administrative cost for the EU-level collection and reporting of information of €41,000 per year.

SAF demand enforcement and verification at Member State and EU level

When it comes to administering the demand side mandate (Policy Options B1, B2) and the obligatory reporting of SAF consumed (Policy Options C1 and C2), Member States would again be assigned to verify the reporting and enforce the compliance of air transport service providers with the mandate provisions. For Policy Options B1 and B2, this process would similarly to the supply side mandate, require competent authorities to perform inspections and take fuel samples to check compliance with the obligation. As the number of regulated entities would be larger than in the supply side mandate, a higher enforcement cost than what is estimated for the supply side mandate can be expected for Policy Option B1 that is involving both intra- and extra-EU. For this Policy Option the high cost estimate of the FQD evaluation is considered (€ 650,000 per Member State). For the Policy Option involving only intra-EU flights (B2), a lower estimated effort can be expected to inspect the smaller number of regulated airlines/flights and so the central value of the cost range is considered (€411,500 per Member State). While for Policy Options C1 and C2 where Member State enforcement limits to verifying the data reported, this activity can be expected to be less burdensome and be closer to the lower band of the administrative burden reported by the FQD evaluation (€173,000)

Monitoring the application of the regulation would be best performed at an EU level assigning the collection of this information to a European organisation to compile it at an airline level. According to the scope of each Policy Option, the activities assigned to this EU agency would vary. Specifically, under Policy Option B1, where the EU agency would be required to i) compile data for SAF usage submitted through the EU ETS for intra-EEA flights, ii) compile data for SAF usage submitted under CORSIA for extra-EEA flights of EU carriers, and iii)

[80] assuming the average labour costs in Belgium (€ 48.4/hour) for the category of professional, scientific and technical activities (lc_lci_lev)

compile date re reported by non-EU carriers related to extra-EEA flights. For the latter, the EU would need to build the digital infrastructure for non-EEA airlines to report on the SAF usage for extra-EE flights. Only the first point of the above is relevant for Policy Options B2, C1 and C2. Drawing a parallel to the effort estimated for combining reporting of data submitted via one database for the supply side mandate, Policy Options B2, C1 and C2 are expected to produce a similar administrative burden to that of POs A1 and A2 (€41,000 per year) while the combination of data from three different data streams can be expected to cause a proportionally higher effort under PO B1 (€123,000 per year)

Jet fuel uplift obligation

The verification of this obligation (under Policy Options C1 and C2) would, similar to the previous, better take place at an EU level by a relevant appointed agency. The verification of relevant information would as explained be submitted to this body for intra-EEA flights via the adapted ETS reporting structure and directly to the agency via a new reporting stream for extra-EEA flights. For verifying and compiling the information from the two data streams, and accounting for the fact that this will require reporting on a flight level, the administrative burden estimated for compiling and verifying the submitted data can be expected to be a bit more burdensome than what is expected for the demand side reporting obligation. Thus, we assume an administrative burden of about 1 FTE per year (€82,000 per year) for the EU body assigned with the task.

A summary of the administrative costs for authorities is provided in Table 27 while Table 26 provides the Present Value estimation of these costs (in 2015 constant prices)

Table 25 Annual administrative burden for authorities (in €)

Present Value	PO A1	PO A2	PO B1	PO B2	PO C1	PO C2
SAF supply Member State enforcement and verification – per Member State	€411,500	€411,500	-	-	€411,500	€411,500
SAF supply EU info compilation	€41,000	€41,000	-	-	€41,000	€41,000
SAF demand Member State enforcement and verification	-	-	€ 650,000	€411,500	€173,000	€173,000
SAF demand enforcement and verification at Member State and EU level			€123,000	€41,000	€41,000	€41,000
Jet fuel uplift obligation - EU level					€82,000	€82,000

Table 26 Net Present Value of costs for authorities in 2020-2050 (in € million 2015 constant prices)

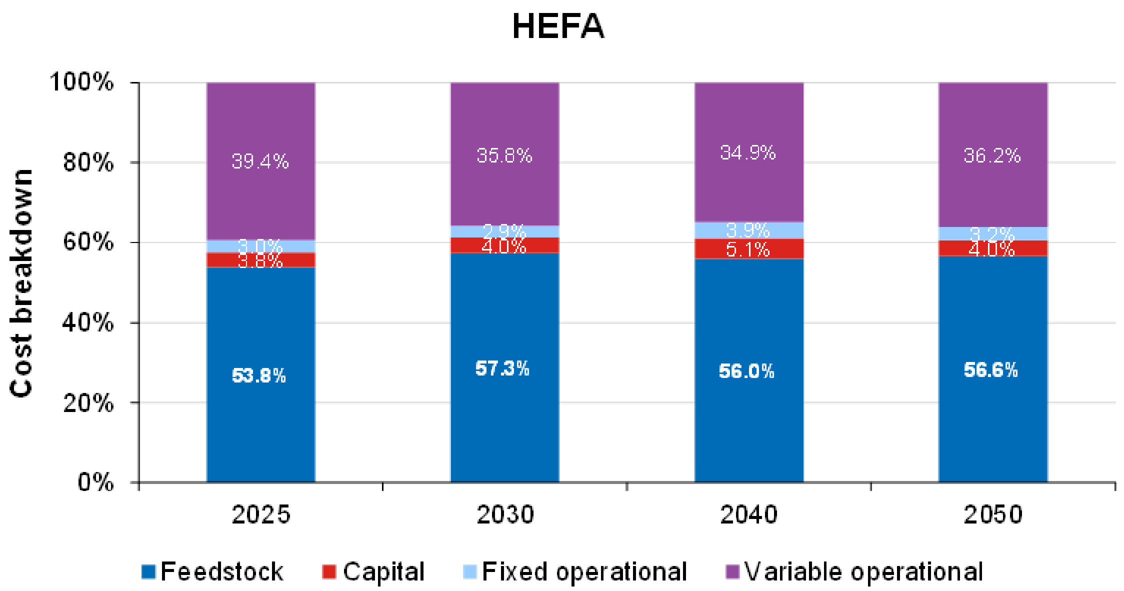
Present Value	PO A1	PO A2	PO B1	PO B2	PO C1	PO C2
Administrative cost for Member State authorities	186	186	293	186	264	264
Administrative cost for EU authorities	0.7	0.7	2.0	0.7	2.7	2.7

Impact on the SAF costs structures

In the following we present the expected development of the cost-structure of biokerosene production per pathway and over time. The cost components are aggregated in main categories, which include capital costs, feedstock costs, fixed operational and variable costs (e.g. energy, enzymes, catalysts, waste management). The costs presented here, exclude the profit margin that was used to form the price of biokerosene (as shown in Figure 13). The cost-structure is presented per pathway from the first year of the technology implementation (i.e. 2025 for HEFA and ATJ, and 2035 for Gasification and FT) and the subsequent 10-year periods leading to 2050. The cost-structure is based on PRIMES Biomass.

The cost-structure of the HEFA route remains relatively unchanged over the time horizon, with the cost of HEFA jet showing small increase mainly driven by feedstock costs. The development of capital costs is in line with literature that expects minimal developments in capital cost component of the technology (ICCT 2019). Higher feedstock costs over time are a direct result of higher demand of jet fuel and the use of UCO. Feedstock costs and variable costs account for more than 90% of the HEFA production costs.

Figure 18 Cost-structure of biokerosene production from the HEFA route in high bioenergy demand context

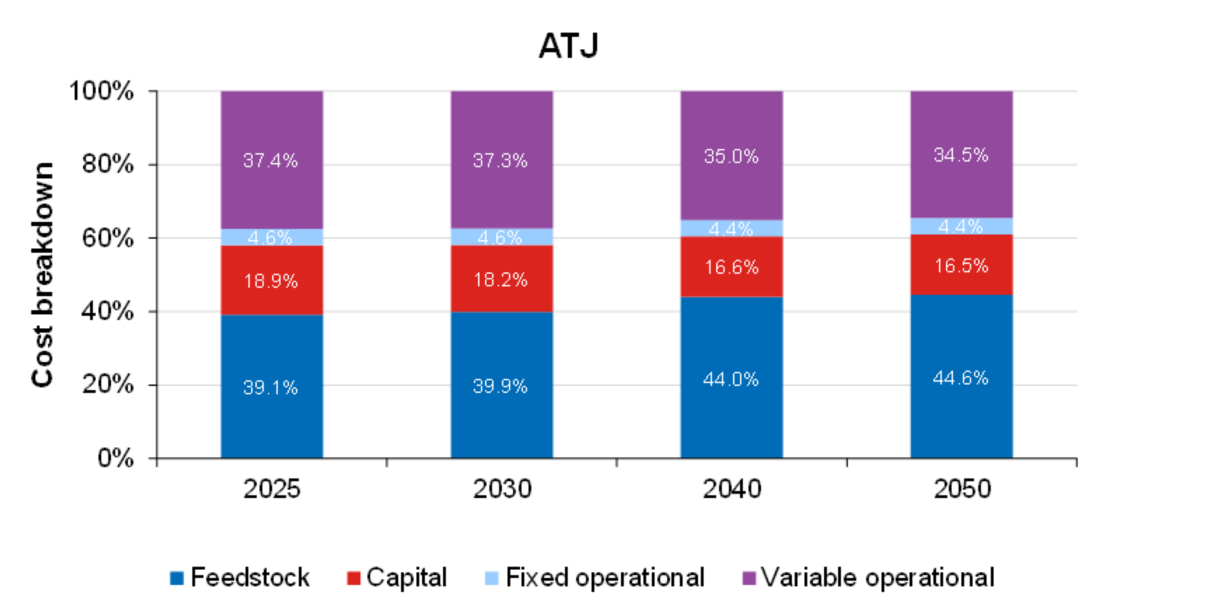


Source: PRIMES Biomass

Two drivers shape the slightly increasing trajectory of biokerosene production costs from the ATJ route (Figure 19) and the Gasification and FT route (Figure 20). The first driver is the decrease of non-feedstock components, such as capital costs, fixed operational costs and variable costs as a result of economies of scale, learning and technology utilisation. This becomes evident when comparing the capital and variable costs of the two routes, from the year they emerge with those of subsequent periods in Figure 19 and Figure 20. Capital unit costs of the Gasification and FT route decrease by 30% between 2035 and 2040, and those of the ATJ route by 10% between 2025 and 2040. In both routes, variable costs decrease by about 2-3% in the same period. These developments are reflected by the lower share of these cost components in 2040 presented in Figure 19 and Figure 20.

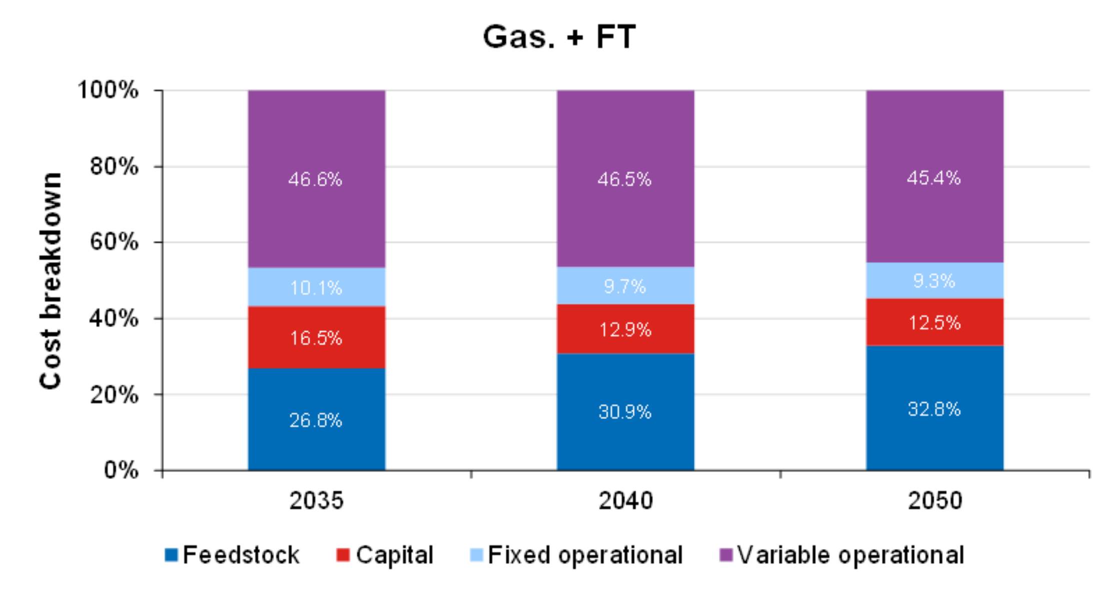
A counterbalancing driver is the increase in production costs driven by feedstock costs. In early years, when the demand for bioenergy is lower, cheap feedstocks (e.g. agricultural residues) are used by the two biokerosene production pathways. However, as bioenergy demand increases, competition for cheap feedstocks emerges from the energy sector and other transport sectors. We remind that the modelling exercise is in the context of the CTP climate ambition for carbon neutrality, hence it also considers the effort from other sectors to decarbonise. As such, lowest-cost feedstocks are quickly depleted and the need for more expensive feedstock emerges, increasing the cost of feedstock used for biokerosene. This is reflected by the increasing share of feedstock in the cost structure of bioenergy in the years leading to 2050.

Figure 19 Cost-structure of biokerosene production from the ATJ route in high bioenergy demand context



Source: PRIMES Biomass

Figure 20 Cost-structure of biokerosene production from the Gasification and FTs route in high bioenergy demand context



Source: PRIMES Biomass

The feedstock costs (in Euro per tonne of feedstock) that drive the production cost of biokerosene are presented in the following table (Table 27). Note that the feedstock prices presented here are average prices at an EU level. These are composed based on more detailed cost-supply curves included in the PRIMES Biomass model, specific per feedstock and Member State. The feedstock costs in biokerosene production that are presented in the previous section, are derived from feedstock prices considering the process conversion efficiency to produce biokerosene for each production pathway. The increase of feedstock cost is evident in used cooking oil (feedstock for HEFA), and agricultural residues, as well as lignocellulosic crops (feedstocks for ATJ and Gasification and FT).

Table 27 Average feedstock prices in the EU, in EUR/tonne of feedstock

Feedstock	2030	2050
Used cooking oil	350	364
Agricultural residues	92	127
Forestry products	163	159
Forestry residues	120	118
Annual lignocellulosic crops	150	153
Perennial lignocellulosic crops	126	139

Note: The contribution of feedstock costs in the SAF production pathway is estimated based on the feedstock price and the conversion efficiency of the SAF production pathway. Depending on the feedstock, prices may be lower by up to 9% in 2050 in the low bioenergy demand context compared to the high bioenergy demand context

Investment costs in SAF

Investment costs in SAF production plants can differ significantly per type of production plant. Whereas the capital costs required are a significant part of the total costs for capital intensive production pathways such as the Alcohol to Jet and the Gasification and Fischer-Tropsch plants, other production routes, such as HEFA, require less intensive capital investments.

The differences in production costs and average plant production capacity for each production pathway are presented in Table 28 (World Economic Forum, 2020).

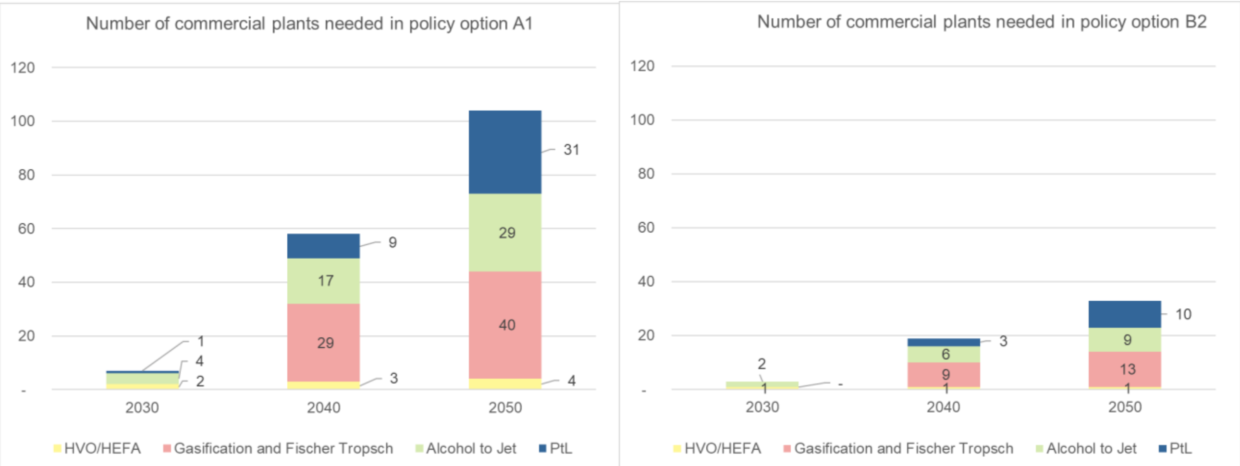
Table 28: Plant data - capacity in million tonnes/year, costs in million €

	Demo capacity	Avg. plant capacity	Cost of avg. plant
HVO/HEFA	0.1	0.5	55
Gasification and Fischer Tropsch	0.05	0.15	187
Alcohol to Jet	0.05	0.2	173
PtL	0.1	0.4	318

Source: Energy Transition Commission Analysis for the Clean Skies for Tomorrow Coalition (2021)

The production capacities provided above concern the SAF production capacity rather than the overall fuel production capacity of the plants or the actual SAF production. In many cases the production process is configured towards maximising the production of biodiesel or other products rather than SAF. As explained also in the problem definition section of this study, although there is currently significant SAF production capacity deployed in plants capable of producing SAF via the HEFA route, actual production is still negligible. This mismatch between SAF production capacity and actual SAF production needs to be noted in the context interpreting the calculated investment needs. The estimated number of SAF plants (Figure 20) and corresponding investments needed are calculated with the assumption of maximised plant configuration towards the production of SAF. In practice more plants may be necessary if this is not the case, or even if smaller average plant sizes prove to be the norm.[81]

Figure 21: Number of SAF production plants needed (post pilot plants)



Source: Own calculations based on PRIMES-Biomass model outputs and Energy Transitions Commission slide deck "Sustainable Aviation Fuels European Production Ramp-up 2020-2050"

In Figure 21, the expected number of plants needed for the mandates with SAF usage for both intra- and extra-EEA flights (Policy Option A1, B1 and C1) are compared to those needed in a scenario of using SAF only for intra-EEA flights (Policy Option B2). The Policy

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[81] as they currently are

Options with a GHG-reduction target result in very similar amounts of SAF production plants as in Policy Option A1 with the only difference being the deployment of a few additional Part A feedstock plants (AtJ and Gas+FT) displacing a some of the PtL plants.

Table 29: Number of SAF production plants needed (based on average capacity and assuming full utilisation for SAF production)[82]

Number of plants required	Baseline			PO A1			PO A2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Total number of plants	0	1	2	7	58	104	7	62	106
HVO/HEFA	0	1	1	2	3	4	2	3	4
Gasification and Fischer Tropsch	0	0	0	0	29	40	0	32	43
Alcohol to Jet	0	0	1	4	17	29	4	20	32
Synthetic fuels	0	0	0	1	9	31	1	7	27
Number of plants required	**Baseline**			**PO B1**			**PO B2**		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Total number of plants	0	1	2	7	58	104	3	19	33
HVO/HEFA	0	1	1	2	3	4	1	1	1
Gasification and Fischer Tropsch	0	0	0	0	29	40	0	9	13
Alcohol to Jet	0	0	1	4	17	29	2	6	9
Synthetic fuels	0	0	0	1	9	31	0	3	10

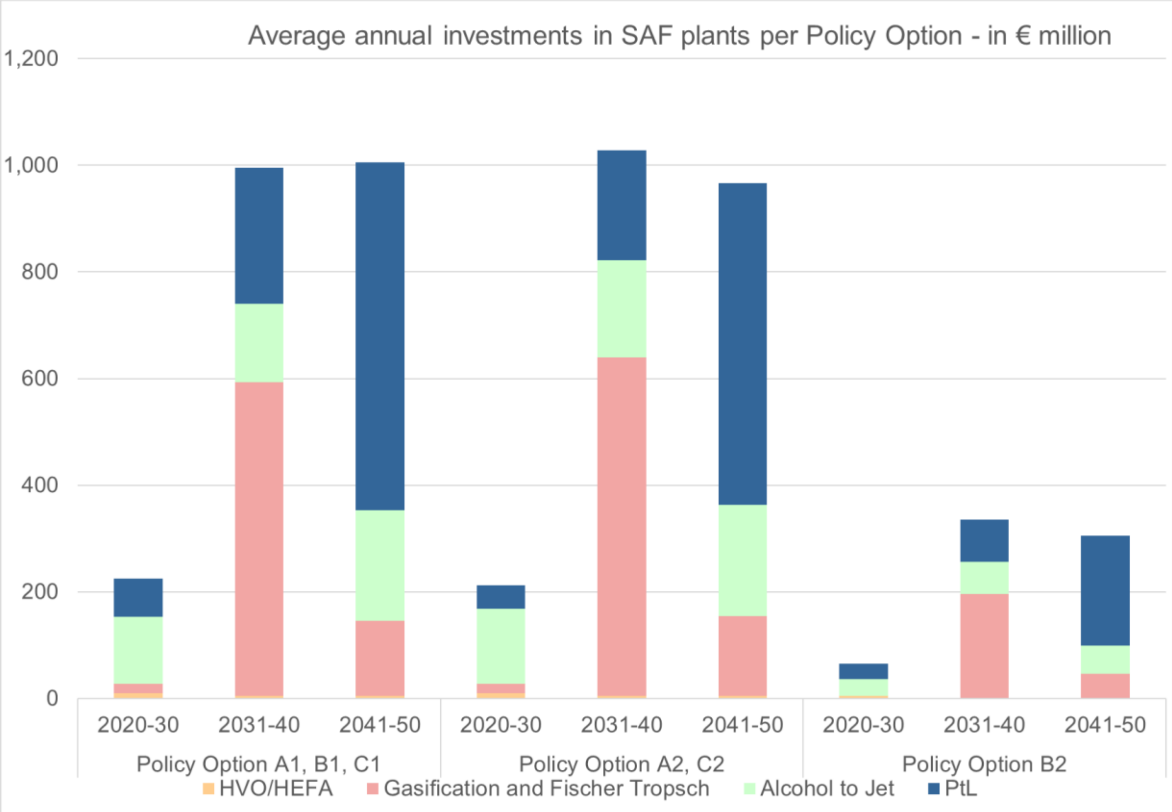
Number of plants required	Baseline			PO C1			PO C2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Total number of plants	0	1	2	7	58	104	7	62	106
HVO/HEFA	0	1	1	2	3	4	2	3	4
Gasification and Fischer Tropsch	0	0	0	0	29	40	0	32	43
Alcohol to Jet	0	0	1	4	17	29	4	20	32
Synthetic fuels	0	0	0	1	9	31	1	7	27

Source: Own calculations based on PRIMES-Biomass model outputs and Energy Transitions Commission slide deck "Sustainable Aviation Fuels European Production Ramp-up 2020-2050"

Taking into account the cost of the average plant, Figure 22 presents the total capital cost needed per decade to deploy the necessary SAF plant capacity in each Policy Options. The capital cost requirements are presented for Policy Option A1 as indicative of the Policy Options with a SAF volume target (A1, B1 and C1), Policy Option A2 presenting the results for Policy Options with a GHG-reduction target (A2 and C2), and Policy Option B2 where a reduced scope of application is the case.

[82] Assuming full utilisation of average plant SAF production capacity (as presented in Table 28Table 29) for each type for SAF

Figure 22 Capital cost investments needed for SAF production plants (in € million)



As seen also in, Policy Options A1 and A2 result in similar investment costs while the costs of deploying SAF plants are significantly lower in the case where a reduced scope is foreseen (Policy Option B2).

Table 30: Average annual investment costs in SAF production capacity needed

Average annual investment	Baseline			PO A1			PO A2		
	2020-2030	2031-2040	2041-2050	2020-2030	2031-2040	2041-2050	2020-2030	2031-2040	2041-2050
Average annual investment	**-**	**23**	**-**	**225**	**995**	**1,005**	**212**	**1,029**	**967**
HVO/HEFA	-	6	-	10	6	6	10	6	6
Gasification and Fischer Tropsch	-	-	-	17	588	140	17	635	149
Alcohol to Jet	-	17	-	126	147	208	142	182	208
Synthetic fuels	-	-	-	72	254	651	43	207	604
Average annual investment	**Baseline**			**PO B1**			**PO B2**		
	2020-2030	2031-2040	2041-2050	2020-2030	2031-2040	2041-2050	2020-2030	2031-2040	2041-2050
Average annual investment	**-**	**23**	**-**	**225**	**995**	**1,005**	**65**	**336**	**305**
HVO/HEFA	-	6	-	10	6	6	5	-	-
Gasification and Fischer Tropsch	-	-	-	17	588	140	-	196	47
Alcohol to Jet	-	17	-	126	147	208	32	61	52
Synthetic fuels	-	-	-	72	254	651	29	79	207
Average annual investment	**Baseline**			**PO C1**			**PO C2**		
	2020-2030	2031-2040	2041-2050	2020-2030	2031-2040	2041-2050	2020-2030	2031-2040	2041-2050
Average annual investment	**-**	**23**	**-**	**225**	**995**	**1,005**	**212**	**1,029**	**967**
HVO/HEFA	-	6	-	10	6	6	10	6	6
Gasification and Fischer Tropsch	-	-	-	17	588	140	17	635	149
Alcohol to Jet	-	17	-	126	147	208	142	182	208
Synthetic fuels	-	-	-	72	254	651	43	207	604

Energy dependence

Compared to the Baseline, for the Policy Options correlated to the high bioenergy scenario, the reduction of fossil kerosene consumption due to lower transport activity in aviation (relative to the Baseline) and due to the increase in SAF blends is about 7% (or about 3 Mtoe) in 2030 and 65% (or about 31 Mtoe) in 2050. We note here, and also elsewhere in this report, that the increased fuel prices, which influence ticket prices (because of the more expensive blended fuels) relative to the Baseline, drive a reduction in the aviation activity and to some modal shifts towards rail. The reduction in Policy Option B2 is lower (3% in 2030 and 22% in 2050) as, per scenario design, the blending mandates are applied only on intra-EU flights. As such, all Policy Options reduce the dependency of the EU on oil imports significantly. On the other hand, the scenario results for the Policy Options suggest that part of the additional demand for biokerosene will be addressed with imports. Biokerosene imports are expected to reach up to about 0.4 Mtoe in 2030 and around 2.3-2.5 Mtoe in 2050 (see Figure 16, and Table 15 presented above). Taking into account the total energy demand in air transport, biokerosene imports represent less than 1% in 2030 and between 3% and 6% in 2050. As such, while there is increase in biokerosene imports, the net effect due to the reduction of fossil fuel consumption still remains significant. Domestic production in the EU is expected to cover 80% of the biokerosene demand in 2030 and more than 85% in 2050. All feedstock that required for biokerosene are expected to be produced in the EU; no feedstock would be imported in order to produce biokerosene. The electricity that required to produce synthetic kerosene is based on gross electricity generated in the EU (the EU is assumed to be a net zero importer of electricity post-2030). The share of electricity demand for synthetic kerosene production is forecasted to reach 0.4% in 2030 and up to 5.5% in 2050 of renewable electricity generation in the EU. As such, taking into account synthetic kerosene, domestic production of SAF in the EU reaches 83% in 2030 and 92% in 2050 (see also Table 15). In addition, electricity is directly consumed by the aviation sector in 2050, with a share reaching about 0.3% of total jet fuel.

Functioning of the internal market and competition

According to the modelling results from the PRIMES-Biomass model, the majority of SAF supply is expected to come from intra-EU production with more than 100 SAF plants expected to come in action in the high SAF Policy Options (A1, A2, B1, C1 and C2). Amongst these Policy Options, the ones that do not foresee a sub-mandate for synthetic fuel and incentivise the uptake of synthetic fuels via a multiplier (A2 and C2) should lead to the development of slightly more biokerosene compared to synthetic kerosene as a market approach to achieve the GHG-reduction mandate at lower cost (as seen also in the fuel cost impacts estimation).

A level playing field is also expected to be achieved for the internal EEA aviation market as a result of the uniform application of a SAF usage obligation in intra-EEA flights. In Policy Options that distinguish intra and extra-EEA flights (B2) a significant difference in the cost of fuel for the two segments is expected to arise as the SAF content obligation rises over time. Additional distortions to competition may arise post-2030 if aviation partner countries do not move in the direction of promoting SAF usage. Moreover, there may be a competitive advantage for air transport service providers providing long-haul flights with intermediate refuelling stops outside the EU. However, any policy to increase SAF usage by these aviation partner countries will reduce the incentives for these behaviours.

Specifically, in Policy Option B2, a fuel price difference between intra-EEA and extra-EEA flights will probably arise as a result of the obligation for higher SAF participation in the fuel mix of intra-EEA flights. Assuming that intra-EEA flights in Policy Option B2 will have a similar fuel mix as presented in Policy Option B1, and considering the prices for SAF fuels as presented in Figure 13, the expected differences in fuel costs between intra- and extra-EEA flights is given in Table 31.

Table 31: Comparison of average fuel costs for intra- and extra-EEA flights in Policy Option B2 (in €/tonne)

	2030	2045	2050
Extra-EEA flights	1,029	1,103	1,148
Intra-EE flights	1,055	1,234	1,382
Price difference	2.60%	11.91%	20.46%

Source: Primes Biomass

Another potential market distortion could be developed as a result of only fuel suppliers being obliged to meet a SAF mandate whereas fuel users would be free of such an obligation in Policy Options A1 and A2. In this case, and as the price difference between fossil kerosene and the SAF blended mix increases over time due to the increasing participation of SAF, there will be an incentive to tanker fuel abroad in the Policy Options where the mandate is only on suppliers (A1 and A2). The methodology for assessing the risk of tankering based on

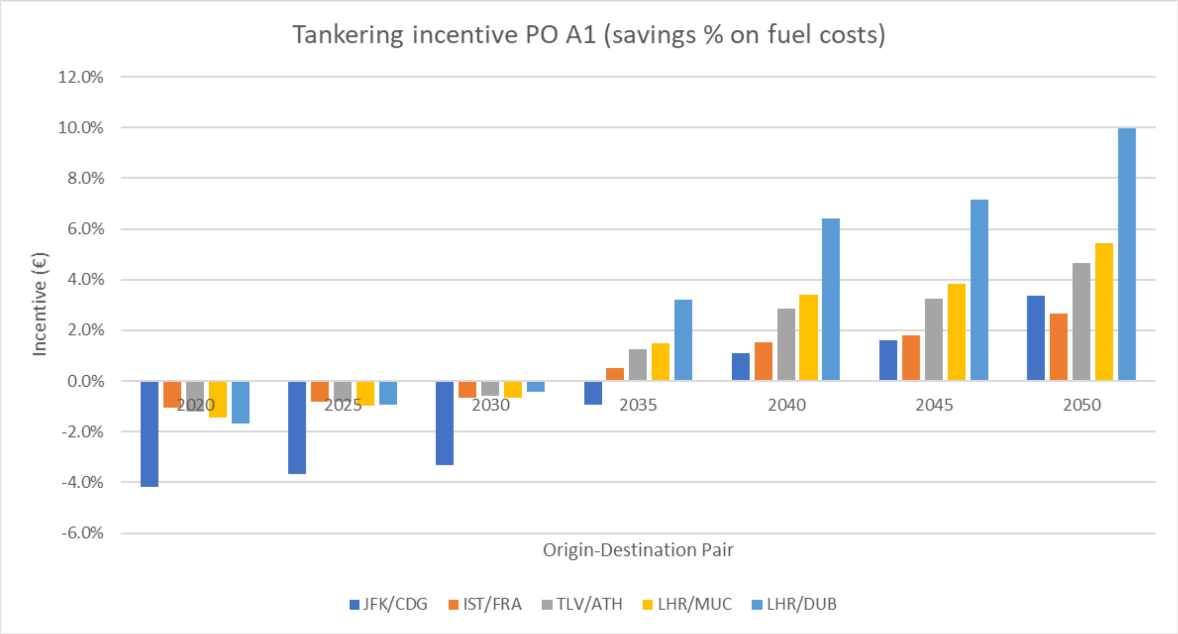
5 selected case studies of popular extra-EU flights, and the analytical results regarding the existence of a tankering incentive potential are given in Annex 6. The selected flight pairs are presented in Table 32. The results of the case studies for Policy Option A1 are presented in Figure 23.

Table 32 Selection of tankering case studies

Case study	Distance (km)	Case study aircraft	Max Passengers	Maximum landing weight (t)
New York – Paris	6047	777-300 ER	396	251.3
Istanbul – Frankfurt	1969	A320	180	66.0
Tel Aviv – Athens	1287	A320	180	66.0
London – Munich	1020	737-800	189	66.4
London – Dublin	559	737-800	189	66.4

Source: simBrief calculator

Figure 23 Fuel tankering incentive for selected aviation routes (in % of fuel cost savings)



The case study results presented in Figure 23 illustrate the financial return in matters of fuel cost savings achieved for tankering fuel when performing each of the five selected air connection pairs. A positive result indicates it is financially advantageous to tanker additional fuel[83] when departing from non-EEA airports to use (part of) it in the return trip. A negative result on the contrary marks that tankering is not financially attractive. The results exhibit that at least until SAF participation in the fuel blend picks up there is a financial counter incentive to tanker fuel abroad, as the increased fuel consumption to carry the tankered fuel exceeds the benefit of buying cheaper fossil fuel. The tipping point comes post-2030 for short-haul flights and post-2035 for long-haul flights. This estimation is based on the average fuel blend and it might be that tankering is more attractive for specific trips with more expensive SAF.

[83] assuming maximum tankering possible based on fuel tank capacity

Over time and as SAF participation in the fuel blend increases, the benefit of tankering is also expected to raise. Also, any further adoption of SAF-friendly policies by aviation partner countries or even by individual airlines may push the tipping point further in time. With Policy Option A2 yielding slightly better results than A1, the conclusion is that there is no large-scale fear of tankering fuel in the short term. Nevertheless, from 2035 and onwards, the risk of airlines tankering fuel abroad becomes larger as the financial incentive reaches 2-10% of the total fuel costs.

Innovation

The measures on funding R&D on SAF and their feedstock development will have an impact on all different SAF production pathways. Extending this support to cover also pilot plants deployment and further technology commercialisation will accelerate the entry of the new technologies and feedstock in the EU market. Similar to the R&D funding, the certification support measure can further assist in maturing much needed technologies that enable the use of new feedstock. Further to the boost in SAF R&D expected to be brought by the mandate and the flanking measures, Policy Options introducing a GHG-based target (A2 and C2) are expected to further promote the development (and use) of more environmentally friendly SAF fuel as there will be a clearer incentive to use fuel with lower emissions rather than fuel with sufficiently low emissions to meet the obligation threshold. On the other hand, Policy Option B2 which promotes the use of SAF only on a sub-set of the total flights (i.e. scope on the intra-EU flights) may lead to slower technological progress, technological lock-ins and a delay in the production of biokerosene from advanced pathways due to lower demand for SAF compared to other policy options and thus less certainty to investors.

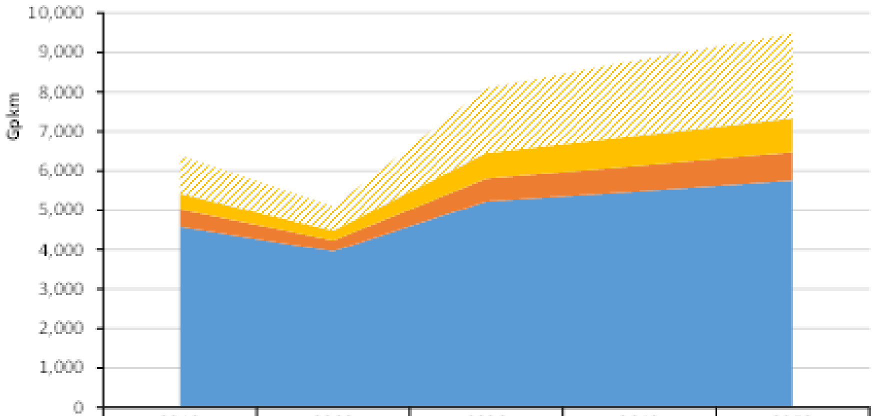
It is not possible to assess how faster technological breakthroughs will occur with the additional funding support. It is reasonable to assume that cutting the duration of the certification process and providing targeted assistance to companies that are going through this process will accelerate the introduction of technological innovation. Nevertheless, as there is a lot of room for technological progress on the domain of SAF it is safe to expect that this support will help mature the EU SAF industry and their development of new production technologies that can help keep the EU at the forefront of these technological developments.

Industry and sectoral competitiveness

Air transport activity

In the Baseline scenario, total passenger transport activity is projected to increase steadily from 2015 to 2050 driven by the evolution of the GDP and population. The total activity increases at a rate of 1% per year but growth rates differ per mode of transport. The modal share of road transport (i.e. passenger cars, public transport and 2-wheelers) is projected to reduce from 69% in 2015 to 61% in 2050. The steepest annual growth, at 1.8% per year, is projected for passenger transport activity in aviation (national, intra-EU and extra-EU flights). That is despite the steep reduction in the transport sector due to the COVID-19 pandemic in 2020. The modal share of aviation in passenger transport activity reaches 32% in 2050, compared to 24% in 2015. As such, in the Baseline scenario, a modal shift from road transport primarily to aviation but also to rail is projected (Figure 24).

Figure 24 Passenger transport activity in the EU27 in the Baseline scenario



	2010	2020	2030	2040	2050
Extra-EU aviation	959	612	1637	1924	2154
Intra-EU aviation	398	244	655	764	850
Rail	444	274	577	653	728
Road	4579	3960	5222	5476	5745

Source: PRIMES-TREMOVE

In the case of Policy scenarios, the increase in the fuel costs of the airliners already analysed (see section on fuel cost impacts earlier) are assumed to be completely reflected (passed through) on the ticket prices seen by the consumers, as part of the modelling. Hence, income and substitution effects[84] are found to take place in all Policy Option scenarios. This is reflected in the reduction of passenger transport activity in intra-EU and extra-EU flights in the Policy Option scenarios compared to the Baseline (Figure 25). All the Policy Options relying on the high bioenergy demand scenario present a similar impact on air transport activity (-2% for 2030 and approximately -5.8% for 2050) with the Policy Options introducing a GHG-based mandate achieving a slightly lower activity reduction compared to the ones introducing a volume-based mandate. This is probably due to the more cost-efficient delivery of the GHG reduction achieved through these Policy Options as explained earlier.

Table 33 Passenger transport activity in the EU27 in 2030, 2030 and 2050 in the Baseline and the Policy Option scenarios

Passenger transport activity (% change to Baseline)	Baseline (Gpkm)			PO A1			PO A2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Passenger transport activity	**8,091**	**8,818**	**9,478**	**-0.5%**	**-1.0%**	**-1.7%**	**-0.5%**	**-1.0%**	**-1.6%**
Road	5,222	5,476	5,745	0.0%	-0.1%	-0.2%	0.0%	-0.1%	-0.2%
Rail	577	653	728	0.4%	2.2%	3.9%	0.3%	2.1%	3.8%
Air transport activity	2,293	2,689	3,004	-2.0%	-3.7%	-5.9%	-2.0%	-3.5%	-5.7%
- of which intra-EU air transport	655	764	850	-1.3%	-3.4%	-4.5%	-1.3%	-3.4%	-4.7%

[84] The modelling assumes that the increase of the jet fuel price (e.g. due to the higher costs of SAF), is transferred to the consumers through the ticket price. Any other assumption regarding the pass through rate of the increased fuel prices would be unrealistic because it would not represent a steady state solution. Thus, the increase of ticket prices deems some of the air transport activity too costly for consumers, leading to activity loss (income effect). Part of the activity, however, may switch from aviation, and particularly of intra-EU flights, to rail (substitution effect).

Passenger transport activity (% change to Baseline)	Baseline (Gpkm)			PO B1			PO B2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Passenger transport activity	**8,091**	**8,818**	**9,478**	**-0.5%**	**-1.0%**	**-1.7%**	**-0.5%**	**-0.7%**	**-0.9%**
Road	5,222	5,476	5,745	0.0%	-0.1%	-0.2%	0.0%	0.0%	0.0%
Rail	577	653	728	0.4%	2.2%	3.9%	0.3%	1.6%	2.6%
Air transport activity	2,293	2,689	3,004	-2.0%	-3.7%	-5.9%	-1.9%	-2.6%	-3.4%
of which intra-EU air transport	655	764	850	-1.3%	-3.4%	-4.5%	-1.3%	-3.4%	-4.5%
Passenger transport activity (% change to Baseline)	**Baseline (Gpkm)**			**PO C1**			**PO C2**		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Passenger transport activity	**8,091**	**8,818**	**9,478**	**-0.5%**	**-1.0%**	**-1.7%**	**-0.5%**	**-1.0%**	**-1.6%**
Road	5,222	5,476	5,745	0.0%	-0.1%	-0.2%	0.0%	-0.1%	-0.2%
Rail	577	653	728	0.4%	2.2%	3.9%	0.3%	2.1%	3.8%
Air transport activity	2,293	2,689	3,004	-2.0%	-3.7%	-5.9%	-2.0%	-3.5%	-5.7%
of which intra-EU air transport	655	764	850	-1.3%	-3.4%	-4.5%	-1.3%	-3.4%	-4.7%

EU fuel industry

The EU fuel industry can benefit by taking a leading role in the technology and production of SAF as this technology is expected to become one of the leading drivers to decarbonisation globally. ICAO includes SAF deployment in the proposed basket of measures to combat climate change. The stimulus offered by this initiative to the aviation and (bio)fuel supplier industry to deploy SAF production can turn the EU in a global market leader in the domain. Under both the high and low bioenergy demand context, the biokerosene industry is expected to absorb a significant part of the EU production of feedstock as seen in Figure 17, meaning that less fuel will be available for other uses, such as biodiesel production. Especially under the high bioenergy demand context, SAF production will require 28% of the available UCO production in 2030 and 53% in 2050, meaning strong competition among sectors for the available feedstock, something that could lead to price increases and affect the competitiveness of the biodiesel industry by reducing the availability of feedstock for biofuels targeting road transport. As suggested by the CTP IA (European Commission, 2020), road transport will be increasingly electrified over time, driven by more stringent CO_2 standards for LDVs and HDVs supported by recharging/refuelling infrastructure. As such, the demand of biodiesel for the road sector would decrease in the medium to long term. Therefore, this shift to SAF production can be expected to have a less severe impact on the road sector and push the biodiesel industry to adjust to producing more SAF content.

The R&D support and stakeholder coordination measures play a special role in supporting the industry's innovation and adjustment to shifting towards producing SAF.

Regional competitiveness

As seen in section 6b, the majority of the biokerosene produced under all Policy Options will be produced in the EU. However regional differences can result in a competitive advantage for specific Member States in producing SAF leading to an additional advantage of these Member States also in matters of job generation and income creation. As seen by the SAF allocation matrix presented in Table 51, for the Policy Options that foresee a high SAF allocation (A1, A2, B1, C1 and C2), Member States with large feedstock availability and high jet fuel demand (e.g. Germany, France, Italy, Spain and Poland) will be more likely to attract investments in deploying SAF plants, although SAF production should become more decentralised in the long term to take advantage of further feedstock availability (especially considering agricultural and forestry residues and municipal solid waste). Under Policy Option B2, SAF production is more concentrated leading to a larger regional imbalance in the production of the reduced SAF volumes needed compared to the other Policy Options. Furthermore, EU and third countries with large solar energy potential may exploit this advantage to deploy more PtL plants. This is especially the case for the Policy Options with sub-mandates (PO A1, B1 and C1) where increased PtL volumes will be required.

c. Analysis of social impacts

This section presents the expected impacts in the following categories:

- Impact on consumers in matters of flight ticket prices (as a result of fuel cost increase);
- Employment in both the aviation and the fuel industry;
- Public health (external costs of pollutant emissions).

Impact to consumers

As introduced earlier, through income and substitution effects induced by the higher ticket prices seen by consumers, there is a reduction of passenger transport activity in intra-EU and extra-EU flights in the Policy Option scenarios (Figure 25) and to some modal shifts of aviation activity towards rail, compared to the Baseline.

The contribution of fuel costs to overall aviation costs can be very volatile as in periods of low fossil fuel prices, these tend to be a lesser contributor while in prices of high fossil fuel prices, these can be a more important factor in price development. In the last decade, fuel costs have fluctuated between 19 and 33% of airline operational costs (European Commission, 2017a) (Statista, 2020). For the purposes of this assessment we assume an average 25% participation of fuel costs on total aviation costs and ticket prices.

Due to the increase in SAF blends in the Policy Options compared to the Baseline, there is an increase in fuel prices (as blended fuels are more expensive). As also explained above, the increase in fuel costs is assumed to pass fully through to the consumers by influencing the ticket prices. These can be expected to increase in parallel with the fuel price increase (as presented in Table 17) and can be seen in the Table below. Ticket price increases can be lower should airlines absorb part of the additional costs meaning that these impacts represent the maximum ticket price increase case.

Table 34 Average jet fuel blend prices in the Baseline and the Policy Options in the EU27 in 2030

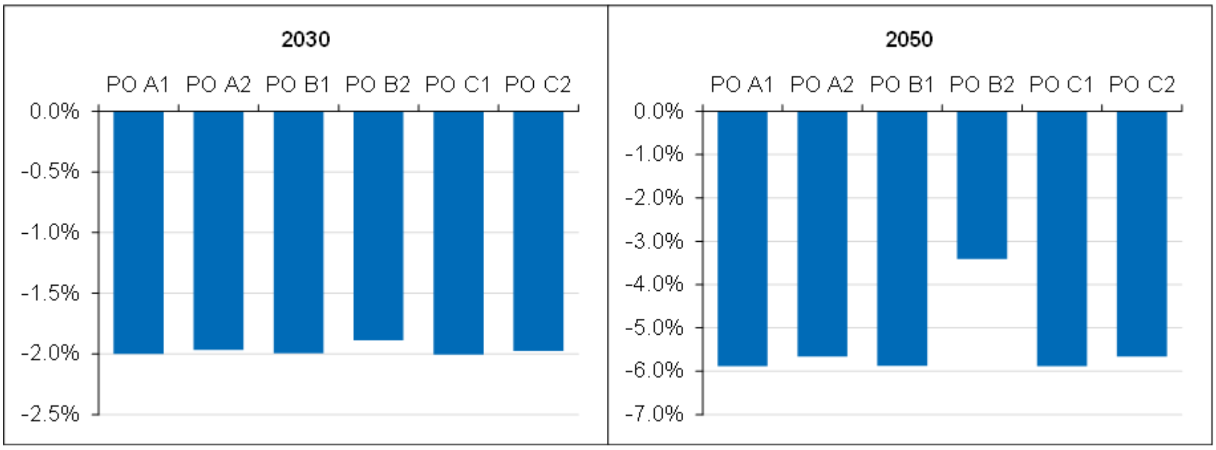
Policy Option	Fuel cost increase			Ticket price increase		
	2030	*2040*	*2050*	*2030*	*2040*	*2050*
Policy Option A1	3.30%	22.23%	32.69%	0.8%	5.6%	8.2%
Policy Option A2	3.08%	21.46%	32.53%	0.8%	5.4%	8.1%
Policy Option B1	3.31%	22.23%	32.70%	0.8%	5.6%	8.2%
Policy Option B2[85]	0.51%	4.20%	6.94%	0.1%	1.1%	1.7%
Policy Option C1	3.32%	22.25%	32.69%	0.8%	5.6%	8.2%
Policy Option C2	3.11%	21.47%	32.50%	0.8%	5.4%	8.1%

[85] Average of price increase for intra- and extra-EEA flights.

Source: Primes-Biomass

In 2030, the impact on ticket prices is relatively small and results to about 2% lower passenger air transport activity due to the more expensive sustainable aviation fuels. Progressing towards 2050, due to the significantly higher supply of sustainable aviation fuels, the income and substitution effects become more prominent leading to between 4% and 6% decrease in air transport activity compared to the Baseline, as all of the increase in jet fuel price is passed through, to the consumers. This can be regarded as a maximum projected impact under the assumption of full pass through of the costs. Income and substitution effects, as reflected in ticket prices are less prominent in Policy Options A2 and C2 as they allocate lower costs sustainable aviation fuels than their Policy Option counterparts A1 and C1. In Policy Option B2 are even less pronounced, as less SAF is blended than in all other Policy Options, hence the effect on ticket price is smaller. Relative to 2015, air transport activity is, however, still increasing substantially in all Policy Options, although at a slower pace than in the Baseline.

Figure 25 Reduction of passenger transport activity in aviation in the EU27 in 2030 and 2050 in the Policy Option scenarios compared to the Baseline



Source: PRIMES-TREMOVE

Employment

According to Eurostat[86] air transport accounted, for 408 thousand direct jobs in the EU27 in 2019. This was up by 14.3% from the 356 thousand jobs in the sector in 2015. At the same period, the number of intra- and extra-EU passengers by air transport ridership increased by 26.2%. Assuming a similar employment elasticity in the future (0.547) to be applied to any impact on the air transport activity the impact of the Policy Options on direct transport employment can be estimated. With the expectation that employment in the sector will follow the projected air traffic volumes, it is estimated that the small drop in air passenger transport foreseen in most Policy Options will result in a proportionate reduction in employment in the sector. This corresponds to a loss of 4,900 direct jobs in 2030 (1.0% reduction) for all Policy Options. This may increase in 2050 to a 1.9% reduction or 9,800 jobs for the low SAF uptake scenario (Policy Options B2) and a 3.1- 3.2% reduction for the high SAF for all the rest of the Policy Options falling under the high uptake scenarios (approx. 16,500 jobs). Indirect job

[86] Eurostat (lfsa_egan22d)

generated from aviation can be as high as 1.4 - 2.0 times the direct ones (European Commission, 2015) and so, considering an average value (1.7) indirect job losses from the aviation activity drop can be as high as 16,700 – 29,000 total jobs lost by 2050).

On the contrary, the increased SAF production and the fact that the majority of the biofuels and synthetic fuels used are projected to be produced in the EU, is expected to lead to respective job gains. Eurostat estimates the 2018 European production of liquid biofuels to be approximately 21.5 Mt. According to the IRENA job database, the estimated direct and indirect jobs in liquid biofuels in the EU where in 2019 as high as 208,000 (IRENA, 2019).[87] In the absence of widely commercially established SAF production capacity to draw relevant labour figures, a similar employment to fuel production ratio as in biofuels, could be assumed. This would mean that for 2030 the expected SAF production of 0.6Mt could lead to a potential job creation of 5,300 jobs (Full-time equivalent) for the low bioenergy demand context Policy Option (B2) and 17,600 jobs for the high bioenergy demand context Policy Options (all the rest) scenario where 1.8 Mt are produced. By 2050, these figures could be as high as 779,700 and 248,100 respectively.

Table 35 Employment impact in the EU27 in 2030, 2030 and 2050 in the Baseline and the Policy Option scenarios (in thousand FTE)

Employment in air transport (% change to baseline)	Baseline ('1000)			PO A1 (impact)			PO A2 (impact)		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Air transport (direct)	447	492	528	-5	-10	-17	-5	-9	-17
Air transport (indirect)	760	837	898	-8	-1	-29	-8	-16	-28
Biokerosene (direct and indirect)	0	2	7	18	123	248	17.4	22	246
Total	**1,207**	**1,331**	**1,433**	**5**	**96**	**202**	**4**	**96**	**202**
Employment in air transport (% change to baseline)	**Baseline ('1000)**			**PO B1 (impact)**			**PO B2 (impact)**		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Air transport (direct)	447	492	528	-5	-10	-17	-5	-7	-10
Air transport (direct)	1,340	1,477	1,585	-8	-17	-29	-8	-12	-17
Biokerosene (direct and indirect)	0	2	7	18	123	247	5	39	80
Total	**1,788**	**1,971**	**2,120**	**4**	**96**	**201**	**-7**	**20**	**53**
Employment in air transport (% change to baseline)	**Baseline ('1000)**			**PO C1 (impact)**			**PO C2 (impact)**		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Air transport (direct)	447	492	528	-4	-10	-17	-5	-9	-17

[87] This means approximately 9.7 thousand jobs for every Mt of biofuel produced

Air transport (direct)	1,340	1,477	1,585	-8	-17	-29	-8	-16	-28
Biokerosene (direct and indirect)	0.4	2	7	18	123	248	18	122	247
Total	**1,788**	**1,971**	**2,120**	**5**	**96**	**202**	**5**	**97**	**202**

Source: Own calculations based on PRIMES-TREMOVE output

Public health

Pollutants

The impacts on public health from air pollution are quantified in terms of reduction in the negative externalities in the Policy Options compared to the Baseline. Indeed, air pollutants are projected to decrease in the policy scenarios compared to the baseline. The reduction of air transport activity, as a result of the more expensive SAF fuels, leads to lower fuel consumption, that eventually leads to a difference of the present value of external costs from air pollution of about €1.5 bn in 2020-2050 compared to the Baseline (see also Annex 5). In the Baseline scenario, the present value (i.e. discounted annual average costs[88]) of external costs due to air pollution in aviation reaches €34 bn in the period 2020-2050.

Table 36 Present value of external costs from air pollution in 2020-2050, compared the Baseline, (in € billion)

	Baseline (bil. € '2015)	PO A1	PO A2	PO B1	PO B2	PO C1	PO C2
External costs of air pollution	34	-1.5	-1.5	-1.6	-1.5	-1.5	-1.5

Source: PRIMES-TREMOVE

d. Analysis of environmental impacts

This section presents the expected environmental impacts in the following categories:

- Use of energy;
- Climate impact;
- Air pollutants (CO, NOx and PM2.5);
- Land use change

Use of energy

Table 37 shows that energy demand in transport reduces in 2030 and 2050 in all Policy Option scenarios compared to the Baseline. That is partly due to the decrease in activity in aviation relative to the Baseline (as described in sections 6b, Table 33 and Annex 5, Table 55), the reduction of fuels used (fossil kerosene), and due to the shift towards rail transport.

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[88] Using 4% as social discount rate.

Table 37 Reduction of energy demand in transport (excluding international shipping) in the Policy Option scenarios compared to the Baseline in the EU in 2030, 2040 and 2050

Energy use in transport (% change to Baseline)	Baseline (Mtoe)			PO A1			PO A2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Energy use (excl. International shipping)	279	245	232	-0.3%	-0.9%	-1.9%	-0.3%	-0.8%	-1.8%
Energy use in transport (% change to Baseline)	**Baseline (Mtoe)**			**PO B1**			**PO B2**		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Energy use (excl. International shipping)	279	245	232	-0.4%	-0.9%	-1.9%	-0.3%	-0.6%	-1.1%
Energy use in transport (% change to Baseline)	**Baseline (Mtoe)**			**PO C1**			**PO C2**		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Energy use (excl. International shipping)	279	245	232	-0.3%	-0.9%	-1.9%	-0.3%	-0.8%	-1.8%

Source: PRIMES-TREMOVE

Relative to the Baseline, the projected reduction of passenger transport activity in aviation is reflected by a decrease in energy use in aviation in all Policy Options (Table 38). In 2030, the decrease in energy use in air transport compared to the Baseline is around 2%, similar across all Policy Options. By 2050, the reduction in energy use compared to the Baseline reaches almost 9% in most Policy Options.

In Policy Option A1 and C1 it reaches 8.5% and in Policy Option B1 the reduction is 8.6%. Policy Option A2 and C2, compared to their Policy Option counterparts A1 and C1, show somewhat lower reduction by about 0.4% p.p. (or 0.2 Mtoe). This is a result of higher passenger air transport activity that is projected in Policy Options A2 and C2 (as shown, of about 0.2% p.p. or 8 Gpkm) and consequently higher energy use. A notable difference in the reduction of fuel consumption compared to the Baseline is observed with the scenario results of Policy Option B2, which applies a blending mandate for biokerosene and synthetic kerosene only on intra-EU flights. In this Policy Option, fuel consumption is reduced by around 5% compared to the Baseline, as this option has higher air transport activity than all other scenarios. Compared to the other Policy Options the additional fuel consumption in Policy Option B2 is 1.7 to 1.9 Mtoe in 2050.

Table 38 Reduction of energy demand in air transport in the Policy Option scenarios compared to the Baseline in the EU in 2030, 2040 and 2050

Air transport energy use (% change to Baseline)	Baseline (Mtoe)			PO A1			PO A2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Air transport energy use	47	48	50	-2.1%	-4.2%	-8.5%	-2.1%	-4.0%	-8.1%
Air transport energy use (% change to Baseline)	**Baseline (Mtoe)**			**PO B1**			**PO B2**		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Air transport energy use	47	48	50	-2.2%	-4.3%	-8.6%	-2.1%	-3.0%	-5.3%
Air transport energy use (% change to Baseline)	**Baseline (Mtoe)**			**PO C1**			**PO C2**		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Air transport energy use	47	48	50	-2.1%	-4.2%	-8.5%	-2.1%	-4.0%	-8.1%

Source: PRIMES-TREMOVE

Climate impact – GHG emissions

In the Baseline scenario, the Tank-to-Wheel (TTW) CO2 emissions in transport (including international shipping) are projected to decrease from approximately 994 Mtons in 2010 to about 888 Mtons in 2030 and to about 713 Mtons in 2050, or by 11% and 28%, respectively (Table 39; ANNEX 5. Well-to-Wheel (WTW) emissions (including those from international shipping) are projected to follow a similar declining trend. In the Baseline scenario they decrease from 1,118 Mtons CO2eq in 2015, to 1,019 Mtons CO2eq in 2030 and 838 Mtons CO2eq in 2050 (Table 39; Annex 5). The share of Well-to-Tank (WTT) emissions in WTW emissions increases from around 11% in 2015, to 13% in 2030 and to 15% in 2050.

Table 39 Reduction of CO_2 emissions from transport in the Policy Option scenarios compared to the Baseline in the EU in 2030, 2040 and 2050

Transport CO2 emissions (% change to Baseline)		Baseline (Mt CO2)			PO A1			PO A2		
	2015	2030	2040	2050	2030	2040	2050	2030	2040	2050
Tank to wheel emissions	994	888	767	713	-1.1%	-6.4%	-13.3%	-1.1%	-6.3%	-13.2%
Well to wheel emissions	1,118	1,019	893	838	-1.2%	-6.6%	-13.8%	-1.1%	-6.5%	-13.6%
Transport CO2 emissions (% change to Baseline)		**Baseline (Mt CO2)**			**PO B1**			**PO B2**		
	2015	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Tank to wheel emissions	994	888	767	713	-1.1%	-6.4%	-13.3%	-0.5%	-2.2%	-4.4%
Well to wheel emissions	1,118	1,019	893	838	-1.2%	-6.6%	-13.8%	-0.6%	-2.1%	-3.9%
Transport CO2 emissions (% change to Baseline)		**Baseline (Mt CO2)**			**PO C1**			**PO C2**		
	2015	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Tank to wheel emissions	994	888	767	713	-1.1%	-6.4%	-13.3%	-1.1%	-6.3%	-13.2%
Well to wheel emissions	1,118	1,019	893	838	-1.2%	-6.6%	-13.8%	-1.1%	-6.5%	-13.6%

Source: PRIMES-TREMOVE

The reduction of energy consumption in aviation and the introduction of sustainable aviation fuels in the jet fuel mix in the Policy Option scenarios, reduce the WTW GHG emissions from aviation significantly[89]. By 2030, GHG emissions are lower by around 6.5% in all Policy Options compared to the Baseline, with the exception of Policy Option B2 which is 3.7% and is the lowest across the Policy Options due to higher jet fuel consumption. The impact of the Policy Options becomes more evident in the years leading to 2050, when, depending on option, WTW GHG emissions in aviation are lower by 17% to 61% compared to the Baseline. The highest emission reduction (i.e. 61%) is projected in Policy Option B1, but the result is similar with the other Policy Options. The lowest emission reduction (i.e. 17%) is projected in Policy Option B2, which applies blending mandates only on the fuel used for intra-EU flights.

Table 40 Reduction of CO2 emissions from air transport in the Policy Option scenarios compared to the Baseline in the EU in 2030, 2040 and 2050

Air transport CO2 emissions (% change to Baseline)	Baseline (Mt CO2)			PO A1			PO A2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Tank to wing emissions	140	143	144	-6.8%	-34.1%	-65.3%	-6.8%	-33.9%	-65.2%
Well to wing emissions	183	187	189	-6.5%	-31.4%	-60.8%	-6.5%	-31.0%	-60.2%
Air transport CO2 emissions (% change to Baseline)	**Baseline (Mt CO2)**			**PO B1**			**PO B2**		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Tank to wing emissions	140	143	144	-6.9%	-34.1%	-65.3%	-3.4%	-11.7%	-21.8%
Well to wing emissions	183	187	189	-6.6%	-31.4%	-60.9%	-3.3%	-10.1%	-17.4%
Air transport CO2 emissions	**Baseline (Mt CO2)**			**PO C1**			**PO C2**		

[89] The impact of the additional SAF logistics on the overall CO2 emissions contributes less than 0.1% to the total impact of the policy measures and is thus omitted from being presented separately in this section.

(% change to Baseline)	2030	2040	2050	2030	2040	2050	2030	2040	2050
Tank to wing emissions	140	143	144	-6.8%	-34.1%	-65.3%	-6.8%	-33.9%	-65.2%
Well to wing emissions	183	187	189	-6.5%	-31.4%	-60.8%	-6.5%	-31.0%	-60.2%

Source: PRIMES-TREMOVE

In the Baseline scenario, the present value of the external costs of CO_2 emissions reaches 330 bn Euro in the period 2020-2050 (i.e. CO_2 emissions from air transport multiplied by the price of CO_2). The introduction of the SAF mandates leads to a reduction in the order of 86-87 bn Euro in the Policy Options, with the exception of Policy Option B2, in which external costs due to CO_2 are lower by €30 bn (see Annex 5).

Air pollutants

All policy options are expected to lead to a decrease in the air pollutants (CO, NOx, and PM) against the Baseline as a result of the reduction in the aviation activity. The latter is driven because of the higher ticket prices in the policy scenarios (due to the more expensive SAF) compared to the Baseline. The modelling does not consider any changes in the air pollutant emission factors of biokerosene or the synthetic kerosene which can be associated with different levels of aromatics and sulphur in these fuels. Projections show that the lowest reduction in air pollutants is expected to take place in the B2 scenario, which shows the smallest reduction in aviation activity.

The emissions of air pollutants (CO, NOx, and PM) are presented in Table 41. It is shown that the introduction of SAF to the jet fuel mix, lowers the emissions of air pollutants by about 3% in 2030 and 7% to 9% in 2050 compared to the Baseline (with the exception of Policy Option B2, in which they reduce by around 3% and 7.3-7.6% in 2030 and 2050, respectively).

Table 41 Emissions of air pollutants in air transport in the EU27 in 2030, 2040 and 2050 in the Baseline and the Policy Option scenarios

Air pollutants from air transport (% change to Baseline)	Baseline (kt)			PO A1			PO A2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
CO emissions	0.3	0.3	0.3	-3.1%	-5.1%	-9.4%	-3.1%	-4.9%	-9.2%
NOx emissions	413	388	366	-3.4%	-5.1%	-9.6%	-3.3%	-5.0%	-9.4%
PM2.5 emissions	9	9	8	-3.4%	-5.1%	-9.6%	-3.3%	-5.0%	-9.3%
Air pollutants from air transport (% change to Baseline)	**Baseline (kt)**			**PO B1**			**PO B2**		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
CO emissions	0.3	0.3	0.3	-3.2%	-5.2%	-9.5%	-3.2%	-4.5%	-7.6%
NOx emissions	413	388	366	-3.5%	-5.3%	-9.7%	-3.4%	-4.3%	-7.3%
PM2.5 emissions	9	9	8	-3.5%	-5.2%	-9.7%	-3.4%	-4.3%	-7.3%
Air pollutants from air transport (% change to Baseline)	**Baseline (kt)**			**PO C1**			**PO C2**		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
CO emissions	0.3	0.3	0.3	-3.1%	-5.1%	-9.4%	-3.1%	-4.9%	-9.2%
NOx emissions	413	388	366	-3.4%	-5.1%	-9.6%	-3.3%	-5.0%	-9.4%
PM2.5 emissions	9	9	8	-3.3%	-5.1%	-9.6%	-3.3%	-5.0%	-9.3%

Impact on land-use

The impact of the use of SAF in land availability was assessed in the framework of the CTP IA. All options are fully consistent with the CTP IA with regard to the overall fuel obligations. The CTP foresees that the levels of biofuel use for aviation, maritime and road transport is not expected to jeopardise the availability of feedstock and will cause manageable LULUCF emissions as far as the shift away from first generation biofuels relying on food and feed crops is achieved. The assessment suggests aviation needs to turn to advanced biofuels produced from woody energy crops and a better mobilisation of agricultural residues and biomass waste and industrial waste streams to avoid negative land-use changes.

The use of advanced feedstock and the limited use of UCOs to produce jet fuel through the HEFA process aims to ensure that the risk of any negative impact on land use is mitigated. The majority of the feedstock used come from the EU market and is of low risk for land-use change. This is true for all policy options; thus we expect no significant impact on this factor to take place as a result of any of the Policy Options.

7. Comparison of the options

In this section, we compare the Policy Options in relation to a number of key criteria:

- Effectiveness: The extent to which the examined options would achieve the identified policy objectives;
- Efficiency: The costs associated with the implementation of the Policy Options – in total and for specific subgroups;
- Coherence with EU policy objectives;
- Proportionality and subsidiarity

a. Effectiveness and efficiency

The criteria to assess the effectiveness of the Policy Options have been developed in Chapter 4 are presented again in Table 41. These reflect in more detail the desired impacts of the proposed intervention.

Table 42: Objectives and assessment criteria related to the effectiveness of Policy Options

Specific objectives	Indicator
General objective Reduce aviation CO_2 emissions by transitioning away from fossil energy dependence and establishing a competitive market for sustainable aviation fuels (in the EU).	
Specific objective 1 Support large scale production in the EU of SAF with high sustainability potential, and ensure adequate levels of supply to the aviation sector at competitive costs	Volume of SAF production capacity
	Sufficiency of feedstock available for SAF production compared to overall needs for SAF as defined per the Climate Target Plan
	Sufficiency of renewable electricity available for SAF production compared to overall needs of renewable electricity as defined per the Climate Target Plan
	Reduction in oil products used by air transport
	Development of sustainable and cost-effective SAF pathways, taking a technology-neutral approach
Specific objective 2 Ensure a gradual and continuous uptake of SAF with high sustainability potential by the aviation sector at competitive prices	Reduction of well to wing CO2 emissions from air transport
	Uptake of SAF in line with the analysis underpinning the impact assessment accompanying the 2030 Climate Target Plan
	Ensure that airlines have access to SAF at airports
	Ensure a level playing field between airlines
	Avoid carbon leakage resulting from fuel tankering
	Reduction of well to wing CO2 emissions from air transport compared to the baseline in 2050
	Reduction of external costs of CO2 emissions relative to the

	baseline, expressed as present value over 2021-2050
	Reduction of external costs of air pollution

In terms of efficiency, the benefits and net costs to the key stakeholders (authorities and suppliers of vehicles) are presented. In presenting the costs to each stakeholder group, we also note the assessment of how far these costs will be passed through before presenting the total net costs.

Table 43 summarises the findings on the basis of the analysis presented in Chapter 6 for each of the Policy Options and sub-options in relation to each of the assessment criteria. It also brings together the estimated Net Present Value (NPV) and the Benefit Cost ratio for each Policy Option.

Table 43: Assessment of effectiveness and efficiency of Policy Options compared to the baseline scenario (€ in '15 constant values)

Key: Impacts expected

✗✗	✗	O	✓	✓✓
Strongly negative	**Weakly negative**	**No or negligible impact**	**Weakly positive**	**Strongly positive**

Indicator	PO A1	PO A2	PO B1	PO B2	PO C1	PO C2
Effectiveness						
Volume of SAF production capacity[90]	✓✓ 25.6Mt of additional SAF capacity deployed by 2050 to match the SAF production necessary to meet the mandate. Minor portions of the SAF needed are imported	✓✓ 25.5Mt of additional SAF capacity deployed by 2050 to match the SAF production necessary to meet the mandate. Minor portions of the SAF needed are imported	✓✓ 25.6Mt of additional SAF capacity deployed by 2050 to match the SAF production necessary to meet the mandate. Minor portions of the SAF needed are imported	✗✗ 8.3Mt of additional SAF capacity deployed by 2050, insufficient to meet the Climate Target Plan Goals due to the reduced SAF mandate	✓✓ 25.6Mt of additional SAF capacity deployed by 2050 to match the SAF production necessary to meet the mandate. Minor portions of the SAF needed are imported	✓✓ 25.5Mt of additional SAF capacity deployed by 2050 to match the SAF production necessary to meet the mandate. Minor portions of the SAF needed are imported
Sufficiency of feedstock available for SAF production compared to overall needs for SAF as defined per the Climate Target Plan	✓ 53% of UCO,11% of agri and wood residues and 9% of energy crops required by 2050	✓ 53% of UCO,11% of agri and wood residues and 9% of energy crops required by 2050	✓ 53% of UCO,11% of agri and wood residues and 9% of energy crops required by 2050	✓✓33% of UCO, 3% of agri and wood residues and 1% of energy crops required by 2050	✓ 53% of UCO,11% of agri and wood residues and 9% of energy crops required by 2050	✓ 53% of UCO,11% of agri and wood residues and 9% of energy crops required by 2050
Sufficiency of renewable electricity for SAF production compared to overall needs for SAF as defined per the Climate Target Plan	✓✓ 5.5% of renewable electricity used for synthetic kerosene	✓✓ 4.7% of renewable electricity used for synthetic kerosene	✓✓ 5.5% of renewable electricity used for synthetic kerosene	✓✓ 1.8% of renewable electricity used for synthetic kerosene	✓✓ 5.5% of renewable electricity used for synthetic kerosene	✓✓ 4.7% of renewable electricity used for synthetic kerosene

[90] Assuming fully used capacity (for all Policy Options)

Key: Impacts expected

✖✖	✖	O	✔	✔✔
Strongly negative	Weakly negative	No or negligible impact	Weakly positive	Strongly positive

Indicator	PO A1	PO A2	PO B1	PO B2	PO C1	PO C2
Reduction of EU's energy dependence on oil imports (compared to the baseline)	✔✔ Reduction in oil products used by air transport by 65% (i.e. around 31 Mtoe) by 2050	✔✔ Reduction in oil products used by air transport by 65% (i.e. around 31 Mtoe) by 2050	✔✔ Reduction in oil products used by air transport by 65% (i.e. around 32 Mtoe) by 2050	✔ Reduction in oil products used by air transport by 22% (i.e. around 11 Mtoe) by 2050	✔ Reduction in oil products used by air transport by 65% (i.e. around 31 Mtoe) by 2050	✔✔ Reduction in oil products used by air transport by 65% (i.e. around 31 Mtoe) by 2050
Development of sustainable and cost-effective SAF pathways, taking a technology-neutral approach	✔ Advanced biofuels and RFNBOs emerge to the market earlier and account for the majority of SAF volumes by 2050	✔✔ A technological neutral approach allows advanced biofuels and RFNBOs to emerge on the market earlier and account for the majority of SAF volumes by 2050	✔ Advanced biofuels and RFNBOs emerge to the market earlier and account for the majority of SAF volumes by 2050	✔ Advanced biofuels and RFNBOs emerge to the market earlier and account for the majority of SAF volumes by 2050	✔ Advanced biofuels and RFNBOs emerge to the market earlier and account for the majority of SAF volumes by 2050	✔✔ A technological neutral approach allows advanced biofuels and RFNBOs to emerge on the market earlier and account for the majority of SAF volumes by 2050
Achieve a gradual and continuous uptake of SAF in line with the analysis underpinning the impact assessment accompanying the 2030 Climate Target Plan	✔✔ Share of SAF in the aviation fuel mix achieved (63% by 2050)	✔✔ Share of SAF in the aviation fuel mix achieved (63% by 2050)	✔✔ Share of SAF in the aviation fuel mix achieved (63% by 2050)	✖✖ The share of SAF use in the fuel mix of approx. 20% is significantly lower than the 63% objective	✔✔ Share of SAF in the aviation fuel mix achieved (63% by 2050)	✔✔ Share of SAF in the aviation fuel mix achieved (63% by 2050)
Ensure that airlines have access to SAF at airports	O Delivering SAF at all airports means additional logistical challenges in the first years	O Delivering SAF at all airports means additional logistical challenges in the first years	O Obligation on all traffic assumes equally challenging logistics in the first years	O Obligation on intra-EEA traffic assumes equally challenging logistics in the first years	✔ Flexibility on the supply means easier logistics in the first years	✔ Flexibility on the supply means easier logistics in the first years

Key: Impacts expected

✗✗	✗	O	✓	✓✓
Strongly negative	**Weakly negative**	**No or negligible impact**	**Weakly positive**	**Strongly positive**

Indicator	PO A1	PO A2	PO B1	PO B2	PO C1	PO C2
Ensure a level playing field between airlines	O All airlines expected to be treated equally by fuel suppliers. Moderate risk of competitive disadvantage with non-EU airlines on some international routes	O All airlines expected to be treated equally by fuel suppliers. Moderate risk of competitive disadvantage with non-EU airlines on some international routes	O All airlines expected to be treated equally by fuel suppliers. Moderate risk of competitive disadvantage with non-EU airlines on some international routes	✗ Risks of competitive distortion between EU airlines within the single market	O All airlines expected to be treated equally by fuel suppliers. Moderate risk of competitive disadvantage with non-EU airlines on some international routes	O All airlines expected to be treated equally by fuel suppliers. Moderate risk of competitive disadvantage with non-EU airlines on some international routes
Avoid carbon leakage resulting from fuel tankering	✗ Risks of fuel tankering for international traffic beyond 2035	✗ Risks of fuel tankering for international traffic beyond 2035	✓ Low risk of tankering due to SAF obligation on airlines	x Risks of fuel tankering for international traffic beyond 2035	✓✓ Very low risk of tankering as a result of jet fuel uplift obligation	✓✓ Very low risk of tankering as a result of jet fuel uplift obligation
Reduction of well to wing CO2 emissions from air transport compared to the baseline in 2050	✓✓ 115 Mt of CO2 emission reductions.	✓✓ 114 Mt of CO2 emission reductions	✓✓ 115 Mt of CO2 emission reductions	✗✗ 33 Mt of CO2 emission reductions	✓✓ 115 Mt of CO2 emission reductions	✓✓ 114 Mt of CO2 emission reductions
Reduction of external costs of CO2 emissions relative to the baseline, expressed as present value over 2021-2050 (accounting also for the increased external costs due to logistics)	✓✓ €86.2 billion (i.e. €86.5 billion reduction due to the SAF uptake and €0.33 billion increase due to logistics)	✓✓ €85.7 billion (i.e. €86.0 billion reduction due to the SAF uptake and €0.33 billion increase due to logistics)	✓✓ €86.4 billion (i.e. €86.7 billion reduction due to the SAF uptake and €0.33 billion increase due to logistics)	✓ €29.7 billion (i.e. €29.8 billion reduction due to the SAF uptake and €0.11 billion increase due to logistics)	✓✓ €86.3 billion (i.e. €86.5 billion reduction due to the SAF uptake and €0.23 billion increase due to logistics)	✓✓ €85.8 billion (i.e. € 86.0 billion reduction due to the SAF uptake and €0.23 billion increase due to logistics)
Reduction of external costs of air pollution relative to the baseline, expressed as present value over 2021-2050	✓ € 1.5 billion	✓ € 1.5 billion	✓ € 1.6 billion	✓ € 1.5 billion	✓ € 1.5 billion	✓ € 1.5 billion

Key: Impacts expected

××	×	O	✓	✓✓
Strongly negative	Weakly negative	No or negligible impact	Weakly positive	Strongly positive

Indicator	PO A1	PO A2	PO B1	PO B2	PO C1	PO C2
Benefits relative to the baseline (PV over 2021-2050)	✓✓ **€ 87.7 billion**	✓✓ **€ 87.2 billion**	✓✓ **€ 87.9 billion**	✓ **€ 31.2 billion**	✓✓ **€ 87.8 billion**	✓✓ **€ 87.3 billion**
Efficiency (values indicated represent NPVs over the reference period)						
Additional costs of jet fuel relative to the baseline, expressed as present value over 2021-2050 - passed through to consumers	× €103.5 billion Additional cost of supplying SAF	× € 88.3 billion Additional cost of supplying SAF	× € 102.7 billion Additional cost of supplying SAF	× € 14.7 billion Additional cost of supplying SAF	× € 103.5 billion Additional cost of supplying SAF	× € 88.2 billion Additional cost of supplying SAF
Reduction of operation and capital costs of air transport relative to the baseline, expressed as present value over 2021-2050	✓✓ - €83.9 billion	✓✓ - €74.4 billion	✓✓ - €83.5 billion	✓ - €35.6 billion	✓✓ - €84.0 billion	✓✓ - €74.5 billion
Additional costs of logistics relative to the baseline, expressed as present value over 2021-2050	O €0.27 billion Cost of logistics to supply SAF to all EU airports	O €0.27 billion Cost of logistics to supply SAF to all EU airports	O €0.27 billion Costs of logistics to upply SAF to all airlines	O €0.09 billion Low logistic costs due to lower levels of SAF supply	O €0.19 billion Transition period allows for improved logistics	O €0.19 billion Transition period allows for improved logistics
Impact on SAF producers – cost passed through to suppliers	× Total capital investments needed of € 10.5 billion	× Total capital investments needed of € 10.4 billion	× Total capital investments needed of € 10.4 billion	O Total capital investments needed of € 3.3 billion	× Total capital investments needed of € 10.5 billion	× Total capital investments needed of € 10.4 billion
Additional cost for consumers per ticket (i.e. increase in ticket prices relative to baseline in 2050)	× Low ticket price increase 8.2% by 2050	× Low ticket price increase 8.1% by 2050	× Low ticket price increase 8.2% by 2050	O Very low ticket price increase 1.7% by 2050	× Low ticket price increase 8.2% by 2050	× Low ticket price increase 8.1% by 2050

Key: Impacts expected

××	×	O	✓	✓✓
Strongly negative	**Weakly negative**	**No or negligible impact**	**Weakly positive**	**Strongly positive**

Indicator	PO A1	PO A2	PO B1	PO B2	PO C1	PO C2
Cost of uplift reporting for airlines relative to the baseline, expressed as present value over 2021-2050 - passed through to consumers	**O**	**O**	**O**	**O**	**O** Cost of uplift reporting €0.34 billion	**O** Cost of uplift reporting €0.34 billion
Costs for authorities (enforcement, verification and monitoring)	**O** Cost of monitoring and enforcement € 0.19 billion	**O** Cost of monitoring and enforcement € 0.19 billion	**O** Cost of monitoring and enforcement € 0.30 billion	**O** Cost of monitoring and enforcement € 0.19 billion	**O** Cost of monitoring and enforcement € 0.27 billion	**O** Cost of monitoring and enforcement € 0.27 billion
Costs relative to the baseline (PV over 2021-2050)	× **€ 20.1 billion**	× **€ 14.4 billion**	× **€ 19.8 billion**	✓ **- € 20.7 billion**	× **€ 20.3 billion**	× **€ 14.6 billion**
NPV	✓✓ **€ 67.6 billion**	✓✓ **€ 72.8billion**	✓✓ **€ 68.2 billion**	✓ **€ 51.8 billion**	✓✓ **€ 67.5 billion**	✓✓ **€ 72.7 billion**

The analysis above indicates that Policy Option B2 (which foresees a low biogenic context), does not manage to meet the objectives of the initiative in terms of SAF production capacity deployment or GHG emissions savings as foreseen in the CTP Impact Assessment. On the other hand, due to this lower usage of SAF, in this option there is less threat of depletion of relevant feedstock, and the feedstock used are the ones that are easiest and cheaper to retrieve, leading to higher emission reductions (2.29 tonnes of CO2eq per tonne of SAF used) and at a cheaper rate (€ 84 per tonne of SAF used) compared to the Policy Options with the high biogenic context.[91] This can be explained by the increased proportional use of the cheaper HEFA route in the SAF fuel mix in this Policy Option (due to the lower overall SAF usage). This is a major contributor to the more efficient performance of this Policy Option as despite the lower overall benefits yielded (€ 31.4 billion), significantly lower costs are incurred (€ -56.4 billion). This Policy Option may further cause market distortions due to the differences in fuel prices for intra- and extra-EU flights.

The POs with the high biogenic context offer the highest possible environmental benefits and reduction on GHG emissions and manage to promote the usage of SAF to meet the goals of the CTP also in terms of GHG emissions reduction. They also achieve the deployment of sufficient SAF production capacity in the EU to meet this obligation. In these POs, a reduction of 1.83 - 1.88 tonnes of CO2eq emissions is achieved for every tonne of SAF fuel used. Eventually they turn in net benefits between €148 and 153 billion. Albeit being less efficient in delivering GHG emission reductions, these Policy Options meet the objectives of initiative while still turning a positive net benefit balance.

Looking into the differences between the high biogenic context Policy Options, these relate mostly to how they administer the mandate. Specifically, the Policy Options A1 and A2 that deliver a mandate on suppliers, produce the lowest administrative burden, due to the limited number of obliged entities (only SAF suppliers). However, the lack of a transition period, would mean some inefficiencies will occur in fuel logistics as SAF will need to be transported from day one of the mandate implementation to all obliged EU airports compared to being delivered where it is most efficient. These Policy Options also induce the risk of carbon leakage through fuel tankering which can become a significant issue post-2030. Policy Option A2, provides some additional flexibility to suppliers in meeting their obligation with the SAF that are most efficient in delivering CO2 reductions brings thus the potential to boost further innovative developments in SAF production. Policy Option A2 also brings slightly lower impacts (by 0.2% p.p.) to the aviation sector activity, as it allocates sustainable aviation fuels with lower cost than Policy Option A1. This leads also to a slightly more positive impact on employment as less aviation jobs are lost.

Policy Option B1 delivers a mandate to all air transport providers flying both intra- and extra-EEA flights. This larger group of obliged bodies increases the cost to administer the mandate for authorities and potentially also for users. The lack of a corresponding mandate for suppliers brings a potential risk to the capacity of air transport service providers to supply with the SAF content needed in all airports. The lack of a transition period would also here mean some inefficiencies will occur in fuel logistics as SAF will need to be transported from day one of the mandate implementation to all obliged EU airports compared to being

[91] Policy Options A1, A2, B1, C1 and C2

delivered where it is most efficient. Including all flights in the mandate overcomes the risk of carbon leakage through fuel tankering although it may cause some coherence issues as described below. The volume-based mandate does not bring long-term incentives for further innovation developments In SAF production.

The Policy Options that bring an obligation to suppliers while at the same time boosting demand by introducing a fuel uplift obligation to users (C1 and C2) produce the highest administrative burden due to the need to monitor both. This includes the highest number of obliged entities. Nevertheless, these Policy Options ensure that there is no discrepancy between the SAF supply and the quantities of SAF required by users. These Policy Options also deliver on preventing the risk of carbon leakage through fuel tankering with the introduction of the fuel uplifting obligation. The introduction of the ten years transition period enables the most efficient delivery of SAF in the early period of deployment. Similarly, to Policy Option A2, Policy Option C2 provides additional flexibility to suppliers in meeting their obligation with the SAF that are most efficient in delivering CO2 reductions brings thus the potential to boost further innovative developments in SAF production. Policy Option C2 also brings slightly lower impacts (by 0.2% p.p.) to the aviation sector activity, as it allocates lower costs sustainable aviation fuels than Policy Option C1. This leads also to a slightly more positive impact on employment as less aviation jobs are lost.

All Policy Options lead to relatively low administrative costs both for the Union and for the stakeholders involved in comparison with the size of benefits achieved.

The efficiency of all Policy Options to deliver on the objectives, will depend on the speed of technology maturity for a number of the production pathways. The extent of achieving SAF cost compression via technology learning and economies of scale of SAF production will impact the overall performance of the Policy Options with the impact for all Policy Options expected to be in the same direction. Further, developments in other industries vying for the same feedstock resources will be detrimental in the development of the costs for the advanced biofuels used.

b. Coherence

In assessing the coherence of the proposed Policy Options, we considered the following aspects:

- Internal coherence of the requirements
- Coherence in relation to relevant EU policies

Internal Coherence

Policy Options C1 and C2 provide the best possible internal coherence as they match the supply side obligation with the demand side. This ensures that the SAF volumes produced by suppliers are then indeed taken up by air transport service providers. Furthermore, the introduction of the fuel uplifting obligation eliminates the risk of carbon leakage through fuel tankering. Policy Options A1 and A2 instead run the risk of carbon leakage as there will be a financial incentive for fuel users to avoid supplying fuel in the EU when the SAF content obligation increases post 2030. Policy Option B2 does not cover all the transport activity necessary to meet the objectives of the initiative and it leads to considerable shortcomings in achieving GHG reductions.

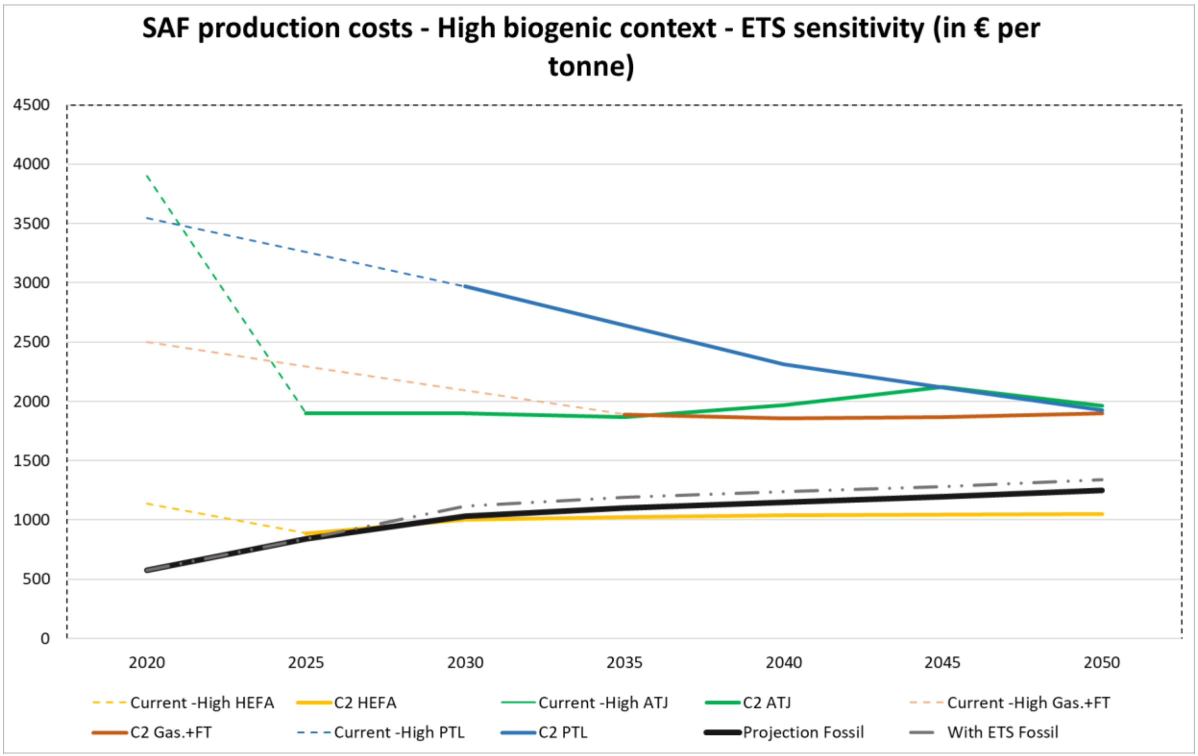
Coherence with relevant EU policies

With the exception of Policy Option B2, all other options are in line with the overall EU policy objectives in matters of GHG emission reductions from aviation and the use of SAF as set out in the Climate Target Plan. They also deliver on the goal of reducing oil dependency from transport at the EU level as identified in the 2011 White Paper on Transport, the 2016 European Strategy for Low Emission Mobility and the 2018 “Clean Planet for All” Long Term Strategy. They further meet the objectives of promoting the use of sustainable, low carbon fuels as one of the pathways available to decarbonise the transport sector as identified in the European Green Deal which recognises the importance of increasing the production and deployment of sustainable alternative transport fuels and makes this one of the priority areas for action.

All Policy Options are also coherent with other elements of the EU legislative framework. To define the types of SAF eligible by this initiative (advanced bio-kerosene and synthetic fuel), it relies on the sustainability framework of the Renewable Energy Directive 2001/2018 and Policy Options A1, A2, C1 and C2 rely on the reporting framework produced by this Directive (Union Database) to efficiently report on the supply side obligation. The Policy Options that bring a user side mandate (B1, B2, C1 and C2) also use the ETS reporting framework to fulfil their reporting obligation although the two will need to be made coherent in terms of reporting fuel GHG on the basis of Well-to-Wing (WTW) emissions.

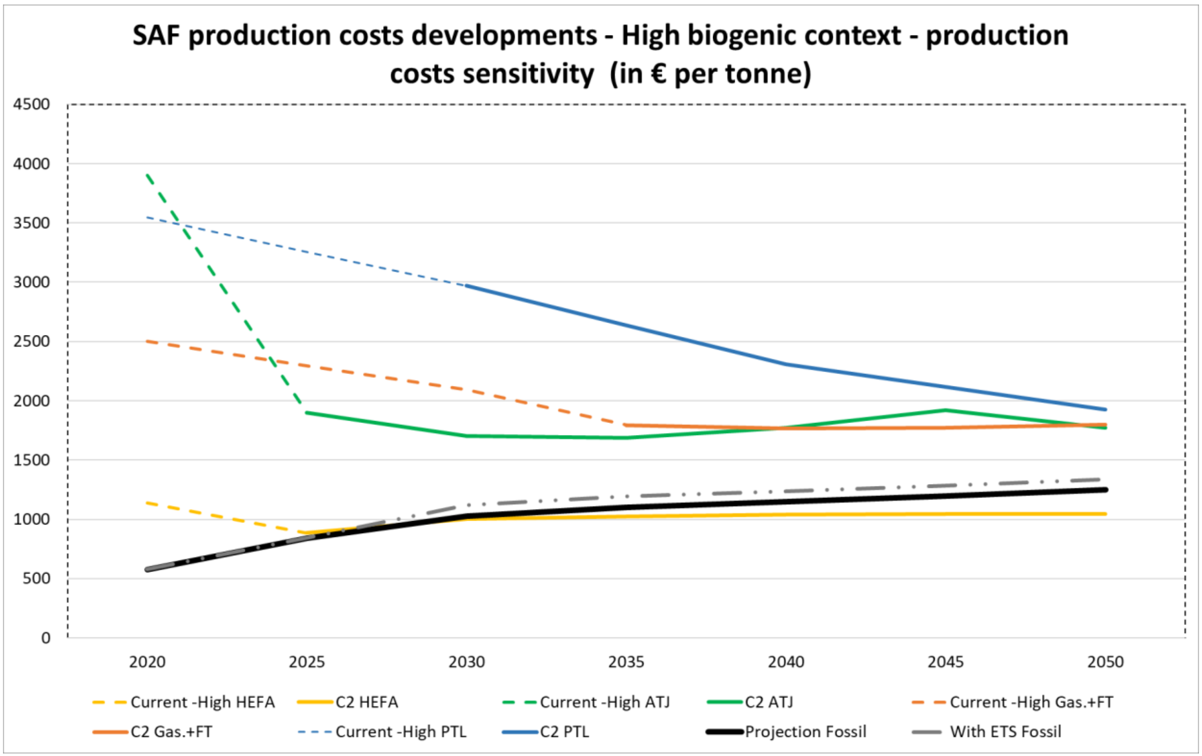
Finally, all Policy Options take a step in reducing the price gap between SAF and conventional fossil fuel to ensure SAF fuel competitiveness. This is not sufficient to make SAF fully competitive to conventional fossil fuel. This objective can be further met if supported with the revision of the Energy Taxation Directive potentially bringing a tax on conventional fossil fuel and the possible increase in the prices of carbon allowance for aviation brought by the EU aviation ETS. In Figure 26, the modelled production cost developments of SAF production pathways are presented. The dashed lines refer to the theoretical/literature prices of fuels at times they are not fully commercially available. Given that the preferred option operates within the high biogenic context, the high literature estimates have been used assuming participation also of more expensive feedstock. A weighted average ETS mark-up is also produced for fossil fuel to align with the CTP expectation of an EU ETS allowances at the level of €44 per tonne of CO2 in 2030. This is 100% attributed to intra-EEA flights but only by 50% to extra-EEA flights. As can be seen, the aviation ETS helps narrow the gap with fossil fuel but falls short of making other production pathways as competitive as fossil fuel.

Figure 26: Production cost development for SAF production pathways – Sensitivity with ETS (in € per tonne of fuel)



In Figure 27, the additional sensitivity is performed where we expect also a sharper decrease in variable costs for AtJ and Gas+FT due to faster technology learning and economies of scale as presented in Figure 15. The combined effects of the cost reduction and the ETS allowance cost increase seem to achieve further price convergence by 2050.

Figure 27 Production cost development for SAF production pathways – Sensitivity with ETS and low production costs (in € per tonne of fuel)



c. Subsidiarity and proportionality

Currently, a number of EU Member States have announced or even implemented a SAF supply mandate. The development of mandates that are not necessarily coherent in their scope, fuels included and levels of ambition, risk creating a patchwork of regulations. This can distort internal competition and within which the administrative burden for industry to comply with all will be disproportionally high. Additionally, it is not expected that in the absence of an EU level action the ambition of EU policies in the area of climate change will be met. These combined justify an EU initiative in this field.

In terms of proportionality, none of the Policy Options goes beyond what is necessary to achieve the objectives. Policy Option B2, which has a reduced scope of application only to intra-EU flights, falls short of achieving the set of objectives. All Policy Options provide a reasonable period before the mandates enter into force considering the time needed to deploy the SAF production capacity needed. It also foresees additional time before mandating the introduction of synthetic fuels recognising the time needed for relevant technologies to mature.

Policy Options C1 and C2, provide additional flexibility to suppliers and users to meet the obligation in a flexible way at the early stage of application of the initiative accounting for the time needed to efficiently integrate SAF into existing fuel supply chains.

8. The preferred option and operational objectives

a. Preferred Policy Option

On the basis of the above analysis we conclude the Policy Options C1 and C2 better meet the initiative's objectives while delivering a higher level of internal and external coherence with the objectives of other relevant EU policies. They seem to be more effective and efficient as they manage to meet the initiative's objectives while also being proportionate by providing additional flexibility to the industry to meet their obligations over a ten-year transition period. They additionally take action to bring together both the supply- and demand-side obligation to further ensure internal coherence.

Between the two, Policy Option C2 achieves slightly higher net benefits and leads to slightly better results in matters of social impacts (employment and transport activity) while at the same time retaining an additional incentive for innovation setting the mandate target at a GHG level.

The other policy options are not considered preferable for the following reasons:

- Policy Options A1 and A2 introduce an issue of internal coherence as the incentives for SAF supply are not matched with equal incentives for demand, the possibility of fuel tankering may jeopardise the effectiveness of the initiative in the long term.
- Policy Option B1 is less proportionate and flexible in developing SAF supply chains due to absence of a transition period.
- Policy Option B2 does not contribute sufficiently towards the initiative's goals in matters of performance towards the objectives of the Climate Target Plan and are bit thus considered sufficiently effective to be the preferred option.

b. Operational objectives of the preferred Policy Option

For the preferred policy option (C2) we have also defined operational objectives derived from the respective specific objectives and reflect the nature and type of measures to be adopted as presented. We also identify relevant indicators to monitor their delivery.

Table 44: Objectives and monitoring indicators of the preferred Policy Option (C2)

Specific objectives	Operational objective	Indicator
Specific objective 1 Support large scale production in the EU of SAF with high sustainability potential, and ensure adequate levels of supply to the aviation sector at competitive costs	Increase the volume of SAF production capacity deployed in the EU	Volume of SAF production capacity (Mt) deployed in the EU for each production route
	Reduce the CO_2eq emissions per tonne of SAF	CO_2eq emissions per tonne of SAF for each SAF pathway AND Avg. CO_2eq emissions per tonne of SAF used in the avg. fuel mix
	Ensure that sufficient feedstock is available for SAF production in the EU	Portion (%) of EU-produced feedstock volume of each category used for SAF production (i.e. UCO, agri and forestry residues, municipal solid waste, energy crops, renewable energy, green hydrogen)

	Reduce over time the cost of replacing conventional jet fuel with SAF	Price gap between SAF-blend and conventional fuel
Specific objective 2 Ensure a gradual and continuous uptake of SAF with high sustainability potential by the aviation sector at competitive prices	Reduce the total CO_2eq emissions of aviation compared to conventional jet fuel	Total CO_2eq emissions from aviation
	Achieve the targeted SAF participation in the aviation fuel mix as in the CTP	Participation of SAF (%) in the aviation mix
	Reduce over time the fuel price for CO_{2eq} tonne avoided when replacing conventional jet fuel with SAF	Market price of CO_2eq emissions per tonne of SAF for each SAF pathway AND Market price of avg. CO_2eq emissions per tonne of SAF used in the avg. fuel mix

c. Impacts of the preferred Policy Option (C2)

For Policy Option C2, an overview of benefits is presented in Table 48, while Table 49 presents an overview of costs for this Policy Option.

Table 45: Format of presentation of benefits (in NPV) for the Policy Option C2

I. Overview of benefits (total for all provisions) – Preferred Options – C1 and C2 (relative to the baseline, expressed as present value over 2021-2050)		
Description	Amount	Comments
Direct benefits		
Reduction of air transport CO2 emissions (well to wing) in 2050 compared to the baseline	-60.8% (C1) -60.2% (C2)	Direct benefit to society at large. It is the effect of the increasing participation of sustainable aviation fuel in the aviation jet fuel mix, in replacement of fossil jet fuel.
Reduction of external costs of climate change from transport relative to the baseline; additionally, including the external costs of logistics (i.e. present value over 2021-2050)	€ 86.3 billion (C1) € 85.8 billion (C2)	
Reduction of external costs reduction of air pollution from transport activity	€ 1.5 billion (C1 and C2)	Direct benefit to society at large. This reflects a reduction of air pollutant emissions (CO, NOx, PM). It results from a decrease in air transport activity by 2050 relative to the baseline.
Increased use in air transport of innovative fuel technologies with high decarbonisation potential (expressed in % of the jet fuel mix by 2050, compared to the baseline)	(C1) RFNBOs: 27.9%; Advanced biofuels: 25.8% (C2) RFNBOs: 23.9% Advanced biofuels: 28.7%	Significant increase of participation in the jet fuel mix of innovative technologies with high decarbonisation potential. These technologies are brought to the market earlier than under the baseline scenario. Prices of RFNBOs and advanced biofuels decrease over time compared to the current estimates.
Indirect benefits		
Employment (net additional jobs in 2050 compared to the baseline)	202,100 jobs (C! and C2)	Increase in employment in the fuel industry compensates for employment reductions in air transport due to slight decrease of activity compared to the baseline.
Reduced dependence on oil imports in 2050 relative to the baseline	65% (i.e. -31Mtoe) (C1 and C2)	Benefits for the EU's energy security and trade balance. Reduction of oil imports used for air transport, as a result of a decrease in fossil jet fuel use by 65% in 2050 (i.e. 31Mtoe) relative to the baseline.
Share of SAF produced in the EU (expressed as a share of total SAF supplied in 2050)	92% (C1 and C2)	Benefits for EU renewable fuels' industry and the EU economy at large. 92% of SAF supplied and used in the EU will be produced in the EU. 100% of feedstock and renewable energy used for SAF production will be EU-sourced.

Table 46: Presentation of costs for the preferred option (recurrent costs introduced in NPV for 2020-2050)

II. Overview of costs – Preferred Option								
		Citizens/consumers		**Businesses**		**Administrations**	
		One-off	**Recurrent**	**One-off**	**Recurrent**	**One-off**	**Recurrent**
Compliance with mandate on SAF content	Direct costs	None		Capital investments in SAF production capacity by fuel producers € 10.5 billion (C1) € 10.4 billion (C2)	Additional cost of fuel for airlines € 103.5 billion (C1) € 88.2 billion (C2) Additional administrative costs for airlines for fuel uplift € 0.34 billion (C1 and C2)		
	Indirect costs	None	Increase of ticket prices by 8.2% (C1) and 8.1% (C2) by 2050, compared to the baseline		Additional SAF fuel logistics costs € 0.19 billion (C1 and C2) - relative to the baseline in present value over 2021-2050 Reduced capital and operational costs of air transport due to lower transport activity. € 84 billion (C1) € 74.5 billion (C2) - relative to the baseline in present value over 2021-2050		
Administrative and enforcement costs	Direct costs	None		Cost for non-EU airlines to link to the new reporting stream on jet fuel uplift - Negligible	No additional costs. Fuel suppliers report in Union database.		Admin costs for Member States EUR 264 million (relative to the baseline in present value over 2021-

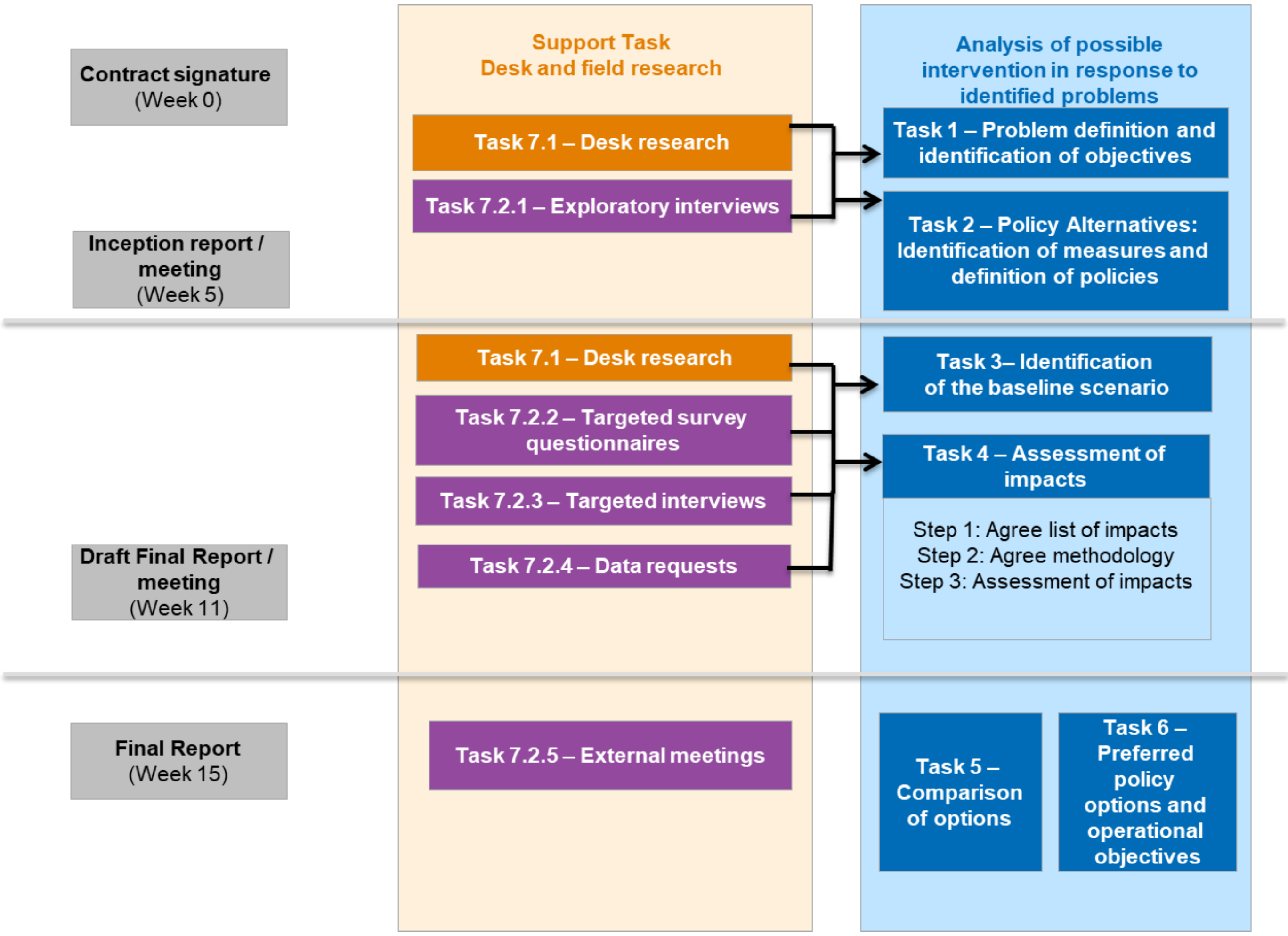
II. Overview of costs – Preferred Option							
					EU airlines report in the EU ETS.		2050) Admin costs for EU authorities €2.7 million (relative to the baseline in present value over 2021-2050)
	Indirect costs						
Fuel uplifting requirement	Direct costs				Air transport service providers report fuel uplift via the EU ETS (for intra-EE flights) or a new reporting stream (for extra-EEA flights) - €335 million per year	IT costs to set up of reporting stream	Costs to monitor and enforce compliance with the requirement (included in the above)
	Indirect costs						

9. Annex 1: Method/process followed

The work was divided into two parts: The **Analysis of possible intervention in response to identified problems (impact assessment related tasks),** and a **Support Task (Task 7 – Evidence collection phase).** Figure 6 provides an overview of the methodology for this study and indicates how the tasks were linked together.

Analysis of possible intervention in response to identified problems included all the tasks intended to support the Impact Assessment for a possible intervention in line with the better regulation guidelines.

Figure 28.1: Overview of the evaluation methodology



- **Task 1: Problem definition (Task 1.1) and identification of the initiative's objectives (Task 1.2)**, to agree on the key problem areas and drivers that require a policy response, and establish the overall objectives of the intervention;
- **Task 2: Policy alternatives: Identification of policy measures (Task 2.1) and definition of Policy Options (Task 2.2),** to identify and develop a full list of possible measures, screen them into a short-list of measures and define packages of policy measures (Policy Options);
- **Task 3: Identification of the baseline scenario**, to define using a combination of quantitative and qualitative analysis the no policy change scenario that will be used as the basis to assess the alternative Policy Options;

- **Task 4: Assessment of impacts**, to assess and/or quantify the impacts of the Policy Options against the baseline (no-change) scenario;
- **Task 5: Comparison of options**, to bring the evidence together and provide an assessment of the preferable policy measures/options;
- **Task 6: Preferred Policy Options and operational objectives,** to identify (if appropriate) the preferred Policy Option and develop an appropriate monitoring framework (including the definition of operational objectives and relevant indicators).

A Support Task included all the activities to collect relevant evidence to support the work under the first two strands.

Task 7: Evidence collection, will run throughout the course of the study and feed into the other tasks of the study.

a. Desk research and data collection

The desk research continued throughout the course of the study to support the different stages of the analysis and help address any gaps in evidence. Assembling the evidence was important to triangulate our findings, inform and support the analysis of all the other tasks, and cross-check input from stakeholders. As a basic principle, the preference was to use quantitative data such as the one used by the Commission. This included, e.g., the most recent Statistical Pocketbook and Eurostat data (for transport activity and energy use in transport).

General desk research

We have used evidence collected from literature (studies, reports, articles) to support our analysis in most of the tasks.

As part of this task we reviewed critical literature highlighted in the ToR and expanded this to include other key publications that the team identified by means of web searching and literature reviews conducted during relevant previous projects as well as from literature provided by stakeholder contacts. The available sources were linked to the various tasks and/or problem areas, providing an overview of data availability and a basis for refining the methodological approach for the different tasks.

The general desk research continued following the submission of the inception report and throughout the course of the study. The review followed an iterative process, with the list of references continuing to grow as new data and evidence are identified.

To ensure a structured, consistent and efficient approach to reviewing the literature we have used a structured database in spreadsheet format that allowed us to easily access the required information by means of efficient search/filtering functions. We collected the following bibliographical data for each of the literature sources identified:

- Basic information about the specific source reviewed (e.g. source ID number, title, author(s), type of study (e.g. evaluation, IA, etc), organisation sponsoring the study, date of publication, link to the source).
- Identification of relevance by reference to the topic covered (e.g. biofuels, electrofuels).
- Identification of relevance to the impact assessment by the problem area(s) the source is more relevant to.

Data collection

In addition to the input from the literature we identified relevant data from data sources that could supplement the analysis under the different tasks. As noted, as a basic principle, the preference was to use quantitative data such as the one used by the Commission.

Table 47: Data sources and quantitative data provided

Source	Quantitative Indicators (Unit)
DG MOVE Statistical Pocketbook 2020	1. Employment by Mode of Transport (in 1000) 2. Transport performance (Passenger-km) 3. Biofuels production (Kilo-tonne of Oil Equivalent KTOE) 4. GHG emissions by mode (Million Tonnes CO_2 Equivalent) 5. CO_2 emissions by mode (Million Tonnes) 6. Transport Fuel Taxes (% of GDP)
Eurostat	7. Number of aviation and airport enterprises (avia_ec_enterp) 8. Employment in aviation and airport enterprises (avia_ec_emp_ent) 9. Air passenger transport by reporting country (avia_paoc) 10. Freight and mail air transport by reporting country (avia_gooc) 11. Airport traffic data by reporting airport and airlines (avia_tf_apal) 12. Environmental tax revenues (env_ac_tax) 13. Complete energy balances (nrg_bal_c)
Eurocontrol	14. Weekly assessments of the traffic situation in Europe, with a comparison to the same period in 2019 15. EUROCONTROL Draft Traffic Scenarios
European Alternative Fuels Observatory	16. Biofuel consumption by type 17. Biofuel feedstock 18. Biofuel production capacity utilisation

b. Field research

As part of the study a number of the stakeholder consultation activities were carried out as part to confirm the problem definition and to assess the potential impacts of a number of policy measures which aim to address issues identified in the problem definition.

The consultation activities included:

- Four exploratory interviews with one each of national authority, European organisation, SAF producer and an airline. Interviews were conducted between 27 July 2020 and 11 August 2020.
- 18 targeted interviews (out of 20 planned) with a selected number of stakeholders representing the views of EU institutions, national authorities, air transport service providers, airports, fuel and feedstock producers and others conducted by Ricardo that took place during the period 19th August 2020 to 11th September 2020 (the programme was extended for some stakeholders who were not available during this period);
- A survey open to all relevant stakeholder groups was launched on 19th August 2020 and was open for responses until 9th September 2020 (3 weeks). A brief extension was provided to stakeholders to respond to the survey until the 18th September 2020. This report includes feedback from responses 21 received within the 3 first weeks of the survey;
- Consultation activities carried out by the Commission which includes a feedback period in the context of the inception impact assessment from 24 March 2020 to 21

April 2020 (4 weeks) and an open public consultation (OPC) from 5 August 2020 and was open for responses until 28 October 2020 (12 weeks).

Further details and outcomes of the activities are detailed in Annex 2 – Stakeholder Consultation Report.

c. Analytical methods/Model

General methodological approach

For the quantification of the Baseline and the Policy Option scenarios, first the PRIMES-Aviation submodule was used in order to simulate in detail the changes in the travel demand induced by the changes in the cost of fuels driven, for example, by blending mandates. For this step, an initial set of assumptions on the biokerosene prices was used. Subsequently, the PRIMES-TREMOVE model was used in order to assess the impacts in all transport segments. The demand for biokerosene that was estimated using PRIMES-TREMOVE, was provided to the PRIMES Biomass supply model. The model was used to estimate the price of biokerosene that reflected the production costs based on the deployed biokerosene production pathways.

The price of biokerosene is based on the PRIMES Biomass supply model for two groups of scenarios that depend on the demand levels of biokerosene over time: the high biokerosene demand scenario is representative for Policy Options A1, A2, B1, C1, and C2 and the low biokerosene demand scenario is representative for Policy Option B2. This distinction is necessary since Policy Option B2 considers mandates only at the intra-EU aviation, leading to substantially lower demand for SAF and biokerosene compared to the rest of the Policy Options. Biokerosene production costs are estimated based on feedstock costs, annualised capital investments (considering the utilisation of each conversion technology in each time period), operational expenditures (fixed and variable costs). Fixed operating costs include account for the operating and maintenance supplies, labour, taxes, overhead and administration costs. Variable costs include energy costs, and process inputs such as enzymes, catalysts, hydrogen and non-energy utilities (e.g. water, waste treatment). The price is then determined based on a profit margin for the producer.

The iterative process of the model runs was then repeated once again, Subsequently, the price of biokerosene was introduced to the PRIMES-Aviation submodule, re-iterating the PRIMES-TREMOVE and PRIMES-Biomass model runs in order to provide the quantified output for each scenario.

Methodological note on Policy Option C

In Policy Option C, during a transition period that lasts until 2035, it is assumed that fuel suppliers may organise their logistics, distributing the jet fuel blend to different airports in the most cost effective way, while meeting an overall blending mandate for sustainable aviation fuels at an EU level, whether prescribed (as in Policy Option C1) or determined on the basis of GHG emission intensity of the fuel blend (as in Policy Option C2). In 2030, the SAF fuel supply in each airport may range between 0% and 50%, and in 2035 between 2% and 50%. The scenario assumes that the largest airports, and those with proximity to blending facilities will be supplied with most of the jet fuel blends. After the transition period, the EU-wide blending mandates apply also to individual Member States.

As such, the distribution of the sustainable advanced fuel blends up until 2035 will differ per Member State. For the development of this scenario, the EU27 blending share for biokerosene and synthetic kerosene is distributed among the different Member States, in line different weighing factors for key indicators (Table 48). In this respect, a multicriteria analysis has been employed, in which the different Member States score differently on the two criteria considered. The criteria are then weighted to derive a single metric so as to rank the various Member States in terms of their overall performance. The weighting factors were determined based on information deriving from questionnaires submitted to fuel suppliers. [92] In this way, the present analysis associates the weights with information from the actual decision makers. As a proxy for the size of airport hubs, passenger air traffic in each Member State is used, based on EUROSTAT data for 2019. As a proxy for proximity to blending facilities with biokerosene, it is assumed that it is more likely these to be developed in areas where there is feedstock availability. Feedstock production data for biomass feedstock availability per Member State where used as a proxy, based on PRIMES Biomass. In 2030, availability of UCO is assumed to be the key feedstock and for years leading to 2050, the proximity to solid biomass is prioritized. Ultimately, based on the weighing factors and the data for each Member State, the scoring matrices presented in Table 42 and Table 43 where used to distribute the fuel blends across Member States.

Table 48 Weighing factors for different assessment criteria used for the distribution of jet fuel supply to different Member States

Indicator	2030	2050
Availability of UCO	50%	-
Availability of Solid biomass feedstocks	-	25%
Synthetic kerosene production	-	25%
Passenger traffic in airports	50%	50%

Table 49 Scoring matrix for the distribution of jet fuel blends to different Member States in 2030

	Proximity to feedstock			Airport traffic	Total score
	UCO	Solids	E-fuels		
DE	2.5	0	0	2.5	5.0
FR	2.5	0	0	2.5	5.0
IT	2.5	0	0	2.5	5.0
ES	2.5	0	0	2.5	5.0
SE	2.5	0	0	2	4.5
PO	2	0	0	2.5	4.5
NL	2	0	0	2	4.0
BE	2	0	0	1.5	3.5
AT	2	0	0	1.5	3.5
RO	2	0	0	1.5	3.5
PT	1.5	0	0	2	3.5
EL	1.5	0	0	2	3.5
DK	1.5	0	0	1.5	3.0
FI	1.5	0	0	1.5	3.0
I£	1	0	0	2	3.0
CZ	1.5	0	0	1	2.5
HU	1	0	0	1	2.0
BG	1	0	0	1	2.0
HR	1	0	0	1	2.0

[92] Responses received from BP, Fulcrum, Nest, Shell and SkyNRG representing both SAF and conventional fuel suppliers

	Proximity to feedstock			Airport traffic	Total score
	UCO	Solids	E-fuels		
SK	1	0	0	0.5	1.5
CY	0.5	0	0	1	1.5
LT	0.5	0	0	0.5	1.0
LV	0.5	0	0	0.5	1.0
SI	0.5	0	0	0.5	1.0
LU	0.5	0	0	0.5	1.0
EE	0.5	0	0	0.5	1.0
MT	0.5	0	0	0.5	1.0

Table 50 Scoring matrix for the distribution of jet fuel blends to different Member States in 2050

	Proximity to feedstock			Airport traffic	Total score
	UCO	Solids	E-fuels		
DE	0	1.25	1.25	2.5	5.0
FR	0	1.25	1.25	2.5	5.0
IT	0	1.25	1.25	2.5	5.0
PL	0	1.25	1.25	2.5	5.0
ES	0	1	1.25	2.5	4.8
SE	0	1	1.25	2	4.3
RO	0	1.25	1.25	1.5	4.0
PT	0	0.5	1.25	2	3.8
FI	0	1	1.25	1.5	3.8
IE	0	0.5	1.25	2	3.8
NL	0	0.25	1.25	2	3.5
AT	0	0.75	1.25	1.5	3.5
EL	0	0.25	1.25	2	3.5
DK	0	0.5	1.25	1.5	3.3
HU	0	1	1.25	1	3.3
BE	0	0.25	1.25	1.5	3.0
CZ	0	0.75	1.25	1	3.0
BG	0	0.75	1.25	1	3.0
HR	0	0.75	1.25	1	3.0
LT	0	1	1.25	0.5	2.8
LV	0	0.75	1.25	0.5	2.5
CY	0	0.25	1.25	1	2.5
SK	0	0.5	1.25	0.5	2.3
EE	0	0.5	1.25	0.5	2.3
SI	0	0.25	1.25	0.5	2.0
LU	0	0.25	1.25	0.5	2.0
MT	0	0.25	1.25	0.5	2.0

Cost of SAF logistics

The required distribution of SAF to Member States (as presented in Table 57 and Table 49) is different from the economically more beneficial distribution presented in Table 50. In the later, SAF would be used flexibly to fulfil SAF obligations of suppliers across the EU expecting the obligated parties to make the more economically beneficial choices. This means SAF supply lines would be developed earlier to supply either airports with large jet fuel demand, economic logistics or those in proximity to SAF production (and feedstock) capacity.

By comparing the optimal and obliged allocation of SAF supply to different EU Member States under the different Policy Options, we can identify the additional logistical effort required to meet the mandate obligations. The calculation of the additional capacity assumes that countries presenting with a larger than obliged SAF usage in the optimal SAF allocation scenario, have a production surplus while countries that have a lower usage have a SAF production deficit. Table 51 presents the estimated SAF surplus and deficit for different Member States. Additional logistical costs may also be induced within each Member State, however, the working assumption is that within each country, SAF supply is expected to enter the conventional fuel supply chain with a reasonable level of logistic costs as more difficult to reach airports are exempt from the mandate obligation.

Table 51: SAF surplus and deficit under the different Policy Options (comparison with flexible allocation) – in thousand tonnes

	PO A1			PO A2			PO B1			PO B2			PO C1			PO C2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
AT	-11	-17	-41	-11	-17	-42	-11	-17	-42	-3	-5	-13	0	-17	-41	0	-17	-42
BE	-21	-47	-121	-21	-47	-121	-21	-47	-121	-7	-15	-39	0	-47	-121	0	-47	-121
BG	-9	-18	-22	-9	-19	-22	-9	-18	-22	-3	-6	-7	0	-18	-22	0	-19	-22
CY	-15	-43	-45	-15	-43	-45	-15	-43	-45	-5	-14	-15	0	-43	-45	0	-43	-45
CZ	-11	-26	-34	-11	-26	-34	-11	-26	-34	-3	-8	-11	0	-26	-34	0	-26	-34
DE	83	137	322	83	138	323	83	140	327	26	45	106	0	137	322	0	138	323
DK	-21	-32	-59	-21	-32	-59	-21	-32	-59	-7	-10	-19	0	-32	-59	0	-32	-59
EE	-3	-7	-8	-3	-7	-8	-3	-7	-8	-1	-2	-2	0	-7	-8	0	-7	-8
EL	-18	-28	-68	-18	-28	-68	-18	-28	-68	-6	-9	-22	0	-28	-68	0	-28	-68
ES	64	112	125	64	112	125	64	110	122	20	35	40	0	112	125	0	112	125
FI	-14	-16	-20	-14	-16	-20	-14	-16	-20	-4	-5	-7	0	-16	-20	0	-16	-20
FR	63	107	217	63	108	218	64	109	220	20	35	71	0	107	217	0	108	218
HR	-5	-12	-14	-5	-12	-14	-5	-12	-14	-2	-4	-5	0	-12	-14	0	-12	-14
HU	-8	-17	-16	-8	-17	-16	-8	-17	-16	-2	-6	-5	0	-17	-16	0	-17	-16
IE	-21	-26	-35	-21	-26	-35	-21	-25	-34	-7	-8	-11	0	-26	-35	0	-26	-35
IT	41	75	154	41	75	155	41	74	153	13	24	49	0	75	154	0	75	155
LT	-5	-10	-9	-5	-10	-9	-5	-10	-9	-1	-3	-3	0	-10	-9	0	-10	-9
LU	-25	-59	-68	-24	-59	-68	-25	-59	-68	-8	-19	-22	0	-59	-68	0	-59	-68
LV	-6	-13	-13	-6	-13	-13	-6	-13	-13	-2	-4	-4	0	-13	-13	0	-13	-13
MT	-8	-22	-24	-8	-22	-24	-8	-22	-25	-3	-7	-8	0	-22	-24	0	-22	-24
NL	-24	-27	-179	-25	-27	-180	-25	-27	-180	-8	-9	-58	0	-27	-179	0	-27	-180
PL	0	8	30	0	8	30	0	8	30	0	3	10	0	8	30	0	8	30
PT	-20	-16	-45	-20	-16	-45	-20	-17	-46	-6	-5	-15	0	-16	-45	0	-16	-45
RO	-5	-5	-9	-5	-5	-9	-5	-5	-10	-2	-2	-3	0	-5	-9	0	-5	-9
SE	0	8	-10	0	8	-10	0	8	-10	0	2	-3	0	8	-10	0	8	-10
SI	-1	-3	-4	-1	-3	-4	-1	-3	-4	0	-1	-1	0	-3	-4	0	-3	-4
SK	-2	-4	-5	-2	-4	-5	-2	-4	-5	0	-1	-2	0	-4	-5	0	-4	-5

Total SAF transported	**252**	**447**	**849**	**251**	**448**	**851**	**252**	**449**	**852**	**80**	**143**	**276**	**0**	**447**	**849**	**0**	**448**	**851**

Source: Own calculations based on PRIMES TREMOVE and PRIMES Biomass model outputs

To calculate the additional logistical effort of transporting SAF between Member States, we have allocated the SAF surplus from the net-supplier to the net-user Member States (see Table 23). Excess supply has been distributed starting from the net-supplier countries that have less available markets of net-user countries in proximity and then progressively moving to allocate the excess SAF supply of countries with more access. Average Member State distances have been used from the TERCET database (European Commission, 2020) to both indicate SAF supply Origin-Destination pairs of Member States and to also account for the average distances SAF fuel would need to be transported.

In calculating the cost of fuel logistics, the usage of 35 tonne trucks is assumed with a diesel consumption of 35 litres per 100 km (Lloyd, 2019) resulting in a fuel consumption of € 1.07 per 100 tonne-km. Other truck operating costs are derived from the average road freight transport costs as estimated for the countries exporting SAF in the national reports issued by CNR (Comité national routier, 2019). External costs of these additional logistics operations are calculated on a tonne-km basis using the unit value for external costs of freight transport as estimated in the 2019 Handbook on external costs (European Commission, 2019).

10. Annex 2: Stakeholder Consultation Report

1. INTRODUCTION

The Commission contracted Ricardo and its partners Oeko Institute and E3M to conduct a "Study supporting the impact assessment of the RefuelEU Aviation Initiative" (hereafter, the 'study') for the Directorate-General for Mobility and Transport (DG MOVE), (contract reference MOVE/E1/SER/2020-219/SI2/831457) between July and December 2020. The study supported the European Commission's Impact Assessment of the ReFuel initiative by looking into policy options that can be applied to support the large scale production and use of Sustainable Aviation Fuel (SAF) of high sustainability potential in the EU at competitive prices. As part of the study the Commission and the study team have actively engaged with stakeholders and conducted comprehensive consultations.

2. STAKEHOLDER GROUPS PARTICIPATING

The consultation activities included:

- An inception impact assessment (IIA);
- Exploratory interviews with one of each of the following stakeholder groups: national authority, international/European industry organisation, SAF producer and an airline;
- An open public consultation (OPC);
- A targeted stakeholder survey;
- Targeted interviews with a broad range of stakeholders;
- A roundtable workshop with industry stakeholders and Member State representatives organised by the Commission
- A follow up survey to the roundtable workshop to conclude the preferred policy options of stakeholders

Table 52 provides an over of the stakeholder groups that participated in the study. A number of annexes supplement this report with an in-depth assessment of the stakeholder participation and outcomes for each of the consultation activities.

Table 52: Stakeholder participation in consultation activities

Stakeholder category	IAA	OPC	Interviews	Survey	Workshop	Follow up survey
EU institutions and international industry organisations	4	2	2	2	2	2
Member State authority	8	14	3	11	20	8
Fuel producer	46	37	7	13	14	11
Airline	11	24	5	19	12	10
NGO	8	13	2	1	2	1
EU citizens	2	0	0	0	0	0
Other[93]	34	66	2	27	16	10
N/A	4	4	0	0	0	0
Total	**117**	**160**	**21**	**73**	**66**	**42**

[93] Including airports, aircraft manufacturers, air navigation service providers, aerospace research centres, employees, trade unions or professional organisations

3. METHODOLOGY

3.1. Feedback on the Inception Impact Assessment

The Commission's inception impact assessment (IIA) open public consultation was open from 24 March 2020 to 21 April 2020 (four weeks). The Commission received 117 responses to the IIA within the consultation window from EU institutions and international organisations, Member States/national authorities/Civil Aviation Authorities, Air transport service providers or representative organisations, Fuel and feedstock producers, suppliers and retailers or representative organisations, NGOs, Other (including airports, aircraft manufacturers, air navigation service providers, aerospace research centres, employees, trade unions or professional organisations) and members of the public. Stakeholders represented 20 countries, including 14 EU Member States[94].

In general, stakeholders welcomed the Commission's initiative on SAF.

3.2. Exploratory interviews

In order to get early involvement of key stakeholders in the study, four exploratory interviews were conducted between 27 July 2020 and 11 August 2020 with the objective to help ensure that all issues that could be relevant to the problem definition and the definition of the policy measures/options are correctly identified early in the process, as well as supporting in identifying all relevant information sources for the study. Furthermore, these interviews were carried out concurrently to the process of designing the draft survey questions and interview guides, and as such the feedback from these stakeholders was incorporated into these tools.

The exploratory interviews were carried out with a national authority (France), European/international organisation working on aviation fuel policy (World Economic Forum), a SAF producer (Neste) and an airline (KLM).

3.3. Open public consultation

The objective of the open public (OPC) consultation was to collect stakeholder views on draft policy measures and policy options of this Commission's initiative. It aimed to gather information on the policy context, verify the problems faced by the sector and obtain the opinion of stakeholders on the appropriateness and expected impacts of possible policy measures to address those problems. The OPC was open from 5 August 2020 until 28 October 2020 (12 weeks).

A total of 159 stakeholders contributed directly to the OPC, as well as a written contribution from an air transport service provider. Responses were received form respondents residing or based in 14 EU Member States (Austria, Belgium, Finland, France, Germany, Hungary, Ireland, Italy, Malta, the Netherlands, Poland, Portugal, Spain and Sweden) as well as Canada, Guinea, Hong Kong, Norway, Switzerland, the United Kingdom and the United States. Most responses were received by stakeholders from Germany (29), followed by Belgium (26), France (14) and Sweden (14).

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[94] AT, BE, DE, EL, ES, FI, FR, IE, IT, NL, PL, PT, SE and SK

3.4. Targeted survey

A survey was developed to obtain the views of a wide range of stakeholders, including national authorities and industry. In addition to enhancing our understanding of the problems, obtaining stakeholder views on the initiative objectives and relevant policy measures, this survey was used to gather information from individual organisations as well as from umbrella organisations representing specific stakeholder groups, about the expected effectiveness of the measures, relevant design options and other impacts related to the implementation of the different measures. It was also an opportunity to directly collect any quantitative information that might be required. The survey was open from 19 August 2020 until 28 September 2020 (six weeks), extended beyond the planned three weeks to allow for additional responses from Member States and other stakeholders to be submitted.

In total, 73 stakeholders submitted a survey response. Stakeholders were from Member States competent authorities (11), fuel/feedstock producer or representative organisation (13), Air transport service provider or representative organisation (19), Other aviation industry representative (15), EU or international orgaisations (2), NGOs (1) and other (12).

Responses were received from stakeholders represneting organisations from 15 EU Member States (Austria, Belguim, Bulgaria, Cyprus, Czech Reoublic, Finland, France, Germany, Ireland, Italy, Latvia, the Netherlands, Portugal, Spain and Sweden) as well as Brazil, Canada, Egypt, Norway, Switzerland, the United Kingdom and the United States.

3.5. Targeted interviews

Targeted interviews were conducted by the study between 19 August 2020 and 9 October 2020 to obtain specific input from stakeholders to validate the identified problems and proposed policy objectives as well as to seek their views on specific aspects and expected impacts of different policy options.

21 interviews were carried out with the aim of covering the full range of interested stakeholders. Interviews were carried out with one EU institution (anonymous), one EU body (anonymous), three Member State/national authority (Netherlands, Poland, anonymous), six air transport service providers and presentative organisations (Lufthansa, EBAA, IATA, three anonymous), one organisation representing airports (ACI), six organisations representing fuel and feedstock producers, suppliers and retailers (FuelsEurope, Sunfire, VDMA, SkyNRG, two anonymous), three NGOs (ICCT, T&E) and one academic institution(anonymous).

The interview questionnaires for each stakeholder group followed the same set of core questions with additional questions tailored for each group, providing a framework of subjects that are most relevant to the individual stakeholder.

Some of the interviews were followed up by a further email questionnaire to obtain further information on specific points. These were aimed at ICCT, World Economic Forum and fuel/feedstock producers.

3.6. Stakeholder workshops

On 10 November 2020, the European Commission held the second roundtable discussion on SAF. Participants from industry and Member States were invited to discuss the potential impacts of different policy options, which were based upon variants of a blending mandate with supporting measures. In total, 45 industry organisations and 20 Member States were represented (Austria, Belgium, Bulgaria, Cyprus, Czech Republic, France, Finland, Germany, Hungary, Ireland, Italy, Latvia, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Spain and Sweden). In the first part of the workshop, industry stakeholders were invited to indicate a preference for policy options presented, providing justification, and to explain the potential impacts of specific mandate criteria. The second session was for Member States representatives only, who indicated their preference by reflecting on the earlier discussion.

3.7. Follow up survey

As a follow-up to the roundtable, the study team distributed a survey to consolidate the preferences of relevant stakeholders regarding the presented policy options. The survey was distributed on 13 November 2020 and was open for responses until 18 November 2020. The objective of the survey was to acquire a conclusion to the discussions held at the workshop and allow participants to provide their final views on the ReFuelEU aviation initiative.

In total, 42 organisations contributed to the survey including eight EU Member States authorities (two representing Spain, one representing Italy, and the remaining contributors wished to remain anonymous).

3.8. Limitations

The objectives of each consultation activity have been largely achieved. The information collected corresponded in general to the objectives and expectations of the consultation activities defined for each stakeholder group, although in some cases quantitative information was not provided.

All relevant stakeholder groups have been represented but only 22 EU Member States have been represented (absent Member States are Croatia, Denmark, Estonia, Lithuania, and Slovenia). Furthermore, a significant proportion of Civil Aviation Authorities (CAA) were from north western Europe. As such, a complete overview of perspectives of CAA from across EU27 has not been possible.

Other limitations identified with the consultation are:

- The time period in which the consultation activities were carried out was shorter than what would have been optimal.
- The assessment of impacts occurred prior to the packaging of policy measures into policy options and as a result stakeholders commented on individual measures, rather than the combined effect of packages in the interviews and initial survey. However, policy options were tested as part of the round table workshop and follow up survey.
- Another important consideration relates to the outlook and trends of SAF pathways, we found that the responses from fuel/feedstock producers were occasionally influenced by their position, interest or preference for particular SAF pathways.

4. SUMMARY OF INPUT

Stakeholders provided significant input that helped validate the definition of the problem and development of policy options. The sections below summarise the input provided across all stakeholder consultation activities. Input came primarily from the OPC and targeted consultation activities and was validated through the IIA feedback and workshop.

4.1. Current situation and policy context

Of those airlines and airports responding to the targeted survey, less than half (eight out of 19 airlines and two out of six airports) responded that either they use advanced biofuels or electro-fuels for commercial operations. Responses in the targeted survey and targeted interviews suggested there is no geographical region where advanced biofuels or electro-fuels are being used more than others. When asked what percentage of fuel volumes are currently SAF, a total of nine industry stakeholders (seven airlines and two airports) provided responses ranging from less than 0.1% up to 1%.

However, the importance of SAF is widely accepted as 148 of 160 respondents in the OPC indicated that SAF is relevant for decarbonisation of the aviation sector and 112 respondents believe that significant SAF uptake is needed prior to 2030 in order to achieve climate neutrality by 2050. Despite this, only 74 respondents could provide an example of a successful introduction of SAF in air transport.

In terms of which specific SAF pathways are known to stakeholders, 55 of 73 respondents in the survey indicated they are familiar with Power-to-liquid (PtL) and Hydroprocessed Esters and Fatty Acids (HEFA-SPK), followed by Biomass Gasification + Fischer-Tropsch (Gas+FT) and Co-processing oils/fats with 53 and 52 positive responses, respectively. Only 37 of 73 stakeholders were familiar with Catalytic Hydrothermolysis (CHJ). For most of the production routes, fuel/feedstock producers had the greatest share of respondents that were familiar with that particular route. Exceptions to this were Hydroprocessed fermented sugars to synthetic Isoparaffins (HFS-SIP) and CHJ, for which other aviation industry representatives showed the highest level of familiarity, and PtL, which was best known by stakeholders from the other category.

4.2. Problems

In the survey, 65 of 73 stakeholders identified '*production and supply of SAF at reasonable costs in the EU is limited'* as an issue hindering the use of SAF in the EU and 48 of 73 similarly identified that '*demand for SAF is low in current market conditions'* as an issue. Considering both statements, there was comparatively more agreement with the initial statement concerning production across all stakeholder categories. Nonetheless, the results from these targeted survey questions indicate that the use of SAF in the EU has been hindered due to issues on both the production and demand side.

When exploring specific challenges for the production and uptake of SAF, 69 of 73 respondents in the survey either agreed or strongly agreed that '*high market prices of SAF compared to conventional jet fuel'* are an issue with stakeholders indicating a price difference between 1.5 tosix times the price of fossil jet fuel depending on the pathway. Furthermore, airlines noted further strain has been placed on the price differential challenge as a result of Covid-19. Similarly, 134 of 160 respondents in the OPC ranked the importance of this issue as four or five (on a scale of one to5). The price gap between SAF and conventional fuel was by far the greatest challenge raised by stakeholders on the uptake side in the IIA feedback. Without other incentives, airlines are not motivated to purchase SAF and will never be motivated for as long as the price gap remains so high.

In the survey, the second most significant challenge identified was '*high upfront capital and operational costs for novel conversion processes at an early commercial stage'*, with 62 of 73 stakeholders agreeing or strongly agreeing. This is in line with the OPC results where the second most significant issue was '*excessive production cost* and *high investment risk in SAF* *plants'*. This is evidenced by the limited production capacity in Europe, indicating that a small number of facilities are operating at commercial scale. In the IIA feedback, the most significant production cost raised by stakeholders related to the building of first-of-a-kind (FOAK) facilities, hence driving up the price of their offtake once they become active and hampering their ability to reach the critical mass of profitability.

61 of 73 respondents in the survey also identified '*lack of clear policy signals and limited impacts of existing legal framework for the aviation sector'* as a challenge, including stakeholders from both the production and demand side. From the production side, the absence of long-term policy in the EU drives producers to focus on the existing road market and on the demand side airlines noted the need for policy instruments to reduce the price differential. The absence of a regulatory framework and the lack of incentives were also a common barrier for stakeholders in the IIA feedback as the necessary confidence for major investments in large scale SAF production is challenging due to difficulty in building a business case that is competitive with traditional fuel.

Price volatility of feedstock (an important part of the final fuel cost) was also a commonly cited barrier to the production of SAF in the IIA feedback. This contributes to the market uncertainty and acts as a disincentive to invest.

The other key challenge identified by 59 of 73 survey respondents was '*competitive air services market with low margins'*, although all other challenges identified still had more than half of respondents either agreeing or strongly agreeing. However, in the OPC there were several challenges that were not seen as important including '*lack of relevant infrastructure', 'lack of certainty on the environmental added value of SAF'* and '*lack of technically mature SAF technologies'* with only 27, 32 and 40 of 160 respondents rating the importance four or 5, respectively.

4.3. Supply and distribution of SAF

Response to the targeted survey indicated that air transport service providers are more likely to either regularly or frequently '*supply fuel directly from fuel producers at each airport'* (eight out of 19); '*supply fuel from the airport operators at each location*' (six out of 19); or '*supply fuel from intermediaries that do not produce fuel themselves (fuel distributors)*' (six out of 19).

In a follow-up survey with fuel producers specifically focusing on SAF supply and distribution, stakeholders were clear that blending should happen prior to supply at the airport and is generally done either at the refinery or a pre-airport fuel terminal. As blending takes place in the storage tank, there is no specialised infrastructure required beyond that present in the regular jet fuel system. Blending is either done by the SAF producer or by the fuel supplier responsible for distributing the jet fuel.

Stakeholders have reported a limitation in using the NATO-operated Central European Pipeline System (CEPS) to supplying SAF to airports. The general understanding is that not all NATO members have approved the use of SAF within their military hardware, and so CEPS cannot approve any SAF in the system. Neste understand that the formal reason is that one or a low number of older military aircraft have not been approved for SAF blends by their manufacturers, and that some decision makers from the national military organisations (notably Germany) regard this as a reason to not authorise CEPS for SAF blends. To lift the restriction, Germany needs to give their approval.

In the case of an obligation for suppliers to distribute a quota of SAF to all EEA airports, there was some dispute over whether this would be technically feasible with the current infrastructure. Neste and BP stated that it is feasible, although it would rely on long supply chains, while another fuel/feedstock producer stated that the only barrier is the NATO pipeline challenge. SkyNRG explained that it is only feasible with NATO CEPS approving SAF and modifications to existing terminals to install blending facilities since these are nonstandard for most terminals.

In terms of cost, BP have estimated logistics costs to be as high as $500 per tonne of SAF delivered for certain supply chains with long truck legs. However, this cost would largely be borne by more remote regional airport, with major airports able to be supplied as low as $10 per tonne.

The majority of stakeholders in the OPC (102 of 160) indicated that '*policy action at EU level to take into account the logistics and infrastructure of SAF supply'* is either relevant or very relevant.

4.4. Outlook and trends

Over half of the respondents in the OPC (97 of 160) believe that uptake of SAF will increase by 2025 under the current conditions, while 51 respondents indicated that SAF uptake would not deviate from the current levels. Similarly, in the survey, stakeholders believe that SAF will account for 1% of aviation fuels in 2025. However, stakeholders see this figure increasing to 20%-35% by 2050, with fuel/feedstock producers holding the most optimistic view.

In the OPC, 63 respondents indicated that *synthetic fuels*[95] are the most promising liquid SAF versus 31 respondents selecting *advanced biofuels*[96]. However, 62 stakeholders answered with *other,* arguing that both types of fuel are needed to decarbonise the aviation sector noting that advanced biofuels should be used in the near-term, while synthetic fuels are needed in the longer term.

This was in line with the survey responses where fuel/feedstock producers identified many SAF routes as important for decarbonisation, namely *HEFA-SPK*, *Co-processing oils and fats*, *PtL*, *Gas + FT* and *AtJ*[97]. Amongst the fuel/feedstock producers interviewed, there was a general consensus that the importance of each pathway will evolve over time. Specifically:

- HEFA-SPK is viewed as important now but is not considered to be as important in the future
- Gas + FT and AtJ will be important in the short to medium term
- PtL is promising in the medium to long-term

In terms of availability of feedstock, stakeholders identified *renewable energy*, *vegetable and animal lipids* and *solid waste* as being the most available. Conversely, *microalgae oils* are seen to be the least available. For HEFA which is commercially available now, feedstock

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[95] Synthetic forms of kerosene made through the conversion of hydrogen to hydrocarbons.

[96] Fuels that can be manufactured from various types of non-food biomass.

[97] All fuels listed come under advanced biofuels, with the exception of PtL, which is a synthetic fuel.

availability is limited. Waste oils, which provide the feedstock in the HEFA process, are already utilised in high quantities to produce road fuels and current EU demand has already necessitated imports from abroad, leading to some allegations of fraud. For *Gas+FT*, lignocellulosic wastes, residues and energy crops have some existing uses, but there are large quantities in the EU that could be available for SAF production without displacing other uses or causing indirect GHG emissions. Electrofuels have low water and land-use requirements but are constrained by price and availability of renewable electricity. Furthermore, they require a carbon source, which in the future will have to be derived from direct air capture.

Stakeholders from both the targeted survey and targeted interviews agreed that the SAF costs are highly dependent on the production route but, in general, the costs consist of CAPEX for the production plant and the OPEX costs for the production inputs including feedstock, (renewable) electricity and CO_2. For HEFA-SPK fuels, the costs are 80-90% driven by the cost of feedstock, as used cooking oil and vegetable oil are expensive and the primary contributor to the levelised fuel cost. The cost drivers for producing electro-fuels are the high levelised costs of energy and the costs for electrolysis, as well as CO_2-capturing and purification. The costs for the other production routes are primarily driven by the upfront capital expenses for conversion facilities.

Stakeholders in the interview and survey were not clear on the certification process and there were some varied responses with regard to requirements, cost and timeline. While fuel/feedstock producers recognised the importance of safety and certification, there was a shared view that the current process is too lengthy, costly and there is some ongoing duplication.

4.5. Policy objectives

In the survey 63 out of 73 stakeholder responses indicated that they either agreed or strongly agreed with the proposed policy objective A[98]. In the targeted interviews, three fuel/feedstock producers and two NGOs stated that 'high sustainability potential' needs to be precisely defined to only consider fuels that meet sustainability standards that provide long-term certainty.

66 out of 73 survey respondents also indicated that they either agreed or strongly agreed with the proposed policy objective B[99]. Interviewees were also in agreement with this policy objective, although one national authority noted that competitive prices will be difficult to achieve without large amounts of subsidies.

In the OPC 101 out of 160 respondents stated that they believe that EU level regulatory intervention is best suited to achieve decarbonisation objectives, followed by international level intervention (by ICAO) with 41 respondents in support.

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[98] Policy objective A is defined as 'Support large scale production in the EU of SAF with high sustainability potential and ensure adequate levels of supply to the aviation sector at competitive costs'

[99] Policy objective B is defined as 'Ensure a gradual increase in the uptake of SAF with high sustainability potential by the aviation sector at competitive prices'

4.6. Policy Measures

Respondents in the survey indicated that funding measures would be the most effective for achieving both policy objectives. '*Funding in support of SAF production deployment'* was seen to be successful for achieving policy objective A and B by 62 and 61 of 73 respondents and '*Funding in SAF research & development'* was seen to be successful for achieving policy objective A and B by 66 and 53 of 73 respondents. Stakeholders believe that this would address the issue of excessive production costs and facilitate the commercialisation of SAF technologies and pathways, as well as promote new technologies for the long-term.

In line with the survey responses, 125 of 160 stakeholders in the OPC ranked the importance of '*encourage investments and make use of public financial instruments'* as four or five[100], followed by '*accelerate research and innovation in new SAF'* (111).

In the survey, most stakeholders were of the opinion that a blending mandate would be either somewhat or highly successful in achieving policy objectives A and B (60 and 53 of 70, respectively). More than half of the 160 stakeholders in the OPC (93) ranked the importance of this measure as four or five (out of a scale of one to five). It can be concluded that, while increased funding has the greatest support, a blending obligation is supported by a majority of stakeholders. Nonetheless, several concerns were raised by stakeholders in the surveys and interviews including competition distortion, only current technologies being used and passing on current high costs onto consumers resulting in a fall in demand. In the roundtable discussion, the need for a blending mandate was recognised and supported by the vast majority of participants. A number of Member State experts argued that an EU mandate should be the minimum level of mandate and that Member States should be allowed to put forward more ambitious targets themselves. In general, respondents in the IIA feedback also agreed with the implementation of a blending mandate, with proponents arguing that mandates have proven to be effective and are quick to implement.

The only other policy measures that had a high level of support in the OPC were '*support and facilitate approval processes for fuel producers'* (92 out of 160) and '*provide specific incentives to use SAF, such as multipliers'* (81 out of 160). However, all other policy measures given in the survey were seen to be either somewhat or highly successful in achieving both policy objectives by more than half of respondents, indicating that all types of policy intervention would be welcomed by stakeholders and successful to some degree. Furthermore, the IIA feedback, the OPC and interview responses all indicated that a combination of policy measures are necessary to achieve increased production and uptake of SAF.

Other policy measures suggested as supportive measures in the targeted interviews include feed-in-tariffs, contracts-for-difference, adjustments to the certification process, carbon pricing, loan guarantees and ticket taxes.

4.7. Mandate specifications

In the case of a mandate being applied, more survey respondents indicated support or strong support for the supplier being the obligated party (45 of 73), compared to the user (36 of 73) and the producer (30 of 73). Arguments for an obligation on the user included the

[100] Out of a scale of one to five where one is the least important and five is the most important

sustainability of the fuel would be prioritised and issues of tankering are more easily avoided, while support for an obligation on the supplier was justified by the fact it is a proven concept that applies in sectors where mandates already exist and it would be easier to manage due to a smaller number of suppliers. Other potential obligated parties suggested in the survey included national authorities, fossil fuel production and supply base, or multiple parties. In the OPC, however, an obligation on both the production/supply side and aviation demand side had the greatest support with 57 of 160 respondents in favour versus an obligation on the production/supply side with 36 and an obligation on the aviation demand side with 28. Many participants of the roundtable indicated a preference for the obligation to be on fuels suppliers only, while some also argued for flexibility for suppliers to organise their fuel distribution at airports of their choice to avoid unnecessary logistics constraints, additional costs and emissions related to the transport of SAF to all airports. However, other stakeholders argued that blending upstream in the value chain would have little impact on logistical costs. Nonetheless, there were participants in favour of a mandate on airlines and a mandate on both parties, although there some discussion over whether the later would introduce unnecessary complexity.

In terms of the scope of a mandate (i.e. covering intra-EEA and extra-EEA flights), there was no clear trend emerging in the roundtable discussion. Some argued that a reduced scope of the mandate to cover only intra-EEA flights is not desirable as it would only cover around a third of overall EU emissions. Furthermore, it would apply to all flights of some airlines (e.g. Ryanair), while applying to only a fraction of flights of other airlines (e.g. KLM), which could lead to market distortions. On the other hand, a full scope obligation on all airlines would run the risk of being challenged by non-EU countries and airlines. Some argued that a full scope obligation on fuel suppliers would not pose the same issues, an option favoured particularly by NGOs. Some airlines or representative organisations recalled that a global approach to SAF should be the end goal.

Stakeholder views in the survey on the subject of the mandate target were similar for each option, with 47 of 73 supporting an obligation based on a GHG emissions reduction target versus 40 of 73 supporting a volume based SAF target. The key argument in support of the former is that it will incentivise the use of feedstocks and fuels that have the greatest GHG emissions reduction, while the latter is viewed as easier to measure and more likely to increase the availability of SAF at competitive prices. Furthermore, a percentage-based mandate would allow for easier implementation of sub-targets for certain categories of SAF. In the roundtable discussion, there was also a slight preference for a GHG-based target. It was also noted that this would require a more complex methodology for auditing and accounting. Of the stakeholders that made reference to the basis of the target in the IIA feedback, all preferred a GHG-based target.

There was very little difference in the survey between the support for all aviation fuel available at EU airports to contain a percentage of SAF versus a book and claim system with 38 and 37 of 73 indicating support, respectively. Air transport service providers, national authorities, fuel or feedstock producers and ‘other stakeholders’ were very in favour of the book and claim system citing is essential to build investment in SAF. They believe it is not important whether that individual batch of fuel is green, but that green energy is fed into the system where possible, as this also avoids unnecessary transport. However, national authorities argued that all aviation fuel should be sustainable at least to a certain degree as it creates a level playing field across Europe, booking can then be used by those who want higher levels than required. In the roundtable discussion, a book and claim system was deemed necessary by the majority of participants. It would allow airlines to purchase tradeable SAF certificates even if they do not have physical access to SAF at airports. It would also allow fuel suppliers to trade obligations in order to meet the obligation in the most cost-effective way. Tracing the exact fuel blend composition in each flight was considered to be a challenging exercise, however.

When asked in the targeted interviews about the target of the proportion of SAF blending in 2025, 2030 and 2040, most interviewees felt that a very gradual and flexible mandate would be the best to accommodate for any changes in technology, supply and demand. Lufthansa stated that a low single digit intermediate target is possible for 2025 (in the 1-2% range) and that by 2025 there will be a much better understanding of the commercially viable technologies available to make long term plans. Sunfire believes that by 2030 a target of 5% could be possible as the production pathways and plants would have matured along with the use of e-fuels. In the roundtable discussion, the proposed ramp-up[101] was generally supported, although some stakeholders argued for earlier and more ambitious targets. All stakeholders in the IIA feedback believe that the mandate should be harmonised at EU level as it would affect all airlines in the same way. It was also advised by NGOs and airlines that an EU wide blend mandate is announced at least three years in advance to allow airlines, airports, and other stakeholders time to prepare for SAF use and ideally this mandate should last for 10 to 15 years to generate confidence amongst investors and create an investible business case.

In the OPC 83 of the 160 respondents believe that it is relevant or very relevant to set sub-targets for the use of certain categories of SAF such as advanced biofuels or PtL fuels. In the roundtable discussion and interviews, some stakeholders stated that an e-fuels sub-mandate would be necessary in any case and that it could start as early as 2027. However, some Member State experts argued that a sub-mandate on e-fuels was premature. In addition, there were proponents for setting sub-targets for both REDII[102] Part A and Part B feedstocks.

In the roundtable discussion, penalties for non-compliance were deemed a key element of policy design by several participants. Some fuel producers explained that penalties act as a price ceiling and should be considered separate for specific sub-mandates. The need to think of the use of collected non-compliance fines was brought up and there was significant backing for the money to be redistributed to funding support for SAF. The same suggestion had been made in the targeted interviews and surveys.

4.8. Incentivisation of feedstocks

In the OPC 96 out of 160 respondents either somewhat agree or fully agree that the RED II framework ensures that SAF would achieve significant emissions savings compared to conventional jet fuel. However, in the IIA feedback, several stakeholders stated that the existing sustainability criteria in the REDII are insufficient due to the inclusion of unsustainable feedstocks in Annex IX part A and the absence of accounting displacement effects. In the SAF roundtable discussion, there was consensus on the use of the REDII

[101] The ramp-up for SAF as proposed in the workshop was: 2% for 2025 (advanced biofuel only); 5% for 2030 (sub-mandates of 4.3% for advanced biofuels and 0.7% for synthetic fuels); 20% for 2035 (sub-mandates of 15% for advanced biofuels and 5% for synthetic fuels);32% for 2040 (sub-mandates of 24% for advanced biofuels and 8% for synthetic fuels); 38% for 2045; (sub-mandates of 27% for advanced biofuels and 11% for synthetic fuels); 63% for 2050 (sub-mandates of 35% for advanced biofuels and 28% for synthetic fuels);

[102] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN

framework (or its successor) for sustainability. Some stakeholders stressed the need to align REDII sustainability framework for aviation biofuels with the CORSIA sustainability framework. This point was also highlighted by several stakeholders in the OPC and IIA feedback.

In the survey, 29 of 73 stakeholders believe that feedstocks in both Annex IX Part A & Part B should be incentivised, while 19 stakeholders responded that only Annex IX Part A feedstocks should be incentivised and only two stakeholders believe that only Annex IX Part B feedstocks should be incentivised. In the roundtable discussion, there was a general support for the choice of Part A, Part B and e-fuels. The bio-diesel industry (echoed by ICCT) voiced strong concerns on making Part B feedstock eligible (waste lipids), as this could displace it from road biofuel production and instead proposed to extend the scope to all waste and residues. Some fuel producers proposed to extend the scope to crop based fuels (except high indirect land use change (ILUC) crops), but this was strongly opposed by NGOs.

Many stakeholders in the survey were feedstock agnostic and stated that we should let the technology mature before funnelling investment into one area. Importance was placed on the ability to guarantee emissions savings. The aviation industry also only relies on one fuel so having a broad selection of sources to feed this is critical to scale up production.

In the OPC, 92 of 160 respondents indicated support for prioritising aviation for the access to feedstock and production of SAF.

4.9. Funding instruments

Concerning the funding instruments that could be used to help reduce the investment risk or bridge the price gap, the greatest support in the OPC was for an *EU Emissions Trading System Innovation Fund* with 89 respondents out of 160 ranking the importance either four or five[103]. Other funding instruments that were seen as important were *NextGenerationEU* (64) and *Horizon Europe* (63). A '*modulation of air traffic control charges under the Single European Sky to create a fund'* and '*an environmental levy on aviation'* were seen to be the least important, with 53 and 50 out of 160 respondents ranking these instruments one or two, respectively.

The responses in the survey were in line with those of the OPC, with the instruments receiving the greatest support being '*EU Emissions Trading System Innovation Fund', 'Horizon Europe'*, and '*a strategical industrial alliance bringing together all actors on the SAF value chain'* with 36, 33 and 33 of 73 respondents rating these four or 5[104], respectively. Again, an '*environmental levy on aviation'* was among the lowest scoring with 14 of 73 respondents rating this instrument four or 5. Other instruments with low scores were the *'Just Transition Fund*', '*Connecting Europe Facility'* and a *modulation of air traffic control charges under the Single European Sky to create a fund'* and with 12, 14 and 15 of 73, respectively.

[103] Out of a scale of one to five where one is the least important and five is the most important

[104] Out of a scale of one to five where one is the least important and five is the most important

4.10. Other considerations

In the OPC, 81 of 160 respondents indicated that the price gap (between SAF and conventional kerosene) should be borne by air passengers, followed by airlines (50) and public authorities (45). 62 stakeholders indicated that the price should be borne by more than one actor.

Some participants in the roundtable discussion pointed to the need for a robust monitoring, reporting and verifying (MRV) system to avoid double counting of SAF use. When asked in the survey to provide expectations of the time required to carry out reporting, respondents indicated minimal time, approximately one full time equivalent per year or less for both airlines and Member States.

4.11. Preferred policy option

In the follow up survey, A2 Flex was the policy option with greatest support with 23 of 42 respondents either supporting or strongly supporting this option (including six of 10 air transport service providers, two of 11 fuel/feedstock producers and five of eight Member States authorities) and was the only policy option with over half of respondents in support. This option also had the fewest respondent either opposing or strongly opposing (12 of 42 respondents).This was followed by A1 Flex with 20 of 42 respondents either supporting or strongly supporting this option (including six of 10 air transport service providers, two of 11 fuel/feedstock producers and four of eight Member States authorities). This indicates that a mandate on the suppliers with flexibility introduced is the preferred option for stakeholders.

For air transport service providers and Member State authorities, the most favoured option was A2 Flex (six of 10 and five of eight in support). However, for fuel/feedstock producers there was no clear preference.

5. IDENTIFIED CAMPAIGNS FOR CONSULTATIONS

In the IIA feedback there was a coordinated response from the biodiesel industry, with 15 fuel/feedstock producers submitting the same or similar responses. The main issue raised was that the inclusion of feedstocks used in waste-based biodiesel production in mandate or prioritisation measures would have a negative impact on small and medium sized businesses.

6. AD-HOC CONTRIBUTIONS

In the OPC, a total 11 position papers were received from air transport service providers, fuel/feedstock producers and an NGO. To supplement their interviews, ICCT and VDMA provided additional studies to support their arguments. Each position paper and study was taken into consideration.

7. HOW INFORMATION FROM CONSULTATION IS USED IN THE IMPACT ASSESSMENT

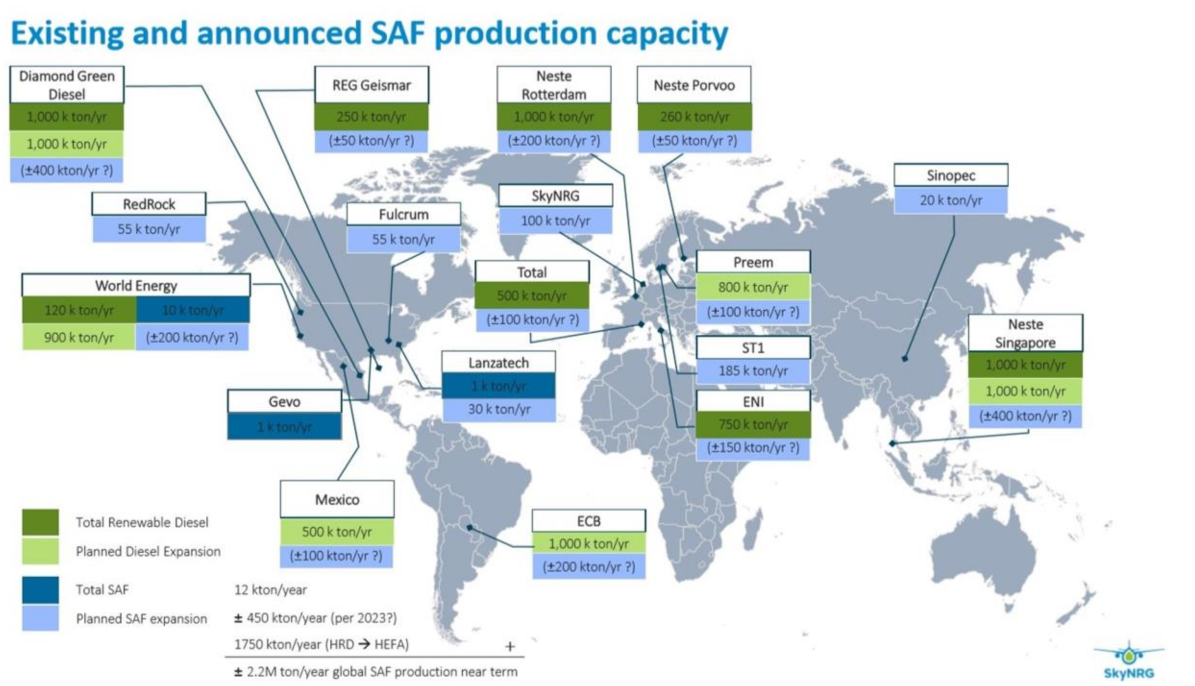
Following the closure of the targeted consultation and OPC, the results were considered as part of the problem definition, the identification of different measures and policy options as well as the analysis of impacts and the design of the preferred policy option, to ensure that the views of key stakeholder groups were accounted for in the context of the study. The consultation results were used to support the identification and quantification of impacts, building on the findings from the modelling activities and desk research conducted as part of this study. Where relevant, some of the charts referenced in Annexes A to C, and open text responses to the consultation activities, were incorporated into the Impact Assessment report.

11. Annex 3: SAF production routes

a. Advanced Biofuels

Despite the fact that a number of SAF production routes have been already developed, with some already certified for a number of years, the deployed production capacity is relatively limited. This means that information on the cost of SAF production mainly comes from less commercially mature installations. Nevertheless, a number of initiatives are either planned or under development with the expectation being that the capacity installed in the near future could potentially increase considerably. Still, the projected capacity could only provide for a small fraction of the EUs aviation fuel need. This would however by no means mean that this capacity would be exploited to actually produce SAF whereas it can be optimised to produce road fuel. Figure 29 presents the identified project plans, which have been researched for relevant information on the identified production routes.

Figure 29: Overview of existing and announced SAF production capacity



Source SkyNRG (ADS Group, 2020)

Hydroprocessed Esters and Fatty Acids (HEFA)

This route was certified by ASTM as HEFA-SPK. The fuel is produced by hydrotreating vegetable oils and animal fats and requires the use of hydrogen in the process. The process is the same as for Hydrotreated Vegetable Oil (HVO) but has an additional isomerisation step. HEFA-SPK is the only SAF currently used commercially (TRL 8-9, depending on sources) due to its simplicity and its low-cost production. The blend with kerosene is limited to 50%, which is the highest blend allowed under RED II. Feedstocks for HEFA production include soy, jatropha, camelina and used cooking oil. When these specific feedstocks are used, GHG emissions savings can respectively reach up to 20-54%, 37%, 46% and 69% (considering fossil jet GHG emissions of 87.5 gCO_2e/MJ) (Bosch, et al., 2017).

Hydroprocessing oils results in a product slate of various fuel types: road fuels (representing about 77% of the product mass), jet fuel (about 14%) and other products (about 9%) (ICCT, 2019). The amount of jet fuel produced through this process therefore highly relies on road fuel sales. The main limit to the development of this production route is that the feedstocks availability is limited by the competition between different markets and sustainability concerns (E4tech, 2019). Certain SAF producers[105] estimate that up to a third of the global aviation fuel production demand could be covered by the HEFA production route should the feedstock used not be constrained by the provisions of RED II - Annex IX. They further indicate that only about a quarter of this abides with the requirements set by the RED II - Annex IX, Part B provisions. This means that the totally exploitable SAF production through this route may suffice to cover only a relatively small part (approximately 8%) of the aviation sector fuel demand. Other estimates place this figure slightly higher with a ceiling of 5 million tonnes of production for this route from the used cooking oil practically available globally (12 Mt) assuming a share for SAF of the total biofuels output of 46% (World Economic Forum, 2020)[106,]. While some studies have suggested lower values for the global availability of UCO e.g. 7.8 Mt/yr in 2020, of which 3 Mt/yr would be within the EU (E4tech, 2014), or 10.1 Mt globally of which 2.3 Mt is within Europe (DBEIS, 2017). WEF suggest that additional feedstocks for HEFA such as animal fats (tallow) and oils from paper production, and by-products from corn and palm oil production, could also contribute to HEFA providing an additional 11-15 Mt of HEFA globally. It is also possible that in the future oils could be available also from ground covering oil plants that can be used as rotational cover crops, or oil bearing trees that can be grown on degraded soils, but successful cultivation of these has yet to be demonstrated fully[107].

The global capacity for HEFA production (including co-processing – see next section) is 5 million tonnes per year. However, in 2018, most of it was used for the road sector, with less than 0.1 million tonnes used for aviation. The lead SAF producer in Europe is Neste with an installed production capacity in Porvoo, Finland of approx. 100k tonnes/year and a much larger plant (200k tonnes/year) planned to start operating in Rotterdam in the near future. SkyNRG and other producers also plan new operations in the near future. With the right policies, the use of HEFA in aviation sector could compete with its use in the road sector.

The production cost of HVO ranges between €1,100 and €1,350 per tonne; because there is an additional isomerisation step in the process, a small additional cost is required to upgrade HVO to HEFA (Bauen & Bitossi, 2020). This is also confirmed by a SAF producer[108] indicating that SAF produced through the HEFA route is about three times more expensive than conventional jet fuel (estimated at €1,500 per tonne). EASA provides a somewhat lower estimation for the cost of HEFA-produced SAF at €950-1,014/tonne (EASA, n.d.). While the ICCT provides an estimation for the levelized cost of production for this production route to be between €1,100-1,250 per tonne depending on the feedstock used (for palm oil and used cooking oil respectively) (ICCT, 2019). WEF places the cost of HEFA through this production route at the area of €1,050 per tonne and projects it could become competiti9ve with fossil fuel and drop as low as €850 per tonne by the late 2030’s (World Economic Forum, 2020). SAF producers and other industry actors place the cost of SAF through this route to anywhere between 2 and 3 times the cost of conventional fossil fuel[109].

Co-processing oils/fats

Co-processing lipids (oils and fats) is already a mature pathway (TRL 8-9) and consists of processing lipids with fossil fuel in already existing refineries’ diesel hydrotreaters. The construction of new plants is therefore not necessary. Generally, the lipids co-feed percentages range from 5 to 10%. However, 30% was commercially achieved in special

[105] Interview with Neste

106 Input from Interview with WEF

107 Input from Interview with WEF

108 Interview with SAF producer Neste

[109] Interviews with SkyNRG and Neste

conditions (Concawe, 2019). This route is certified by the ASTM as D1655 and currently limits the co-feed of lipids with jet fuel to 5%. The process and feedstocks required for this route are quite similar to HEFA, so the same constraints apply to the resources' availability.

Direct Sugars to Hydrocarbons (DSHC)

This route is comprised of several sub-routes that all consist of having modified microorganisms converting sugars into hydrocarbons or lipids. One of them was certified by the ASTM as HFS-SIP, or Hydroprocessing of Fermented Sugars – Synthetic Iso-Paraffinic fuels. The blend of this fuel with kerosene is limited to 10%. The main resources required to produce HFS-SIP are conventional sugar (from sugarcane), used as feedstock, and hydrogen. The use of conventional sugar allows for up to 18% GHG emissions savings (considering fossil jet GHG emissions of 87.5 gCO_2e/MJ) (Bosch, et al., 2017). This production route is at TRL 7-8 but is only at TRL 5 when the feedstock consists of lignocellulosic sugars (E4tech, 2019). One important point to note is that the resulting product from this route can only be used for jet fuel, which implies the construction of new dedicated plants.

DSHC is a complex process and has a low efficiency. This results in higher feedstock cost and energy consumption, making this route one of the most expensive (more than EUR 4,000 per tonne). As of June 2019, operational plants had a global production capacity of about 35 kt/y. Additional plants with a total production capacity of 143 kt/y are also planned (Bauen & Bitossi, 2020).

Alcohols to Jet (AtJ)

This route, currently at TRL 6-7, is certified by ASTM as ATJ-SPK and consists of converting alcohol into jet fuel. The alcohol is the product resulting from the fermentation of sugar or starch crops (corn, sugarcane, wheat). Alternatively, the alcohol can also result from processed lignocellulosic feedstocks (agricultural and forest residues). Regardless of the feedstock used, hydrogen is required in the process. The certification currently limits the blend of alcohol in jet fuels to 50% (E4tech, 2019). When corn, corn stover and sugarcane are used as feedstock, GHG emissions savings of 37%, 60% and 70%, respectively, are made possible (considering fossil jet GHG emissions of 87.5 gCO_2e/MJ) (Bosch, et al., 2017). Several products are generated through this process: jet fuels, representing 74% of the overall product by mass, road fuels (7%) and other co-products (19%). Future AtJ plants will therefore be mainly dedicated to the supply of jet biofuel. Other AtJ routes have the potential to produce jet fuel containing aromatics. These routes are currently being thoroughly investigated so that certification of 100% use of the produced jet fuel is obtained. As of June 2019, the global production capacity was around 30 kt per year with 20 additional kt/y in commissioning and a 324 kt/y planned capacity (Bauen & Bitossi, 2020).

Studies have estimated the availability of relevant feedstock in the EU (Ruiz, et al., 2019) (European Commission, 2017) suggest that in 2050 feedstocks, suitable for the production of SAF via the AtJ or FT+Gas production routes, could have an energy content of 9 to 11.4 Exajoule (EJ) under a reference scenario, with more optimistic estimates (e.g. due to increased innovation) of 13.2 to 16.7 EJ. However, there will be competing demands for these biomass feedstocks, both for use for heat and power and for other biofuels production for the road transport sector, for segments such as heavy goods vehicles which like aviation have relatively limited decarbonisation options. In the power sector, there may be particularly strong demand for biomass for power plants equipped with carbon capture and storage, as these 'negative emissions' technologies are widely considered to be important in meeting net zero or other ambitious GHG reduction targets. In 2018, data from Eurostat suggests that 4.4 EJ of domestically produced solid biomass feedstocks, mainly wood, were used for heat and power production in the EU, which even if this did not increase, would reduce availability of these feedstocks for biofuels production to 4.6 to 12.3 EJ. The conversion efficiency of SAF production routes varies considerably between routes[110], but using an average value of 50% that might be achieved in the medium to long term, and assuming that two-thirds of the biofuels produced are SAF[111], this equates to between 1.5 to 4.1 EJ (34 to 93 Mt) of SAF from production routes using these feedstocks, if no additional biomass was used in BECCs.

To set this in context current aviation fuel consumption in the EU was expected to reach about 57 Mt in 2020. Globally, the ongoing work by WEF (World Economic Forum, 2020) suggests that these feedstocks could produce about 395 Mt of SAF providing a large part of the 410 Mt needed to cover the 2030 global aviation fuel needs. This means that these feedstock can potentially cover a considerable amount of the EU aviation fuel needs in the future but may fall short of covering the full needs of the sector while a large level of uncertainty remains as to the future availability of these feedstock for aviation vis-à-vis the needs of other sectors.

The ICCT estimates a current price of between €2,100 and €3,040 per tonne for SAF produced via this production route (depending on the feedstock, for sugars and starches and energy crops respectively) (ICCT, 2019). WEF on the other hand provides a lower estimate of approx. €1,800 per tonne with the potential to drop to about €1,275 in the late 2030's as the technology matures (World Economic Forum, 2020).

Biomass Gasification + Fischer-Tropsch (Gas+FT)

This route was certified by the ASTM as FT-SPK and currently stands at TRL 7-8. Biogas is obtained from the gasification of the feedstock followed by Fischer-Tropsch synthesis (E4tech, 2019). Blending is limited to 50%. Common feedstocks include energy crops (for example, miscanthus, willow, poplar), lignocellulosic biomass and solid waste. When energy crops are used as feedstock, GHG emissions savings can reach up to 85-90%, and can reach even higher levels (95%) when forestry residues are used (Bosch, et al., 2017). This technology mostly produces road fuels (51%), followed by jet fuel (24%) and other products (25%). The process' individual components have already been commercially demonstrated in biogas to heat and power applications and coal-to-liquid plants but scaling it up requires additional research and tests to make it economically viable. To reduce capital costs, this route could involve the production of FT waxes that could be co-processed in already existing refineries. As of June 2019, a production capacity of around 40 kt/y was under construction globally. Additional plants with a total of 215 kt/y production capacity are also planned (Bauen & Bitossi, 2020). The ICCT estimates a current price of between €1,675 and €2,225 per tonne for SAF produced via this production route (depending on the feedstock, for landfill waste and agricultural residues respectively) (ICCT, 2019). WEF's estimate is closer to the lower bound of this estimation with an approx. €1,785 per tonne with the potential to drop to about €1,275 in the late 2030's as the technology matures (World Economic Forum, 2020).

Biomass Gasification + FT with Aromatics

This route is a variation of FT-SPK and was certified as FT-SPK/A. It uses the same process and feedstocks as FT-SPK but alkylation of light aromatics is added to the process. This creates aromatic compounds that are then blended into the fuel. The blend ratio is limited to 50% (EASA, n.d.).

Catalytic Hydrothermolysis (CHJ)

110 See for example, IRENA, 2016 'Innovation Outlook Advanced Liquid Biofuels'

111 Based on assumptions in (World Economic Forum, 2020)'

In January 2020, CHJ was the 6th addition to ASTM D7566 Annexes that adhere to SAF specification (Greenair Online, 2020). Under the specification the fuel is limited up to a 50% blend with traditional jet fuel. Applied Research Associates (ARA) are the only producers of the fuel at their 4 barrel per day pilot plant and 100 barrel per day demonstration plant. The resultant fuel undergoes fractionation to create drop-in diesel and jet fuel that has been trademarked “Readijet”. ARA tested the fuel in flight the world’s first 100% biofuel demonstration flight in 2012. ARA state that, at a 100% blend, the fuel offers GHG emissions savings over 80% of traditional fuels (ARA, n.d.).

Much like HEFA, input feedstocks for the CH process consist of lipids such as animal tallows, used cooking oils, algal oils and seed oils (ARA, n.d.). The production pathway of CH fuel consists of three major steps. It starts with Catalytic Hydrothermolysis, where triglyceride oils, other esters or fatty acids are converted into iso-alkanes, cycloalkanes and aromatic compounds. In the next step, the material is mildly hydrotreated to saturate residual olefins and remove residual oxygenates, preserving aromatics and cycloparaffins. In the final step the output stream is distilled and fractionated into the final products of which kerosene is one (Deutsche Lufthansa AG; WIWEB, 2012).

The CH process faces similar challenges as the HEFA/HVO pathway regarding feedstock availability and sustainability because it uses waste and virgin vegetable oils. Additionally, the technology is still at demonstration stage and the fuel production cost is high relative to fossil jet (NREL, 2016, p. 99).

HEFA from algae - HC-HEFA-SPK

In May 2020, HC-HEFA-SPK was the 7th addition to ASTM’s list of fuels that adhere to SAF specification. Under the specification the fuel is limited up to a 10% blend with traditional jet fuel and is under consideration to be recognised by the CORSIA carbon scheme. IHI Group have developed a process to produce jet fuel from microalgae in partnership with the Japanese government agency New Energy and Industrial Technology Development Organization (NEDO) and Kobe University.

The jet fuel is produced at the site of a 10,000 m2 demonstration facility in Thailand. The plot size is to provide a large surface area to capture sunlight and carbon to grow a microalgae named Botryococcus Braunii. This species of algae is defined by its exceptionally high growth rate and high hydrocarbon oil content compared to other oil crops. The climate of Thailand has been found to be well suited for the culturing of algae, due to its long hours of sunlight and relatively even temperatures between day and night.

An analysis on a pilot-scale microalgae based HEFA facility in America provided cost estimates of $9.86/gal, 242% higher than conventional jet fuel. The study also found that lifecycle emissions of HC-HEFA-SPK are 64% lower than jet fuel (Ames, 2015).

The less commercially developed HC-HEFA-SPK route relies on the cultivation of a specific algae plant, something that is still at a pilot phase. However, if this can be demonstrated successfully at large scale, the potential for this route could be large. For example, one study estimated that between 0.7 and 6.6 EJ of algae feedstocks could be available in 2050 (European Commission, 2017), potentially contributing another couple of percentage points of the total fuel need in the EU. As algae would be grown specifically for biofuels production, competition from other sectors would be limited.

IHI have begun working with Showa Shell Sekiyu K.K. to develop solutions for various shipping and aviation fuels.

Summary

Table 53 presents a summary of the different advanced bio-fuels' main characteristics.

Table 53: Summary of certified advanced biofuels and their technological maturity

Route	Feedstocks	Certification	TRL	GHG emissions savings	Production capacity (kiloton/year)[112]
Hydroprocessed Esters and Fatty Acids (HEFA)	Vegetable and animal lipids	HEFA-SPK, up to 50% blend	8-9	20-69%[113]	Operational: 5,000 per year[114]
Co-processing oils/fats	Vegetable and animal lipids	D1655, 5 to 10% co-feed	8-9	n/a	See footnote 23
Direct Sugars to Hydrocarbons (DSHC)	Conventional sugars, lignocellulosic sugars	HFS-SIP, up to 10% blend	7-8 or 5[115]	18%	Operational: 35 Planned: 143
Alcohols to Jet (AtJ)	Sugar, starch crops, lignocellulosic biomass	ATJ-SPK, up to 50% blend	6-7	37-70%[116]	Operational: 30 In commissioning: 20 Planned: 324
Biomass Gasification + Fischer-Tropsch (Gas+FT)	Energy crops, lignocellulosic biomass, solid waste	FT-SPK, up to 50%	7-8	85-95%[117]	Under construction: 40 Planned: 215
Biomass Gasification + FT with Aromatics	Energy crops, lignocellulosic biomass, solid waste	FT-SPK/A, up to 50% blend	6-7	n/a	n/a
Catalytic Hydrothermolysis (CHJ)	Vegetable and animal lipids	CHJ, up to 50%	6	<80%[118]	n/a
HEFA from algae	Microalgae oils	HC-HEFA-SPK, up to 10% blend	5	n/a	n/a

b. Synthetic electrofuels

Fuel production pathways

Hydrogen production via electrolysis

For the market uptake of possible aviation electrofuels, it is relevant that today's global market for new electrolyser capacities is small. Only about 4% of today's global hydrogen demand comes from electrolysis, mostly a by-product of chlor-alkali electrolysis, which produces the commodity chemicals chlorine and (IRENA, 2018) sodium hydroxide for the industrial sector. The global market for new water electrolysers is estimated at around 100 MW per year (NOW GmbH, 2018)[119], so that there is currently no automation of electrolyser production. Despite the generally available technologies, a short time delay for the establishment of automated production processes may occur if the demand for electrolysers grows strongly in a short time.

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[112] Data available as of June 2019

[113] Varies based on feedstock: soy (20-54%), jatropha (37%), camelina (46%) and used cooking oil (69%)

[114] This is the global production of HEFA, of which only 100 kilotonne was produced for the aviation sector. This amount also includes the HEFA produced through the co-processing route.

[115] TRL 7-8 when conventional sugars are used as feedstock; TRL 5 when the feedstock consists in lignocellulosic sugars

[116] Varies based on feedstock: corn (37%), corn stover (60%), sugarcane (70%)

[117] Varies based on feedstock: energy crops (80-90%) and forestry residues (up to 95%)

[118] Applied Research Associates (ARA) states that, at a 100% blend, the fuel offers GHG emissions savings over 80% of traditional fuels

[119] The electrolysis capacity of 100 MW corresponds to approx. 0.04 kg of fuel production.

In principle, hydrogen can be produced via low-temperature electrolysis (LTEL) and high-temperature electrolysis (HTEL) with LTEL's technologies having a higher level of technical maturity. Alkaline electrolysis (AEL) is well established on the market (TRL 8-9) (Wuppertal, 2018), but polymer electrolyte membrane electrolysis (PEMEL) has recently undergone technical development (TRL 6-8)[120], gained attention and increased its market share (Schmidt, 2019). In contrast, the HTEL, which permits higher efficiencies (see later section on Energy efficiency of hydrogen production), but also requires a constant high-temperature (700 – 1000°C) supply and is significantly less dynamic in operation, is less developed. Solid oxide electrolysis (SOEL) is used in demonstration plants and literature rates the TRL as 4-7 (Skov & Mathiesen, 2017) (Wuppertal, 2018). However, a larger scale SOEL unit is planned as part of a first e-crude production in Norway (Holen, 2019). In contrast to the LTEL technologies, the feed stream of SOEL is superheated steam and not water. Process integration with an external heat source (e.g. from the exothermic synthesis processes) is therefore extremely useful for high energy efficiency of the process (see later section on Efficiency of total fuel production pathway). Co-electrolysis, in which syngas (CO and H2) is produced from CO_2 and water using electricity in one single process, is less developed and has not been demonstrated yet. This technology needs more research and development than the other technologies to become a realistic technical option for fuel production.

For integration into the power system, the partial load behaviour and the dynamics for load changes are of high importance for electrolysers. PEMEL have the largest operating range and the fastest dynamics (Schidt, et al., 2017) (FLEXCHX, 2018). They can change their load in the millisecond range and have an operating range up to almost 0% of the nominal load. AEL also have a wide operating range (minimum load approx. 10% of nominal load) and they can change their load in the range of seconds. With SOEL, the load range is smaller (30 - 50% of nominal load). The challenge for the SOEL technology is to maintain the temperature of 700 - 1000°C to avoid stress on the electrolyser materials due to frequent and rapid temperature changes. This may require electrical auxiliary heating with the corresponding energy demand in partial load ranges. Therefore, the cold start behaviour is considerably slower for SOEL than for PEMEL and AEL (several hours compared to minutes for SOEL) which might make electrical heating of the electrolyser necessary for very dynamic integration into the power system.

Synthetic electrofuel production via Fischer-Tropsch synthesis

The Fischer-Tropsch synthesis (FT synthesis) is a well-established synthesis process (TRL 9) (Skov & Mathiesen, 2017) which is used today when crude oil is not available as a feedstock for the production of fuels and other products for the chemical industry. If FT synthesis is to be used for the production of electric fuel, a mixture of different hydrocarbons is produced which is often referred to as e-crude to show the chemical similarity to crude oil. The feedstock input to the FT synthesis is a syngas, which consists to a large extent of carbon monoxide (CO) and hydrogen. The reverse water gas shift reaction (RWGS) is used to produce the syngas from carbon dioxide (CO_2) and hydrogen. This process is at a lower stage of development and is currently "only" shown in demonstration plants (TRL 5-6) (Schmidt, et al., 2016). The RWGS is therefore also the missing part of the overall process to produce fuels from electricity via the FT pathway on an industrial scale from a purely technical point of view. However, a first small industrial-scale electrofuel production site via the FT route has been announced to start production in the early to mid-2020s (Holen, 2019).

The composition of e-crude produced in FT synthesis can vary and be influenced by the operating parameters (e.g. pressure and temperature), the catalysts used (typically iron or cobalt based) and the composition of the syngas. The product share suitable for jet fuel is

[120] idem

about 30 to 60% (ICCT, 2019) (Schmidt, et al., 2016). Research on catalyst materials promises higher jet fuel selectivity of about 70% fraction for bifunctional catalysis which are at research stage (Li, et al., 2018). In the final processing step, the resulting mixture of different hydrocarbons can be upgraded to produce end products for various applications and sectors. The "business-as-usual case" would be upgrading in existing refineries, where fossil crude oil could be replaced with e-crude. The exclusive production of aviation fuels is therefore not possible, as by-products are always formed during their production.

A different approach[121] could be to optimise operation and design of FT synthesis to form high shares of hydrocarbon chains longer than kerosene. These long hydrocarbon chains could be processed to high jet fuel yields in the subsequent refinery process (i.e. hydrocracking and hydrotreatment). Jet fuel yields of approx. 90% from the overall process seem possible.

The system consisting of RWGS and FT synthesis cannot be operated very variably due to the complex process dynamics if a fixed defined e-crude is to be produced for upgrading or refining. For the production of electrofuel, therefore, it must be considered that FT synthesis has rather little possibility to adapt the operation parameters if a strong integration of the various processes is to be implemented. In particular when combined with electrolysers that react flexibly to the power system, hydrogen storage must be used for the rather constant operation of the synthesis process.

Synthetic electrofuel production via methanol synthesis

The hydrogen produced by electrolysis can also be further processed in methanol. There are two different processes for this. The standard process used today for methanol production (TRL 9) (Bruna & Jean-Michel, 2019) requires syngas as the material input, as does FT synthesis. RWGS, which has not yet been available on an industrial scale, is therefore also a missing process stage for this fuel production pathway. There is an alternative process which is currently available on a small industrial scale (TRL 6-7) (Carbon Recycling International, n.d.) and which can use carbon dioxide and hydrogen directly for methanol production. To produce aviation fuel, the methanol would have to be further processed into aviation fuel in an upgrading process. Although the necessary upgrading processes are used in today's refineries, this conversion step has not been shown yet (TRL 7-8) (Schmidt, et al., 2016). For this reason, kerosene via this production path has not been approved for use in aviation.

Similar to the FT synthesis, it can be assumed that the methanol synthesis process does not have a very large operating range at the present time. Therefore, hydrogen storage systems must be used for the flexible operation of the entire plant and the flexibility of a highly integrated plant is limited.

Carbon dioxide supply options

The carbon dioxide required for the production of synthetic electrofuels can come from a variety of sources, differing in the local quantity available and the carbon dioxide concentration level in the possible sources of supply. Possible sources are combustion processes, by-products from industrial processes and ambient air (Reiter & Lindorfer, 2015) (Fröhlich, et al., 2019). From an economic and production point of view, the large, local availability and the high carbon dioxide concentration of the possible source are advantageous, so that (fossil) point sources, i.e. industrial and combustion processes such as steel plants, power plants, etc., are often seen as possible carbon dioxide sources. These fossil and process carbon dioxide emissions will have to decrease significantly over time to

[121] Input from stakeholder interview with Sunfire.

meet the EU's climate mitigation targets (European Commission, 2018). When using these carbon dioxide sources for the production of electrofuels, it must therefore be prevented that the decline in fossil and process carbon dioxide emissions is slowed down and reduced by high demand from electrofuel production (Oeko, 2019).

Alternative carbon dioxide sources that allow a carbon cycle with the atmosphere are the direct capture of carbon dioxide from the atmosphere (DAC) or capture from industrial and combustion processes in which sustainable biogenic materials are used as feedstock. These two carbon dioxide sources will have to be the relevant carbon dioxide sources for electric fuel production in the medium to long term for the EU to meet the carbon neutrality target in 2050.

Various methods (different types of adsorption and absorption processes, cryogenic condensation, etc.) are available for the capture of carbon dioxide in industrial processes (Reiter & Lindorfer, 2015) (Fröhlich, et al., 2019). Depending on the carbon dioxide source, they are already in industrial use (e.g. biogas upgrading to biomethane) or must be adapted for the respective carbon source and process. The methods for capturing carbon dioxide can be used after or before combustion (post- or pre-combustion) or oxyfuel processes try to generate easily separable carbon dioxide streams by combustion with pure oxygen. The technical maturity of the carbon dioxide capturing units depends on the respective combustion or industrial process (TRL 5-9, depending on the source) (Skov & Mathiesen, 2017).

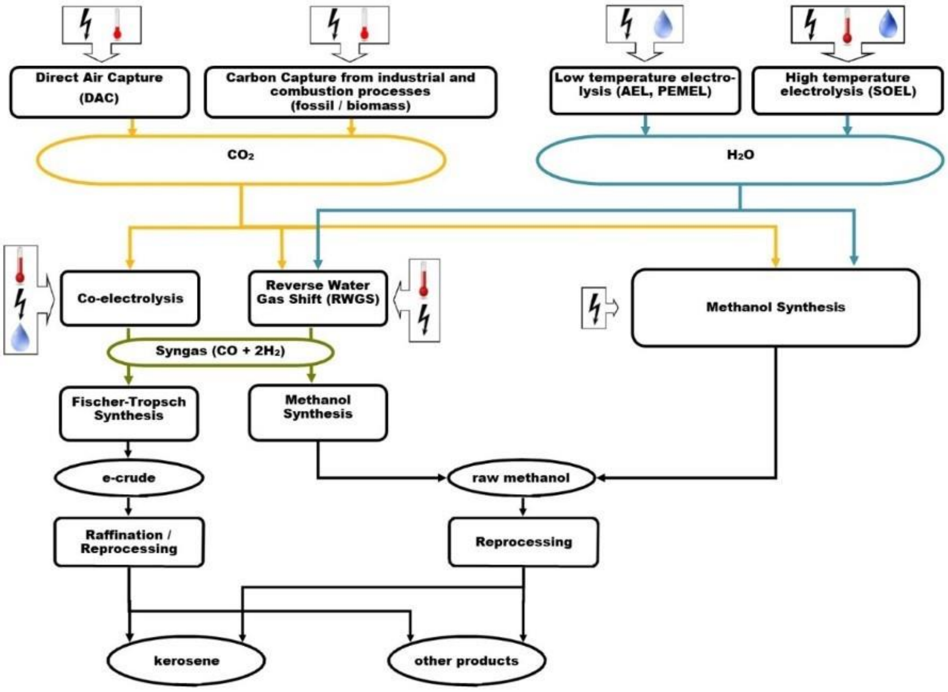
The level of development is much lower for the DAC technology as it has only been shown yet at demonstration scale level (TRL 3-6)[122]. For this purpose, the ambient air is directed over surfaces that remove carbon dioxide via solvents or sorbents. In a second step, the regeneration phase of the surfaces is carried out, in which the carbon dioxide is released from the solvents and sorbents and passed on for further processing. The energy input and the associated costs for carbon capture are always higher for the DAC technology than the technologies mentioned above, even with strong process improvements and high cost regression.

Comparison of overall production pathways

Figure 30 shows an overview of different production pathways. There is currently no production path for electrofuels that can be used to produce aviation fuels on an industrial scale. Key technical processes that need to be further developed for industrial production are the RWGS reaction, the upscaling of methanol synthesis from carbon dioxide and hydrogen, the post-processing of methanol into jet fuel and, in the medium to long term, CO_2 capturing from the air. High-temperature electrolysers (e.g. SOEL, Co-electrolysis) could also be an important technology for electrofuel production if such systems allow for a flexible and dynamic operation. The development and commissioning of the first production plants on a relevant industrial scale (approx. 100 kt of fuel production) seems to be feasible on a purely technical basis in 6 to 10 years from today (Ausfelder & Dura, 2019).

[122] idem

Figure 30: Overview of different electrofuel production routes



Process efficiencies and resources needed

Energy efficiency of hydrogen production

The efficiency of the standard low-temperature hydrogen production processes AEL and PEMEL are similar, although today AEL has a slight efficiency advantage over PEMEL. In the long term, however, the efficiency differences between the two technologies may be negligible (NOW GmbH, 2018). Based on the lower heating value (LHV), the efficiency of these electrolysis processes is currently around 65% (Frontier Economics, 2018) (Brynolf, et al., 2018) and is assumed in many studies to be 70% in 2030 (Frontier Economics, 2018). In the long term, efficiency may increase further: some studies assume the efficiency to be approx. 75 % (E4tech; Element Energy, 2014). However, other studies expect lower efficiency gains and anticipate a system efficiency of below 70% by 2050 (NOW GmbH, 2018). Thus, there is no clear consensus on future efficiency gains in LT electrolysis with implications on required electricity and the cost of production.

The efficiency of SOEL depends, among other things, on whether the energy required to generate the superheated steam must be obtained electrically or is available from waste heat from other processes. Figures for electrical energy efficiency when the steam is generated via external heat sources are currently around 80% and could theoretically rise to around 90% (Frontier Economics, 2018) (NOW GmbH, 2018). If no external heat source is available, the theoretical maximum efficiency is around 83% (Schidt, et al., 2017) (FLEXCHX, 2018). In real-world operation, however, lower efficiencies can be expected if the SOEL is not operated at its nominal load but has to react dynamically to the varying power generation of renewable energies. The values given are therefore to be understood as best-case considerations.

Energy efficiency of liquid fuel synthesis

In the literature it is often assumed that the FT route and the Methanol route have similar energy requirements and hydrogen conversion rates, so that they are not differentiated in terms of energy efficiency. In other studies (Brynolf, et al., 2018), however, the methanol route for gasoline production has a slightly lower efficiency than fuel production via the FT process. Significant efficiency improvements over time are not expected in the synthesis processes, as these are already well developed and industrially scaled. Literature references for the entire process chain from synthesis gas production and synthesis reaction to refining or upgrading of the raw products are in the range of 65-72% (Fasihi, et al., 2017) (Brynolf, et al., 2018) (Timmerberg & Kaltschmitt, 2019), i.e. per MJ fuel (total output of process in HHV) 1.39 - 1.54 MJ of hydrogen (HHV) are required. The energy share of kerosene in the end products depends on the specific process design.

Energy requirements of carbon dioxide capturing technologies

Depending on the product composition of the overall process, 2.9-3.6 kg of carbon dioxide are required per litre of electric fuel (Concawe, 2019). In principle, various carbon dioxide sources are available as the material carbon feedstock for the production of electrofuels (see earlier section on Carbon dioxide supply options). The lower the carbon dioxide content of the source, the higher the energy required to separate the carbon dioxide. The highest energy input and costs are therefore necessary for carbon dioxide capture from the air (DAC). Most studies refer to Climeworks' Temperature Swing Adsorption technology for the energy required to capture CO_2 from the ambient air (dena, 2017) (Wuppertal, 2018) (Fröhlich, et al., 2019). According to these sources, 1.5 - 2.5 kWh of low temperature thermal energy and 0.2 - 0.5 kWh of electricity are required to provide 1 kg of carbon dioxide. A purification step with additional energy demand may also be necessary for the use of carbon dioxide in electrofuel production (dena, 2017).

The use of carbon dioxide from processes of biomass processing to energy sources (biogas and bioethanol) produces exhaust gas streams with high carbon dioxide contents. Therefore, the energy requirements for the separation of carbon dioxide are much lower than with DAC technology. Depending on the technology used, the electricity required for carbon dioxide capturing from biogas production is 0.03-0.15 kWh per kg CO_2. Absorption processes also have a low temperature requirement of 0.15-0.4 kWh per kg CO_2 (Fröhlich, et al., 2019). Bioethanol production as a carbon source has even lower energy requirement (0,1 kWh of electricity per kg CO_2) due to the very high carbon dioxide concentration in the production waste stream.

The energy for capturing carbon dioxide from large-scale point sources strongly depends on the type of carbon source. Some processes such as ammonia production have very high concentrated carbon dioxide waste streams and similar energy requirements occur as for bioethanol production processes. The capture of carbon dioxide from iron and steel production and from cement production, for example, has similar energy requirements of 0.1-0.14 kWh of electricity and 0.7-1.2 kWh of heat per kg of CO_2.

Efficiency of total fuel production pathway

As is clear from the discussion on the individual processes, the overall efficiency of electricity-to-fuel depends strongly on the electrolyser technology and the carbon dioxide source used for electrofuel production. In addition, it will be relevant in practice to what extent highly heat-integrated plants can also achieve the high efficiencies in possibly dynamic operating situations. When LT electrolysers are used, various studies indicate overall efficiencies of 36 - 39% (today) and 42-43% (long-term potential) if carbon dioxide is made available via DAC technology today (dena, 2017). At 48%, the efficiency is considerably higher with very high heat integration (Fasihi, et al., 2017). When concentrated carbon dioxide sources are used, generally higher efficiencies of 47-48% (today) and 53-54% (long-term) are possible (Schmidt, et al., 2018).

If the use of HT electrolysers in industrial plants becomes possible, it is feasible to achieve higher efficiencies. However, this depends strongly on the operation mode of these plants since the efficient integration of waste heat from the synthesis processes is decisive for high efficiencies. The literature values for overall efficiency when using carbon dioxide from the air are 41-47% (today) and 47-50% (long-term) (dena, 2017) (Fraunhofer IWES, 2017) (Schmidt, et al., 2016). If highly concentrated carbon dioxide sources are available, the efficiency of the overall process increases to 62-63%. However, Sunfire claims to be able to achieve higher overall efficiencies with its technology (sunfire, 2018).

Water requirements

The production of electrofuels requires 3.7 to 4.5 litres of water per litre of fuel (Concawe, 2019), depending on the composition of the end products. Since the electrolysers require high purity water, it is not possible to use salt water for hydrogen production. In regions without easy access to fresh water or with a scarcity of fresh water, it may therefore be necessary to treat seawater in desalination plants. No relevant energy requirements are associated with seawater desalination, but the local impact on water availability and prices could be severe if large-scale fuel production is located in area of water scarcity.

GHG emission savings

For the use of aviation electrofuels, the climate protection benefits depend essentially on the electricity used to produce the fuels and how the production plant is integrated into the power system. In addition, the use of CO_2 from industrial processes can indirectly generate additional emissions if it slows down the reduction of emissions in the industrial sector and of energy production.

The production of electrofuels creates an additional load in the respective power system. In power systems with fossil electricity generation capacities, the production of the fuels can therefore cause greater utilisation of fossil power generation capacities and thus lead to additional GHG emissions in the power system. The production of electrofuels in electricity systems that use fossil energy sources is therefore only possible in a climate-neutral manner if additional renewable electricity generation is integrated into the system and if fossil electricity generation does not increase in the aggregate balance (Oeko, 2019). Full additionality of renewable electricity generation is achieved, for example, if new renewable capacities, which are added to the system for fuel production, do not count towards existing renewable electricity production expansion targets. The operation mode of the production facilities and the location of the production facilities are also relevant for a reasonable integration into the electricity system. As the share of renewable electricity generation increases, the volatility of the electricity supply increases. Accordingly, fuel production, in particular electrolysers, should be operated flexibly according to the availability of renewable energy. LT electrolysers are technically capable of this today. From an economic perspective, however, high capacity utilisation of the plants is advantageous. Such an operation mode would therefore have to be stimulated by regulations. It is also cost-efficient and necessary in the long-term to integrate the plants into the electricity system in such a way that possible bottlenecks in the electricity grid are not increased. Production locations in the front of such grid bottlenecks are therefore advantageous in order to avoid possible shutdowns by the grid operator in the event of a grid bottleneck.

Figure 31: GHG emissions from electrofuels as a function of the GHG intensity of the electricity used and the efficiency of the production process

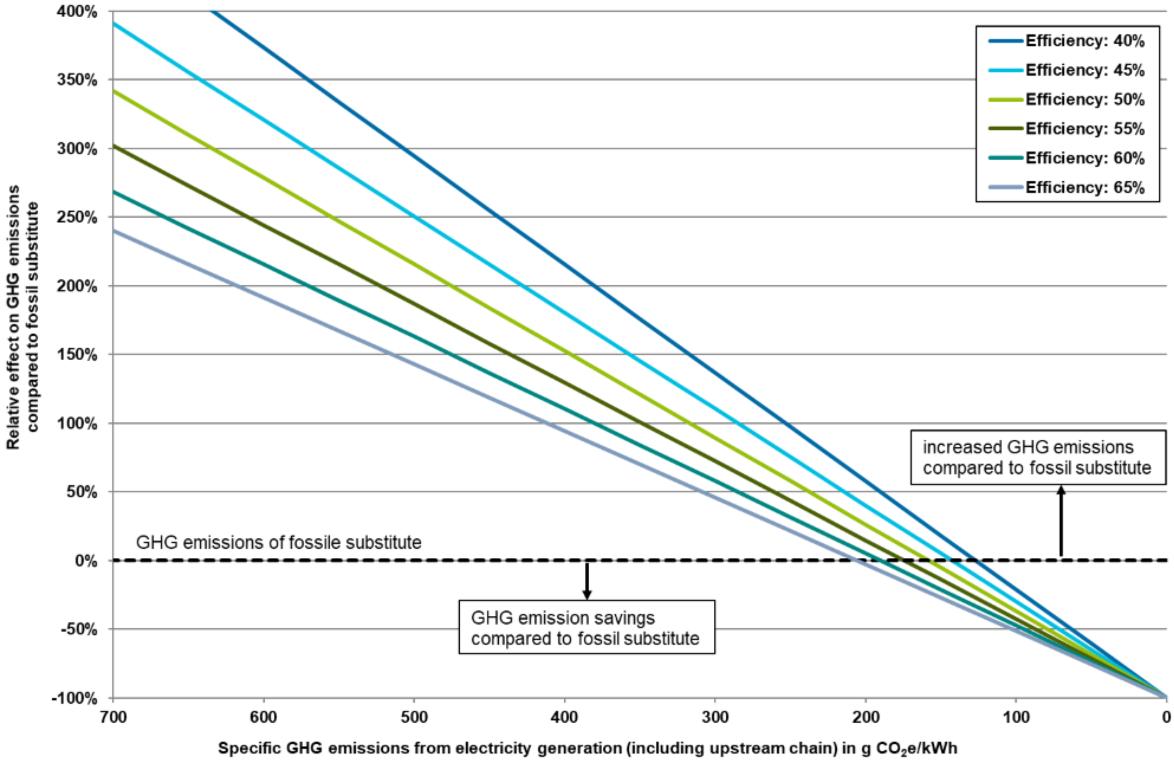


Figure 31 shows the dependence of GHG emissions from electrofuel production on the GHG intensity of electricity generation. In fossil-fuelled power systems, the production of electrofuels can result in significantly higher GHG emissions than with combustion of fossil jet fuel if the above requirements are not met. Due to the high conversion losses during production, embedded GHG emissions from power generation are not negligible for the GHG emission balance and should be considered in GHG emission considerations. However, by means of delegated acts within the framework of RED II, the Commission is developing criteria for electricity use and a GHG emission calculation method by the end of 2021, which should ensure GHG emission reductions in the production of electrofuels.

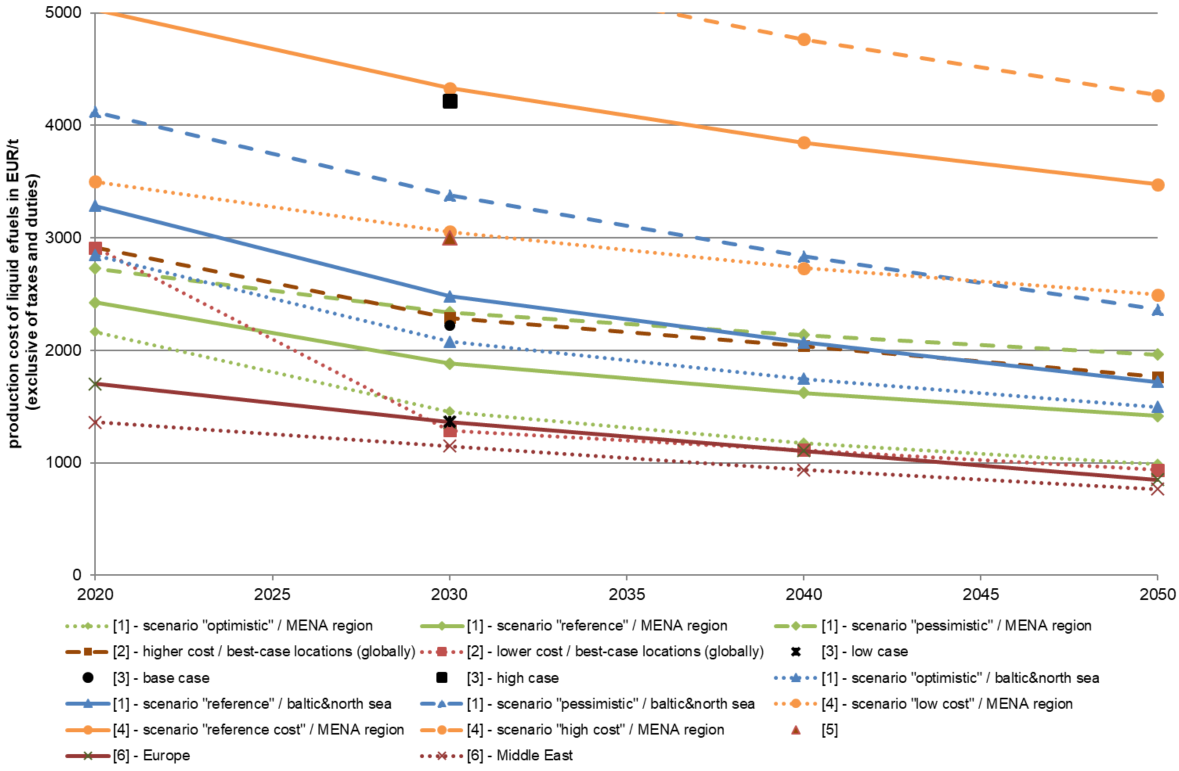
However, the additionally required electricity generation is always in competition with electricity demands from other applications and sectors, so that, depending on the electricity system, competition for preferential areas for renewable electricity generation and possibly other limiting factors (available skilled workers and production resources, available investment funds) may arise. This causes potentially undesirable effects on other sectors and applications, such as higher electricity procurement costs for other demands in the electricity system. The use of hydrogen for the production of aviation electrofuels is also in direct competition with the possible increasing use of green hydrogen in other sectors and applications (e.g. industrial sector; long-term chemical storage of electricity). It is important that the criteria are not only complied with as far as possible for production in the EU, but also for production in other regions of the world, in order to avoid undesirable effects and ensure the reduction in GHG emissions.

Cost of electrofuel production

From today's perspective, the development of production costs for electric fuels is subject to a high degree of uncertainty. Current studies show a high deviation between optimistic and less optimistic cost developments for the same site selection alone due to the different developments in plant efficiency and investment costs of the individual plant components

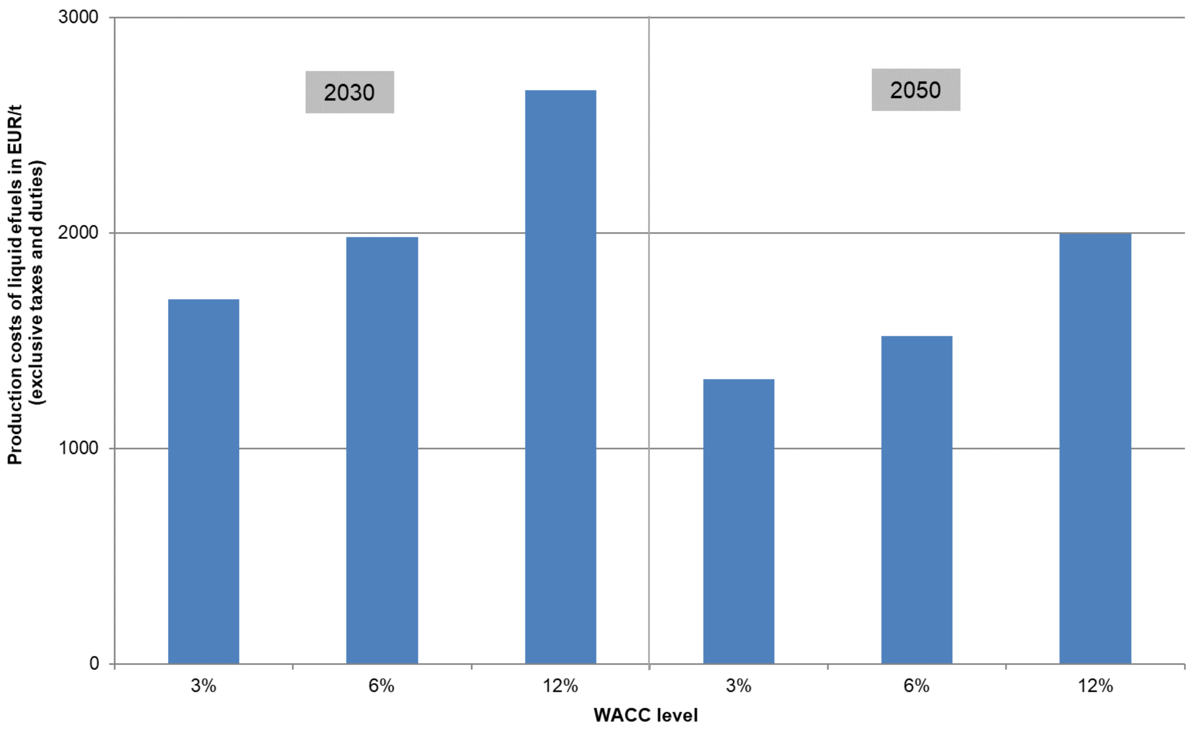
(Figure 32). However, most cost calculations show that even with very positive cost developments, the production of e-fuels will not become cheaper than fossil fuels.

Figure 32: Comparison of possible cost development of electrofuels from 2020-2050 (Frontier Economics, 2018)



Key factors for the production costs are the electricity procurement costs for electrofuel production, the investment costs for the production plants (especially electrolysers and CO_2 capturing units), the utilisation rate of the production plants and the financing costs (see impact of WACC level in Figure 33). Low electricity procurement costs and high utilisation rates of electrolysers and synthesis plants will occur at possible production locations where renewable capacities achieve full high load hours. Low financing costs can especially be expected in regions of low risk for failing investments (e.g. countries of high governance level). In particular, first-of-its-kind electrofuel production plants may face an additional premium on financing costs due to the increased risk of technical flaws of the upscaling from demonstration sized and small-scale industrial production to large-scale plants with high investment costs. The often assumed WACC of 5-7% appears to underestimate these issues of financing the upfront investments of production plants and higher interests rates (and higher expectations on return on equity (Brynolf, et al., 2018) can be expected in the very short-term upscaling phase of electrofuel plants and for production in regions with rather low governance level. Due to the low transport costs of liquid fuels, it can therefore be assumed that a global market for electrofuels will emerge, in which parameters such as low electricity procurement costs, high investment security and available land for renewable electricity generation will have a relevant influence.

Figure 33: Electrofuel production costs as a function of WACC level (Energiewende, n.d.)[123]



Summary

Table 54 presents a summary of the different electrofuel production pathways with critical technical processes which have not reached commercial availability. Possible GHG emission savings are not included in the table as they are mainly influenced by the characteristics of the electricity used for fuel production. A critical element for all electrofuel processes is the availability of sustainable CO_2 as a feedstock. Direct air capture (DAC) technology is at TRL 3-6 and very energy consuming compared to more concentrated CO_2 sources. CO_2 emissions from fossil point sources will have to decrease over time to meet EU's GHG mitigation targets and the technical maturity of capturing CO_2 from combustion and industrial processes is at TRL 5-9 (depends on the process).

Table 54: Summary of electrofuel production pathways and their critical processes

Route	Certification	Critical technical processes
FT route (LT electrolysis)	FT-SPK, up to 50%	Reverse water gas shift reaction (TRL 5-6)
FT route (HT electrolysis)	FT-SPK, up to 50%	Solid oxide electrolysis (TRL 4-7) Reverse water gas shift reaction (TRL 5-6) or Co-Electrolysis (TRL <5)
Methanol route (two-step methanol synthesis / LT electrolysis	Not certified	Reverse water gas shift reaction (TRL 5-6) Final conversion to jet fuel (TRL 7-8)
Methanol route (two-step methanol synthesis / HT electrolysis	Not certified	Reverse water gas shift reaction (TRL 5-6) Final conversion to jet fuel (TRL 7-8) Solid oxide electrolysis (TRL 4-7) or

[123] Production cost in North Africa (wind/solar combination); PtL cost calculation tool applied.

Route	Certification	Critical technical processes
		Co-Electrolysis (TRL <5) Final conversion to jet fuel (TRL 7-8)
Methanol route (one-step methanol synthesis / LT electrolysis	Not certified	Methanol synthesis (TRL 6-7) Final conversion to jet fuel (TRL 7-8)
Methanol route (one-step methanol synthesis / HT electrolysis	Not certified	Methanol synthesis (TRL 6-7) Final conversion to jet fuel (TRL 7-8) Solid oxide electrolysis (TRL 4-7)

12. Annex 4: Screening of policy measures

Key:	Low / poor assessment against criterion	Medium	High / good	Depends on specific requirements

Proposed policy measure	Source	Legal feasibility	Technical feasibility	Effectiveness and efficiency	Political feasibility	Proportionality
SAF supply mandate	ToR	No problems foreseen	SAF as a drop-in fuel can be used on existing jet fuel infrastructure	Can be expected to provide a strong push in providing a solid regulatory framework for SAF and promote the deployment of sufficient capacity. Flanking measures may be needed to further support the deployment of production capacity by SAF producers or to reduce the SAF price premium required by SAF users. . Tankering outside the EU might reduce its effectiveness.	Relative acceptance from stakeholders if combined with other flanking measures	No problems foreseen
SAF demand mandate	ToR		Can be expected to provide a strong push in providing a solid regulatory framework for SAF and promote the deployment of sufficient capacity. Supporting flanking measures may be needed to further support the deployment	Opposition from a number of stakeholders[124] with a stronger preference for a supply mandate.	Possible strong push back from non-EU airlines if a demand obligation applies to all flights departing from the EU, similarly to the discussion on the full scope of the EU ETS.	No problems foreseen

[124] including fuel suppliers, airlines and Member States

			of production capacity by SAF producers or to reduce the SAF price premium required by SAF users.			
Demand mandate all flights		Potential limitations to the capacity to impose a mandate to extra-EEA routes	Same as above	Increased effectiveness as it addresses tankering issues	Strong opposition from non-EEA operators	No problems foreseen
Demand mandate intra-EEA flights		No legal uncertainty	Likely market distortion between EU and non-EU airlines	Reduced effectiveness in reaching the CTP objectives as it can apply only to a very reduced part of GHG emissions	Opposition from NGOs due to the reduced effectiveness	No problems foreseen
RFNBO sub-mandate		No problems foreseen	No problems foreseen	Effective in boosting the use of RFNBOs	No stakeholder objection	No problems foreseen
RFNBO multiplier		No problems foreseen	Need to establish reference LCA GHG emission calculation methodologies for SAF and fossil jet fuel	Slightly reduced effectiveness due to less quantities of SAF needed to fulfil the obligation	No stakeholder objection	No problems foreseen
SAF certified trading system	Consultations	Requires an adjustment of RED II	Would be set up under RED II or the new initiative.	Effective in linking the demand and supply of SAF via the creation of a market mechanism. Considered very efficient as it allows for fuel supply chain optimisation	Strong stakeholder support	No problems foreseen
Funding SAF R&D	ToR + team development	No problems foreseen	Addition of SAF topics to the funds working programmes might be needed	Can be expected to boost SAF market maturity for less developed processes / SAF. Not sufficient to deal with the problem drivers at their full extent on its own as the risk of SAF investments is also steaming from the regulatory framework conditions.	A combination of existing funding instruments can be used to provide the funding sources needed. Strong stakeholder support.	No problems foreseen

Funding in support of SAF production deployment	ToR + team development	No problems foreseen	Alignment of the eligible funding activities of CEF and the Just Transition Fund would be required	Strong impact expected, however a very costly measure to implement with public funding without other measures supporting the partial bridging of the price gap.	Strong support by industry stakeholders to measures supporting production deployment. Identifying a source of funding would potentially mean diverting funds from other activities, something that will need to be addressed with the relevant stakeholders	Could be considered disproportionate depending on the overall level of funding needed to achieve the initiative goals
Contracts for difference	ToR	Should (part) of the funding be expected from Member States a political agreement would be needed. Also, the amendment of existing funding instruments to target SAF investments. This will depend on the financing instrument eventually chosen.	Depending on the level of implementation of the contracts for difference and the potential use of EU and Member States resources to fund these.	Strong impact expected, however a somewhat costly measure to implement with public funding without other measures supporting the partial bridging of the price gap. Average efficiency as a standalone measure	Depending on the level and source of EU (and Member States) funding, opposition to the measure might be triggered.	Could be considered as expensive and disproportionate depending on the level of funding needed to achieve the initiative goals
Technical facilitation and support facilities	Developed in consultation with EC	No problems foreseen	Cooperation agreement needed with the USA Clearing house. Cooperation mode needs definition	Limited effectiveness expected as a standalone measure. Can be an efficient flanking measure dealing in specific with accelerating the time needed to technology certification especially complementing R&D funding	Support by a number of stakeholders	No major problems foreseen
Monitoring mechanism	Developed in consultation with EC	No problems foreseen	No major problem expected. Coordination with existing reporting schemes will be needed depending on the mandate targeting and reporting structure.	Effective and efficient measure in supporting the implementation of the initiative goals when combined with potential reuse of existing data streams from the REDII	No problems foreseen. Stakeholders suggest alignment with existing reporting mechanisms to reduce administrative burden	No major problems foreseen

				or EU aviation ETS reporting structures		
Voluntary agreements	ToR	No problems foreseen	No problems foreseen	Poor effectiveness of voluntary arrangements is expected based on existing experience.	No major problems foreseen	No major problems foreseen

13. Annex 5: Model results

Methodological approach

For the quantification of the Baseline and the Policy Option scenarios, first the PRIMES-Aviation submodule was used in order to simulate in detail the changes in the travel demand induced by the changes in the cost of fuels driven, for example, by blending mandates. For this step, an initial set of assumptions on the biokerosene prices was used. Subsequently, the PRIMES-TREMOVE model was used in order to assess the impacts in all transport segments. The demand for biokerosene that was estimated using PRIMES-TREMOVE, was provided to the PRIMES Biomass supply model. The model was used to estimate the price of biokerosene that reflected the production costs based on the deployed biokerosene production pathways. The iterative process of the model runs was then repeated once again, Subsequently, the price of biokerosene was introduced to the PRIMES-Aviation submodule, re-iterating the PRIMES-TREMOVE and PRIMES-Biomass model runs in order to provide the quantified output for each scenario.

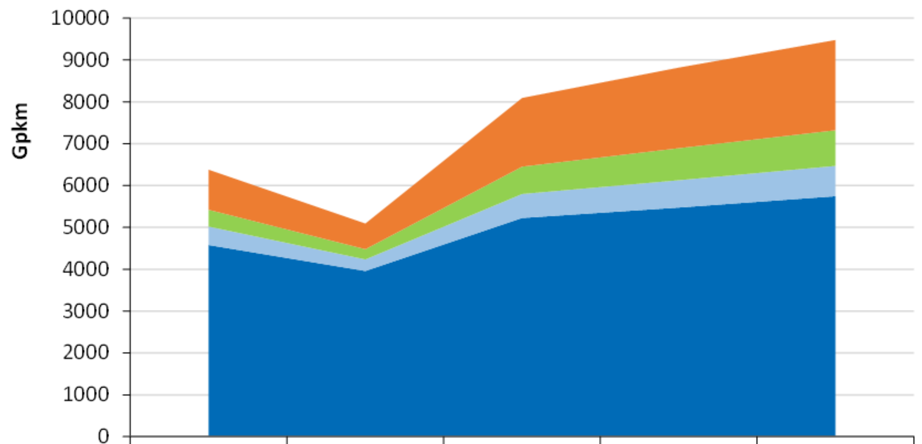
Results of the Baseline scenario based on PRIMES-TREMOVE

The aim of this section is to provide a more in-depth presentation of the modelling results of the Baseline scenario. Results are presented for the transport sector for transport activity, final energy demand and CO2 emissions for the EU27, for the period 2010 to 2050. Detailed model outputs are presented at the end of this Annex.

Transport activity

In the Baseline scenario, total passenger transport activity is projected to increase steadily from 2010 to 2050 driven by the evolution of the GDP and population. The total activity increases at a rate of 1% per year but growth rates differ per mode of transport. The modal share of road transport (i.e. passenger cars, public transport and 2-wheelers) is projected to reduce from 69% in 2015 to 61% in 2050. The steepest annual growth, at 1.8% per year, is projected for passenger transport activity in aviation (national, intra-EU and extra-EU flights). That is despite the steep reduction in the transport sector due to the COVID-19 pandemic in 2020 (a reduction between 36-39% from 2010 to 2020), as the sector is projected to recover beyond 2010 activity levels by 2025. The modal share of aviation in passenger transport activity reaches 32% in 2050, compared to 24% in 2015. As such, in the Baseline scenario, a modal shift from road transport primarily to aviation but also to rail is projected (Figure 34).

Figure 34 Passenger transport activity in the EU27 in the Baseline scenario



	2010	2020	2030	2040	2050
Extra-EU aviation	959	612	1637	1924	2154
Intra-EU aviation	398	244	655	764	850
Rail	444	274	577	653	728
Road	4579	3960	5222	5476	5745

Source: PRIMES-TREMOVE

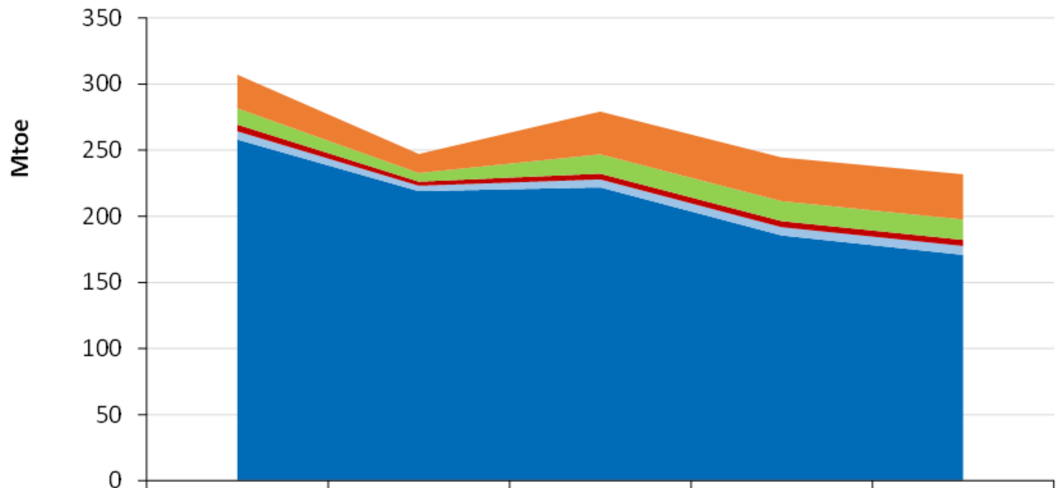
Energy demand

In the Baseline scenario, energy demand for transport (passenger and freight, excluding international shipping) reduces by about 60 Mtoe (or 20%) between 2010 and 2020 as a result of reduced transport activity due to the COVID-19 outbreak in 2020. As the activity recovers, the energy demand in the sector increases, peaking at 280 Mtoe in 2030. The decline that is projected thereafter is primarily due to the reduction of final energy demand in road transport driven by the deployment of more efficient conventional and hybrid technologies, and EVs in passenger road transport, and to a lesser extent due to LNG and electrification of road freight transport.

Aviation is the second largest segment in terms of final energy demand, and in contrast to all other transport segments, its demand increases gradually from 2020 onwards driven by growth in transport activity. In the Baseline scenario, final energy demand in aviation is projected to be 21 Mtoe in 2020 and 50 Mtoe in 2050. By 2050, the segment consumes 22% of total energy demand in transport. Extra-EU flights are responsible for about two-thirds of final energy consumption in aviation. In the Baseline scenario, by 2050 the segment of rail retains its energy consumption at rather constant levels compared to 2010, at 6 Mtoe (Figure 35).

In the Baseline scenario, the share of biokerosene is 0.2% in 2030 and 3% in 2050, while no synthetic kerosene is projected to be deployed.

Figure 35 Energy demand by transport segment in passenger and freight transport in the Baseline scenario in the EU27



	2010	2020	2030	2040	2050
Extra-EU aviation	25.6	14.4	32.1	33.0	34.0
Intra-EU aviation	12.2	6.5	14.7	15.2	15.6
Inland navigation	5.1	3.3	4.3	4.5	4.6
Rail	6.3	4.0	6.0	6.4	6.5
Road	258	219	222	186	171

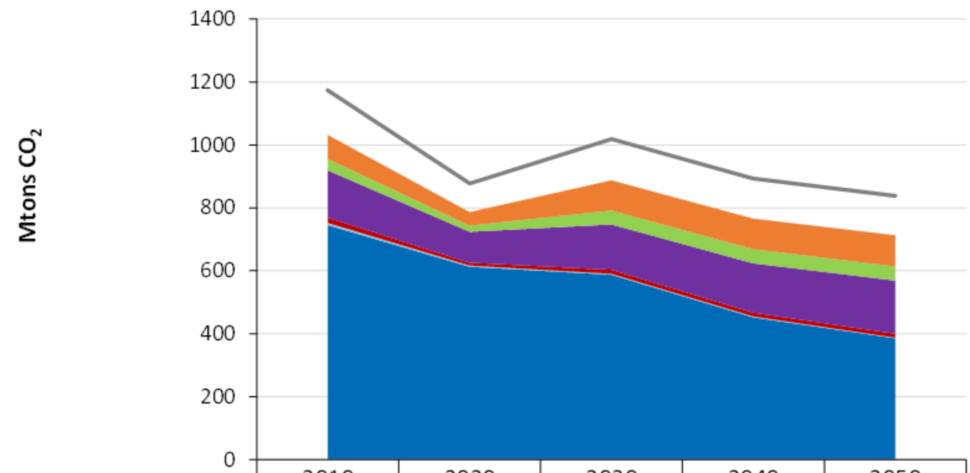
Note: Excluding international shipping. Source: PRIMES-TREMOVE

CO2 emissions

In the Baseline scenario the Tank-to-Wheel (TTW) CO_2 emissions are projected to decrease from approximately 995 Mtons in 2015 to about 888 Mtons in 2030 and to about 713 Mtons in 2050, or by 11% and 28%, respectively (Figure 36, including international maritime). As seen in Figure 37, the reduction in CO_2 emissions is primarily achieved in road transport due to the rollout of efficient internal combustion engine vehicles and due to the uptake of electric vehicles, especially in the period after 2030. Specifically, the emissions of road transport are projected to decrease from 732 Mtons in 2015, to 588 Mtons in 2030 (or 20% compared to 2015) and to 386 Mtons in 2050 (or 47% compared to 2015). Emissions in rail also decrease, by 3 Mtons in 2050 (or 65% compared 2015). The reduction in these segments compensates for the increase of CO_2 emissions in aviation, which from 120 Mtons in 2015, increases to 140 Mtons in 2030 (or by 17%) and 144 Mtons (or by 21%) in 2050, and international shipping that increases its emissions by 42 Mtons between 2015 and 2050.

Well-to-Wheel (WTW) emissions (including those from international maritime) are projected to follow a similar declining trend. In the Baseline scenario they decrease from 1,118 Mtons CO_{2eq} in 2015, to 1,020 Mtons CO_{2eq} in 2030 and 838 Mtons CO_{2eq} in 2050 (Figure 36). The share of Well-to-Tank (WTT) emissions in WTW emissions increases from 11% in 2015 to 13% in 2030 and to 15% in 2050.

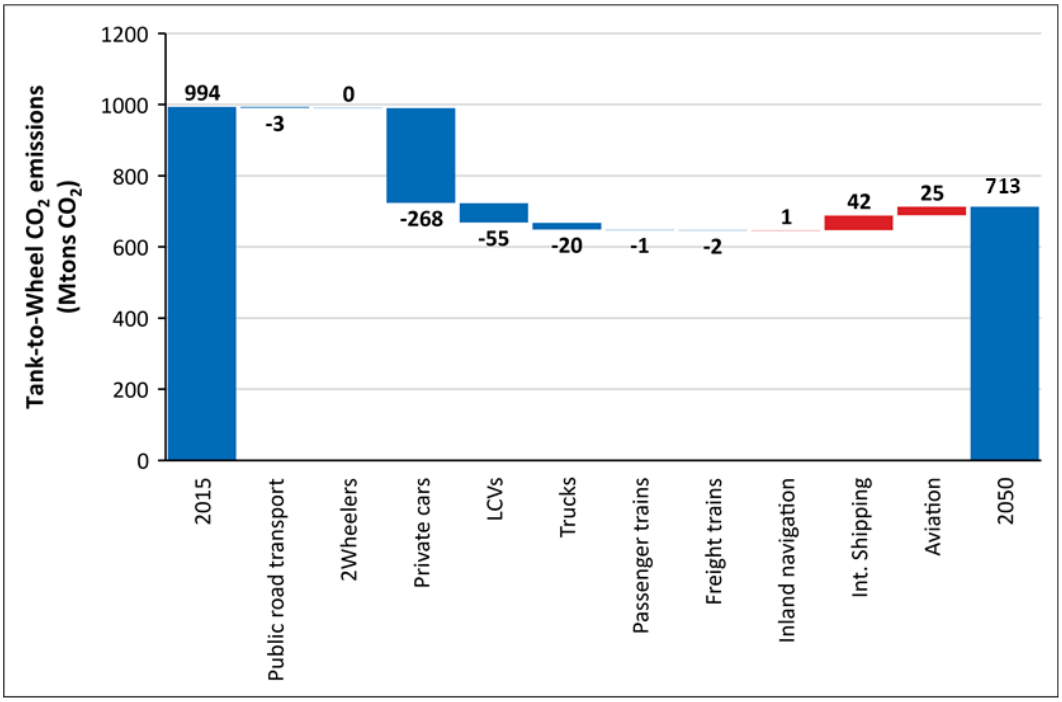
Figure 36 Tank-to-Wheel CO_2 emissions by transport mode and Well-to-Wheel GHG emissions in transport in the EU27 in the Baseline scenario



	2010	2020	2030	2040	2050
Extra-EU aviation	77	43	96	98	99
Intra-EU aviation	36	19	44	45	45
Int. maritime	150	98	145	157	169
Inland navigation	16	10	12	13	13
Rail	7	3	3	2	1
Road	746	614	588	452	386
Well-to-Wheel (CO2eq)	1174	878	1019	893	838

Source: PRIMES-TREMOVE

Figure 37 Reduction of Tank-to-Wheel CO_2 emissions by transport segment in the EU27 between 2010 and 2050 in the Baseline scenario



Source: PRIMES-TREMOVE

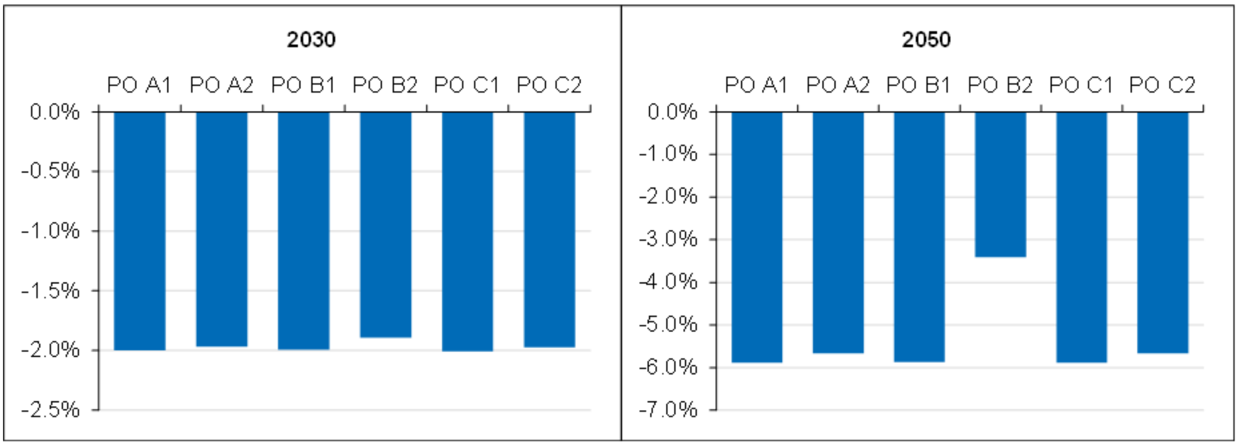
Results of the Policy Option scenarios based on PRIMES-TREMOVE

The aim of this section is to provide a more in-depth presentation of the modelling results for the Policy Option scenarios in comparison to the Baseline. Results are presented for the aviation sector for transport activity, final energy demand, CO2 emissions and costs for the EU27. The comparison against the Baseline is presented in figures for 2030 and 2050, and a summary of the Policy Option results is presented in a tabular format for the years 2030, 2040, and 2050. Results for biokerosene production chains based on the PRIMES Biomass supply model are also presented for a high bioenergy demand context (relevant for PO A1, A2, B1, C1, and C2), and a low bioenergy demand context (relevant for PO B2). Detailed model outputs are presented at the end of this Annex.

Transport activity

The increase in the fuel costs of the airliners are assumed to be completely reflected on the ticket prices seen by the consumers, as part of the modelling. Hence, income and substitution effects are found to take place in all Policy Option scenarios. This is reflected in the reduction of passenger transport activity in intra-EU and extra-EU flights in the Policy Option scenarios compared to the Baseline (Figure 38).

Figure 38 Reduction of passenger transport activity in aviation in the EU27 in 2030 and 2050 in the Policy Option scenarios compared to the Baseline



Source: PRIMES-TREMOVE

In 2030, passenger air transport activity is projected to be lower by about 2% across all Policy Options compared to the Baseline. This is a result of more expensive sustainable aviation fuels being introduced into the fuel mix (primarily biokerosene) albeit at a relatively small volume. Progressing towards 2050, due to the significantly higher supply of sustainable aviation fuels, the income and substitution effects become more prominent leading to between 3% and 6% loss of air transport activity compared to the Baseline. The activity loss is slightly higher in Policy Options A1, B1 and C1, which prescribe blending mandates specific to biokerosene and synthetic kerosene. Policy Options A2 and C2 impact by 0.2% p.p. less the activity in the sector, as they allocate sustainable aviation fuels more cost-effectively than their Policy Option counterparts A1 and C1. In Policy Option B2, the mandates are applicable only to intra-EU flights. As such, income and substitution effects, as reflected in ticket prices, are less prominent in this Policy Option leading to the lowest loss of passenger air transport activity, affecting more the activity loss from intra-EU flights. Compared to all Policy Options, the air transport activity in Policy Option B2 is higher by 68 to 75 Gpkm in 2050.

The introduction of sustainable aviation fuels reduces the EU27 passenger air transport activity by 95 to 180 Gpkm in 2050, compared to the Baseline (Table 55). Part of this activity (or about 15 Gpkm) is substituted by other modes, such as rail.

Summary tables of passenger transport activity in the Baseline scenario and the Policy Options are presented in Table 55.

Table 55 Passenger transport activity in the EU27 in 2030, 2030 and 2050 in the Baseline and the Policy Option scenarios

Activity Gpkm	Baseline			Policy Option A1			Policy Option A2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Total	8091	8818	9478	8048	8728	9317	8048	8733	9324
Road	5222	5476	5745	5222	5471	5733	5222	5472	5734
Rail	577	653	728	579	667	757	579	666	756
Air (intra & extra EU)	2293	2689	3004	2247	2590	2827	2248	2595	2834

Activity Gpkm	Baseline			Policy Option B1			Policy Option B2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Total	8091	8818	9478	8048	8728	9317	8050	8757	9394
Road	5222	5476	5745	5222	5471	5733	5223	5475	5744

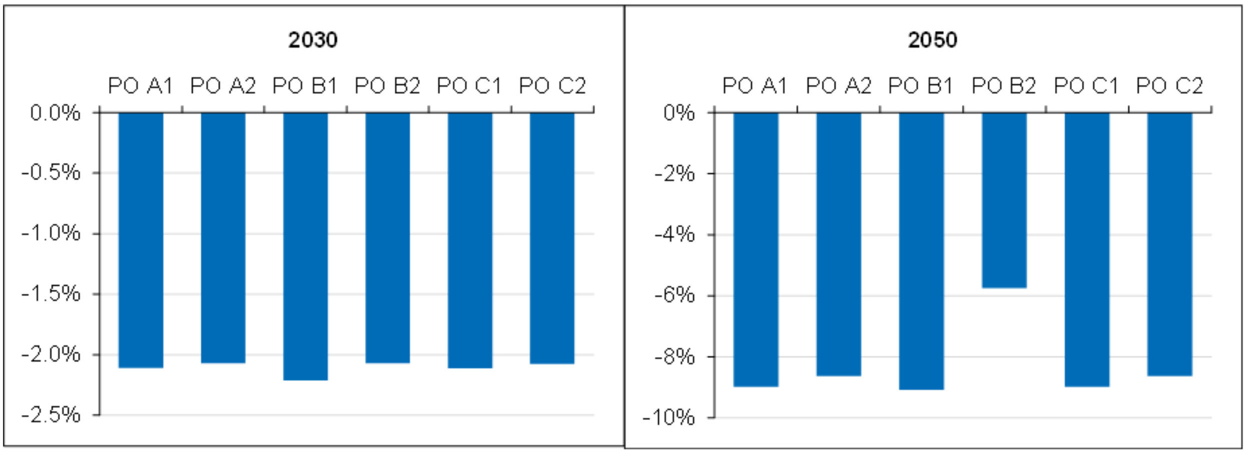
Rail	577	653	728	579	667	757	578	663	747
Air (intra & extra EU)	2293	2689	3004	2247	2590	2828	2249	2619	2902

Activity Gpkm	Baseline			Policy Option C1			Policy Option C2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Total	8091	8818	9478	8048	8728	9317	8049	8733	9324
Road	5222	5476	5745	5222	5471	5733	5222	5472	5734
Rail	577	653	728	579	667	757	579	666	756
Air (intra & extra EU)	2293	2689	3004	2247	2590	2827	2247	2595	2834

Energy demand

Relative to the Baseline, the projected reduction of passenger transport activity in aviation is reflected by a decrease in jet fuel consumption in all Policy Options (Figure 39). In 2030, the decrease compared to the Baseline is around 2%, similar across all Policy Options. By 2050 the reduction compared to the Baseline reaches around 8-8.5%% in most Policy Options. In Policy Option A1 and C1 it reaches 8.5% and in Policy Option B1 the reduction is 8.6%. Policy Option A2 and C2, compared to their Policy Option counterparts A1 and C1, show somewhat lower reduction by about 0.4% p.p. (or 0.2 Mtoe). This is a result of higher passenger air transport activity that is projected in Policy Options A2 and C2 (of about 0.2% p.p. or 8 Gpkm). A notable difference in the reduction of fuel consumption compared to the Baseline is observed with the scenario results of Policy Option B2, which applies a blending mandate for biokerosene and synthetic kerosene only on intra-EU flights. In this Policy Option, fuel consumption is reduced by about 5% compared to the Baseline, as this option has higher air transport activity than all other scenarios. Compared to the other Policy Options the additional fuel consumption in Policy Option B2 is 1.4 to 1.7 Mtoe in 2050.

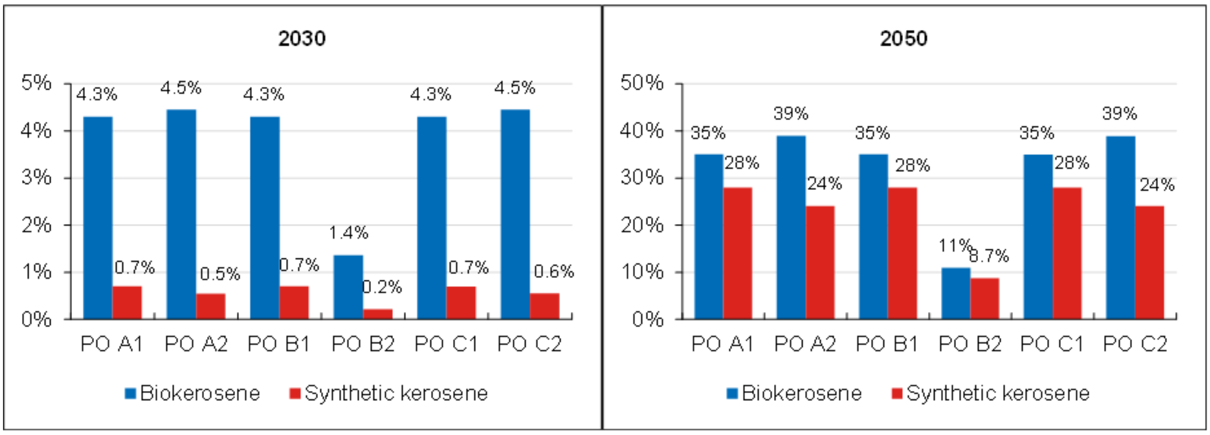
Figure 39 Reduction of energy consumption in aviation in the Policy Option scenarios in the EU27 in 2030 and 2050 compared to the Baseline



Source: PRIMES-TREMOVE

Figure 40, shows the shares of sustainable aviation fuels in the different Policy Options for 2030 and 2050. Based on the scenario design, the prescriptive mandates for sustainable aviation fuels are identical in Policy Options A1, B1, and C1. For biokerosene, these are 4.3% in 2030 and 35% in 2050, and for synthetic kerosene these are 0.7% in 2030 and 28% in 2050. In Policy Option B2, the same shares apply but only to intra-EU flights, leading to an overall lower share compared to the Policy Options A1, B1, and C1. In Policy Options A2 and C2, the blending shares of biokerosene and synthetic kerosene are not predetermined. These Policy Options are designed to investigate the impacts of a maximum limit on the GHG content of energy used in the aviation sector, by achieving the same GHG emission intensity target as their Policy Option counterparts. In such case, it is projected that biokerosene, due to its lower cost compared to synthetic kerosene, increases its market share by 0.2% p.p. in 2030 and by 4% p.p. in 2050, to the detriment of synthetic kerosene. The difference in 2050 is about 2 Mtoe, equivalent to all sustainable aviation fuel consumption that is projected for 2030 in the Policy Options.

Figure 40 Share of sustainable aviation fuels in total jet fuel consumption in the Policy Option scenarios in the EU27 in 2030 and 2050



Source: PRIMES-TREMOVE

Summary tables of jet fuel consumption and the fuel mix in aviation in the Baseline and the Policy Option scenarios are presented in Table 56.

Table 48 and Table 49 present the shares of sustainable aviation fuels per Member State in the Baseline and the Policy Options.

Policy Options C differ in that C1 prescribes individual mandates on biokerosene and synthetic kerosene on fuel suppliers for intra-EU and extra-EU flights and on airliners on intra-EU flights only. Policy Option C2, on the other hand, allocates the blending mandate to biokerosene and synthetic kerosene by achieving the same Well-to-Wing emission intensity for the fuel blend as Policy Option C1. Furthermore, this set of policy options assumes a transition period in which fuel suppliers are free to organise their supply chains. During this transition period, which lasts until 2035, the blending mandates whether prescribed (Policy Option C1) or determined by the GHG intensity target (Policy Option C2) are differentiated per Member State depending on passenger traffic in airports and domestic feedstock availability for biokerosene production. In the period after 2035, the EU-wide mandates apply to all Member States, similar to Policy Option A.

Table 56 Total jet fuel consumption in the EU27 in 2030, 2040 and 2050 in the Baseline and the Policy Option scenarios

Air transport energy mix (in %)	Baseline			PO A1			PO A2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Air transport energy use, Mtoe	46.9	48.2	49.7	45.9	46.2	45.4	45.9	46.3	45.6
Kerosene	99.8%	98.8%	97.1%	95.0%	68.0%	36.8%	95.0%	68.0%	36.8%
Biokerosene	0.2%	1.2%	2.9%	4.3%	24.0%	34.8%	4.5%	25.8%	38.7%
HVO/HEFA	0.1%	0.4%	1.2%	1.6%	2.9%	4.0%	1.7%	3.1%	4.5%
Gasification and Fischer Tropsch	0.0%	0.0%	0.0%	0.0%	9.7%	12.9%	0.0%	10.4%	14.4%
Alcohol to Jet	0.0%	0.1%	0.3%	1.8%	7.6%	12.9%	1.9%	8.2%	14.3%
Imports biokerosene	0.1%	0.7%	1.5%	0.9%	3.8%	5.0%	0.9%	4.1%	5.6%
Synthetic fuels	0.0%	0.0%	0.0%	0.7%	8.0%	27.9%	0.5%	6.2%	23.9%
Electricity	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.5%
Air transport energy mix (in %)	**Baseline**			**PO B1**			**PO B2**		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Air transport energy use, Mtoe	46.9	48.2	49.7	45.9	46.2	45.4	45.9	46.8	47.1
Kerosene	99.8%	98.8%	97.1%	95.0%	68.0%	36.8%	98.4%	89.9%	79.9%

Biokerosene	0.2%	1.2%	2.9%	4.3%	24.0%	34.8%	1.4%	7.6%	10.9%
HVO/HEFA	0.1%	0.4%	1.2%	1.6%	2.9%	4.0%	1.1%	2.6%	2.5%
Gasification and Fischer Tropsch	0.0%	0.0%	0.0%	0.0%	9.7%	12.9%	0.0%	0.3%	0.3%
Alcohol to Jet	0.0%	0.1%	0.3%	1.8%	7.6%	12.9%	0.0%	2.4%	4.8%
Imports biokerosene	0.1%	0.7%	1.5%	0.9%	3.8%	5.0%	0.3%	2.3%	3.3%
Synthetic fuels	0.0%	0.0%	0.0%	0.7%	8.0%	27.9%	0.2%	2.5%	8.7%
Electricity	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.5%

Air transport energy mix (in %)	Baseline			PO C1			PO C2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Air transport energy use, Mtoe	46.9	48.2	49.7	45.9	46.2	45.4	45.9	46.3	45.6
Kerosene	99.8%	98.8%	97.1%	95.0%	68.0%	36.8%	95.0%	68.0%	36.8%
Biokerosene	0.2%	1.2%	2.9%	4.3%	24.0%	34.8%	4.5%	25.8%	38.7%
HVO/HEFA	0.1%	0.4%	1.2%	1.6%	2.9%	4.0%	1.7%	3.1%	4.5%
Gasification and Fischer Tropsch	0.0%	0.0%	0.0%	0.0%	9.7%	12.9%	0.0%	10.4%	14.4%
Alcohol to Jet	0.0%	0.1%	0.3%	1.8%	7.6%	12.9%	1.9%	8.2%	14.3%
Imports biokerosene	0.1%	0.7%	1.5%	0.9%	3.8%	5.0%	0.9%	4.1%	5.6%
Synthetic fuels	0.0%	0.0%	0.0%	0.7%	8.0%	27.9%	0.6%	6.2%	23.9%
Electricity	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.5%

This allocation of SAF fuel follows the horizontal obligation to supply/use SAF across all EU Member States.[125] For Policy Option B2 the SAF shares are the same for all Member States when considering the intra-EEA scope. When reporting however the share of SAF in total aviation fuel mix at Member State level, the relative part of intra-EU aviation in total aviation (intra- and extra-EU) is different, and thus leading to different SAF shares by Member State (as in Table 57 and

Table 58).

Under a flexible SAF allocation scenario following the methodology presented in Annex 1 (and used to derive the SAF allocation for Policy Options C1 and C2), SAF is used where more economically relevant. This allocation is based on feedstock availability and SAF demand in each Member State (see Table 48 and Table 42).

The projections show that by 2030, compared to the overall blending share for the EU27, the shares for individual Member State on biokerosene be lower by 2.5% p.p. in Member States with small passenger traffic and low feedstock availability and up to 0.7% p.p. higher for Member States with the busiest airports and highest feedstock availability across Europe. Similarly, the shares for individual Member States on synthetic kerosene may be lower by 0.6% p.p. and higher by 0.1% p.p. in Member States with low and high passenger traffic, respectively (see the methodology followed in Annex 1).

Table 57 Share of biokerosene in jet fuel consumption in the EU27 per Member State in 2025, 2030, 2035 and 2050 in the Baseline and the Policy Options

Biokerosene share	Baseline			
	2025	2030	2035	2050
AT	0.0%	0.0%	0.5%	2.6%
BE	0.0%	0.0%	0.5%	3.3%
BG	0.0%	0.0%	0.6%	3.3%
CY	0.0%	0.0%	0.3%	1.7%
CZ	0.0%	0.0%	0.8%	4.1%
DE	0.0%	0.0%	0.4%	2.2%
DK	0.0%	0.0%	0.6%	3.9%

[125] albeit with some exceptions that would not impact the overall achievement of the targeted SAF consumption or GHG reduction

Biokerosene share	Baseline			
	2025	2030	2035	2050
EE	0.0%	0.0%	0.8%	4.7%
EL	0.0%	0.0%	0.6%	4.2%
ES	0.0%	0.0%	0.5%	2.5%
FI	0.0%	1.4%	2.2%	6.6%
FR	0.0%	1.1%	1.7%	4.5%
HR	0.0%	0.0%	0.4%	2.3%
HU	0.0%	0.0%	0.5%	2.8%
IE	0.0%	0.0%	0.3%	1.6%
IT	0.0%	0.0%	0.5%	2.6%
LT	0.0%	0.0%	0.4%	2.2%
LU	0.0%	0.0%	0.5%	3.2%
LV	0.0%	0.0%	0.4%	2.4%
MT	0.0%	0.0%	0.4%	3.0%
NL	0.0%	0.0%	0.4%	2.0%
PL	0.0%	0.0%	0.5%	3.2%
PT	0.0%	0.0%	0.5%	3.1%
RO	0.0%	0.0%	0.4%	2.6%
SE	0.0%	0.0%	1.3%	2.7%
SI	0.0%	0.0%	0.6%	3.7%
SK	0.0%	0.0%	0.6%	4.0%
EU27	0.0%	0.2%	0.7%	2.9%

Biokerosene share	PO A1				PO A2			
	2025	2030	2035	2050	2025	2030	2035	2050
AT	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
BE	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
BG	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
CY	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
CZ	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
DE	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
DK	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
EE	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
EL	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
ES	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
FI	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
FR	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
HR	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
HU	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
IE	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
IT	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
LT	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
LU	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
LV	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
MT	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
NL	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
PL	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%

Biokerosene share	PO A1				PO A2			
	2025	2030	2035	2050	2025	2030	2035	2050
PT	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
RO	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
SE	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
SI	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
SK	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%
EU27	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%

Biokerosene share	PO B1				PO B2			
	2025	2030	2035	2050	2025	2030	2035	2050
AT	2.0%	4.3%	15.0%	35.0%	0.6%	1.2%	4.2%	9.4%
BE	2.0%	4.3%	15.0%	35.0%	0.6%	1.4%	4.6%	10.7%
BG	2.0%	4.3%	15.0%	35.0%	1.0%	2.1%	7.2%	16.5%
CY	2.0%	4.3%	15.0%	35.0%	0.5%	1.0%	3.4%	7.7%
CZ	2.0%	4.3%	15.0%	35.0%	0.7%	1.5%	5.1%	11.6%
DE	2.0%	4.3%	15.0%	35.0%	0.4%	0.9%	3.0%	6.7%
DK	2.0%	4.3%	15.0%	35.0%	0.7%	1.5%	5.1%	11.5%
EE	2.0%	4.3%	15.0%	35.0%	1.1%	2.5%	8.5%	19.7%
EL	2.0%	4.3%	15.0%	35.0%	1.1%	2.3%	8.2%	18.7%
ES	2.0%	4.3%	15.0%	35.0%	0.9%	1.9%	6.3%	14.6%
FI	2.0%	4.3%	15.0%	35.0%	0.7%	1.5%	5.0%	11.4%
FR	2.0%	4.3%	15.0%	35.0%	0.5%	1.1%	3.8%	9.0%
HR	2.0%	4.3%	15.0%	35.0%	1.2%	2.5%	8.7%	19.8%
HU	2.0%	4.3%	15.0%	35.0%	0.9%	2.0%	6.8%	15.5%
IE	2.0%	4.3%	15.0%	35.0%	0.8%	1.7%	5.9%	13.7%
IT	2.0%	4.3%	15.0%	35.0%	0.7%	1.5%	5.3%	12.4%
LT	2.0%	4.3%	15.0%	35.0%	1.0%	2.3%	7.9%	18.2%
LU	2.0%	4.3%	15.0%	35.0%	1.4%	3.3%	11.6%	27.0%
LV	2.0%	4.3%	15.0%	35.0%	1.0%	2.2%	7.7%	17.6%
MT	2.0%	4.3%	15.0%	35.0%	1.0%	2.2%	7.5%	17.4%
NL	2.0%	4.3%	15.0%	35.0%	0.2%	0.5%	1.7%	3.9%
PL	2.0%	4.3%	15.0%	35.0%	0.7%	1.5%	5.2%	11.7%
PT	2.0%	4.3%	15.0%	35.0%	0.8%	1.6%	5.4%	12.6%
RO	2.0%	4.3%	15.0%	35.0%	1.4%	2.9%	10.1%	23.6%
SE	2.0%	4.3%	15.0%	35.0%	1.0%	2.1%	7.4%	17.1%
SI	2.0%	4.3%	15.0%	35.0%	0.7%	1.4%	4.9%	11.3%
SK	2.0%	4.3%	15.0%	35.0%	0.8%	1.7%	5.8%	13.1%
EU27	2.0%	4.3%	15.0%	35.0%	0.6%	1.4%	4.7%	10.9%

Biokerosene share	PO C1				PO C2			
	2025	2030	2035	2050	2025	2030	2035	2050
AT	1.4%	3.2%	15.0%	32.3%	1.4%	3.3%	17.1%	36.3%
BE	1.4%	3.2%	15.0%	30.8%	1.4%	3.3%	17.1%	34.7%
BG	0.8%	1.8%	15.0%	30.8%	0.8%	1.9%	17.1%	34.7%
CY	0.5%	1.8%	15.0%	29.2%	0.5%	2.0%	17.1%	33.2%
CZ	1.0%	2.1%	15.0%	30.8%	1.0%	2.3%	17.1%	34.7%
DE	2.3%	5.0%	15.0%	36.9%	2.3%	5.1%	17.1%	40.9%

Biokerosene share	PO C1				PO C2			
	2025	2030	2035	2050	2025	2030	2035	2050
DK	1.1%	2.5%	15.0%	31.7%	1.1%	2.7%	17.1%	35.6%
EE	0.2%	1.9%	15.0%	28.6%	0.2%	2.1%	17.1%	32.6%
EL	1.4%	3.2%	15.0%	32.3%	1.4%	3.3%	17.1%	36.3%
ES	2.3%	5.0%	15.0%	36.0%	2.3%	5.1%	17.1%	40.0%
FI	1.1%	2.5%	15.0%	33.2%	1.1%	2.7%	17.1%	37.2%
FR	2.3%	5.0%	15.0%	36.9%	2.3%	5.1%	17.1%	40.9%
HR	0.8%	1.8%	15.0%	30.8%	0.8%	1.9%	17.1%	34.7%
HU	0.8%	1.8%	15.0%	31.7%	0.8%	1.9%	17.1%	35.6%
IE	1.1%	2.5%	15.0%	33.2%	1.1%	2.7%	17.1%	37.2%
IT	2.3%	5.0%	15.0%	36.9%	2.3%	5.1%	17.1%	40.9%
LT	0.2%	1.9%	15.0%	30.2%	0.2%	2.1%	17.1%	34.1%
LU	0.2%	1.9%	15.0%	27.7%	0.2%	2.1%	17.1%	31.6%
LV	0.2%	1.9%	15.0%	29.2%	0.2%	2.1%	17.1%	33.2%
MT	0.2%	1.9%	15.0%	27.7%	0.2%	2.1%	17.1%	31.6%
NL	1.7%	3.8%	15.0%	32.3%	1.7%	3.9%	17.1%	36.3%
PL	2.0%	4.3%	15.0%	36.9%	2.0%	4.4%	17.1%	40.9%
PT	1.4%	3.2%	15.0%	33.2%	1.4%	3.3%	17.1%	37.2%
RO	1.4%	3.2%	15.0%	33.9%	1.4%	3.3%	17.1%	37.8%
SE	2.0%	4.3%	15.0%	34.5%	2.0%	4.4%	17.1%	38.4%
SI	0.2%	1.9%	15.0%	27.7%	0.2%	2.1%	17.1%	31.6%
SK	0.5%	1.8%	15.0%	28.6%	0.5%	2.0%	17.1%	32.6%
EU27	2.0%	4.3%	15.0%	35.0%	2.0%	4.5%	17.1%	38.9%

Table 58 Share of synthetic kerosene in jet fuel consumption in the EU27 per Member State in 2025, 2030, 2035 and 2050 in the Baseline and the Policy Options

Synthetic kerosene share	Baseline			
	2025	2030	2035	2050
AT	0.0%	0.0%	0.0%	0.0%
BE	0.0%	0.0%	0.0%	0.0%
BG	0.0%	0.0%	0.0%	0.0%
CY	0.0%	0.0%	0.0%	0.0%
CZ	0.0%	0.0%	0.0%	0.0%
DE	0.0%	0.0%	0.0%	0.0%
DK	0.0%	0.0%	0.0%	0.0%
EE	0.0%	0.0%	0.0%	0.0%
EL	0.0%	0.0%	0.0%	0.0%
ES	0.0%	0.0%	0.0%	0.0%
FI	0.0%	0.0%	0.0%	0.0%
FR	0.0%	0.0%	0.0%	0.0%
HR	0.0%	0.0%	0.0%	0.0%
HU	0.0%	0.0%	0.0%	0.0%
IE	0.0%	0.0%	0.0%	0.0%
IT	0.0%	0.0%	0.0%	0.0%
LT	0.0%	0.0%	0.0%	0.0%
LU	0.0%	0.0%	0.0%	0.0%
LV	0.0%	0.0%	0.0%	0.0%

Synthetic kerosene share	Baseline			
	2025	2030	2035	2050
MT	0.0%	0.0%	0.0%	0.0%
NL	0.0%	0.0%	0.0%	0.0%
PL	0.0%	0.0%	0.0%	0.0%
PT	0.0%	0.0%	0.0%	0.0%
RO	0.0%	0.0%	0.0%	0.0%
SE	0.0%	0.0%	0.0%	0.0%
SI	0.0%	0.0%	0.0%	0.0%
SK	0.0%	0.0%	0.0%	0.0%
EU27	0.0%	0.0%	0.0%	0.0%

Synthetic kerosene share	PO A1				PO A2			
	2025	2030	2035	2050	2025	2030	2035	2050
AT	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
BE	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
BG	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
CY	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
CZ	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
DE	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
DK	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
EE	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
EL	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
ES	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
FI	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
FR	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
HR	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
HU	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
IE	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
IT	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
LT	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
LU	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
LV	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
MT	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
NL	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
PL	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
PT	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
RO	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
SE	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
SI	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
SK	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%
EU27	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	2.9%	24.1%

Synthetic kerosene share	PO B1				PO B2			
	2025	2030	2035	2050	2025	2030	2035	2050
AT	0.0%	0.7%	5.0%	28.0%	0.0%	0.2%	1.4%	7.5%
BE	0.0%	0.7%	5.0%	28.0%	0.0%	0.2%	1.5%	8.5%
BG	0.0%	0.7%	5.0%	28.0%	0.0%	0.3%	2.4%	13.2%
CY	0.0%	0.7%	5.0%	28.0%	0.0%	0.2%	1.1%	6.2%

CZ	0.0%	0.7%	5.0%	28.0%	0.0%	0.2%	1.7%	9.3%
DE	0.0%	0.7%	5.0%	28.0%	0.0%	0.1%	1.0%	5.3%
DK	0.0%	0.7%	5.0%	28.0%	0.0%	0.2%	1.7%	9.2%
EE	0.0%	0.7%	5.0%	28.0%	0.0%	0.4%	2.8%	15.7%
EL	0.0%	0.7%	5.0%	28.0%	0.0%	0.4%	2.7%	14.9%
ES	0.0%	0.7%	5.0%	28.0%	0.0%	0.3%	2.1%	11.7%
FI	0.0%	0.7%	5.0%	28.0%	0.0%	0.2%	1.7%	9.2%
FR	0.0%	0.7%	5.0%	28.0%	0.0%	0.2%	1.3%	7.2%
HR	0.0%	0.7%	5.0%	28.0%	0.0%	0.4%	2.9%	15.9%
HU	0.0%	0.7%	5.0%	28.0%	0.0%	0.3%	2.3%	12.4%
IE	0.0%	0.7%	5.0%	28.0%	0.0%	0.3%	2.0%	11.0%
IT	0.0%	0.7%	5.0%	28.0%	0.0%	0.3%	1.8%	9.9%
LT	0.0%	0.7%	5.0%	28.0%	0.0%	0.4%	2.6%	14.5%
LU	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	3.9%	21.6%
LV	0.0%	0.7%	5.0%	28.0%	0.0%	0.4%	2.6%	14.1%
MT	0.0%	0.7%	5.0%	28.0%	0.0%	0.4%	2.5%	13.9%
NL	0.0%	0.7%	5.0%	28.0%	0.0%	0.1%	0.6%	3.1%
PL	0.0%	0.7%	5.0%	28.0%	0.0%	0.2%	1.7%	9.3%
PT	0.0%	0.7%	5.0%	28.0%	0.0%	0.3%	1.8%	10.1%
RO	0.0%	0.7%	5.0%	28.0%	0.0%	0.5%	3.4%	18.9%
SE	0.0%	0.7%	5.0%	28.0%	0.0%	0.3%	2.5%	13.7%
SI	0.0%	0.7%	5.0%	28.0%	0.0%	0.2%	1.6%	9.1%
SK	0.0%	0.7%	5.0%	28.0%	0.0%	0.3%	1.9%	10.5%
EU27	0.0%	0.7%	5.0%	28.0%	0.0%	0.2%	1.6%	8.7%

Synthetic kerosene share	PO C1				PO C2			
	2025	2030	2035	2050	2025	2030	2035	2050
AT	0.0%	0.5%	5.0%	25.8%	0.0%	0.4%	2.9%	21.9%
BE	0.0%	0.5%	5.0%	24.6%	0.0%	0.4%	2.9%	20.7%
BG	0.0%	0.3%	5.0%	24.6%	0.0%	0.1%	2.9%	20.7%
CY	0.0%	0.2%	5.0%	23.4%	0.0%	0.0%	2.9%	19.4%
CZ	0.0%	0.3%	5.0%	24.6%	0.0%	0.2%	2.9%	20.7%
DE	0.0%	0.8%	5.0%	29.5%	0.0%	0.7%	2.9%	25.6%
DK	0.0%	0.4%	5.0%	25.4%	0.0%	0.3%	2.9%	21.4%
EE	0.0%	0.1%	5.0%	22.9%	0.0%	0.0%	2.9%	18.9%
EL	0.0%	0.5%	5.0%	25.8%	0.0%	0.4%	2.9%	21.9%
ES	0.0%	0.8%	5.0%	28.8%	0.0%	0.7%	2.9%	24.9%
FI	0.0%	0.4%	5.0%	26.6%	0.0%	0.3%	2.9%	22.6%
FR	0.0%	0.8%	5.0%	29.5%	0.0%	0.7%	2.9%	25.6%
HR	0.0%	0.3%	5.0%	24.6%	0.0%	0.1%	2.9%	20.7%
HU	0.0%	0.3%	5.0%	25.4%	0.0%	0.1%	2.9%	21.4%
IE	0.0%	0.4%	5.0%	26.6%	0.0%	0.3%	2.9%	22.6%
IT	0.0%	0.8%	5.0%	29.5%	0.0%	0.7%	2.9%	25.6%
LT	0.0%	0.1%	5.0%	24.1%	0.0%	0.0%	2.9%	20.2%
LU	0.0%	0.1%	5.0%	22.2%	0.0%	0.0%	2.9%	18.2%
LV	0.0%	0.1%	5.0%	23.4%	0.00%	0.01%	2.92%	19.4%
MT	0.0%	0.1%	5.0%	22.2%	0.00%	0.01%	2.92%	18.2%
NL	0.0%	0.6%	5.0%	25.8%	0.00%	0.47%	2.92%	21.9%
PL	0.0%	0.7%	5.0%	29.5%	0.00%	0.55%	2.92%	25.6%

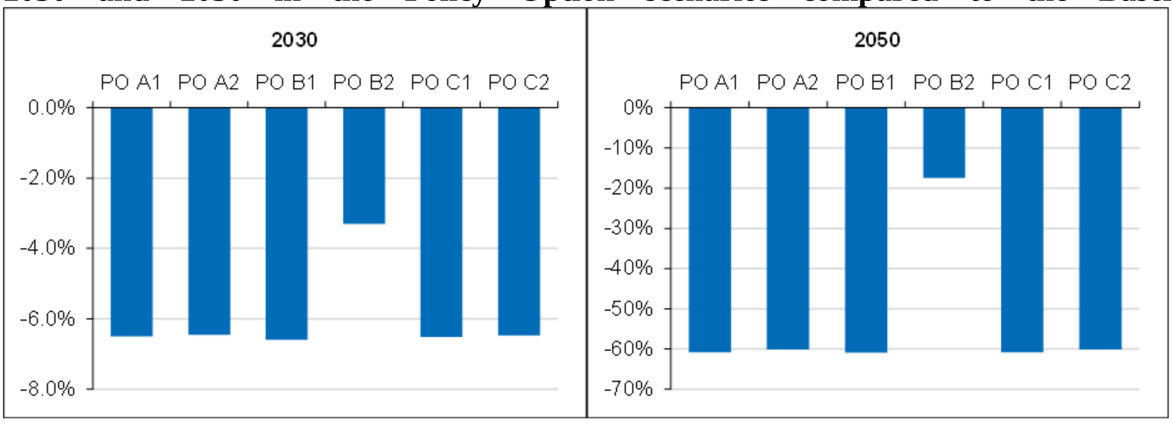
Synthetic kerosene share	PO C1				PO C2			
	2025	2030	2035	2050	2025	2030	2035	2050
PT	0.0%	0.5%	5.0%	26.6%	0.00%	0.36%	2.92%	22.6%
RO	0.0%	0.5%	5.0%	27.1%	0.00%	0.36%	2.92%	23.1%
SE	0.0%	0.7%	5.0%	27.6%	0.00%	0.55%	2.92%	23.6%
SI	0.0%	0.1%	5.0%	22.2%	0.00%	0.01%	2.92%	18.2%
SK	0.0%	0.2%	5.0%	22.9%	0.00%	0.03%	2.92%	18.9%
EU27	0.0%	0.7%	5.0%	28.0%	0.0%	0.6%	2.9%	24.0%

GHG emissions

The reduction of energy consumption in aviation and the introduction of sustainable aviation fuels in the jet fuel mix in the Policy Option scenarios, reduce the WTW GHG emissions from aviation significantly. By 2030, GHG emissions are lower by up to 6.6% in all Policy Options compared to the Baseline. The reduction in Policy Option B2 is 3.4% and is the lowest across the Policy Options due to higher jet fuel consumption. The impact of the Policy Options becomes evident in the years leading to 2050, when, depending on option, WTW GHG emissions are lower by 17% to 61% compared to the Baseline. The highest emission reduction (i.e. 61%) is projected in Policy Option B1, when there are no incentives for airliners to tanker fuel outside the EU, but the result is similar with the other Policy Options. The lowest emission reduction (i.e. 17%) is projected in Policy Option B2, which applies blending mandates only on the fuel used for intra-EU flights.

Emission reduction of air pollutants is similar across all Policy Options, at around 3% in 2030 and 9.5% in 2050 in all Policy Options compared to the Baseline, with the exception of Policy Option B2, in which they reduce by around 5% and 7.5% in 2030 and 2050, respectively (Table 60). Summary tables of WTW GHG emissions in aviation and emissions of air pollutants in aviation in the Baseline and the Policy Option scenarios are presented in Table 59 and Table 60, respectively.

Figure 41 Reduction of WTW GHG emissions in passenger air transport in the EU27 in 2030 and 2050 in the Policy Option scenarios compared to the Baseline



Source: PRIMES-TREMOVE

Table 59 GHG emissions in air transport in the EU27 in 2030, 2040 and 2050 in the Baseline and the Policy Option scenarios

GHG emissions, Mt CO2eq	Baseline			Policy Option A1			Policy Option A2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Tank-To-Wing	139.9	142.5	144.2	130.4	94.0	50.0	130.5	94.2	50.2
Well-To-Wing	183.5	186.8	188.8	171.5	128.3	73.9	171.6	129.0	75.2

GHG emissions,	Baseline	Policy Option B1	Policy Option B2

Mt CO2eq	2030	2040	2050	2030	2040	2050	2030	2040	2050
Tank-To-Wing	139.9	142.5	144.2	130.3	93.9	50.0	135.1	125.9	112.8
Well-To-Wing	183.5	186.8	188.8	171.4	128.1	73.9	177.4	167.9	155.8

GHG emissions, Mt CO2eq	Baseline			Policy Option C1			Policy Option C2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Tank-To-Wing	139.9	142.5	144.2	130.4	94.0	50.0	130.4	94.2	50.2
Well-To-Wing	183.5	186.8	188.8	171.5	128.2	73.9	171.6	129.0	75.2

Table 60 Emissions of air pollutants in air transport in the EU27 in 2030, 2040 and 2050 in the Baseline and the Policy Option scenarios

Air pollutants aviation, ktons	Baseline			Policy Option A1			Policy Option A2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
CO	0.34	0.32	0.30	0.33	0.30	0.27	0.33	0.30	0.2
NOx	412.6	387.5	366.2	398.8	367.6	331.1	398.9	368.3	331.9
PM2.5	9.2	8.6	8.1	8.9	8.2	7.3	8.9	8.2	7.3

Air pollutants aviation, ktons	Baseline			Policy Option B1			Policy Option B2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
CO	0.34	0.32	0.30	0.33	0.30	0.27	0.33	0.31	0.28
NOx	412.6	387.5	366.2	398.3	367.2	330.6	398.5	370.8	339.8
PM2.5	9.1	8.6	8.1	8.9	8.1	7.3	8.9	8.2	7.5

Air pollutants aviation, ktons	Baseline			Policy Option C1			Policy Option C2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
CO	0.34	0.32	0.30	0.33	0.30	0.27	0.33	0.30	0.27
NOx	412.6	387.5	366.2	398.8	367.6	331.1	398.9	368.3	331.9
PM2.5	9.2	8.6	8.1	8.9	8.2	7.3	8.9	8.2	7.3

Total costs

In 2030, the total costs of aviation (capital costs, fixed and variable non-fuel costs, and fuel costs) are lower than the Baseline by almost 0.15% (about 0.5 bn Euro) in all Policy Options and by almost 0.3% (about 1 bn Euro) in Policy Option B2. This is primarily due to the decline in passenger air transport activity, which leads to lower demand for aircrafts that reduces the capital, fixed and variable non-fuel expenditures (the latter include fixed costs for maintenance, indirect operating costs and crew costs). The introduction of more expensive sustainable aviation fuels in the Policy Option scenarios leads to an increase in the fuel costs, which counterbalance the cost reduction due to lower capital, ultimately leading to lower costs in the Policy Option scenarios compared to the Baseline. This effect is more prominent in Policy Option B2, leading to about 0.15% p.p. lower costs than all other Policy Options in 2030. By 2050, the strong increase of SAF blending rates in the Policy Options increases the fuel costs to an extent that total system costs of aviation are higher by 1.8% to 2.1% (or up to about 10 bn Euro) despite the reduction in all other cost components, compared to the Baseline. An exception is Policy Option B2, which leads to lower total costs in aviation by 0.2% (or 1 bn Euro) in 2050, compared to the Baseline. The increase of fuel costs due to the more expensive sustainable aviation fuels in Policy Option B2 is at such levels that does not counterbalance the overall cost reduction that is projected due to lower energy demand and capital costs resulting from loss of air transport activity (compared to the Baseline).

Table 61 also shows that the Policy Options A2 and C2 lead to lower costs than their Policy Option counterparts A1 and C1, due higher blends of biokerosene, and its lower production costs compared to synthetic kerosene. Therefore, the deployment of sustainable aviation fuels shares on the basis of a Well-to-Wing emission intensity for the jet fuel blend, in terms of present value over the 2020-2050 horizon leads to 5 bn Euro lower costs than the Policy Options with prescribed volume-based targets (Table 62).

Excluding Policy Option B2 that leads to lower costs than the Baseline, the lowest present value of total costs in aviation in 2020-2050 is estimated for Policy Option C2 at 13.8 bn Euro, which corresponds to an increase in the share of the total costs of the aviation sector of below 0.1% of the EU GDP additional to the Baseline (Table 62). Including external costs of air pollution and CO_2, all Policy Options lead to lower costs than the Baseline, between 30 bn Euro (Policy Option B2), and around 86.5 bn Euro (al other Policy Options). Introducing a transition period for fuel suppliers to meet the EU-wide blending mandates by distributing SAF within a given range, as in the set of Policy Options C, leads to lower total costs of about 0.1 bn Euro (present value) in the period 2020-2050, compared to their Policy Option A counterparts.

Summary tables of total costs in aviation in the Baseline and the Policy Option scenarios and present value of total costs in aviation in 2020-2050 are presented in Table 61 and Table 62, respectively.

Table 61 Total costs in aviation in the Baseline and the Policy Options in the EU27 in 2030, 2040 and 2050

Total costs aviation, bn Euro '15	Baseline			Policy Option A1			Policy Option A2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Total costs	362.6	434.0	491.9	362.1	435.8	502.2	362.1	435.1	500.8
Capital costs	134.9	167.9	193.9	134.4	164.1	189.6	134.5	164.4	190.0
Fixed and variable non-fuel costs	179.4	210.4	235.2	178.6	204.8	222.5	178.7	205.3	223.2
Fuel costs	48.3	55.6	62.7	49.0	66.9	90.1	48.9	65.4	87.5

Total costs aviation, bn Euro '15	Baseline			Policy Option B1			Policy Option B2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Total costs	362.6	434.0	491.9	362.1	435.7	502.2	361.6	431.6	490.9
Capital costs	134.9	167.9	193.9	134.5	164.1	189.6	134.7	166.0	194.8
Fixed and variable non-fuel costs	179.4	210.4	235.2	178.6	204.8	222.6	179.0	207.9	230.2
Fuel costs	48.3	55.6	62.7	49.0	66.8	90.0	47.9	57.8	65.9

Total costs aviation, bn Euro '15	Baseline			Policy Option C1			Policy Option C2		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Total costs	362.6	434.0	491.9	362.1	435.8	502.2	362.0	435.1	500.8
Capital costs	134.9	167.9	193.9	134.4	164.1	189.6	134.5	164.4	190.0
Fixed and variable non-fuel costs	179.4	210.4	235.2	178.6	204.8	222.5	178.7	205.3	223.2
Fuel costs	48.3	55.6	62.7	49.0	66.9	90.1	48.9	65.4	87.5

Table 62 Present value of total costs in aviation the EU27 in 2020-2050 in the Policy Options compared to the Baseline

Present value 2020-2050, compared	Baseline	PO A1	PO A2	PO B1	PO B2	PO C1	PO C2

to Baseline, bn Euro '15							
Capital costs	2442.1	-31.1	-27.2	-30.9	-12.1	-31.0	-27.2
Fuel costs	791.9	103.5	88.3	102.7	14.7	103.5	88.2
Fixed and variable non-fuel costs	3064.5	-52.9	-47.2	-52.6	-23.5	-53.0	-47.3
Total costs excluding external costs	6298.5	19.6	13.9	19.2	-20.9	19.5	13.8
External costs of air pollution	34.3	-1.5	-1.5	-1.6	-1.5	-1.5	-1.5
External costs of CO2	330.1	-86.5	-86.0	-86.7	-29.8	-86.5	-86.0
Total costs including external costs	6662.8	-68.4	-73.6	-69.0	-52.2	-68.5	-73.7

Biokerosene production chains

In this section we present a more in-depth analysis of the results on biokerosene production chains that are deployed based on the PRIMES Biomass supply model that derive from the demand for biokerosene estimated with PRIMES-TREMOVE. The results are presented for a high biokerosene demand context and a low biokerosene demand context. The high biokerosene demand context can be considered representative for the demand projections in Policy Options A1, A2, B1, C1 and C2. The low biokerosene demand context can be considered representative for the demand projections Policy Option B2. Results are presented for biokerosene produced by the different conversion chains (Figure 42) and for the demand for domestic biomass feedstock required to produce biokerosene (Figure 43).

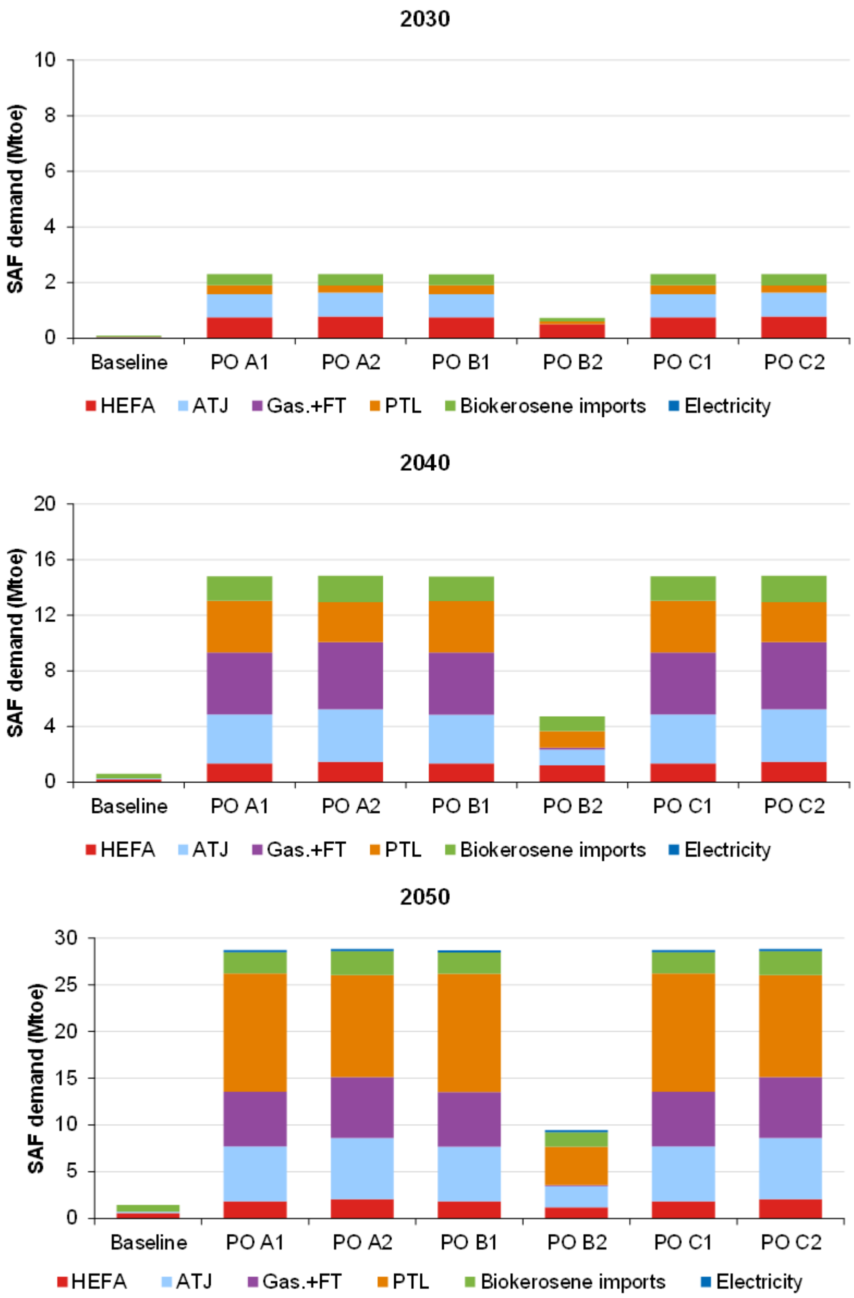
In 2030, the demand for biokerosene in the high and low demand scenarios is 1.9 Mt and 0.6 Mt, respectively. In the high biokerosene demand context, the demand is met by the HEFA and the Alcohol-to-Jet production routes that supply biokerosene in roughly equal shares (0.7 Mt and 0.8 Mt, respectively), while extra-EU imports account for the remainder (0.4 Mt or about 20%). In the low biokerosene demand context, HEFA supply is prominent as it covers about 80% of total demand, reaching 0.5 Mt in 2030. A key difference with the high demand context, is that in when demand for biokerosene is comparably low then HEFA is the only production route that is deployed in the EU in 2030.

By 2050, the contribution of advanced production technologies, that convert lignocellulosic feedstocks to biokerosene, is projected to increase significantly in both scenarios. In the high biokerosene demand context, the Alcohol-to-Jet and the Gasification and Fischer-Tropsch production pathways have the lion's share of the EU biokerosene market. In the period leading to 2050, the Alcohol-to-Jet route that is deployed somewhat earlier than Gasification and Fischer-Tropsch, produces 3.4 Mt in 2035. The Gasification and Fischer-Tropsch route emerges in 2035, producing about 0.3 Mt of biokerosene. In the years that follow, Gasification and Fischer-Tropsch scales up rapidly as demand increases. By 2050, Alcohol-to-Jet and Gasification and Fischer-Tropsch supply almost 75% of biokerosene demand in 2050. Biokerosene production from HEFA, increases gradually towards 2050, from 0.7 Mt in 2030 to 1.8 Mt in 2050, ultimately supplying about 10% of biokerosene demand. These projected developments occur to the gradual detriment of imports, that on the one hand show an increase in production volume (2.2 Mt in 2050 compared to 0.4 Mt in 2030), but on the other hand their market share drops to 14%, compared to 20% in 2030.

Similarly, in the low biokerosene demand context, the production output from the HEFA route continues to increase after 2030, stabilising at around 1.1 Mt towards 2050. However, most of the additional demand for biokerosene is met by the Alcohol-to-Jet route (around 2.2 Mt in 2050), and to a somewhat lower extent by imports (around 1.5 Mt in 2050).

As such, higher biokerosene demand enables the deployment of several biokerosene production pathways (i.e. HEFA, Alcohol-to-Jet, and Gasification and Fischer-Tropsch), a fast ramp up of technologies that use lignocellulosic feedstocks, and to less dependency on imports, taking advantage of lower production costs due to economies of scale and learning. In contrast, when demand for biokerosene is comparably low, there are less opportunities for large-scale technology deployment, impacting the diversification of advanced conversion pathways, as primarily the Alcohol-to-Jet route is deployed, leading to higher reliance on HEFA jet fuel produced from used cooking oils, and higher dependency on biokerosene imports.

Figure 42 SAF production in the EU27 in 2030, 2040 and 2050



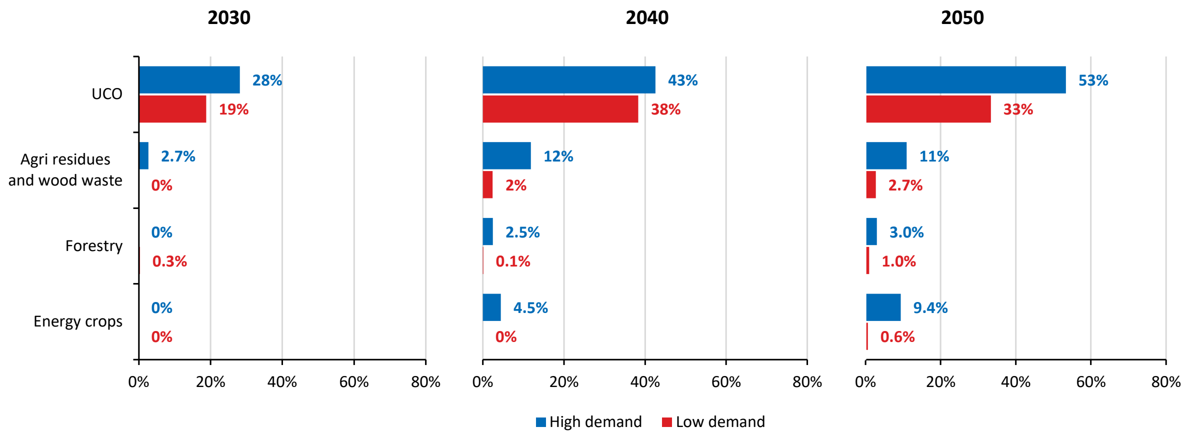
Source: PRIMES-TREMOVE and PRIMES Biomass

In 2030, HEFA, as one of the main pathways producing biokerosene in the high demand scenario, is a key consumer of UCO requiring 28% of total available potential in the EU (Figure 43). The remaining of the available potential of UCO is consumed in other transport segments such as road transport and maritime. The scenario in which the demand for biokerosene is comparably lower, shows that the HEFA route requires about one-fifth of the UCO potential in the EU in 2030. The deployment of the Alcohol-to-Jet route in 2030, leads to the consumption mainly of agricultural residues, and about 3% of the available potential in the EU is used for biokerosene production.

Towards 2050, the increase of biokerosene demand and the significant ramp up of other advanced biokerosene production technologies lead to an increase in the volumes of lignocellulosic feedstocks and of the share of the available potential in the EU used for biokerosene. These feedstocks are primarily agricultural residues, wood waste, and new energy crops. In the high biokerosene demand context, the Alcohol-to-Jet and the

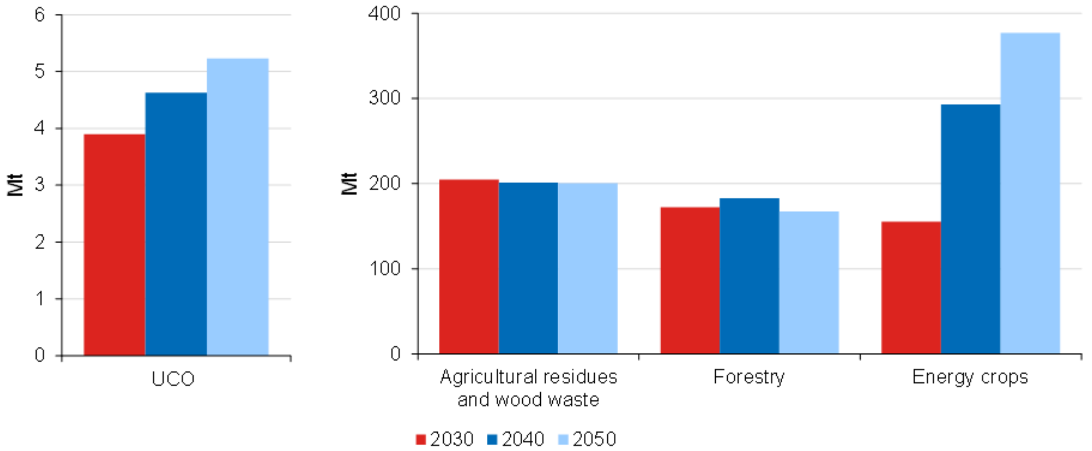
Gasification and Fischer-Tropsch routes consume about 11% of the available potential of agricultural residues and wood waste, 3% of the available potential of forestry products and residues, and around 9% of the available potential of energy crops in the EU in 2050. The gradual increase of production from the HEFA route in the high biokerosene demand context, leads to an increase in the use of UCO for biokerosene. In 2050, biokerosene consumes up to 53% of the total available potential of UCO in the EU, compared to about 28% that it requires in 2030. In the low biokerosene demand context, the production from the HEFA chain also increases post-2030 and so does its consumption share of UCO that is available in the EU. From about 20% in 2030, the HEFA route consumes 33% of the EU's UCO potential. There is also an increase of lignocellulosic feedstock consumption, yet less than 3% of the available lignocellulosic feedstocks for bioenergy in the EU in 2050.

Figure 43 Share of the available biomass feedstock in the EU used for biokerosene production in the high and low biokerosene demand context



Source: PRIMES Biomass

Figure 44 Feedstock availability for bioenergy production in the EU



Source: PRIMES Biomass

Model results

Baseline scenario detailed results (1/2)

EU27noUK:REF2020_v1(SAF)											SUMMARY (A)			
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % change			
Transport activity														
Passenger transport activity (Gpkm)	**5281**	**5457**	**5622**	**4499**	**6120**	**6496**	**6729**	**6938**	**7153**	**7370**	**-1.9**	**3.7**	**0.7**	**0.6**
Public road transport	498	484	487	313	473	498	503	517	526	532	-4.3	4.8	0.4	0.3
Private cars	3532	3657	3721	3252	4003	4205	4314	4410	4517	4634	-1.2	2.6	0.5	0.5
2wheelers	115	115	120	100	124	131	135	139	144	150	-1.3	2.7	0.6	0.7
Passenger light duty vehicles	309	324	335	294	365	388	401	411	420	430	-1.0	2.8	0.6	0.5
Rail	417	444	471	274	530	577	622	653	691	728	-4.7	7.7	1.2	1.1
Aviation	373	398	450	244	584	655	710	764	809	850	-4.8	10.4	1.6	1.1
Inland navigation	36	35	38	21	40	42	44	45	46	46	-5.1	7.4	0.5	0.4
Freight transport activity (Gtkm)	**2362**	**2320**	**2314**	**2377**	**2756**	**3022**	**3179**	**3334**	**3462**	**3564**	**0.2**	**2.4**	**1.0**	**0.7**
Heavy duty vehicles	1582	1564	1552	1644	1870	2031	2116	2206	2281	2332	0.5	2.1	0.8	0.6
Freight light duty vehicles	94	81	76	76	88	96	101	106	111	115	-0.6	2.3	1.0	0.8
Rail	395	375	396	382	473	550	603	651	688	724	0.2	3.7	1.7	1.1
Inland waterway navigation	291	301	290	274	325	345	358	371	382	393	-0.9	2.4	0.7	0.6
Final Energy Demand (ktoe)	**307729**	**307180**	**303451**	**247263**	**298510**	**279165**	**258806**	**244616**	**235312**	**231732**	**-2.1**	**1.2**	**-1.3**	**-0.5**
by transport mode														
Passenger transport	**232204**	**229838**	**234406**	**178433**	**227184**	**209296**	**192412**	**179392**	**169787**	**165287**	**-2.5**	**1.6**	**-1.5**	**-0.8**
Public road transport	8572	8321	9070	5748	8540	8506	8402	8449	8511	8530	-3.6	4.0	-0.1	0.1
Private cars	159751	153951	157553	129280	145363	127726	112431	100350	91946	87477	-1.7	-0.1	-2.4	-1.4
2wheelers	3704	3421	3674	2984	3588	3706	3747	3795	3845	3905	-1.4	2.2	0.2	0.3
Passenger light duty vehicles	19153	22373	20565	17489	19902	18692	16551	14662	12496	11735	-2.4	0.7	-2.4	-2.2
Rail	2742	2738	2612	1484	2684	2764	2856	2850	2907	2937	-5.9	6.4	0.3	0.3
Aviation	37042	37782	39975	20939	46127	46890	47394	48249	49042	49666	-5.7	8.4	0.3	0.3
Inland navigation	1240	1252	957	509	979	1012	1031	1036	1038	1038	-8.6	7.1	0.2	0.0
Freight transport	**75525**	**77342**	**69045**	**68830**	**71326**	**69869**	**66394**	**65224**	**65526**	**66444**	**-1.2**	**0.1**	**-0.7**	**0.2**
Heavy duty vehicles	54076	56954	52572	52889	54215	53229	51504	50863	51534	52559	-0.7	0.1	-0.5	0.3
Freight light duty vehicles	13037	12937	10753	10580	10868	10048	8093	7413	6964	6758	-2.0	-0.5	-3.0	-0.9
Rail	4029	3576	2798	2556	3025	3285	3432	3517	3556	3602	-3.3	2.5	0.7	0.2
Inland waterway navigation	4383	3875	2921	2806	3218	3306	3365	3431	3472	3525	-3.2	1.7	0.4	0.3
by fuel														
Oil products	**299776**	**290356**	**284864**	**226120**	**269138**	**239478**	**212625**	**193077**	**178409**	**170181**	**-2.5**	**0.6**	**-2.1**	**-1.3**
Gasoline	94548	75865	64529	53064	56517	45063	35591	29418	24939	22009	-3.5	-1.6	-4.2	-2.9
Diesel	162148	170056	173527	145252	156149	136463	119118	106175	96369	91237	-1.6	-0.6	-2.5	-1.5
Kerosene	37042	37782	39975	20939	46127	46798	47062	47656	47818	48210	-5.7	8.4	0.2	0.1
Liquefied Petroleum Gas	4691	5198	5895	6277	9678	10574	10383	9459	9022	8564	1.9	5.4	-1.1	-1.0
Residual fuel oil	1346	1455	938	588	667	580	471	368	261	161	-8.7	-0.1	-4.4	-7.9
Biofuels	**3134**	**11567**	**12886**	**16360**	**19257**	**20775**	**19081**	**17202**	**16514**	**16151**	**3.5**	**2.4**	**-1.9**	**-0.6**
Bio Gasoline	551	2480	2385	3341	3922	4316	3597	3003	2599	2338	3.0	2.6	-3.6	-2.5
Bio Diesel	2583	9064	10409	12504	14324	14729	13177	11454	10469	9986	3.3	1.7	-2.5	-1.4
Bio Kerosene	0	0	0	0	0	93	332	593	1224	1456	0.0	0.0	20.4	9.4
DME	0	0	0	0	0	0	0	0	0	0	-18.7	16.6	0.1	-0.6
Bio Heavy	0	0	0	45	52	54	45	34	25	16	0.0	1.7	-4.4	-7.6
Biogas	0	22	92	470	960	1584	1929	2118	2197	2356	35.7	12.9	2.9	1.1
Electricity	4269	4108	4102	3384	5560	10559	15691	20103	23952	25905	**-1.9**	**12.1**	**6.7**	**2.6**
Natural Gas	551	1149	1599	1398	4533	8191	10256	11182	11595	12652	**2.0**	**19.3**	**3.2**	**1.2**
Hydrogen	0	0	0	1	22	162	1153	3052	4841	6841	**0.0**	**64.7**	**34.1**	**8.4**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**44.0**	**42.1**	**41.7**	**39.7**	**37.1**	**32.2**	**28.6**	**25.9**	**23.7**	**22.4**	**-0.6**	**-2.1**	**-2.2**	**-1.4**
Public road transport	17.2	17.2	18.6	18.4	18.0	17.1	16.7	16.4	16.2	16.0	0.7	-0.7	-0.4	-0.2
Private cars	45.2	42.1	42.3	39.8	36.3	30.4	26.1	22.8	20.4	18.9	-0.6	-2.7	-2.8	-1.9
2wheelers	32.2	29.8	30.5	29.7	28.8	28.3	27.7	27.2	26.6	26.1	0.0	-0.5	-0.4	-0.4
Passenger light duty vehicles	62.0	69.1	61.4	59.4	54.6	48.2	41.3	35.7	29.7	27.3	-1.5	-2.1	-3.0	-2.6
Rail	6.6	6.2	5.6	5.4	5.1	4.8	4.6	4.4	4.2	4.0	-1.3	-1.2	-0.9	-0.8
Aviation	99.4	94.8	88.8	85.9	79.0	71.5	66.8	63.1	60.6	58.4	-1.0	-1.8	-1.2	-0.8
Inland navigation	34.3	35.7	25.5	24.6	24.2	24.0	23.6	23.2	22.8	22.4	-3.7	-0.2	-0.3	-0.4
Freight transport activity (toe/Mtkm)	**32.0**	**33.3**	**29.8**	**29.0**	**25.9**	**23.1**	**20.9**	**19.6**	**18.9**	**18.6**	**-1.4**	**-2.2**	**-1.7**	**-0.5**
Heavy duty vehicles	34.2	36.4	33.9	32.2	29.0	26.2	24.3	23.1	22.6	22.5	-1.2	-2.0	-1.3	-0.2
Freight light duty vehicles	138.3	159.8	141.5	138.4	123.3	104.7	79.9	69.7	62.6	58.9	-1.4	-2.8	-4.0	-1.7
Rail	10.2	9.5	7.1	6.7	6.4	6.0	5.7	5.4	5.2	5.0	-3.5	-1.1	-1.0	-0.8
Inland waterway navigation	15.1	12.9	10.1	10.3	9.9	9.6	9.4	9.2	9.1	9.0	-2.3	-0.7	-0.3	-0.3
CO_2 EMISSIONS (in ktons CO_2)	**906190**	**881844**	**867524**	**689023**	**824888**	**743342**	**666799**	**609897**	**566422**	**544115**	**-2.4**	**0.8**	**-2.0**	**-1.1**
Passenger transport	681645	659116	670291	497615	631210	560897	500394	450683	409614	387372	-2.8	1.2	-2.2	-1.5
Public road transport	26176	24543	26528	16298	23966	23220	22801	22957	23082	23078	-4.0	3.6	-0.1	0.1
Private cars	469864	440509	449925	358696	399272	332191	279052	234702	201892	182378	-2.0	-0.8	-3.4	-2.5
2wheelers	10708	9666	10357	8220	9821	9979	10054	10184	10298	10444	-1.6	2.0	0.2	0.3
Passenger light duty vehicles	58428	65863	59766	49697	56445	51864	44128	36816	27974	24067	-2.8	0.4	-3.4	-4.2
Rail	1802	1606	1179	616	934	838	739	623	496	386	-9.1	3.1	-2.9	-4.7
Aviation	110776	112987	119547	62618	137942	139950	140740	142516	143002	144172	-5.7	8.4	0.2	0.1
Inland navigation	3890	3942	2989	1469	2831	2856	2881	2884	2869	2847	-9.4	6.9	0.1	-0.1
Freight transport	224545	222729	197233	191408	193677	182445	166405	159215	156808	156743	**-1.5**	**-0.5**	**-1.4**	**-0.2**
Heavy duty vehicles	165281	167617	153782	150732	151405	143685	135354	131684	132097	134092	-1.1	-0.5	-0.9	0.2
Freight light duty vehicles	39662	37862	31251	30065	30456	27095	19522	16140	13580	11697	-2.3	-1.0	-5.0	-3.2
Rail	5925	5156	3115	2420	2493	2261	2015	1701	1365	1074	-7.3	-0.7	-2.8	-4.5
Inland waterway navigation	13677	12094	9086	8191	9323	9404	9514	9690	9766	9880	-3.8	1.4	0.3	0.2

Source: PRIMES-TREMOVE Transport Model

Baseline scenario detailed results (2/2)

SUMMARY (B)													SUMMARY (B)	
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
												Annual % change		
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**215414**	**238232**	**250794**	**263300**	**259542**	**265069**	**270809**	**276970**	**282363**	**284806**	**1.0**	**0.1**	**0.4**	**0.3**
Diesel Conventional	73600	105878	122727	128035	110803	93060	78117	63756	52971	44858	1.9	-3.1	-3.7	-3.5
Diesel Hybrid	0	73	401	2414	12457	20616	25616	26647	25149	24374	41.9	23.9	2.6	-0.9
Diesel plug-in hybrid	0	0	57	301	1053	6222	14531	20406	24734	26702	0.0	35.4	12.6	2.7
Gasoline Conventional	135523	125022	118877	118198	101112	75222	54620	38715	29434	23525	-0.6	-4.4	-6.4	-4.9
Gasoline Hybrid	21	162	783	3106	15060	20462	22496	21759	19048	17417	34.4	20.7	0.6	-2.2
Gasoline plug-in hybrid	0	0	86	461	2368	7081	11756	19438	24625	26594	0.0	31.4	10.6	3.2
LPG	5422	5710	5839	7634	9318	10726	11303	10385	9823	9163	2.9	3.5	-0.3	-1.2
CNG	848	1343	1757	1897	2615	3851	4991	5719	5739	5747	3.5	7.3	4.0	0.0
E85	0	45	89	151	392	605	656	650	618	598	12.9	14.9	0.7	-0.8
Electric	0	0	179	1102	4323	26885	45343	64391	81123	91545	0.0	37.6	9.1	3.6
Hydrogen	0	0	0	2	39	339	1380	5104	9100	14284	0.0	69.9	31.1	10.8
2wheelers	**30747**	**33150**	**32272**	**31649**	**33457**	**35245**	**36103**	**37322**	**38717**	**40087**	**-0.5**	**1.1**	**0.6**	**0.7**
Gasoline	30747	33150	32272	31649	33456	35241	36077	37230	38449	39669	-0.5	1.1	0.6	0.6
Electricity	0	0	0	0	1	4	26	92	268	418	0.0	68.5	35.8	16.3
HDVs, buses and coaches	**5943**	**6229**	**6109**	**6710**	**6789**	**7119**	**7698**	**8009**	**8247**	**8438**	**0.7**	**0.6**	**1.2**	**0.5**
Diesel Conventional	5935	6219	6094	6582	6134	5466	4927	4375	4113	4047	0.6	-1.8	-2.2	-0.8
Diesel Hybrid	0	4	8	84	408	1030	1736	2256	2554	2648	36.7	28.5	8.2	1.6
LPG	4	3	2	3	9	17	26	34	44	48	1.6	17.9	6.9	3.5
Natural Gas	4	4	5	38	232	567	901	1160	1291	1428	26.1	31.0	7.4	2.1
Electric	0	0	0	3	5	36	72	117	149	158	0.0	28.9	12.6	3.1
Hydrogen	0	0	0	0	0	2	36	66	98	109	0.0	182.6	38.8	5.1
Total annual cost excl. disutility (in million Euro'13)	**1891259**	**2150744**	**2114877**	**1977033**	**2322147**	**2535841**	**2615813**	**2698292**	**2774582**	**2856984**	**-0.8**	**2.5**	**0.6**	**0.6**
Passenger transport	**1537932**	**1766015**	**1765521**	**1616091**	**1917748**	**2092943**	**2148199**	**2208761**	**2264099**	**2327109**	**-0.9**	**2.6**	**0.5**	**0.5**
Public road transport	59819	63241	63046	51707	62798	67694	69768	71984	73747	75174	-2.0	2.7	0.6	0.4
Private cars	1069129	1202301	1174706	1104540	1216674	1310539	1312237	1325546	1336420	1353817	-0.8	1.7	0.1	0.2
2wheelers	32189	37774	37029	34320	40381	43751	44354	45632	48424	50374	-1.0	2.5	0.4	1.0
Passenger light duty vehicles	123532	157731	155305	151295	164881	175413	180557	185899	188054	192890	-0.4	1.5	0.6	0.4
Rail	73749	90370	98037	87556	113942	123927	131948	135927	145460	152569	-0.3	3.5	0.9	1.2
Aviation	172343	207591	230129	180193	310667	362584	399796	434000	461952	491850	-1.4	7.2	1.8	1.3
Inland navigation	7170	7007	7268	6479	8405	9035	9537	9773	10043	10434	-0.8	3.4	0.8	0.7
Freight transport	**353326**	**384730**	**349357**	**360942**	**404399**	**442899**	**467615**	**489531**	**510483**	**529875**	**-0.6**	**2.1**	**1.0**	**0.8**
Heavy duty vehicles	237997	263276	234646	240469	269473	293571	309408	321866	334344	345445	-0.9	2.0	0.9	0.7
Freight light duty vehicles	36600	40043	36351	42091	41170	44460	46938	49290	51258	53070	0.5	0.5	1.0	0.7
Rail	49953	52314	49071	49807	60519	68862	73302	79402	84227	89196	-0.5	3.3	1.4	1.2
Inland waterway navigation	28777	29098	29289	28576	33238	36006	37966	38973	40654	42164	-0.2	2.3	0.8	0.8
External costs (in million Euro'13) [1]	**735604**	**648641**	**617688**	**492737**	**574649**	**569220**	**562262**	**559255**	**561007**	**566773**	**-2.7**	**1.5**	**-0.2**	**0.1**
Total costs (incl. external costs)	**1891259**	**2150744**	**2114877**	**1977033**	**2322147**	**2535841**	**2615813**	**2698292**	**2774582**	**2856984**	**-0.8**	**2.5**	**0.6**	**0.6**

[1] *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport

Policy Option A1 detailed results (1/2)

EU27noUK:SAF_scenA1	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	SUMMARY (A) '10-'20	'20-'30	'30-'40	'40-'50
											Annual % change			
Transport activity														
Passenger transport activity (Gpkm)	**5281**	**5457**	**5622**	**4499**	**6118**	**6490**	**6716**	**6922**	**7136**	**7351**	**-1.9**	**3.7**	**0.6**	**0.6**
Public road transport	498	484	487	313	474	499	505	519	528	537	-4.3	4.8	0.4	0.3
Private cars	3532	3657	3721	3252	4003	4205	4311	4403	4509	4619	-1.2	2.6	0.5	0.5
2wheelers	115	115	120	100	124	131	135	139	144	149	-1.3	2.7	0.6	0.7
Passenger light duty vehicles	309	324	335	294	365	388	400	410	419	428	-1.0	2.8	0.6	0.4
Rail	417	444	471	274	531	579	632	667	707	757	-4.7	7.8	1.4	1.3
Aviation	373	398	450	244	580	647	689	739	782	812	-4.8	10.2	1.3	0.9
Inland navigation	36	35	38	21	41	42	45	46	47	49	-5.1	7.4	0.8	0.7
Freight transport activity (Gtkm)	**2362**	**2320**	**2314**	**2377**	**2757**	**3022**	**3178**	**3334**	**3461**	**3562**	**0.2**	**2.4**	**1.0**	**0.7**
Heavy duty vehicles	1582	1564	1552	1644	1871	2030	2116	2206	2281	2331	0.5	2.1	0.8	0.6
Freight light duty vehicles	94	81	76	76	88	96	101	106	111	115	-0.6	2.3	1.0	0.8
Rail	395	375	396	382	473	550	603	651	688	724	0.2	3.7	1.7	1.1
Inland waterway navigation	291	301	290	274	325	345	358	371	382	393	-0.9	2.4	0.7	0.6
Final Energy Demand (ktoe)	**307729**	**307180**	**303451**	**247263**	**298127**	**278214**	**257179**	**242502**	**232789**	**227341**	**-2.1**	**1.2**	**-1.4**	**-0.6**
by transport mode														
Passenger transport	**232204**	**229838**	**234406**	**178433**	**226781**	**208339**	**190787**	**177291**	**167276**	**160941**	**-2.5**	**1.6**	**-1.6**	**-1.0**
Public road transport	8572	8321	9070	5748	8545	8509	8417	8466	8531	8569	-3.6	4.0	0.0	0.1
Private cars	159751	153951	157553	129280	145375	127730	112338	100201	91782	87178	-1.7	-0.1	-2.4	-1.4
2wheelers	3704	3421	3674	2984	3588	3705	3744	3791	3839	3893	-1.4	2.2	0.2	0.3
Passenger light duty vehicles	19153	22373	20565	17489	19901	18698	16536	14630	12466	11682	-2.4	0.7	-2.4	-2.2
Rail	2742	2738	2612	1484	2691	2774	2906	2914	2973	3047	-5.9	6.5	0.5	0.4
Aviation	37042	37782	39975	20939	45696	45902	45779	46208	46606	45443	-5.7	8.2	0.1	-0.2
Inland navigation	1240	1252	957	509	984	1021	1066	1081	1079	1129	-8.6	7.2	0.6	0.4
Freight transport	**75525**	**77342**	**69045**	**68830**	**71346**	**69875**	**66392**	**65211**	**65513**	**66400**	**-1.2**	**0.2**	**-0.7**	**0.2**
Heavy duty vehicles	54076	56954	52572	52889	54233	53228	51499	50850	51524	52524	-0.7	0.1	-0.5	0.3
Freight light duty vehicles	13037	12937	10753	10580	10870	10055	8098	7416	6964	6754	-2.0	-0.5	-3.0	-0.9
Rail	4029	3576	2798	2556	3025	3286	3431	3516	3556	3599	-3.3	2.5	0.7	0.2
Inland waterway navigation	4383	3875	2921	2806	3218	3306	3364	3430	3471	3523	-3.2	1.7	0.4	0.3
by fuel														
Oil products	**299776**	**290356**	**284864**	**226120**	**267837**	**236652**	**204461**	**180467**	**164510**	**151197**	**-2.5**	**0.5**	**-2.7**	**-1.8**
Gasoline	94548	75865	64529	53064	56506	45038	35551	29372	24899	21935	-3.5	-1.6	-4.2	-2.9
Diesel	162148	170056	173527	145252	156205	136535	119155	106162	96338	91179	-1.6	-0.6	-2.5	-1.5
Kerosene	37042	37782	39975	20939	44783	43928	38912	35118	34000	29383	-5.7	7.7	-2.2	-1.8
Liquefied Petroleum Gas	4691	5198	5895	6277	9675	10568	10372	9445	9009	8538	1.9	5.3	-1.1	-1.0
Residual fuel oil	1346	1455	938	588	668	582	472	370	263	162	-8.7	-0.1	-4.4	-7.9
Biofuels	**3134**	**11567**	**12886**	**16360**	**20174**	**22659**	**25612**	**27690**	**27857**	**30501**	**3.5**	**3.3**	**2.0**	**1.0**
Bio Gasoline	551	2480	2385	3341	3921	4314	3594	2998	2595	2330	3.0	2.6	-3.6	-2.5
Bio Diesel	2583	9064	10409	12504	14328	14736	13181	11452	10466	9980	3.3	1.7	-2.5	-1.4
Bio Kerosene	0	0	0	0	914	1974	6867	11090	12575	15822	0.0	0.0	18.8	3.6
DME	0	0	0	0	0	0	0	0	0	0	-18.7	16.6	0.1	-0.7
Bio Heavy	0	0	0	45	52	54	45	34	25	16	0.0	1.8	-4.4	-7.5
Biogas	0	22	92	470	959	1582	1926	2116	2195	2353	35.7	12.9	3.0	1.1
Electricity	4269	4108	4102	3384	5565	10568	15724	20132	24000	26164	**-1.9**	**12.1**	**6.7**	**2.7**
Natural Gas	551	1149	1599	1398	4530	8189	10248	11171	11587	12639	**2.0**	**19.3**	**3.2**	**1.2**
Hydrogen	0	0	0	1	21	146	1133	3042	4836	6841	**0.0**	**63.0**	**35.5**	**8.4**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**44.0**	**42.1**	**41.7**	**39.7**	**37.1**	**32.1**	**28.4**	**25.6**	**23.4**	**21.9**	**-0.6**	**-2.1**	**-2.2**	**-1.6**
Public road transport	17.2	17.2	18.6	18.4	18.0	17.1	16.7	16.3	16.2	16.0	0.7	-0.7	-0.4	-0.2
Private cars	45.2	42.1	42.3	39.8	36.3	30.4	26.1	22.8	20.4	18.9	-0.6	-2.7	-2.8	-1.9
2wheelers	32.2	29.8	30.5	29.7	28.8	28.3	27.7	27.2	26.6	26.1	0.0	-0.5	-0.4	-0.4
Passenger light duty vehicles	62.0	69.1	61.4	59.4	54.6	48.2	41.3	35.7	29.8	27.3	-1.5	-2.1	-3.0	-2.6
Rail	6.6	6.2	5.6	5.4	5.1	4.8	4.6	4.4	4.2	4.0	-1.3	-1.2	-0.9	-0.8
Aviation	99.4	94.8	88.8	85.9	78.7	71.0	66.5	62.6	59.6	56.0	-1.0	-1.9	-1.3	-1.1
Inland navigation	34.3	35.7	25.5	24.6	24.2	24.0	23.8	23.5	23.0	22.8	-3.7	-0.2	-0.2	-0.3
Freight transport activity (toe/Mtkm)	**32.0**	**33.3**	**29.8**	**29.0**	**25.9**	**23.1**	**20.9**	**19.6**	**18.9**	**18.6**	**-1.4**	**-2.2**	**-1.7**	**-0.5**
Heavy duty vehicles	34.2	36.4	33.9	32.2	29.0	26.2	24.3	23.1	22.6	22.5	-1.2	-2.0	-1.3	-0.2
Freight light duty vehicles	138.3	159.8	141.5	138.4	123.3	104.7	80.0	69.7	62.6	58.9	-1.4	-2.7	-4.0	-1.7
Rail	10.2	9.5	7.1	6.7	6.4	6.0	5.7	5.4	5.2	5.0	-3.5	-1.1	-1.0	-0.8
Inland waterway navigation	15.1	12.9	10.1	10.3	9.9	9.6	9.4	9.2	9.1	9.0	-2.3	-0.7	-0.3	-0.3
CO_2 EMISSIONS (in ktons CO_2)	**906190**	**881844**	**867524**	**689023**	**820996**	**733936**	**635533**	**561115**	**509518**	**449468**	**-2.4**	**0.6**	**-2.6**	**-2.2**
Passenger transport	681645	659116	670291	497615	627257	551466	469110	401918	352727	292840	-2.8	1.0	-3.1	-3.1
Public road transport	26176	24543	26528	16298	23979	23228	22845	23008	23142	23196	-4.0	3.6	-0.1	0.1
Private cars	469864	440509	449925	358696	399312	332249	278876	234398	201555	181764	-2.0	-0.8	-3.4	-2.5
2wheelers	10708	9666	10357	8220	9821	9978	10047	10171	10281	10411	-1.6	2.0	0.2	0.2
Passenger light duty vehicles	58428	65863	59766	49697	56441	51885	44097	36736	27908	23958	-2.8	0.4	-3.4	-4.2
Rail	1802	1606	1179	616	936	840	745	630	503	394	-9.1	3.2	-2.8	-4.6
Aviation	110776	112987	119547	62618	133923	130407	109523	93966	86357	50019	-5.7	7.6	-3.2	-6.1
Inland navigation	3890	3942	2989	1469	2845	2879	2978	3009	2981	3097	-9.4	7.0	0.4	0.3
Freight transport	224545	222729	197233	191408	193738	182470	166424	159197	156791	156628	**-1.5**	**-0.5**	**-1.4**	**-0.2**
Heavy duty vehicles	165281	167617	153782	150732	151459	143684	135351	131651	132080	134001	-1.1	-0.5	-0.9	0.2
Freight light duty vehicles	39662	37862	31251	30065	30464	27121	19544	16158	13583	11681	-2.3	-1.0	-5.0	-3.2
Rail	5925	5156	3115	2420	2494	2262	2015	1701	1365	1074	-7.3	-0.7	-2.8	-4.5
Inland waterway navigation	13677	12094	9086	8191	9322	9404	9513	9687	9762	9872	-3.8	1.4	0.3	0.2

Source: PRIMES-TREMOVE Transport Model

Policy Option A1 detailed results (2/2)

SUMMARY (B)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**215414**	**238232**	**250794**	**263300**	**259531**	**265050**	**270619**	**276582**	**281833**	**283894**	**1.0**	**0.1**	**0.4**	**0.3**
Diesel Conventional	73600	105878	122727	128035	110825	93134	78156	63738	52907	44741	1.9	-3.1	-3.7	-3.5
Diesel Hybrid	0	73	401	2414	12463	20625	25607	26618	25106	24296	41.9	23.9	2.6	-0.9
Diesel plug-in hybrid	0	0	57	301	1053	6220	14507	20364	24679	26605	0.0	35.4	12.6	2.7
Gasoline Conventional	135523	125022	118877	118198	101076	75174	54572	38673	29404	23474	-0.6	-4.4	-6.4	-4.9
Gasoline Hybrid	21	162	783	3106	15064	20454	22479	21732	19019	17371	34.4	20.7	0.6	-2.2
Gasoline plug-in hybrid	0	0	86	461	2368	7089	11746	19391	24549	26460	0.0	31.4	10.6	3.2
LPG	5422	5710	5839	7634	9316	10721	11293	10372	9810	9140	2.9	3.5	-0.3	-1.3
CNG	848	1343	1757	1897	2614	3848	4985	5711	5730	5732	3.5	7.3	4.0	0.0
E85	0	45	89	151	392	604	655	649	617	596	12.9	14.9	0.7	-0.8
Electric	0	0	179	1102	4320	26880	45282	64259	80928	91196	0.0	37.6	9.1	3.6
Hydrogen	0	0	0	2	39	299	1336	5075	9084	14283	0.0	67.8	32.7	10.9
2wheelers	**30747**	**33150**	**32272**	**31649**	**33457**	**35243**	**36081**	**37279**	**38655**	**39970**	**-0.5**	**1.1**	**0.6**	**0.7**
Gasoline	30747	33150	32272	31649	33456	35238	36055	37187	38388	39553	-0.5	1.1	0.5	0.6
Electricity	0	0	0	0	1	4	26	92	267	417	0.0	68.5	35.8	16.3
HDVs, buses and coaches	**5943**	**6229**	**6109**	**6710**	**6790**	**7119**	**7699**	**8010**	**8248**	**8439**	**0.7**	**0.6**	**1.2**	**0.5**
Diesel Conventional	5935	6219	6094	6582	6136	5467	4929	4377	4115	4051	0.6	-1.8	-2.2	-0.8
Diesel Hybrid	0	4	8	84	408	1030	1736	2256	2554	2647	36.7	28.5	8.2	1.6
LPG	4	3	2	3	9	17	26	34	43	48	1.6	17.9	6.9	3.5
Natural Gas	4	4	5	38	232	566	900	1160	1290	1426	26.1	31.0	7.4	2.1
Electric	0	0	0	3	5	36	72	117	148	158	0.0	28.8	12.6	3.0
Hydrogen	0	0	0	0	0	2	35	66	98	109	0.0	182.2	39.0	5.1
Total annual cost excl. disutility (in million Euro'13)	**1891259**	**2150744**	**2114877**	**1977033**	**2321900**	**2535383**	**2617829**	**2701217**	**2778661**	**2868763**	**-0.8**	**2.5**	**0.6**	**0.6**
Passenger transport	**1537932**	**1766015**	**1765521**	**1616090**	**1917559**	**2092484**	**2150322**	**2211800**	**2268306**	**2339178**	**-0.9**	**2.6**	**0.6**	**0.6**
Public road transport	59819	63241	63046	51707	62820	67718	69921	72195	73998	75709	-2.0	2.7	0.6	0.5
Private cars	1069129	1202301	1174706	1104540	1216354	1310071	1310827	1323258	1333663	1348738	-0.8	1.7	0.1	0.2
2wheelers	32189	37774	37029	34320	40376	43742	44318	45577	48353	50234	-1.0	2.5	0.4	1.0
Passenger light duty vehicles	123532	157731	155305	151294	164832	175333	180300	185474	187556	192028	-0.4	1.5	0.6	0.3
Rail	73749	90370	98037	87556	114298	124456	134791	139431	149007	159142	-0.3	3.6	1.1	1.3
Aviation	172343	207591	230129	180193	310445	362077	400384	435772	465358	502227	-1.4	7.2	1.9	1.4
Inland navigation	7170	7007	7268	6479	8435	9086	9781	10092	10370	11099	-0.8	3.4	1.1	1.0
Freight transport	**353326**	**384730**	**349357**	**360942**	**404340**	**442900**	**467508**	**489417**	**510356**	**529585**	**-0.6**	**2.1**	**1.0**	**0.8**
Heavy duty vehicles	237997	263276	234646	240469	269451	293572	309336	321796	334254	345243	-0.9	2.0	0.9	0.7
Freight light duty vehicles	36600	40043	36351	42091	41159	44464	46929	49277	51245	53057	0.5	0.6	1.0	0.7
Rail	49953	52314	49071	49807	60511	68862	73285	79383	84213	89149	-0.5	3.3	1.4	1.2
Inland waterway navigation	28777	29098	29289	28576	33220	36002	37958	38961	40643	42136	-0.2	2.3	0.8	0.8
External costs (in million Euro'13) (1)	**735604**	**648641**	**617688**	**492737**	**574625**	**569050**	**561221**	**557673**	**559063**	**563053**	**-2.7**	**1.5**	**-0.2**	**0.1**
Total costs (incl. external costs)	**1891259**	**2150744**	**2114877**	**1977033**	**2321900**	**2535383**	**2617829**	**2701217**	**2778661**	**2868763**	**-0.8**	**2.5**	**0.6**	**0.6**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport

Policy Option A2 detailed results (1/2)

EU27noUK:SAF_scenA2	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	SUMMARY (A) '10-'20	'20-'30	'30-'40	'40-'50
											Annual % change			
Transport activity														
Passenger transport activity (Gpkm)	**5281**	**5457**	**5622**	**4499**	**6118**	**6490**	**6717**	**6923**	**7136**	**7350**	**-1.9**	**3.7**	**0.6**	**0.6**
Public road transport	498	484	487	313	474	499	504	518	528	536	-4.3	4.8	0.4	0.3
Private cars	3532	3657	3721	3252	4003	4205	4312	4404	4509	4620	-1.2	2.6	0.5	0.5
2wheelers	115	115	120	100	124	131	135	139	144	149	-1.3	2.7	0.6	0.7
Passenger light duty vehicles	309	324	335	294	365	388	400	410	419	428	-1.0	2.8	0.6	0.4
Rail	417	444	471	274	531	579	630	666	707	756	-4.7	7.7	1.4	1.3
Aviation	373	398	450	244	580	647	691	739	782	810	-4.8	10.2	1.3	0.9
Inland navigation	36	35	38	21	41	42	45	46	47	50	-5.1	7.4	0.8	0.7
Freight transport activity (Gtkm)	**2362**	**2320**	**2314**	**2377**	**2757**	**3022**	**3178**	**3334**	**3461**	**3562**	**0.2**	**2.4**	**1.0**	**0.7**
Heavy duty vehicles	1582	1564	1552	1644	1871	2030	2116	2206	2281	2331	0.5	2.1	0.8	0.6
Freight light duty vehicles	94	81	76	76	88	96	101	106	111	115	-0.6	2.3	1.0	0.8
Rail	395	375	396	382	473	550	603	651	688	724	0.2	3.7	1.7	1.1
Inland waterway navigation	291	301	290	274	325	345	358	371	382	393	-0.9	2.4	0.7	0.6
Final Energy Demand (ktoe)	**307729**	**307180**	**303451**	**247263**	**298127**	**278233**	**257379**	**242652**	**232958**	**227561**	**-2.1**	**1.2**	**-1.4**	**-0.6**
by transport mode														
Passenger transport	**232204**	**229838**	**234406**	**178433**	**226781**	**208357**	**190995**	**177439**	**167443**	**161157**	**-2.5**	**1.6**	**-1.6**	**-1.0**
Public road transport	8572	8321	9070	5748	8545	8508	8414	8464	8532	8567	-3.6	4.0	-0.1	0.1
Private cars	159751	153951	157553	129280	145375	127733	112363	100224	91800	87205	-1.7	-0.1	-2.4	-1.4
2wheelers	3704	3421	3674	2984	3588	3705	3745	3791	3840	3894	-1.4	2.2	0.2	0.3
Passenger light duty vehicles	19153	22373	20565	17489	19901	18698	16552	14634	12469	11687	-2.4	0.7	-2.4	-2.2
Rail	2742	2738	2612	1484	2691	2773	2897	2911	2971	3047	-5.9	6.5	0.5	0.5
Aviation	37042	37782	39975	20939	45696	45919	45964	46330	46764	45623	-5.7	8.2	0.1	-0.2
Inland navigation	1240	1252	957	509	984	1020	1061	1084	1067	1135	-8.6	7.2	0.6	0.5
Freight transport	**75525**	**77342**	**69045**	**68830**	**71346**	**69876**	**66384**	**65213**	**65515**	**66404**	**-1.2**	**0.2**	**-0.7**	**0.2**
Heavy duty vehicles	54076	56954	52572	52889	54233	53228	51501	50852	51525	52527	-0.7	0.1	-0.5	0.3
Freight light duty vehicles	13037	12937	10753	10580	10870	10056	8087	7416	6964	6755	-2.0	-0.5	-3.0	-0.9
Rail	4029	3576	2798	2556	3025	3286	3432	3516	3556	3600	-3.3	2.5	0.7	0.2
Inland waterway navigation	4383	3875	2921	2806	3218	3306	3364	3430	3471	3523	-3.2	1.7	0.4	0.3
by fuel														
Oil products	**299776**	**290356**	**284864**	**226120**	**267837**	**236602**	**203681**	**179735**	**163609**	**149548**	**-2.5**	**0.5**	**-2.7**	**-1.8**
Gasoline	94548	75865	64529	53064	56506	45039	35558	29379	24905	21942	-3.5	-1.6	-4.2	-2.9
Diesel	162148	170056	173527	145252	156205	136537	119164	106176	96339	91195	-1.6	-0.6	-2.5	-1.5
Kerosene	37042	37782	39975	20939	44783	43875	38113	34363	33092	27707	-5.7	7.7	-2.4	-2.1
Liquefied Petroleum Gas	4691	5198	5895	6277	9675	10568	10373	9447	9011	8540	1.9	5.3	-1.1	-1.0
Residual fuel oil	1346	1455	938	588	668	582	472	370	263	162	-8.7	-0.1	-4.4	-7.9
Biofuels	**3134**	**11567**	**12886**	**16360**	**20174**	**22729**	**26598**	**28569**	**28925**	**32359**	**3.5**	**3.3**	**2.3**	**1.3**
Bio Gasoline	551	2480	2385	3341	3921	4314	3594	2999	2596	2331	3.0	2.6	-3.6	-2.5
Bio Diesel	2583	9064	10409	12504	14328	14736	13182	11453	10467	9982	3.3	1.7	-2.5	-1.4
Bio Kerosene	0	0	0	0	914	2044	7851	11967	13643	17677	0.0	0.0	19.3	4.0
DME	0	0	0	0	0	0	0	0	0	0	-18.7	16.6	0.1	-0.7
Bio Heavy	0	0	0	45	52	54	45	34	25	16	0.0	1.8	-4.4	-7.5
Biogas	0	22	92	470	959	1582	1926	2116	2195	2353	35.7	12.9	3.0	1.1
Electricity	4269	4108	4102	3384	5565	10567	15718	20133	24002	26171	**-1.9**	**12.1**	**6.7**	**2.7**
Natural Gas	551	1149	1599	1398	4530	8188	10249	11172	11586	12641	**2.0**	**19.3**	**3.2**	**1.2**
Hydrogen	0	0	0	1	21	146	1133	3042	4837	6843	**0.0**	**63.0**	**35.5**	**8.4**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**44.0**	**42.1**	**41.7**	**39.7**	**37.1**	**32.1**	**28.4**	**25.6**	**23.5**	**21.9**	**-0.6**	**-2.1**	**-2.2**	**-1.5**
Public road transport	17.2	17.2	18.6	18.4	18.0	17.1	16.7	16.3	16.2	16.0	0.7	-0.7	-0.4	-0.2
Private cars	45.2	42.1	42.3	39.8	36.3	30.4	26.1	22.8	20.4	18.9	-0.6	-2.7	-2.8	-1.9
2wheelers	32.2	29.8	30.5	29.7	28.8	28.3	27.7	27.2	26.6	26.1	0.0	-0.5	-0.4	-0.4
Passenger light duty vehicles	62.0	69.1	61.4	59.4	54.6	48.2	41.4	35.7	29.8	27.3	-1.5	-2.1	-3.0	-2.6
Rail	6.6	6.2	5.6	5.4	5.1	4.8	4.6	4.4	4.2	4.0	-1.3	-1.2	-0.9	-0.8
Aviation	99.4	94.8	88.8	85.9	78.7	71.0	66.5	62.7	59.8	56.3	-1.0	-1.9	-1.2	-1.1
Inland navigation	34.3	35.7	25.5	24.6	24.2	24.0	23.8	23.5	22.9	22.9	-3.7	-0.2	-0.2	-0.3
Freight transport activity (toe/Mtkm)	**32.0**	**33.3**	**29.8**	**29.0**	**25.9**	**23.1**	**20.9**	**19.6**	**18.9**	**18.6**	**-1.4**	**-2.2**	**-1.7**	**-0.5**
Heavy duty vehicles	34.2	36.4	33.9	32.2	29.0	26.2	24.3	23.1	22.6	22.5	-1.2	-2.0	-1.3	-0.2
Freight light duty vehicles	138.3	159.8	141.5	138.4	123.3	104.7	79.9	69.7	62.6	58.9	-1.4	-2.7	-4.0	-1.7
Rail	10.2	9.5	7.1	6.7	6.4	6.0	5.7	5.4	5.2	5.0	-3.5	-1.1	-1.0	-0.8
Inland waterway navigation	15.1	12.9	10.1	10.3	9.9	9.6	9.4	9.2	9.1	9.0	-2.3	-0.7	-0.3	-0.3
CO_2 EMISSIONS (in ktons CO_2)	**906190**	**881844**	**867524**	**689023**	**820996**	**733993**	**636031**	**561435**	**509833**	**449750**	**-2.4**	**0.6**	**-2.6**	**-2.2**
Passenger transport	681645	659116	670291	497615	627257	551520	469643	402232	353037	293112	-2.8	1.0	-3.1	-3.1
Public road transport	26176	24543	26528	16298	23979	23228	22836	23003	23144	23188	-4.0	3.6	-0.1	0.1
Private cars	469864	440509	449925	358696	399312	332256	278936	234451	201595	181819	-2.0	-0.8	-3.4	-2.5
2wheelers	10708	9666	10357	8220	9821	9979	10049	10172	10282	10414	-1.6	2.0	0.2	0.2
Passenger light duty vehicles	58428	65863	59766	49697	56441	51886	44150	36745	27914	23967	-2.8	0.4	-3.4	-4.2
Rail	1802	1606	1179	616	936	840	744	630	503	394	-9.1	3.2	-2.8	-4.6
Aviation	110776	112987	119547	62618	133923	130456	109964	94215	86651	50217	-5.7	7.6	-3.2	-6.1
Inland navigation	3890	3942	2989	1469	2845	2877	2964	3016	2949	3113	-9.4	7.0	0.5	0.3
Freight transport	224545	222729	197233	191408	193738	182472	166389	159202	156795	156638	**-1.5**	**-0.5**	**-1.4**	**-0.2**
Heavy duty vehicles	165281	167617	153782	150732	151458	143685	135357	131656	132084	134009	-1.1	-0.5	-0.9	0.2
Freight light duty vehicles	39662	37862	31251	30065	30464	27122	19504	16158	13584	11682	-2.3	-1.0	-5.0	-3.2
Rail	5925	5156	3115	2420	2494	2262	2016	1701	1365	1074	-7.3	-0.7	-2.8	-4.5
Inland waterway navigation	13677	12094	9086	8191	9322	9404	9513	9687	9762	9872	-3.8	1.4	0.3	0.2

Source: PRIMES-TREMOVE Transport Model

Policy Option A2 detailed results (2/2)

SUMMARY (B)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**215414**	**238232**	**250794**	**263300**	**259531**	**265055**	**270669**	**276639**	**281892**	**283977**	**1.0**	**0.1**	**0.4**	**0.3**
Diesel Conventional	73600	105878	122727	128035	110825	93136	78168	63749	52917	44752	1.9	-3.1	-3.7	-3.5
Diesel Hybrid	0	73	401	2414	12463	20626	25612	26623	25111	24303	41.9	23.9	2.6	-0.9
Diesel plug-in hybrid	0	0	57	301	1053	6220	14513	20370	24685	26613	0.0	35.4	12.6	2.7
Gasoline Conventional	135523	125022	118877	118198	101076	75176	54579	38680	29409	23479	-0.6	-4.4	-6.4	-4.9
Gasoline Hybrid	21	162	783	3106	15064	20455	22483	21737	19023	17375	34.4	20.7	0.6	-2.2
Gasoline plug-in hybrid	0	0	86	461	2368	7089	11750	19397	24556	26470	0.0	31.4	10.6	3.2
LPG	5422	5710	5839	7634	9316	10721	11293	10373	9812	9142	2.9	3.5	-0.3	-1.3
CNG	848	1343	1757	1897	2614	3848	4985	5712	5731	5734	3.5	7.3	4.0	0.0
E85	0	45	89	151	392	604	655	649	617	596	12.9	14.9	0.7	-0.8
Electric	0	0	179	1102	4320	26880	45294	64274	80947	91226	0.0	37.6	9.1	3.6
Hydrogen	0	0	0	2	39	299	1337	5075	9086	14287	0.0	67.8	32.7	10.9
2wheelers	**30747**	**33150**	**32272**	**31649**	**33457**	**35243**	**36087**	**37285**	**38661**	**39980**	**-0.5**	**1.1**	**0.6**	**0.7**
Gasoline	30747	33150	32272	31649	33456	35239	36061	37193	38394	39563	-0.5	1.1	0.5	0.6
Electricity	0	0	0	0	1	4	26	92	267	417	0.0	68.5	35.8	16.3
HDVs, buses and coaches	**5943**	**6229**	**6109**	**6710**	**6790**	**7119**	**7699**	**8010**	**8248**	**8439**	**0.7**	**0.6**	**1.2**	**0.5**
Diesel Conventional	5935	6219	6094	6582	6136	5467	4929	4377	4115	4051	0.6	-1.8	-2.2	-0.8
Diesel Hybrid	0	4	8	84	408	1030	1737	2256	2554	2647	36.7	28.5	8.2	1.6
LPG	4	3	2	3	9	17	26	34	43	48	1.6	17.9	6.9	3.5
Natural Gas	4	4	5	38	232	566	900	1160	1290	1426	26.1	31.0	7.4	2.1
Electric	0	0	0	3	5	36	72	117	148	158	0.0	28.8	12.6	3.0
Hydrogen	0	0	0	0	0	2	35	66	98	109	0.0	182.2	39.0	5.1
Total annual cost excl. disutility (in million Euro'13)	**1891259**	**2150744**	**2114877**	**1977033**	**2321899**	**2535326**	**2617149**	**2700845**	**2778261**	**2867975**	**-0.8**	**2.5**	**0.6**	**0.6**
Passenger transport	**1537932**	**1766015**	**1765521**	**1616090**	**1917559**	**2092427**	**2149611**	**2211413**	**2267893**	**2338367**	**-0.9**	**2.6**	**0.6**	**0.6**
Public road transport	59819	63241	63046	51707	62820	67714	69884	72170	73996	75673	-2.0	2.7	0.6	0.5
Private cars	1069129	1202301	1174706	1104540	1216354	1310097	1311152	1323579	1333934	1349178	-0.8	1.7	0.1	0.2
2wheelers	32189	37774	37029	34320	40376	43743	44326	45584	48359	50246	-1.0	2.5	0.4	1.0
Passenger light duty vehicles	123532	157731	155305	151294	164832	175338	180371	185523	187602	192105	-0.4	1.5	0.6	0.3
Rail	73749	90370	98037	87556	114297	124403	134264	139374	148971	159243	-0.3	3.6	1.1	1.3
Aviation	172343	207591	230129	180193	310445	362051	399873	435086	464707	500801	-1.4	7.2	1.9	1.4
Inland navigation	7170	7007	7268	6479	8435	9081	9741	10097	10325	11122	-0.8	3.4	1.1	1.0
Freight transport	**353326**	**384730**	**349357**	**360942**	**404340**	**442899**	**467538**	**489431**	**510369**	**529608**	**-0.6**	**2.1**	**1.0**	**0.8**
Heavy duty vehicles	237997	263276	234646	240469	269450	293570	309345	321806	334262	345264	-0.9	2.0	0.9	0.7
Freight light duty vehicles	36600	40043	36351	42091	41159	44464	46947	49278	51247	53059	0.5	0.6	1.0	0.7
Rail	49953	52314	49071	49807	60511	68862	73288	79385	84217	89156	-0.5	3.3	1.4	1.2
Inland waterway navigation	28777	29098	29289	28576	33220	36003	37958	38962	40643	42129	-0.2	2.3	0.8	0.8
External costs (in million Euro'13) (1)	**735604**	**648641**	**617688**	**492737**	**574625**	**569073**	**561462**	**557872**	**559252**	**563345**	**-2.7**	**1.5**	**-0.2**	**0.1**
Total costs (incl. external costs)	**1891259**	**2150744**	**2114877**	**1977033**	**2321899**	**2535326**	**2617149**	**2700845**	**2778261**	**2867975**	**-0.8**	**2.5**	**0.6**	**0.6**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport

Policy Option B1 detailed results (1/2)

EU27noUK:SAF_scenB1	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	SUMMARY (A) '10-'20	'20-'30	'30-'40	'40-'50
											Annual % change			
Transport activity														
Passenger transport activity (Gpkm)	**5281**	**5457**	**5622**	**4499**	**6118**	**6490**	**6716**	**6922**	**7136**	**7351**	**-1.9**	**3.7**	**0.6**	**0.6**
Public road transport	498	484	487	313	474	499	505	519	528	537	-4.3	4.8	0.4	0.3
Private cars	3532	3657	3721	3252	4003	4205	4311	4403	4509	4619	-1.2	2.6	0.5	0.5
2wheelers	115	115	120	100	124	131	135	139	144	149	-1.3	2.7	0.6	0.7
Passenger light duty vehicles	309	324	335	294	365	388	400	410	419	428	-1.0	2.8	0.6	0.4
Rail	417	444	471	274	531	579	632	667	707	757	-4.7	7.8	1.4	1.3
Aviation	373	398	450	244	580	647	689	739	782	812	-4.8	10.2	1.3	0.9
Inland navigation	36	35	38	21	41	42	45	46	47	49	-5.1	7.4	0.8	0.7
Freight transport activity (Gtkm)	**2362**	**2320**	**2314**	**2377**	**2757**	**3022**	**3178**	**3334**	**3461**	**3562**	**0.2**	**2.4**	**1.0**	**0.7**
Heavy duty vehicles	1582	1564	1552	1644	1871	2030	2116	2206	2281	2331	0.5	2.1	0.8	0.6
Freight light duty vehicles	94	81	76	76	88	96	101	106	111	115	-0.6	2.3	1.0	0.8
Rail	395	375	396	382	473	550	603	651	688	724	0.2	3.7	1.7	1.1
Inland waterway navigation	291	301	290	274	325	345	358	371	382	393	-0.9	2.4	0.7	0.6
Final Energy Demand (ktoe)	**307729**	**307180**	**303451**	**247263**	**298127**	**278166**	**257123**	**242447**	**232734**	**227288**	**-2.1**	**1.2**	**-1.4**	**-0.6**
by transport mode														
Passenger transport	**232204**	**229838**	**234406**	**178433**	**226781**	**208291**	**190730**	**177236**	**167221**	**160888**	**-2.5**	**1.6**	**-1.6**	**-1.0**
Public road transport	8572	8321	9070	5748	8545	8509	8417	8466	8531	8569	-3.6	4.0	0.0	0.1
Private cars	159751	153951	157553	129280	145375	127731	112339	100203	91783	87179	-1.7	-0.1	-2.4	-1.4
2wheelers	3704	3421	3674	2984	3588	3705	3744	3791	3839	3893	-1.4	2.2	0.2	0.3
Passenger light duty vehicles	19153	22373	20565	17489	19901	18698	16536	14630	12467	11682	-2.4	0.7	-2.4	-2.2
Rail	2742	2738	2612	1484	2691	2774	2906	2914	2973	3047	-5.9	6.5	0.5	0.4
Aviation	37042	37782	39975	20939	45696	45854	45722	46151	46550	45389	-5.7	8.2	0.1	-0.2
Inland navigation	1240	1252	957	509	984	1020	1066	1081	1079	1129	-8.6	7.2	0.6	0.4
Freight transport	**75525**	**77342**	**69045**	**68830**	**71346**	**69875**	**66393**	**65211**	**65513**	**66400**	**-1.2**	**0.2**	**-0.7**	**0.2**
Heavy duty vehicles	54076	56954	52572	52889	54233	53228	51499	50850	51524	52523	-0.7	0.1	-0.5	0.3
Freight light duty vehicles	13037	12937	10753	10580	10870	10055	8098	7416	6964	6754	-2.0	-0.5	-3.0	-0.9
Rail	4029	3576	2798	2556	3025	3286	3432	3516	3556	3600	-3.3	2.5	0.7	0.2
Inland waterway navigation	4383	3875	2921	2806	3218	3306	3364	3430	3471	3523	-3.2	1.7	0.4	0.3
by fuel														
Oil products	**299776**	**290356**	**284864**	**226120**	**267837**	**236607**	**204413**	**180425**	**164470**	**151163**	**-2.5**	**0.5**	**-2.7**	**-1.8**
Gasoline	94548	75865	64529	53064	56506	45039	35551	29373	24900	21935	-3.5	-1.6	-4.2	-2.9
Diesel	162148	170056	173527	145252	156205	136536	119155	106162	96338	91179	-1.6	-0.6	-2.5	-1.5
Kerosene	37042	37782	39975	20939	44783	43882	38863	35075	33959	29348	-5.7	7.7	-2.2	-1.8
Liquefied Petroleum Gas	4691	5198	5895	6277	9675	10568	10372	9445	9009	8538	1.9	5.3	-1.1	-1.0
Residual fuel oil	1346	1455	938	588	668	582	472	370	263	162	-8.7	-0.1	-4.4	-7.9
Biofuels	**3134**	**11567**	**12886**	**16360**	**20174**	**22657**	**25604**	**27677**	**27841**	**30482**	**3.5**	**3.3**	**2.0**	**1.0**
Bio Gasoline	551	2480	2385	3341	3921	4314	3594	2998	2595	2330	3.0	2.6	-3.6	-2.5
Bio Diesel	2583	9064	10409	12504	14328	14736	13181	11452	10466	9980	3.3	1.7	-2.5	-1.4
Bio Kerosene	0	0	0	0	914	1972	6858	11076	12560	15803	0.0	0.0	18.8	3.6
DME	0	0	0	0	0	0	0	0	0	0	-18.7	16.6	0.1	-0.7
Bio Heavy	0	0	0	45	52	54	45	34	25	16	0.0	1.8	-4.4	-7.5
Biogas	0	22	92	470	959	1582	1926	2116	2195	2352	35.7	12.9	3.0	1.1
Electricity	4269	4108	4102	3384	5565	10568	15724	20132	24000	26164	**-1.9**	**12.1**	**6.7**	**2.7**
Natural Gas	551	1149	1599	1398	4530	8189	10248	11171	11587	12639	**2.0**	**19.3**	**3.2**	**1.2**
Hydrogen	0	0	0	1	21	146	1133	3042	4836	6841	**0.0**	**63.0**	**35.5**	**8.4**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**44.0**	**42.1**	**41.7**	**39.7**	**37.1**	**32.1**	**28.4**	**25.6**	**23.4**	**21.9**	**-0.6**	**-2.1**	**-2.2**	**-1.6**
Public road transport	17.2	17.2	18.6	18.4	18.0	17.1	16.7	16.3	16.2	16.0	0.7	-0.7	-0.4	-0.2
Private cars	45.2	42.1	42.3	39.8	36.3	30.4	26.1	22.8	20.4	18.9	-0.6	-2.7	-2.8	-1.9
2wheelers	32.2	29.8	30.5	29.7	28.8	28.3	27.7	27.2	26.6	26.1	0.0	-0.5	-0.4	-0.4
Passenger light duty vehicles	62.0	69.1	61.4	59.4	54.6	48.2	41.3	35.7	29.8	27.3	-1.5	-2.1	-3.0	-2.6
Rail	6.6	6.2	5.6	5.4	5.1	4.8	4.6	4.4	4.2	4.0	-1.3	-1.2	-0.9	-0.8
Aviation	99.4	94.8	88.8	85.9	78.7	70.9	66.4	62.5	59.5	55.9	-1.0	-1.9	-1.3	-1.1
Inland navigation	34.3	35.7	25.5	24.6	24.2	24.0	23.8	23.5	23.0	22.8	-3.7	-0.2	-0.2	-0.3
Freight transport activity (toe/Mtkm)	**32.0**	**33.3**	**29.8**	**29.0**	**25.9**	**23.1**	**20.9**	**19.6**	**18.9**	**18.6**	**-1.4**	**-2.2**	**-1.7**	**-0.5**
Heavy duty vehicles	34.2	36.4	33.9	32.2	29.0	26.2	24.3	23.1	22.6	22.5	-1.2	-2.0	-1.3	-0.2
Freight light duty vehicles	138.3	159.8	141.5	138.4	123.3	104.7	80.0	69.7	62.6	58.9	-1.4	-2.7	-4.0	-1.7
Rail	10.2	9.5	7.1	6.7	6.4	6.0	5.7	5.4	5.2	5.0	-3.5	-1.1	-1.0	-0.8
Inland waterway navigation	15.1	12.9	10.1	10.3	9.9	9.6	9.4	9.2	9.1	9.0	-2.3	-0.7	-0.3	-0.3
CO_2 EMISSIONS (in ktons CO_2)	**906190**	**881844**	**867524**	**689023**	**820996**	**733801**	**635398**	**561003**	**509417**	**449410**	**-2.4**	**0.6**	**-2.6**	**-2.2**
Passenger transport	681645	659116	670291	497615	627257	551331	468974	401806	352626	292783	-2.8	1.0	-3.1	-3.1
Public road transport	26176	24543	26528	16298	23979	23228	22844	23008	23142	23196	-4.0	3.6	-0.1	0.1
Private cars	469864	440509	449925	358696	399312	332250	278878	234402	201558	181767	-2.0	-0.8	-3.4	-2.5
2wheelers	10708	9666	10357	8220	9821	9978	10047	10171	10281	10411	-1.6	2.0	0.2	0.2
Passenger light duty vehicles	58428	65863	59766	49697	56441	51885	44096	36735	27908	23959	-2.8	0.4	-3.4	-4.2
Rail	1802	1606	1179	616	936	840	745	630	503	394	-9.1	3.2	-2.8	-4.6
Aviation	110776	112987	119547	62618	133923	130270	109385	93851	86253	49959	-5.7	7.6	-3.2	-6.1
Inland navigation	3890	3942	2989	1469	2845	2879	2978	3008	2981	3097	-9.4	7.0	0.4	0.3
Freight transport	224545	222729	197233	191408	193738	182470	166424	159197	156791	156628	**-1.5**	**-0.5**	**-1.4**	**-0.2**
Heavy duty vehicles	165281	167617	153782	150732	151459	143684	135351	131651	132080	134000	-1.1	-0.5	-0.9	0.2
Freight light duty vehicles	39662	37862	31251	30065	30464	27121	19544	16159	13583	11681	-2.3	-1.0	-5.0	-3.2
Rail	5925	5156	3115	2420	2494	2262	2015	1701	1365	1074	-7.3	-0.7	-2.8	-4.5
Inland waterway navigation	13677	12094	9086	8191	9322	9404	9513	9687	9762	9872	-3.8	1.4	0.3	0.2

Source: PRIMES-TREMOVE Transport Model

Policy Option B1 detailed results (2/2)

SUMMARY (B)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**215414**	**238232**	**250794**	**263300**	**259531**	**265051**	**270621**	**276585**	**281836**	**283898**	**1.0**	**0.1**	**0.4**	**0.3**
Diesel Conventional	73600	105878	122727	128035	110825	93135	78157	63738	52907	44741	1.9	-3.1	-3.7	-3.5
Diesel Hybrid	0	73	401	2414	12463	20625	25607	26618	25106	24296	41.9	23.9	2.6	-0.9
Diesel plug-in hybrid	0	0	57	301	1053	6220	14508	20364	24679	26605	0.0	35.4	12.6	2.7
Gasoline Conventional	135523	125022	118877	118198	101076	75175	54572	38674	29404	23474	-0.6	-4.4	-6.4	-4.9
Gasoline Hybrid	21	162	783	3106	15064	20454	22479	21732	19019	17371	34.4	20.7	0.6	-2.2
Gasoline plug-in hybrid	0	0	86	461	2368	7089	11746	19391	24550	26460	0.0	31.4	10.6	3.2
LPG	5422	5710	5839	7634	9316	10721	11293	10372	9810	9140	2.9	3.5	-0.3	-1.3
CNG	848	1343	1757	1897	2614	3848	4985	5711	5730	5732	3.5	7.3	4.0	0.0
E85	0	45	89	151	392	604	655	649	617	596	12.9	14.9	0.7	-0.8
Electric	0	0	179	1102	4320	26880	45283	64260	80929	91198	0.0	37.6	9.1	3.6
Hydrogen	0	0	0	2	39	299	1336	5075	9085	14283	0.0	67.8	32.7	10.9
2wheelers	**30747**	**33150**	**32272**	**31649**	**33457**	**35243**	**36082**	**37279**	**38656**	**39970**	**-0.5**	**1.1**	**0.6**	**0.7**
Gasoline	30747	33150	32272	31649	33456	35238	36056	37187	38388	39554	-0.5	1.1	0.5	0.6
Electricity	0	0	0	0	1	4	26	92	267	417	0.0	68.5	35.8	16.3
HDVs, buses and coaches	**5943**	**6229**	**6109**	**6710**	**6790**	**7119**	**7699**	**8010**	**8248**	**8439**	**0.7**	**0.6**	**1.2**	**0.5**
Diesel Conventional	5935	6219	6094	6582	6136	5467	4929	4377	4115	4051	0.6	-1.8	-2.2	-0.8
Diesel Hybrid	0	4	8	84	408	1030	1736	2256	2554	2647	36.7	28.5	8.2	1.6
LPG	4	3	2	3	9	17	26	34	43	48	1.6	17.9	6.9	3.5
Natural Gas	4	4	5	38	232	566	900	1160	1290	1426	26.1	31.0	7.4	2.1
Electric	0	0	0	3	5	36	72	117	148	158	0.0	28.8	12.6	3.0
Hydrogen	0	0	0	0	0	2	35	66	98	109	0.0	182.2	39.0	5.1
Total annual cost excl. disutility (in million Euro'13)	**1891259**	**2150744**	**2114877**	**1977033**	**2321900**	**2535366**	**2617805**	**2701192**	**2778636**	**2868728**	**-0.8**	**2.5**	**0.6**	**0.6**
Passenger transport	**1537932**	**1766015**	**1765521**	**1616090**	**1917559**	**2092466**	**2150297**	**2211774**	**2268278**	**2339142**	**-0.9**	**2.6**	**0.6**	**0.6**
Public road transport	59819	63241	63046	51707	62820	67717	69919	72194	73997	75707	-2.0	2.7	0.6	0.5
Private cars	1069129	1202301	1174706	1104540	1216354	1310079	1310843	1323278	1333681	1348758	-0.8	1.7	0.1	0.2
2wheelers	32189	37774	37029	34320	40376	43743	44319	45577	48353	50235	-1.0	2.5	0.4	1.0
Passenger light duty vehicles	123532	157731	155305	151294	164832	175334	180300	185475	187559	192030	-0.4	1.5	0.6	0.3
Rail	73749	90370	98037	87556	114298	124453	134786	139426	149001	159137	-0.3	3.6	1.1	1.3
Aviation	172343	207591	230129	180193	310445	362055	400350	435733	465318	502176	-1.4	7.2	1.9	1.4
Inland navigation	7170	7007	7268	6479	8435	9085	9780	10092	10369	11099	-0.8	3.4	1.1	1.0
Freight transport	**353326**	**384730**	**349357**	**360942**	**404340**	**442900**	**467508**	**489418**	**510357**	**529587**	**-0.6**	**2.1**	**1.0**	**0.8**
Heavy duty vehicles	237997	263276	234646	240469	269451	293572	309336	321796	334254	345241	-0.9	2.0	0.9	0.7
Freight light duty vehicles	36600	40043	36351	42091	41159	44464	46928	49277	51245	53057	0.5	0.6	1.0	0.7
Rail	49953	52314	49071	49807	60511	68862	73285	79384	84215	89153	-0.5	3.3	1.4	1.2
Inland waterway navigation	28777	29098	29289	28576	33220	36002	37958	38961	40643	42136	-0.2	2.3	0.8	0.8
External costs (in million Euro'13) (1)	**735604**	**648641**	**617688**	**492737**	**574625**	**569054**	**561228**	**557682**	**559072**	**563064**	**-2.7**	**1.5**	**-0.2**	**0.1**
Total costs (incl. external costs)	**1891259**	**2150744**	**2114877**	**1977033**	**2321900**	**2535366**	**2617805**	**2701192**	**2778636**	**2868728**	**-0.8**	**2.5**	**0.6**	**0.6**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport

Policy Option B2 detailed results (1/2)

EU27noUK:SAF_scenB2	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	SUMMARY (A) '10-'20	'20-'30	'30-'40	'40-'50
											Annual % change			
Transport activity														
Passenger transport activity (Gpkm)	**5281**	**5457**	**5622**	**4499**	**6118**	**6490**	**6716**	**6922**	**7137**	**7352**	**-1.9**	**3.7**	**0.6**	**0.6**
Public road transport	498	484	487	313	473	498	504	517	526	534	-4.3	4.8	0.4	0.3
Private cars	3532	3657	3721	3252	4004	4205	4314	4408	4515	4632	-1.2	2.6	0.5	0.5
2wheelers	115	115	120	100	124	131	135	139	144	150	-1.3	2.7	0.6	0.7
Passenger light duty vehicles	309	324	335	294	365	388	401	411	420	430	-1.0	2.8	0.6	0.5
Rail	417	444	471	274	531	578	630	663	702	747	-4.7	7.7	1.4	1.2
Aviation	373	398	450	244	580	647	689	739	782	812	-4.8	10.2	1.3	0.9
Inland navigation	36	35	38	21	41	42	45	46	46	49	-5.1	7.4	0.7	0.6
Freight transport activity (Gtkm)	**2362**	**2320**	**2314**	**2377**	**2757**	**3022**	**3179**	**3334**	**3462**	**3563**	**0.2**	**2.4**	**1.0**	**0.7**
Heavy duty vehicles	1582	1564	1552	1644	1871	2030	2116	2206	2281	2332	0.5	2.1	0.8	0.6
Freight light duty vehicles	94	81	76	76	88	96	101	106	111	115	-0.6	2.3	1.0	0.8
Rail	395	375	396	382	473	550	603	651	688	724	0.2	3.7	1.7	1.1
Inland waterway navigation	291	301	290	274	325	345	358	371	382	393	-0.9	2.4	0.7	0.6
Final Energy Demand (ktoe)	**307729**	**307180**	**303451**	**247263**	**298169**	**278251**	**257611**	**243209**	**233764**	**229222**	**-2.1**	**1.2**	**-1.3**	**-0.6**
by transport mode														
Passenger transport	**232204**	**229838**	**234406**	**178433**	**226822**	**208376**	**191211**	**177988**	**168235**	**162782**	**-2.5**	**1.6**	**-1.6**	**-0.9**
Public road transport	8572	8321	9070	5748	8543	8507	8408	8454	8519	8551	-3.6	4.0	-0.1	0.1
Private cars	159751	153951	157553	129280	145385	127749	112411	100315	91912	87426	-1.7	-0.1	-2.4	-1.4
2wheelers	3704	3421	3674	2984	3588	3706	3746	3794	3844	3903	-1.4	2.2	0.2	0.3
Passenger light duty vehicles	19153	22373	20565	17489	19903	18703	16551	14651	12489	11723	-2.4	0.7	-2.4	-2.2
Rail	2742	2738	2612	1484	2690	2773	2897	2901	2957	3019	-5.9	6.5	0.5	0.4
Aviation	37042	37782	39975	20939	45728	45919	46138	46801	47449	47055	-5.7	8.2	0.2	0.1
Inland navigation	1240	1252	957	509	983	1019	1059	1071	1066	1105	-8.6	7.2	0.5	0.3
Freight transport	**75525**	**77342**	**69045**	**68830**	**71347**	**69875**	**66401**	**65222**	**65529**	**66440**	**-1.2**	**0.2**	**-0.7**	**0.2**
Heavy duty vehicles	54076	56954	52572	52889	54234	53229	51506	50858	51536	52556	-0.7	0.1	-0.5	0.3
Freight light duty vehicles	13037	12937	10753	10580	10870	10054	8098	7416	6965	6758	-2.0	-0.5	-3.0	-0.9
Rail	4029	3576	2798	2556	3025	3286	3432	3517	3556	3602	-3.3	2.5	0.7	0.2
Inland waterway navigation	4383	3875	2921	2806	3218	3306	3365	3431	3471	3524	-3.2	1.7	0.4	0.3
by fuel														
Oil products	**299776**	**290356**	**284864**	**226120**	**268506**	**238034**	**209571**	**188701**	**173992**	**163696**	**-2.5**	**0.5**	**-2.3**	**-1.4**
Gasoline	94548	75865	64529	53064	56508	45043	35573	29404	24934	21995	-3.5	-1.6	-4.2	-2.9
Diesel	162148	170056	173527	145252	156213	136547	119187	106208	96389	91281	-1.6	-0.6	-2.5	-1.5
Kerosene	37042	37782	39975	20939	45441	45293	43962	43267	43388	41701	-5.7	8.0	-0.5	-0.4
Liquefied Petroleum Gas	4691	5198	5895	6277	9675	10570	10376	9453	9019	8557	1.9	5.3	-1.1	-1.0
Residual fuel oil	1346	1455	938	588	668	582	472	370	263	162	-8.7	-0.1	-4.4	-7.9
Biofuels	**3134**	**11567**	**12886**	**16360**	**19549**	**21313**	**20927**	**20143**	**19322**	**19810**	**3.5**	**2.7**	**-0.6**	**-0.2**
Bio Gasoline	551	2480	2385	3341	3921	4314	3596	3001	2599	2337	3.0	2.6	-3.6	-2.5
Bio Diesel	2583	9064	10409	12504	14329	14737	13184	11457	10472	9991	3.3	1.7	-2.5	-1.4
Bio Kerosene	0	0	0	0	288	626	2175	3534	4030	5111	0.0	0.0	18.9	3.8
DME	0	0	0	0	0	0	0	0	0	0	-18.7	16.6	0.1	-0.6
Bio Heavy	0	0	0	45	52	54	45	34	25	16	0.0	1.8	-4.4	-7.5
Biogas	0	22	92	470	959	1582	1927	2117	2197	2356	35.7	12.9	3.0	1.1
Electricity	4269	4108	4102	3384	5564	10568	15726	20141	24015	26207	**-1.9**	**12.1**	**6.7**	**2.7**
Natural Gas	551	1149	1599	1398	4530	8189	10254	11179	11594	12652	**2.0**	**19.3**	**3.2**	**1.2**
Hydrogen	0	0	0	1	21	146	1134	3045	4842	6857	**0.0**	**63.0**	**35.5**	**8.5**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**44.0**	**42.1**	**41.7**	**39.7**	**37.1**	**32.1**	**28.5**	**25.7**	**23.6**	**22.1**	**-0.6**	**-2.1**	**-2.2**	**-1.5**
Public road transport	17.2	17.2	18.6	18.4	18.0	17.1	16.7	16.3	16.2	16.0	0.7	-0.7	-0.4	-0.2
Private cars	45.2	42.1	42.3	39.8	36.3	30.4	26.1	22.8	20.4	18.9	-0.6	-2.7	-2.8	-1.9
2wheelers	32.2	29.8	30.5	29.7	28.8	28.3	27.7	27.2	26.6	26.1	0.0	-0.5	-0.4	-0.4
Passenger light duty vehicles	62.0	69.1	61.4	59.4	54.6	48.2	41.3	35.7	29.8	27.3	-1.5	-2.1	-3.0	-2.6
Rail	6.6	6.2	5.6	5.4	5.1	4.8	4.6	4.4	4.2	4.0	-1.3	-1.2	-0.9	-0.8
Aviation	99.4	94.8	88.8	85.9	78.8	71.0	67.0	63.4	60.6	58.0	-1.0	-1.9	-1.1	-0.9
Inland navigation	34.3	35.7	25.5	24.6	24.2	24.0	23.8	23.5	23.0	22.8	-3.7	-0.2	-0.2	-0.3
Freight transport activity (toe/Mtkm)	**32.0**	**33.3**	**29.8**	**29.0**	**25.9**	**23.1**	**20.9**	**19.6**	**18.9**	**18.6**	**-1.4**	**-2.2**	**-1.7**	**-0.5**
Heavy duty vehicles	34.2	36.4	33.9	32.2	29.0	26.2	24.3	23.1	22.6	22.5	-1.2	-2.0	-1.3	-0.2
Freight light duty vehicles	138.3	159.8	141.5	138.4	123.3	104.7	80.0	69.7	62.6	58.9	-1.4	-2.8	-4.0	-1.7
Rail	10.2	9.5	7.1	6.7	6.4	6.0	5.7	5.4	5.2	5.0	-3.5	-1.1	-1.0	-0.8
Inland waterway navigation	15.1	12.9	10.1	10.3	9.9	9.6	9.4	9.2	9.1	9.0	-2.3	-0.7	-0.3	-0.3
CO_2 EMISSIONS (in ktons CO_2)	**906190**	**881844**	**867524**	**689023**	**822996**	**738042**	**649938**	**583192**	**533661**	**471009**	**-2.4**	**0.7**	**-2.3**	**-2.1**
Passenger transport	681645	659116	670291	497615	629255	555573	483497	423975	376834	314286	-2.8	1.1	-2.7	-2.9
Public road transport	26176	24543	26528	16298	23975	23223	22819	22973	23104	23139	-4.0	3.6	-0.1	0.1
Private cars	469864	440509	449925	358696	399340	332298	279050	234651	201830	182260	-2.0	-0.8	-3.4	-2.5
2wheelers	10708	9666	10357	8220	9821	9980	10053	10180	10294	10438	-1.6	2.0	0.2	0.3
Passenger light duty vehicles	58428	65863	59766	49697	56448	51899	44135	36789	27958	24038	-2.8	0.4	-3.4	-4.2
Rail	1802	1606	1179	616	936	840	744	629	502	392	-9.1	3.2	-2.8	-4.6
Aviation	110776	112987	119547	62618	135891	134459	123737	115771	110201	70987	-5.7	7.9	-1.5	-4.8
Inland navigation	3890	3942	2989	1469	2844	2875	2959	2981	2947	3032	-9.4	6.9	0.4	0.2
Freight transport	224545	222729	197233	191408	193741	182468	166441	159217	156827	156723	**-1.5**	**-0.5**	**-1.4**	**-0.2**
Heavy duty vehicles	165281	167617	153782	150732	151461	143685	135369	131670	132113	134085	-1.1	-0.5	-0.9	0.2
Freight light duty vehicles	39662	37862	31251	30065	30464	27118	19543	16156	13585	11687	-2.3	-1.0	-5.0	-3.2
Rail	5925	5156	3115	2420	2494	2262	2016	1701	1365	1074	-7.3	-0.7	-2.8	-4.5
Inland waterway navigation	13677	12094	9086	8191	9322	9404	9514	9690	9765	9877	-3.8	1.4	0.3	0.2

Source: PRIMES-TREMOVE Transport Model

Policy Option B2 detailed results (2/2)

SUMMARY (B)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**215414**	**238232**	**250794**	**263300**	**259539**	**265080**	**270768**	**276859**	**282221**	**284633**	**1.0**	**0.1**	**0.4**	**0.3**
Diesel Conventional	73600	105878	122727	128035	110831	93144	78189	63787	52964	44832	1.9	-3.1	-3.7	-3.5
Diesel Hybrid	0	73	401	2414	12466	20629	25622	26642	25137	24353	41.9	23.9	2.6	-0.9
Diesel plug-in hybrid	0	0	57	301	1053	6221	14522	20390	24716	26680	0.0	35.4	12.6	2.7
Gasoline Conventional	135523	125022	118877	118198	101078	75179	54590	38698	29431	23515	-0.6	-4.4	-6.4	-4.9
Gasoline Hybrid	21	162	783	3106	15064	20456	22490	21750	19040	17406	34.4	20.7	0.6	-2.2
Gasoline plug-in hybrid	0	0	86	461	2367	7090	11758	19426	24604	26564	0.0	31.4	10.6	3.2
LPG	5422	5710	5839	7634	9316	10722	11296	10379	9819	9157	2.9	3.5	-0.3	-1.2
CNG	848	1343	1757	1897	2614	3849	4987	5716	5737	5745	3.5	7.3	4.0	0.1
E85	0	45	89	151	392	605	655	650	617	597	12.9	14.9	0.7	-0.8
Electric	0	0	179	1102	4320	26887	45320	64342	81059	91466	0.0	37.6	9.1	3.6
Hydrogen	0	0	0	2	39	299	1338	5081	9096	14318	0.0	67.8	32.7	10.9
2wheelers	**30747**	**33150**	**32272**	**31649**	**33458**	**35246**	**36099**	**37310**	**38700**	**40065**	**-0.5**	**1.1**	**0.6**	**0.7**
Gasoline	30747	33150	32272	31649	33457	35242	36074	37218	38433	39647	-0.5	1.1	0.5	0.6
Electricity	0	0	0	0	1	4	26	92	268	418	0.0	68.5	35.8	16.3
HDVs, buses and coaches	**5943**	**6229**	**6109**	**6710**	**6790**	**7119**	**7699**	**8009**	**8248**	**8439**	**0.7**	**0.6**	**1.2**	**0.5**
Diesel Conventional	5935	6219	6094	6582	6136	5467	4929	4376	4114	4050	0.6	-1.8	-2.2	-0.8
Diesel Hybrid	0	4	8	84	408	1030	1737	2256	2554	2648	36.7	28.5	8.2	1.6
LPG	4	3	2	3	9	17	26	34	43	48	1.6	17.9	6.9	3.5
Natural Gas	4	4	5	38	232	566	900	1160	1290	1427	26.1	31.0	7.4	2.1
Electric	0	0	0	3	5	36	72	117	148	158	0.0	28.9	12.6	3.0
Hydrogen	0	0	0	0	0	2	35	66	98	109	0.0	182.2	39.0	5.1
Total annual cost excl. disutility (in million Euro'13)	**1891259**	**2150744**	**2114877**	**1977033**	**2321785**	**2535042**	**2615845**	**2698388**	**2774984**	**2861083**	**-0.8**	**2.5**	**0.6**	**0.6**
Passenger transport	**1537932**	**1766015**	**1765521**	**1616090**	**1917446**	**2092135**	**2148288**	**2208888**	**2264538**	**2331266**	**-0.9**	**2.6**	**0.5**	**0.5**
Public road transport	59819	63241	63046	51707	62801	67696	69810	72038	73824	75412	-2.0	2.7	0.6	0.5
Private cars	1069129	1202301	1174706	1104540	1216436	1310279	1311798	1324920	1335750	1352965	-0.8	1.7	0.1	0.2
2wheelers	32189	37774	37029	34320	40378	43747	44342	45616	48406	50351	-1.0	2.5	0.4	1.0
Passenger light duty vehicles	123532	157731	155305	151294	164853	175375	180470	185740	187903	192728	-0.4	1.5	0.6	0.4
Rail	73749	90370	98037	87556	114272	124392	134438	138945	148403	157962	-0.3	3.6	1.1	1.3
Aviation	172343	207591	230129	180193	310274	361570	397704	431616	459984	490936	-1.4	7.2	1.8	1.3
Inland navigation	7170	7007	7268	6479	8431	9075	9726	10013	10269	10913	-0.8	3.4	1.0	0.9
Freight transport	**353326**	**384730**	**349357**	**360942**	**404339**	**442907**	**467557**	**489500**	**510446**	**529817**	**-0.6**	**2.1**	**1.0**	**0.8**
Heavy duty vehicles	237997	263276	234646	240469	269454	293576	309368	321842	334319	345406	-0.9	2.0	0.9	0.7
Freight light duty vehicles	36600	40043	36351	42091	41158	44466	46934	49283	51253	53070	0.5	0.6	1.0	0.7
Rail	49953	52314	49071	49807	60509	68863	73294	79401	84222	89191	-0.5	3.3	1.4	1.2
Inland waterway navigation	28777	29098	29289	28576	33219	36003	37962	38973	40652	42150	-0.2	2.3	0.8	0.8
External costs (in million Euro'13) (1)	**735604**	**648641**	**617688**	**492737**	**574683**	**569193**	**561932**	**558765**	**560457**	**565873**	**-2.7**	**1.5**	**-0.2**	**0.1**
Total costs (incl. external costs)	**1891259**	**2150744**	**2114877**	**1977033**	**2321785**	**2535042**	**2615845**	**2698388**	**2774984**	**2861083**	**-0.8**	**2.5**	**0.6**	**0.6**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport

Policy Option C1 detailed results (1/2)

EU27noUK:SAF_scenC1	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	SUMMARY (A) '10-'20	'20-'30	'30-'40	'40-'50
											Annual % change			
Transport activity														
Passenger transport activity (Gpkm)	**5281**	**5457**	**5622**	**4499**	**6118**	**6491**	**6716**	**6922**	**7136**	**7351**	**-1.9**	**3.7**	**0.6**	**0.6**
Public road transport	498	484	487	313	473	499	505	519	528	537	-4.3	4.8	0.4	0.3
Private cars	3532	3657	3721	3252	4003	4205	4311	4403	4509	4619	-1.2	2.6	0.5	0.5
2wheelers	115	115	120	100	124	131	135	139	144	149	-1.3	2.7	0.6	0.7
Passenger light duty vehicles	309	324	335	294	365	388	400	410	419	428	-1.0	2.8	0.6	0.4
Rail	417	444	471	274	531	579	632	667	707	757	-4.7	7.8	1.4	1.3
Aviation	373	398	450	244	580	647	689	739	782	812	-4.8	10.2	1.3	0.9
Inland navigation	36	35	38	21	41	42	45	46	47	49	-5.1	7.4	0.8	0.7
Freight transport activity (Gtkm)	**2362**	**2320**	**2314**	**2377**	**2757**	**3022**	**3178**	**3334**	**3461**	**3562**	**0.2**	**2.4**	**1.0**	**0.7**
Heavy duty vehicles	1582	1564	1552	1644	1871	2030	2116	2206	2281	2331	0.5	2.1	0.8	0.6
Freight light duty vehicles	94	81	76	76	88	96	101	106	111	115	-0.6	2.3	1.0	0.8
Rail	395	375	396	382	473	550	603	651	688	724	0.2	3.7	1.7	1.1
Inland waterway navigation	291	301	290	274	325	345	358	371	382	393	-0.9	2.4	0.7	0.6
Final Energy Demand (ktoe)	**307729**	**307180**	**303451**	**247263**	**298131**	**278214**	**257177**	**242501**	**232789**	**227341**	**-2.1**	**1.2**	**-1.4**	**-0.6**
by transport mode														
Passenger transport	**232204**	**229838**	**234406**	**178433**	**226784**	**208340**	**190786**	**177290**	**167275**	**160942**	**-2.5**	**1.6**	**-1.6**	**-1.0**
Public road transport	8572	8321	9070	5748	8544	8510	8417	8466	8532	8569	-3.6	4.0	-0.1	0.1
Private cars	159751	153951	157553	129280	145380	127731	112337	100202	91782	87178	-1.7	-0.1	-2.4	-1.4
2wheelers	3704	3421	3674	2984	3588	3705	3744	3791	3839	3893	-1.4	2.2	0.2	0.3
Passenger light duty vehicles	19153	22373	20565	17489	19901	18699	16537	14630	12466	11682	-2.4	0.7	-2.4	-2.2
Rail	2742	2738	2612	1484	2691	2775	2906	2914	2973	3047	-5.9	6.5	0.5	0.4
Aviation	37042	37782	39975	20939	45696	45900	45777	46207	46605	45444	-5.7	8.2	0.1	-0.2
Inland navigation	1240	1252	957	509	984	1020	1066	1081	1079	1129	-8.6	7.2	0.6	0.4
Freight transport	**75525**	**77342**	**69045**	**68830**	**71346**	**69874**	**66392**	**65211**	**65514**	**66400**	**-1.2**	**0.2**	**-0.7**	**0.2**
Heavy duty vehicles	54076	56954	52572	52889	54234	53227	51498	50850	51524	52523	-0.7	0.1	-0.5	0.3
Freight light duty vehicles	13037	12937	10753	10580	10870	10055	8097	7416	6964	6754	-2.0	-0.5	-3.0	-0.9
Rail	4029	3576	2798	2556	3025	3286	3431	3516	3556	3600	-3.3	2.5	0.7	0.2
Inland waterway navigation	4383	3875	2921	2806	3218	3306	3364	3430	3471	3523	-3.2	1.7	0.4	0.3
by fuel														
Oil products	**299776**	**290356**	**284864**	**226120**	**267858**	**236655**	**204461**	**180467**	**164510**	**151197**	**-2.5**	**0.5**	**-2.7**	**-1.8**
Gasoline	94548	75865	64529	53064	56506	45040	35551	29373	24900	21935	-3.5	-1.6	-4.2	-2.9
Diesel	162148	170056	173527	145252	156213	136539	119155	106162	96339	91179	-1.6	-0.6	-2.5	-1.5
Kerosene	37042	37782	39975	20939	44796	43926	38911	35117	34000	29383	-5.7	7.7	-2.2	-1.8
Liquefied Petroleum Gas	4691	5198	5895	6277	9674	10568	10372	9445	9009	8538	1.9	5.3	-1.1	-1.0
Residual fuel oil	1346	1455	938	588	668	582	472	370	263	162	-8.7	-0.1	-4.4	-7.9
Biofuels	**3134**	**11567**	**12886**	**16360**	**20160**	**22660**	**25612**	**27690**	**27856**	**30501**	**3.5**	**3.3**	**2.0**	**1.0**
Bio Gasoline	551	2480	2385	3341	3921	4314	3594	2998	2595	2330	3.0	2.6	-3.6	-2.5
Bio Diesel	2583	9064	10409	12504	14329	14736	13181	11452	10466	9980	3.3	1.7	-2.5	-1.4
Bio Kerosene	0	0	0	0	900	1974	6867	11090	12575	15822	0.0	0.0	18.8	3.6
DME	0	0	0	0	0	0	0	0	0	0	-18.7	16.6	0.1	-0.7
Bio Heavy	0	0	0	45	52	54	45	34	25	16	0.0	1.8	-4.4	-7.5
Biogas	0	22	92	470	959	1582	1926	2116	2195	2352	35.7	12.9	3.0	1.1
Electricity	4269	4108	4102	3384	5565	10568	15724	20132	24000	26164	**-1.9**	**12.1**	**6.7**	**2.7**
Natural Gas	551	1149	1599	1398	4526	8185	10247	11171	11587	12638	**2.0**	**19.3**	**3.2**	**1.2**
Hydrogen	0	0	0	1	21	146	1133	3042	4836	6841	**0.0**	**63.0**	**35.5**	**8.4**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**44.0**	**42.1**	**41.7**	**39.7**	**37.1**	**32.1**	**28.4**	**25.6**	**23.4**	**21.9**	**-0.6**	**-2.1**	**-2.2**	**-1.6**
Public road transport	17.2	17.2	18.6	18.4	18.0	17.1	16.7	16.3	16.2	16.0	0.7	-0.7	-0.4	-0.2
Private cars	45.2	42.1	42.3	39.8	36.3	30.4	26.1	22.8	20.4	18.9	-0.6	-2.7	-2.8	-1.9
2wheelers	32.2	29.8	30.5	29.7	28.8	28.3	27.7	27.2	26.6	26.1	0.0	-0.5	-0.4	-0.4
Passenger light duty vehicles	62.0	69.1	61.4	59.4	54.6	48.2	41.3	35.7	29.8	27.3	-1.5	-2.1	-3.0	-2.6
Rail	6.6	6.2	5.6	5.4	5.1	4.8	4.6	4.4	4.2	4.0	-1.3	-1.2	-0.9	-0.8
Aviation	99.4	94.8	88.8	85.9	78.7	71.0	66.5	62.6	59.6	56.0	-1.0	-1.9	-1.3	-1.1
Inland navigation	34.3	35.7	25.5	24.6	24.2	24.0	23.8	23.5	23.0	22.8	-3.7	-0.2	-0.2	-0.3
Freight transport activity (toe/Mtkm)	**32.0**	**33.3**	**29.8**	**29.0**	**25.9**	**23.1**	**20.9**	**19.6**	**18.9**	**18.6**	**-1.4**	**-2.2**	**-1.7**	**-0.5**
Heavy duty vehicles	34.2	36.4	33.9	32.2	29.0	26.2	24.3	23.1	22.6	22.5	-1.2	-2.0	-1.3	-0.2
Freight light duty vehicles	138.3	159.8	141.5	138.4	123.3	104.7	80.0	69.7	62.6	58.9	-1.4	-2.7	-4.0	-1.7
Rail	10.2	9.5	7.1	6.7	6.4	6.0	5.7	5.4	5.2	5.0	-3.5	-1.1	-1.0	-0.8
Inland waterway navigation	15.1	12.9	10.1	10.3	9.9	9.6	9.4	9.2	9.1	9.0	-2.3	-0.7	-0.3	-0.3
CO_2 EMISSIONS (in ktons CO_2)	**906190**	**881844**	**867524**	**689023**	**821051**	**733937**	**635529**	**561113**	**509518**	**449468**	**-2.4**	**0.6**	**-2.6**	**-2.2**
Passenger transport	681645	659116	670291	497615	627310	551468	469107	401915	352727	292841	-2.8	1.0	-3.1	-3.1
Public road transport	26176	24543	26528	16298	23977	23233	22845	23008	23143	23196	-4.0	3.6	-0.1	0.1
Private cars	469864	440509	449925	358696	399325	332251	278875	234399	201556	181765	-2.0	-0.8	-3.4	-2.5
2wheelers	10708	9666	10357	8220	9821	9978	10047	10171	10281	10411	-1.6	2.0	0.2	0.2
Passenger light duty vehicles	58428	65863	59766	49697	56443	51887	44098	36735	27908	23958	-2.8	0.4	-3.4	-4.2
Rail	1802	1606	1179	616	936	840	745	630	503	394	-9.1	3.2	-2.8	-4.6
Aviation	110776	112987	119547	62618	133963	130400	109519	93964	86356	50019	-5.7	7.6	-3.2	-6.1
Inland navigation	3890	3942	2989	1469	2845	2878	2978	3009	2981	3097	-9.4	7.0	0.4	0.3
Freight transport	224545	222729	197233	191408	193741	182469	166422	159198	156791	156627	**-1.5**	**-0.5**	**-1.4**	**-0.2**
Heavy duty vehicles	165281	167617	153782	150732	151463	143684	135351	131652	132081	134000	-1.1	-0.5	-0.9	0.2
Freight light duty vehicles	39662	37862	31251	30065	30462	27120	19543	16159	13584	11681	-2.3	-1.0	-5.0	-3.2
Rail	5925	5156	3115	2420	2494	2262	2015	1701	1365	1074	-7.3	-0.7	-2.8	-4.5
Inland waterway navigation	13677	12094	9086	8191	9322	9404	9513	9687	9762	9872	-3.8	1.4	0.3	0.2

Source: PRIMES-TREMOVE Transport Model

Policy Option C1 detailed results (2/2)

SUMMARY (B)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**215414**	**238232**	**250794**	**263300**	**259531**	**265050**	**270618**	**276582**	**281833**	**283895**	**1.0**	**0.1**	**0.4**	**0.3**
Diesel Conventional	73600	105878	122727	128035	110828	93133	78154	63737	52907	44741	1.9	-3.1	-3.7	-3.5
Diesel Hybrid	0	73	401	2414	12464	20626	25607	26618	25106	24296	41.9	23.9	2.6	-0.9
Diesel plug-in hybrid	0	0	57	301	1053	6220	14507	20364	24679	26605	0.0	35.4	12.6	2.7
Gasoline Conventional	135523	125022	118877	118198	101077	75176	54573	38674	29404	23474	-0.6	-4.4	-6.4	-4.9
Gasoline Hybrid	21	162	783	3106	15062	20454	22479	21733	19019	17371	34.4	20.7	0.6	-2.2
Gasoline plug-in hybrid	0	0	86	461	2367	7088	11746	19391	24549	26460	0.0	31.4	10.6	3.2
LPG	5422	5710	5839	7634	9316	10721	11292	10372	9810	9140	2.9	3.5	-0.3	-1.3
CNG	848	1343	1757	1897	2614	3848	4985	5711	5730	5732	3.5	7.3	4.0	0.0
E85	0	45	89	151	392	604	655	649	617	596	12.9	14.9	0.7	-0.8
Electric	0	0	179	1102	4319	26880	45283	64260	80928	91196	0.0	37.6	9.1	3.6
Hydrogen	0	0	0	2	39	299	1336	5075	9084	14283	0.0	67.8	32.7	10.9
2wheelers	**30747**	**33150**	**32272**	**31649**	**33457**	**35243**	**36081**	**37279**	**38655**	**39970**	**-0.5**	**1.1**	**0.6**	**0.7**
Gasoline	30747	33150	32272	31649	33456	35238	36056	37187	38388	39553	-0.5	1.1	0.5	0.6
Electricity	0	0	0	0	1	4	26	92	267	417	0.0	68.5	35.8	16.3
HDVs, buses and coaches	**5943**	**6229**	**6109**	**6710**	**6791**	**7119**	**7699**	**8010**	**8248**	**8439**	**0.7**	**0.6**	**1.2**	**0.5**
Diesel Conventional	5935	6219	6094	6582	6136	5468	4929	4377	4115	4051	0.6	-1.8	-2.2	-0.8
Diesel Hybrid	0	4	8	84	408	1030	1737	2256	2554	2647	36.7	28.5	8.2	1.6
LPG	4	3	2	3	9	17	26	34	43	48	1.6	17.9	6.9	3.5
Natural Gas	4	4	5	38	232	566	900	1160	1290	1426	26.1	31.0	7.4	2.1
Electric	0	0	0	3	5	36	72	117	148	158	0.0	28.8	12.6	3.0
Hydrogen	0	0	0	0	0	2	35	66	98	109	0.0	182.2	39.0	5.1
Total annual cost excl. disutility (in million Euro'13)	**1891259**	**2150744**	**2114877**	**1977033**	**2321910**	**2535402**	**2617827**	**2701216**	**2778668**	**2868768**	**-0.8**	**2.5**	**0.6**	**0.6**
Passenger transport	**1537932**	**1766015**	**1765521**	**1616090**	**1917568**	**2092506**	**2150319**	**2211798**	**2268312**	**2339181**	**-0.9**	**2.6**	**0.6**	**0.6**
Public road transport	59819	63241	63046	51707	62810	67724	69922	72192	74001	75709	-2.0	2.7	0.6	0.5
Private cars	1069129	1202301	1174706	1104540	1216381	1310090	1310825	1323262	1333666	1348740	-0.8	1.7	0.1	0.2
2wheelers	32189	37774	37029	34320	40376	43742	44318	45577	48353	50235	-1.0	2.5	0.4	1.0
Passenger light duty vehicles	123532	157731	155305	151294	164838	175339	180301	185473	187556	192027	-0.4	1.5	0.6	0.3
Rail	73749	90370	98037	87556	114300	124466	134788	139432	149006	159144	-0.3	3.6	1.1	1.3
Aviation	172343	207591	230129	180193	310427	362060	400383	435771	465361	502227	-1.4	7.2	1.9	1.4
Inland navigation	7170	7007	7268	6479	8435	9085	9781	10092	10370	11099	-0.8	3.4	1.1	1.0
Freight transport	**353326**	**384730**	**349357**	**360942**	**404342**	**442896**	**467508**	**489418**	**510356**	**529587**	**-0.6**	**2.1**	**1.0**	**0.8**
Heavy duty vehicles	237997	263276	234646	240469	269464	293568	309336	321797	334255	345241	-0.9	2.0	0.9	0.7
Freight light duty vehicles	36600	40043	36351	42091	41152	44464	46929	49277	51245	53057	0.5	0.5	1.0	0.7
Rail	49953	52314	49071	49807	60509	68863	73285	79383	84213	89152	-0.5	3.3	1.4	1.2
Inland waterway navigation	28777	29098	29289	28576	33217	36002	37958	38961	40643	42136	-0.2	2.3	0.8	0.8
External costs (in million Euro'13) (1)	**735604**	**648641**	**617688**	**492737**	**574629**	**569045**	**561221**	**557674**	**559064**	**563054**	**-2.7**	**1.5**	**-0.2**	**0.1**
Total costs (incl. disutility and external costs)	**1891259**	**2150744**	**2114877**	**1977033**	**2321910**	**2535402**	**2617827**	**2701216**	**2778668**	**2868768**	**-0.8**	**2.5**	**0.6**	**0.6**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport

Policy Option C2 detailed results (1/2)

EU27noUK:SAF_scenC2											SUMMARY (A)			
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % change			
Transport activity														
Passenger transport activity (Gpkm)	**5281**	**5457**	**5622**	**4499**	**6118**	**6491**	**6717**	**6923**	**7136**	**7350**	**-1.9**	**3.7**	**0.6**	**0.6**
Public road transport	498	484	487	313	473	499	504	518	528	536	-4.3	4.8	0.4	0.3
Private cars	3532	3657	3721	3252	4004	4205	4312	4404	4509	4620	-1.2	2.6	0.5	0.5
2wheelers	115	115	120	100	124	131	135	139	144	149	-1.3	2.7	0.6	0.7
Passenger light duty vehicles	309	324	335	294	365	388	400	410	419	428	-1.0	2.8	0.6	0.4
Rail	417	444	471	274	531	579	630	666	707	756	-4.7	7.7	1.4	1.3
Aviation	373	398	450	244	580	647	691	739	782	810	-4.8	10.2	1.3	0.9
Inland navigation	36	35	38	21	41	42	45	46	47	50	-5.1	7.4	0.8	0.7
Freight transport activity (Gtkm)	**2362**	**2320**	**2314**	**2377**	**2757**	**3022**	**3178**	**3334**	**3461**	**3562**	**0.2**	**2.4**	**1.0**	**0.7**
Heavy duty vehicles	1582	1564	1552	1644	1871	2030	2116	2206	2281	2331	0.5	2.1	0.8	0.6
Freight light duty vehicles	94	81	76	76	88	96	101	106	111	115	-0.6	2.3	1.0	0.8
Rail	395	375	396	382	473	550	603	651	688	724	0.2	3.7	1.7	1.1
Inland waterway navigation	291	301	290	274	325	345	358	371	382	393	-0.9	2.4	0.7	0.6
Final Energy Demand (ktoe)	**307729**	**307180**	**303451**	**247263**	**298130**	**278233**	**257378**	**242651**	**232959**	**227561**	**-2.1**	**1.2**	**-1.4**	**-0.6**
by transport mode														
Passenger transport	**232204**	**229838**	**234406**	**178433**	**226784**	**208357**	**190984**	**177438**	**167442**	**161157**	**-2.5**	**1.6**	**-1.6**	**-1.0**
Public road transport	8572	8321	9070	5748	8544	8510	8414	8464	8532	8567	-3.6	4.0	-0.1	0.1
Private cars	159751	153951	157553	129280	145380	127734	112363	100225	91801	87205	-1.7	-0.1	-2.4	-1.4
2wheelers	3704	3421	3674	2984	3588	3705	3745	3791	3840	3894	-1.4	2.2	0.2	0.3
Passenger light duty vehicles	19153	22373	20565	17489	19901	18698	16542	14634	12469	11686	-2.4	0.7	-2.4	-2.2
Rail	2742	2738	2612	1484	2691	2774	2897	2911	2971	3047	-5.9	6.5	0.5	0.5
Aviation	37042	37782	39975	20939	45696	45917	45962	46329	46763	45623	-5.7	8.2	0.1	-0.2
Inland navigation	1240	1252	957	509	984	1019	1061	1084	1067	1135	-8.6	7.2	0.6	0.5
Freight transport	**75525**	**77342**	**69045**	**68830**	**71346**	**69876**	**66394**	**65213**	**65516**	**66404**	**-1.2**	**0.2**	**-0.7**	**0.2**
Heavy duty vehicles	54076	56954	52572	52889	54234	53228	51500	50852	51526	52526	-0.7	0.1	-0.5	0.3
Freight light duty vehicles	13037	12937	10753	10580	10870	10056	8097	7416	6964	6755	-2.0	-0.5	-3.0	-0.9
Rail	4029	3576	2798	2556	3025	3286	3432	3516	3556	3600	-3.3	2.5	0.7	0.2
Inland waterway navigation	4383	3875	2921	2806	3218	3306	3365	3430	3470	3523	-3.2	1.7	0.4	0.3
by fuel														
Oil products	**299776**	**290356**	**284864**	**226120**	**267857**	**236604**	**203681**	**179734**	**163609**	**149548**	**-2.5**	**0.5**	**-2.7**	**-1.8**
Gasoline	94548	75865	64529	53064	56506	45041	35559	29380	24905	21942	-3.5	-1.6	-4.2	-2.9
Diesel	162148	170056	173527	145252	156212	136541	119165	106176	96340	91195	-1.6	-0.6	-2.5	-1.5
Kerosene	37042	37782	39975	20939	44796	43873	38112	34362	33091	27708	-5.7	7.7	-2.4	-2.1
Liquefied Petroleum Gas	4691	5198	5895	6277	9674	10568	10373	9447	9011	8540	1.9	5.3	-1.1	-1.0
Residual fuel oil	1346	1455	938	588	668	582	472	369	262	162	-8.7	-0.1	-4.4	-7.9
Biofuels	**3134**	**11567**	**12886**	**16360**	**20160**	**22730**	**26598**	**28569**	**28924**	**32359**	**3.5**	**3.3**	**2.3**	**1.3**
Bio Gasoline	551	2480	2385	3341	3921	4314	3594	2999	2596	2331	3.0	2.6	-3.6	-2.5
Bio Diesel	2583	9064	10409	12504	14329	14736	13182	11453	10467	9982	3.3	1.7	-2.5	-1.4
Bio Kerosene	0	0	0	0	900	2044	7851	11967	13642	17677	0.0	0.0	19.3	4.0
DME	0	0	0	0	0	0	0	0	0	0	-18.7	16.6	0.1	-0.7
Bio Heavy	0	0	0	45	52	54	45	34	25	16	0.0	1.8	-4.4	-7.5
Biogas	0	22	92	470	959	1582	1926	2116	2195	2353	35.7	12.9	3.0	1.1
Electricity	4269	4108	4102	3384	5565	10568	15718	20133	24003	26171	**-1.9**	**12.1**	**6.7**	**2.7**
Natural Gas	551	1149	1599	1398	4526	8185	10247	11172	11586	12641	**2.0**	**19.3**	**3.2**	**1.2**
Hydrogen	0	0	0	1	21	146	1133	3043	4837	6843	**0.0**	**63.0**	**35.5**	**8.4**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**44.0**	**42.1**	**41.7**	**39.7**	**37.1**	**32.1**	**28.4**	**25.6**	**23.5**	**21.9**	**-0.6**	**-2.1**	**-2.2**	**-1.5**
Public road transport	17.2	17.2	18.6	18.4	18.0	17.1	16.7	16.3	16.2	16.0	0.7	-0.7	-0.4	-0.2
Private cars	45.2	42.1	42.3	39.8	36.3	30.4	26.1	22.8	20.4	18.9	-0.6	-2.7	-2.8	-1.9
2wheelers	32.2	29.8	30.5	29.7	28.8	28.3	27.7	27.2	26.6	26.1	0.0	-0.5	-0.4	-0.4
Passenger light duty vehicles	62.0	69.1	61.4	59.4	54.6	48.2	41.3	35.7	29.8	27.3	-1.5	-2.1	-3.0	-2.6
Rail	6.6	6.2	5.6	5.4	5.1	4.8	4.6	4.4	4.2	4.0	-1.3	-1.2	-0.9	-0.8
Aviation	99.4	94.8	88.8	85.9	78.7	71.0	66.5	62.7	59.8	56.3	-1.0	-1.9	-1.2	-1.1
Inland navigation	34.3	35.7	25.5	24.6	24.2	24.0	23.8	23.5	22.9	22.9	-3.7	-0.2	-0.2	-0.3
Freight transport activity (toe/Mtkm)	**32.0**	**33.3**	**29.8**	**29.0**	**25.9**	**23.1**	**20.9**	**19.6**	**18.9**	**18.6**	**-1.4**	**-2.2**	**-1.7**	**-0.5**
Heavy duty vehicles	34.2	36.4	33.9	32.2	29.0	26.2	24.3	23.1	22.6	22.5	-1.2	-2.0	-1.3	-0.2
Freight light duty vehicles	138.3	159.8	141.5	138.4	123.3	104.7	80.0	69.7	62.6	58.9	-1.4	-2.7	-4.0	-1.7
Rail	10.2	9.5	7.1	6.7	6.4	6.0	5.7	5.4	5.2	5.0	-3.5	-1.1	-1.0	-0.8
Inland waterway navigation	15.1	12.9	10.1	10.3	9.9	9.6	9.4	9.2	9.1	9.0	-2.3	-0.7	-0.3	-0.3
CO_2 EMISSIONS (in ktons CO_2)	**906190**	**881844**	**867524**	**689023**	**821050**	**733990**	**636030**	**561432**	**509833**	**449749**	**-2.4**	**0.6**	**-2.6**	**-2.2**
Passenger transport	681645	659116	670291	497615	627310	551516	469603	402229	353036	293113	-2.8	1.0	-3.1	-3.1
Public road transport	26176	24543	26528	16298	23977	23232	22836	23002	23145	23188	-4.0	3.6	-0.1	0.1
Private cars	469864	440509	449925	358696	399325	332259	278937	234451	201596	181819	-2.0	-0.8	-3.4	-2.5
2wheelers	10708	9666	10357	8220	9821	9979	10049	10173	10282	10414	-1.6	2.0	0.2	0.2
Passenger light duty vehicles	58428	65863	59766	49697	56443	51884	44112	36745	27913	23967	-2.8	0.4	-3.4	-4.2
Rail	1802	1606	1179	616	936	840	744	630	503	394	-9.1	3.2	-2.8	-4.6
Aviation	110776	112987	119547	62618	133964	130445	109961	94212	86649	50217	-5.7	7.6	-3.2	-6.1
Inland navigation	3890	3942	2989	1469	2845	2876	2964	3015	2948	3113	-9.4	6.9	0.5	0.3
Freight transport	224545	222729	197233	191408	193740	182474	166427	159203	156797	156636	**-1.5**	**-0.5**	**-1.4**	**-0.2**
Heavy duty vehicles	165281	167617	153782	150732	151462	143685	135355	131656	132087	134008	-1.1	-0.5	-0.9	0.2
Freight light duty vehicles	39662	37862	31251	30065	30462	27123	19542	16159	13585	11682	-2.3	-1.0	-5.0	-3.2
Rail	5925	5156	3115	2420	2494	2262	2015	1701	1365	1074	-7.3	-0.7	-2.8	-4.5
Inland waterway navigation	13677	12094	9086	8191	9322	9404	9514	9687	9761	9873	-3.8	1.4	0.3	0.2

Source: PRIMES-TREMOVE Transport Model

Policy Option C2 detailed results (2/2)

SUMMARY (B)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**215414**	**238232**	**250794**	**263300**	**259531**	**265054**	**270669**	**276639**	**281893**	**283978**	**1.0**	**0.1**	**0.4**	**0.3**
Diesel Conventional	73600	105878	122727	128035	110828	93134	78166	63748	52917	44752	1.9	-3.1	-3.7	-3.5
Diesel Hybrid	0	73	401	2414	12464	20626	25612	26623	25111	24303	41.9	23.9	2.6	-0.9
Diesel plug-in hybrid	0	0	57	301	1053	6220	14512	20370	24685	26613	0.0	35.4	12.6	2.7
Gasoline Conventional	135523	125022	118877	118198	101077	75177	54580	38681	29409	23479	-0.6	-4.4	-6.4	-4.9
Gasoline Hybrid	21	162	783	3106	15062	20454	22483	21737	19023	17375	34.4	20.7	0.6	-2.2
Gasoline plug-in hybrid	0	0	86	461	2367	7088	11750	19396	24556	26470	0.0	31.4	10.6	3.2
LPG	5422	5710	5839	7634	9316	10721	11294	10374	9812	9142	2.9	3.5	-0.3	-1.3
CNG	848	1343	1757	1897	2614	3848	4985	5712	5731	5734	3.5	7.3	4.0	0.0
E85	0	45	89	151	392	605	655	649	617	596	12.9	14.9	0.7	-0.8
Electric	0	0	179	1102	4319	26881	45294	64275	80947	91226	0.0	37.6	9.1	3.6
Hydrogen	0	0	0	2	39	299	1337	5076	9086	14287	0.0	67.8	32.7	10.9
2wheelers	**30747**	**33150**	**32272**	**31649**	**33457**	**35243**	**36087**	**37285**	**38661**	**39980**	**-0.5**	**1.1**	**0.6**	**0.7**
Gasoline	30747	33150	32272	31649	33456	35239	36062	37193	38394	39563	-0.5	1.1	0.5	0.6
Electricity	0	0	0	0	1	4	26	92	267	417	0.0	68.5	35.8	16.3
HDVs, buses and coaches	**5943**	**6229**	**6109**	**6710**	**6790**	**7119**	**7699**	**8010**	**8248**	**8439**	**0.7**	**0.6**	**1.2**	**0.5**
Diesel Conventional	5935	6219	6094	6582	6136	5468	4929	4377	4115	4051	0.6	-1.8	-2.2	-0.8
Diesel Hybrid	0	4	8	84	408	1030	1737	2256	2554	2647	36.7	28.5	8.2	1.6
LPG	4	3	2	3	9	17	26	34	43	48	1.6	17.9	6.9	3.5
Natural Gas	4	4	5	38	232	566	900	1160	1290	1426	26.1	31.0	7.4	2.1
Electric	0	0	0	3	5	36	72	117	148	158	0.0	28.8	12.6	3.0
Hydrogen	0	0	0	0	0	2	35	66	98	109	0.0	182.2	39.0	5.1
Total annual cost excl. disutility (in million Euro'13)	**1891259**	**2150744**	**2114877**	**1977033**	**2321911**	**2535342**	**2617130**	**2700844**	**2778263**	**2867981**	**-0.8**	**2.5**	**0.6**	**0.6**
Passenger transport	**1537932**	**1766015**	**1765521**	**1616090**	**1917569**	**2092449**	**2149609**	**2211413**	**2267895**	**2338372**	**-0.9**	**2.6**	**0.6**	**0.6**
Public road transport	59819	63241	63046	51707	62810	67721	69885	72166	73999	75673	-2.0	2.7	0.6	0.5
Private cars	1069129	1202301	1174706	1104540	1216382	1310118	1311158	1323580	1333939	1349182	-0.8	1.7	0.1	0.2
2wheelers	32189	37774	37029	34320	40376	43742	44326	45584	48359	50246	-1.0	2.5	0.4	1.0
Passenger light duty vehicles	123532	157731	155305	151294	164838	175341	180360	185523	187601	192105	-0.4	1.5	0.6	0.3
Rail	73749	90370	98037	87556	114300	124413	134262	139375	148970	159244	-0.3	3.6	1.1	1.3
Aviation	172343	207591	230129	180193	310428	362034	399877	435088	464703	500800	-1.4	7.2	1.9	1.4
Inland navigation	7170	7007	7268	6479	8435	9080	9741	10097	10325	11122	-0.8	3.4	1.1	1.0
Freight transport	**353326**	**384730**	**349357**	**360942**	**404342**	**442894**	**467522**	**489432**	**510368**	**529609**	**-0.6**	**2.1**	**1.0**	**0.8**
Heavy duty vehicles	237997	263276	234646	240469	269462	293567	309341	321807	334269	345259	-0.9	2.0	0.9	0.7
Freight light duty vehicles	36600	40043	36351	42091	41152	44462	46931	49278	51248	53059	0.5	0.5	1.0	0.7
Rail	49953	52314	49071	49807	60510	68863	73288	79385	84226	89152	-0.5	3.3	1.4	1.2
Inland waterway navigation	28777	29098	29289	28576	33218	36002	37962	38962	40624	42140	-0.2	2.3	0.8	0.8
External costs (in million Euro'13) (1)	**735604**	**648641**	**617688**	**492737**	**574629**	**569067**	**561464**	**557873**	**559252**	**563346**	**-2.7**	**1.5**	**-0.2**	**0.1**
Total costs (incl. external costs)	**1891259**	**2150744**	**2114877**	**1977033**	**2321911**	**2535342**	**2617130**	**2700844**	**2778263**	**2867981**	**-0.8**	**2.5**	**0.6**	**0.6**

(1) External costs include accidents, noise, air pollution and congestion

Source: PRIMES-TREMOVE Transport

14. Annex 6: Tankering cases

Introduction

Fuel tankering is a term that defines the loading of more fuel than required for a flight in order to reduce or avoid refuelling at the destination airport. Research by Eurocontrol (2019) has found that in practice tankering is performed on 30% of flights in the European Civil Aviation Conference (ECAC) area. The practice of fuel tankering exploits the fuel cost differentials between airports. However, carrying more fuel than necessary increases the fuel consumption and thus the amount of CO2 emitted. The purpose of this case study is to provide information on the increased incentives for conventional kerosene fuel tankering outside the EU as the requirement for EU jet fuel to contain more costly Sustainable Aviation Fuel (SAF) increases over time.

Methods

The potential cost advantage of tankering was estimated for the following five popular return flights between EEA and non-EEA airports (see Table 63). These are selected in different flight distance classes so as to be able to estimate what is the tipping point where tinkering practices become economically attractive for each distance class. Specific aircraft and flight data such as fuel, allowable take-off weight and allowable landing weight were gathered from the SimBrief Despatch System (2020), a detailed virtual flight planning software.

Table 63 Selection of tankering case studies

Case study	Distance (km)	Case study aircraft	Max Passengers	Maximum landing weight (t)
New York – Paris	6047	777-300 ER	396	251.3
Istanbul – Frankfurt	1969	A320	180	66.0
Tel Aviv – Athens	1287	A320	180	66.0
London – Munich	1020	737-800	189	66.4
London – Dublin	559	737-800	189	66.4

Source: simBrief calculator

Flights are normally planned with data from flight planning software and the determination to tanker would be made at this point. It is also assumed that for all calculations, the flight is running at full passenger capacity with associated luggage. The amount of fuel tankered was estimated to either be the maximum tankering potential whilst meeting the safety and structural limits of the aircraft or the amount of fuel planned for the return flight.

Factors that were accounted for include the maximum take-off weight, maximum landing weight, and fuel capacity. The most constraining factor for tankering for each flight was the maximum landing weight and was used to estimate the tankering potential. The cost of carrying extra fuel onboard an aircraft is known as the cost to carry. The cost to carry equations used are from Ryerson et al. (2015) and models fuel consumption for a range of take-off weight values that capture different amounts of fuel uplift and distances for a range of aircraft types. The equation does not consider the cost of greater wear on brakes, tires and reversers caused by landing with higher weight. The results of these calculations enable us to estimate the extra fuel consumed for tankering on each of the five chosen return flights.

The price of fuel mix and conventional kerosene were estimated by E3M in five-year intervals (2025-2050) for the following Policy Options:

- Policy Option A1 obliged fuel suppliers to supply jet fuel that is blended with a minimum share of Sustainable Aviation Fuel (SAF)
- Policy Option A2 obliged fuel suppliers to supply all EU airports SAF-blended jet fuel that achieves a minimum GHG saving.

These prices allowed us to estimate the incentives for airlines to tanker conventional kerosene fuel outside the EU. Using the above, the cost incentives to tanker fuel have been calculated for Policy Options A1 and A2 as seen in Table 64 and Table 65.

Table 64 Incentive of tankering for the selected case studies under Policy Option A1 (% of fuel cost savings)

Case study	2020	2025	2030	2035	2040	2045	2050
New York – Paris	-4.2%	-3.7%	-3.3%	-0.5%	1.3%	1.7%	3.4%
Istanbul – Frankfurt	-1.1%	-0.8%	-0.6%	0.8%	1.6%	1.8%	2.7%
Tel Aviv – Athens	-1.2%	-0.8%	-0.5%	1.6%	3.0%	3.3%	4.7%
London – Munich	-1.4%	-1.0%	-0.6%	1.9%	3.5%	3.9%	5.5%
London – Dublin	-1.7%	-0.9%	-0.3%	3.9%	6.7%	7.3%	10.0%

Source: simBrief and own calculations

Table 65 Incentive of tankering for the selected case studies under Policy Option A2 (% of fuel cost savings)

Case study	2020	2025	2030	2035	2040	2045	2050
New York – Paris	-4.2%	-3.7%	-3.3%	-0.9%	1.1%	1.6%	3.3%
Istanbul – Frankfurt	-1.1%	-0.8%	-0.6%	0.5%	1.5%	1.8%	2.7%
Tel Aviv – Athens	-1.2%	-0.8%	-0.6%	1.3%	2.9%	3.2%	4.7%
London – Munich	-1.4%	-1.0%	-0.7%	1.5%	3.4%	3.8%	5.4%
London – Dublin	-1.7%	-0.9%	-0.4%	3.2%	6.4%	7.2%	10.0%

Source: simBrief and own calculations

Under both Policy Options and all cases there is a counter-incentive to tanker fuel from extra-EEA airports until post-2030 for short-haul flights and post-2035 for long-haul flights. This is due to the relatively low SAF participation in the aviation mix which makes the cost of carrying additional fuel not worth it. Policy Option A2 performs slightly better than A1 due to the slightly lower SAF prices achieved by the absence of the sub-mandate.

15. References

Transport & Environment, 2018. *Roadmap to decarbonising European Aviation,* s.l.: s.n.

ADS Group, 2020. *A Guide to Sustainable Aviation Fuels.* [Online]
Available at: https://www.adsgroup.org.uk/blog/sustainable-aviation-fuels/

Ames, J. L., 2015. Microalgae-derived HEFA jet fuel : environmental and economic impacts of scaled/integrated growth facilities and global production potential. *Massachusetts Institute of Technology.*

ARA, n.d. *Feedstocks.* [Online]
Available at: https://www.ara.com/products/feedstocks/

ARA, n.d. *ReadiJet.* [Online]
Available at: https://www.ara.com/products/readijet/

ATAG, n.d. *Producing sustainable aviation fuel.* [Online]
Available at: https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel/producing-sustainable-aviation-fuel/

Ausfelder, F. & Dura, H., 2019. *Roadmap des Kopernikus-Projektes „Power-to-X“: Flexible Nutzung erneuerbarer Ressourcen (P2X),* s.l.: s.n.

Bauen, A. & Bitossi, N., 2020. Sustainable Aviation Fuels: Status, challenges and prospects of drop-in liquid fuels, hydrogen and electrification in aviation. *Johnson Matthey Technology Review,* 64(3).

Bosch, J., Jong, S. D., Hoefnagels, R. & Slade, R., 2017. *Aviation biofuels: strategically important, technically achievable, tough to deliver,* London: Grantham Institute.

Bruna, R. & Jean-Michel, L., 2019. Recent Advances in Power-to-X Technology for the Production of Fuels and Chemicals. *rontiers in Chemistry.*

Brynolf, S., Taljegard, M., Grahn, M. & J.Hansson, 2018. Electrofuels for the transport sector: A review of production costs. *Renewable and Sustainable Energy Reviews,* Volume 81, pp. 1887-1905.

Bullis, K., 2012. *Amyris Gives Up Making Biofuels: Update.* [Online]
Available at: https://www.technologyreview.com/2012/02/10/20483/amyris-gives-up-making-biofuels-update/

CAPA, n.d. *Supplier Profiles.* [Online]
Available at: https://centreforaviation.com/data/profiles/suppliers

Carbon Recycling International, n.d. *Methanol.* [Online]
Available at: https://www.carbonrecycling.is/products

CE Delft, 2014. *Emissions trading for transport and the built environment. Analysis of the options to include transport and the built environment in the EU ETS,* Delft: CE Delft.

Comité national routier, 2019. *Comité national routier.* [Online]
Available at: https://www.cnr.fr/en/publications
[Accessed 26 October 2020].

Commission, E., 2020. *Feedback received on: Sustainable aviation fuels – ReFuelEU Aviation.* [Online]
Available at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12303-ReFuelEU-Aviation-Sustainable-Aviation-Fuels/feedback?p_id=7650222

Concawe, 2019. A look into the role of e-fuels in the transport system in Europe (2030–2050). *Concawe Review,* 28(1).

Concawe, 2019. *Refinery 2050: Conceptual Assessment: Exploring opportunities and challenges for the EU refining industry to transition towards a low-CO2 intensive economy,* s.l.: s.n.

DBEIS, 2017. *UK and Global Bioenergy Resource Model.* [Online] Available at: https://www.gov.uk/government/publications/uk-and-global-bioenergy-resource-model

DBEIS, 2020. *Contracts for Difference.* [Online] Available at: https://www.gov.uk/government/publications/contracts-for-difference/contract-for-difference

dena, 2017. *The potential of electricity-based fuels for low-emission transportin the EU,* s.l.: s.n.

Deutsche Lufthansa AG; WIWEB, 2012. *High Biofuel Blendsin Aviation (HBBA),* s.l.: s.n.

DIW Berlin, 2019. *Contracts for Difference (Differenzverträge).* [Online] Available at: https://www.diw.de/de/diw_01.c.670596.de/differenzvertraege_contracts_for_difference.html

E4tech; Element Energy, 2014. *Development of Water Electrolysis in the European Union,* s.l.: s.n.

E4tech, 2014. *Advanced Biofuel Feedstocks – An Assessment of Sustainability ,* s.l.: s.n.

E4tech, 2017. *Report on market and industrial development intelligence for sustainable advanced biofuels,* s.l.: s.n.

E4tech, 2019. *Study on the potential effectiveness of a renewable energy obligation for aviation in the Netherlands,* s.l.: s.n.

EASA; EEA; EUROCONTROL, 2019. *European Aviation Environmental Report 2019,* s.l.: s.n.

EASA; EEA; EUROCONTROL, n.d. *Sustainable Aviation Fuels.* [Online] Available at: https://www.easa.europa.eu/eaer/climate-change/sustainable-aviation-fuels

EASA, 2020. *Sustainable Aviation Fuel 'Facilitation Initiative' ,* s.l.: s.n.

EASA, n.d. *Bio-based aviation fuels.* [Online] Available at: https://www.easa.europa.eu/eaer/topics/sustainable-aviation-fuels/bio-based-aviation-fuels

EEA, 2020. *EU Emissions Trading System (ETS) data viewer.* [Online] Available at: https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

Eionet, 2019. *Trends and projections in the EU ETS in 2019: The EU Emissions Trading System in numbers,* s.l.: s.n.

Energiewende, A., n.d. *PtG/PtL Rechner.* [Online] Available at: https://www.agora-energiewende.de/veroeffentlichungen/ptg-ptl-rechner/

EUROCONTROL, 2019. *Fuel Tankering: economic benefitsand environmental impact,* s.l.: s.n.

EUROCONTROL, 2020. *Five-Year Forecast 2020-2024,* s.l.: s.n.

European Commission , n.d. *A European Green Deal.* [Online] Available at: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

European Commission, 2011. *Launch of the European Advanced Biofuels Flightpath,* s.l.: s.n.

European Commission, 2012. Commission Regulation (EU) No 601/2012 of 21 June 2012 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council Text with EEA relevance. *Official Journal of the European Union,* Volume 181.

European Commission, 2014. *COMMISSION DECISIONof 08.10.2014 ON THE AID MEASURE SA.34947 (2013/C) (ex 2013/N) which the United Kingdom is planning to implement for Support to the Hinkley Point C Nuclear Power Station,* s.l.: s.n.

European Commission, 2014. Guidelines on State aid for environmental protection and energy 2014-20. *Official Journal of the European Union,* Volume 200.

European Commission, 2015. *An Aviation Strategy for Europe - COM(2015) 598.* s.l.:s.n.

European Commission, 2016. *Support to an impact assessment of an EU ETS review and possible proposal,* s.l.: s.n.

European Commission, 2017a. *Annual Analyses of the EU Air Transport Market 2016,* Croydon, United Kingdom: Mott MacDonald.

European Commission, 2017. *Research and Innovation perspective of the mid-and long-term Potential for Advanced Biofuels in Europe,* s.l.: s.n.

European Commission, 2018. *A Clean Planet for all.* [Online] Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0773 [Accessed 14 December 2020].

European Commission, 2018. *A Clean Planet for all: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy,* s.l.: s.n.

European Commission, 2019. *Handbook on the external costs of transport, Version 2019 – 1.1,* Brussels: European Commission.

European Commission, 2020. *2030 climate & energy framework.* [Online] Available at: https://ec.europa.eu/clima/policies/strategies/2030_en [Accessed 14 December 2020].

European Commission, 2020. *A hydrogen strategy for a climate-neutral Europe,* s.l.: s.n.

European Commission, 2020. *Communication: Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people.* s.l.:s.n.

European Commission, 2020. *Communication: Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people.* s.l.:s.n.

European Commission, 2020. *Impact Assessment Report: Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people,* s.l.: s.n.

European Commission, 2020. *State of the Art on Alternative Fuels Transport Systems in the European Union,* s.l.: s.n.

European Commission, 2020. *State of the Union: Commission raises climate ambition and proposes 55% cut in emissions by 2030.* [Online] Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1599

European Commission, 2020. *TERCET.* [Online] Available at: https://gisco-services.ec.europa.eu/tercet/flat-files

European Parliament and of the Council of the European Union, 2009. DIRECTIVE 2009/30/EC. *Official Journal of the European Union,* Volume 140.

European Parliament and the Council of the European Union, 2008. Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community. *Official Journal of the European Union.*

European Parliament and the Council of the European Union, 2009. Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002. *Official Journal of the European Union,* 300(1).

Eurostat, n.d. *Data Explorer.* [Online]
Available at: https://appsso.eurostat.ec.europa.eu/nui/mainPage.do

Fasihi, M., Bogdanov, D. & Breyer, C., 2017. Long-Term Hydrocarbon Trade Options for the Maghreb Region and Europe—Renewable Energy Based Synthetic Fuels for a Net Zero Emissions World. *Sustainability,* 9(2).

FLEXCHX, 2018. *Flexible combined production of power, heat andtransport fuels from renewable energy sources,* s.l.: s.n.

Fraunhofer IWES, 2017. *Mittel - und Langfristige Ppotenziale von PTL- und H2-Importen aus Internationalen EE-Vorzugsregionen,* s.l.: s.n.

Fröhlich, T., Blömer, S., Münter, D. & Brischke, L., 2019. *CO2-Quellen für die PtX-Herstellung in Deutschland -Technologien, Umweltwir-kung, Verfügbarkeit,* s.l.: ifeu.

Frontier Economics, 2018. *The Future Cost of Electricity-Based Synthetic Fuels,* Cologne: s.n.

Greenair Online, 2020. *ASTM approves ARA's synthetic kerosene process for the production of sustainable aviation fuel.* [Online]
Available at: https://www.greenaironline.com/news.php?viewStory=2665

Holen, G., 2019. *100% Carbon Neutral, Disrupt or be disrupted. Kraftstoffe der Zu-kunt -16. Internationaler Fachkongress für erneuerbare Mobilität..* Berlin, Nordic Blue Crude.

ICAO, 2013. *Basket of Measures to Reduce Aviation CO2 Emissions: Progress since the 37th Session of the ICAO Assembly,* s.l.: s.n.

ICAO, 2018. *International Standards and Recommended Practices: Annex 16 to the Convention on International Civil Aviation,* s.l.: s.n.

ICCT, 2019. *Long-term aviation fuel decarbonization: Progress, roadblocks, and policy opportunities,* s.l.: s.n.

ICCT, 2019. *The cost of supporting alternative jet fuels in the European Union,* s.l.: s.n.

IEA, 2019. *Are aviation biofuels ready for take off?.* [Online]
Available at: https://www.iea.org/commentaries/are-aviation-biofuels-ready-for-take-off

IPCC, 2006. *Guidelines for National Greenhouse Gas Inventories ,* s.l.: s.n.

IRENA, 2018. *Hydrogen from Renewable Power: Technology Outlook for the Energy Transition,* s.l.: s.n.

IRENA, 2019. *Renewable Energy and Jobs – Annual Review 2019,* s.l.: IRENA.

Li, J., Y., H. & al., L. T. e., 2018. Integrated tuneable synthesis of liquid fuels via Fischer–Tropsch technology.. *Natural Catalysis,* pp. 787-793.

Lloyd, W. A. a. S., 2019. Comparing the Costs to Transport Liquids Using Pipelines, Trucks and Ships. *Pipes and Pipelines International,* July 2019(30).

Lord Deben, 2019. *et-zero and the approach to international aviation and shipping emissions.* s.l.:s.n.

Low Carbon Contracts Company, n.d. *How does the CfD Work?.* [Online]
Available at: https://www.lowcarboncontracts.uk/how-does-the-cfd-work

Nova Institute, 2017. *Biorefineries in Europe 2017.* [Online] Available at: https://biconsortium.eu/sites/biconsortium.eu/files/downloads/MappingBiorefineriesAppendix_171219.pdf

NOW GmbH, 2018. *Industrialisierung der Wasserelektrolyse in Deutschland: Chancen und Herausforderungen für nachhaltigen Wasserstoff für Verkehr, Strom und Wärme,* Berlin: s.n.

NREL, 2016. *Review of Biojet Fuel Conversion Technologies,* s.l.: s.n.

Oeko, 2019. *Not to be taken forgranted:climate protection and sustainability through PtX,* Berlin: s.n.

Pache, E., 2019. *Implementation of Kerosene Fuel Taxation in Europe - Part I: Legal Foundations and Issues,* s.l.: Universitat Wurzburg.

Prussi, M., O'Connell, A. & Lonza, L., 2019. Analysis of current aviation biofuel technical production potential in EU28. *Biomass and Bioenergy,* Volume 130.

Reiter, G. & Lindorfer, J., 2015. Evaluating CO2 sources for power-to-gas applications – A case study for Austria. *Journal of CO2 Utilization,* Volume 10, pp. 40-49.

Richstein, J. C., 2017. *Project-Based Carbon Contracts: A Way to Finance Innovative Low-Carbon Investments,* s.l.: Deutsches Institut für Wirtschaftsforschung .

Ruiz, P. et al., 2019. ENSPRESO - an open, EU-28 wide, transparent and coherent database of wind, solar and biomass energy potentials. *Energy Strategy Reviews,* Volume 26.

Rumizen, M., 2019. *JETSCREEN.* s.l., FuelsEurope.

S. Hanke, 2020. *Mehrheit der CFD-Befürworter wächst.* [Online] Available at: https://background.tagesspiegel.de/energie-klima/mehrheit-der-cfd-befuerworter-waechst

Schidt, O. et al., 2017. Future cost and performance of water electrolysis: An expert elicitation study. *International Journal of Hydrogen Energy,* 42(52), pp. 30470-30492.

Schmidt, P., 2019. *Hydrogen from electrolysis as a key element in PtX pathways - Scenarios for a massive scale-up,* Berlin: Fuels of the Future - 16th International Conference on Renewable Mobility.

Schmidt, P., Batteiger, V., Weindorf, W. & Raksja, T., 2018. Power-to-Liquids as Renewable Fuel Option for Aviation: A Review. *Chemie Ingenieur Technik,* 90(1-2).

Schmidt, P. et al., 2016. Power-to-Liquids – Potentials and Perspectives for the Future Supply of Renewable Aviation Fuel. *Umweltbundesamt.*

Seber, G. et al., 2014. Environmental and economic assessment of producing hydroprocessed jet and diesel fuel from waste oils and tallow. *Biomass and Bioenergy,* Volume 67, pp. 108-118.

Skov, I. & Mathiesen, B., 2017. *Danish roadmap for large-scale implementation of electrolysers,* s.l.: Department of Development and Planning, Aalborg University.

Statista, 2020. *Aviation industry fuel costs.* [Online] Available at: https://www.statista.com/statistics/591285/aviation-industry-fuel-cost/ [Accessed 27 November 2020].

sunfire, 2018. *PtL for Aviation: Erneuerbarer Kraftstoff aus CO2, Wasser und Strom für eine saubere Luftfahrt.* s.l., s.n.

The European Parliament and the Council of the European Union, 2018. DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) (Text with EEA relevance). *Official Journal of the European Union,* Volume 328, p. 204.

The European Parliament and the Council of the European Union, 2018. DIRECTIVE (EU) 2018/410 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 March 2018 amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments, and Decision (EU) 2015/1814 (Text with EEA relevance). *Official Journal of the European Union.*

Timmerberg, S. & Kaltschmitt, M., 2019. *Untersuchung zum PtX-Hochlauf: Wie schnell kann PtX produziert werden?.* s.l., TUHH.

Transport & Environment, 2020. *Legislating for aviation alternative fuels,* s.l.: s.n.

World Economic Forum, 2020. *Clean Skies for Tomorrow: SAF feasibility and sutainability. Unpublished,* s.l.: s.n.

World Economic Forum, 2020. *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation,* s.l.: s.n.

Wuppertal, 2018. *Technologien für die Energiewende: Technologiebericht – Band 2,* s.l.: s.n.

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