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Comprehensive LCA of Biobased Sustainable Aviation Fuels and JET A-1 Multiblend

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Abstract: The use of sustainable biofuels in the aviation sector with correspondingly high reduction in specific GHG emissions will make an important contribution to reducing GHG emissions from air traffic. It is expected that airports in Europe will be supplied with JET A-1 blends that also contain various types of sustainable aviation fuels (SAF) in variable proportions ("multiblend"). This article presents the results of a study assessing the environmental impact of various sustainable aviation fuels (SAF) and multiblends, including all relevant parts of their value chains, starting from SAF production to mixing of different SAF with conventional JET A-1 and finally the use of the produced multiblend. The results of the life cycle assessment indicated that the production of some SAF caused less GHG emissions than others due to the use of waste or residues as SAF feedstock or the use of by-products to meet the internal process energy demand. A detailed assessment of GHG emissions of the studied multiblend JET A-1 showed a reduction in greenhouse gas emissions of up to 35% compared to fossil JET A-1.

Keywords: sustainable aviation fuels; SAF; multiblend; LCA; GHG emissions; GHG mitigation

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1. Introduction

For the rapidly growing aviation sector [1], national climate protection targets and international voluntary commitments by the industry to reduce GHG emissions represent enormous challenges. Currently, there are several climate protection strategies regarding the aviation sector, e.g., International Air Transport Association (IATA) targets [2], the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) of the International Civil Aviation Organization (ICAO) [3], and targets related to the share of renewables in the European transport sector defined in the Renewable Energy Directive 2018/2001 (RED II) [4]. With its ReFuelEU aviation proposal as part of the "Fit-for-55" package, the European Union has set mandates for sustainable aviation fuels (SAF) in the future [5].

1.1. Background

Biobased SAF can be a potential way to reduce GHG emissions in the aviation sector and to fulfill climate protection targets. In this case, there will be a huge demand for SAF with a high GHG mitigation potential compared to fossil jet fuel. It is expected that airports in Europe will be supplied with JET A-1 containing various types of renewable SAF in the medium term (so called multiblend JET A-1) [6]. In order to count SAF towards national targets for the use of renewable energy (e.g., under the RED II framework), compliance with sustainability criteria has to be monitored along the entire supply chain [4]. Furthermore, it must be ensured that fuel mixtures containing different alternative fuel components are in line with current fuel specifications for JET A-1. As the composition of sustainable aviation fuels may differ from that of conventional fossil JET A-1 kerosene depending on the process used, market introduction is subject to certain restrictions. For example, synthetic kerosene cannot yet be placed on the market in its pure form and instead has to be mixed ("blended") with fossil-based JET A-1 [7]. The SAF, the blending process, and the final product all have to fulfil the requirements of ASTM D7566 ("Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons") [7]. Once certified, the blend is considered a turbine fuel in accordance with the requirements of ASTM D1655 [8] and can be used accordingly.

The DEMO-SPK research and demonstration project (R&D), a model project under the German Mobility and Fuel Strategy (MFS) [9] that ran from 2016 to 2020, investigated the use of multiblends consisting of several types of SAF and fossil JET A-1 under realistic conditions within the general fuel supply infrastructure of a large airport [10]. It also included a comprehensive environmental and economic assessment of the used multiblends. The selection of SAF used in DEMO-SPK was based on market availability in 2017/2018 and included alcohol-to-jet (ATJ), hydroprocessed esters and fatty acids (HEFA), and synthetic iso-paraffinic fuels (SIP).

In addition, the properties of SAF and multiblends were analyzed, and a logistic chain to the airport as well as combustion emissions from SAF use in aircraft under real conditions were studied [11]. Moreover, issues relating to sustainability analyses and documentation as well as options to verify and account for the use of SAF in the European emissions trading system were investigated.

The DEMO-SPK project offered a unique opportunity to address open questions directly relating to the large-scale introduction of alternative aviation fuels and multiblends [6].

1.2. Scope of the Study

The introduction of alternative aviation fuels, in particular multiblend JET A-1 built and tested under real conditions, has also led to outstanding questions relating to environmental assessment that need to be answered through further research.

What is the environmental performance of the used SAF? What are the main drivers of the environmental impacts? How can the supply chains be optimized? Based on these questions, the overall objective of this study was to answer the following question: What is the GHG mitigation potential of using multiblends of conventional JET A-1 with either two or three sustainable aviation fuels that have been built and tested under real conditions?

While the environmental impact assessment of sustainable aviation fuels has been addressed in several studies [12] either by individual consideration of different types of renewable and alternative fuels for aircraft [13,14] or in scenario analyses [15], the environmental impact of the production and use of multiblends taking into consideration the current mixing restrictions has rarely been assessed. Existing studies often refer to a 1:1 substitution of fossil fuels with SAF [16] or discuss blending rates discussed in a more qualitative manner [17,18].

In this context and to answer the scoping question, a comprehensive life cycle assessment (LCA) of multiblends was conducted, as described in subsequent parts of the article. The analysis covered all relevant aspects of the multiblends, starting from SAF production to mixing of different SAF with conventional JET A-1 and finally the use of the produced multiblend under real conditions.

2. Materials and Methods

In order to assess the environmental impact of different SAF and multiblend JET A-1 fuels, we (i) examined different options of SAF, (ii) built two supply chain cases for the supply of multiblends, and (iii) determined the conditions for assessment.

2.1. Selected Options of Biobased SAF

Within the DEMO-SPK project, three specific SAF were considered. In order to build a multiblend JET A-1 supply chain that could be tested under real conditions, the main criteria for selection was market availability at that point in time (2017/2018). The SAF selection included alcohol-to-jet (ATJ), hydroprocessed esters and fatty acids (HEFA), and synthetic iso-paraffinic fuels (SIP). The three SAF options reflected the current practice, and the mass and energy flows for the SAF components were based on actual data and information from the literature. In particular, the used feedstock and information regarding process energy demand and provision were based on actual data from SAF producers. Status and progress with regard to technology development, certification according to ASTM, and available capacities have been described in publications such as [19] for Europe and [20,21] worldwide.

In the following sections, the specific processes for the three considered options are briefly characterized, and the main assumptions are described.

2.1.1. ATJ

Alcohol-to-jet (ATJ), a synthetic paraffinic kerosene, is made from sugar or raw materials that can be broken down into sugar molecules. Alcohols such as ethanol and butanol are produced and further dewatered at high temperatures and high pressure. The dehydrated molecules are converted into longer-chain hydrocarbons by oligomerization and separated by thermal fractionation. The kerosene fraction is finally saturated with hydrogen by hydrotreating [10].

In the present case, ATJ was mainly produced from isobutanol from the fermentation of maize. Besides ATJ, isooctane was produced and separated via distillation after hydrotreatment. For the considered concept, a system capacity of approximately 31 kt a^{-1} ATJ-SPK [22] and an annual operating time of 8200 h were assumed. The maize was pressed in the pretreatment process, which resulted in maize oil as a by-product. Then, fermentation took place with the addition of yeast, whereby CO_2 was emitted. During product separation, waste water (including impurities) and dry stillage were separated from the fermentation products. The heating was done with natural gas. Electricity was required for operation of the complete system (especially for pretreatment).

2.1.2. HEFA

Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids (HEFA) is produced from biobased oils or animal fats using hydrogen in a thermo-catalytic, pressurized process. As a first step, double bonds are saturated, and heteroatoms, such as oxygen and nitrogen, are removed. To adapt the product properties, isomerization and hydrocracking are conducted. Finally, product fractions in the form of naphtha, kerosene and diesel are separated [10].

In the present case, HEFA was produced by conversion of tallow oil. For the concept analyzed in this study, a system capacity of 136 kt a^{-1} HEFA SPK [23] and an annual operating time of 8200 h were assumed. The hydrogen required for hydrotreatment was generated from by-products of the process (naphtha) by means of steam reforming. Additional steam (79.7 t a^{-1}) was generated for pretreatment and distillation. The naphtha (46 kt a^{-1}) and fuel gas fraction (23 kt a^{-1}) were used proportionally.

2.1.3. SIP

The synthetic iso-paraffinic (SIP) pathway involves a yeast fermentation process fed by sugarcane or other sugars in two main production steps: (i) yeast fermentation is used to convert sugar to farnesene (C15 chain, branched unsaturated hydrocarbon) and (ii) catalytic conversion of farnesene with hydrogen to modified alkane farnesane (a molecule with no double bonds), which is then purified by distillation [10].

In the present case, a system capacity of 40 kt a^{-1} SIP [24] and an annual operating time of 8200 h were assumed. The sugar cane was washed, minced, and pressed in pretreatment. The resulting juice was prepared with phosphoric acid, lime, and flocculants (auxiliary material pretreatment). The bagasse that was produced during the pressing process was converted internally into electricity and process heat together with the sugar cane leaves (biomass residues that could not be used for sugar production). Excess electricity was fed into the grid. Nutrients were added as auxiliary materials as well as process water for fermentation. The addition of yeast was not included in the balance because it was assumed that the cultures would continue to be used. The yeast increment was separated from the liquid phase after fermentation and could be further processed into animal feed in the future. Finally, the wastewater still contained impurities, product residues, and other inhibiting substances. During fermentation, biogenic CO_2 was also produced as waste gas. Trans-β-farnesene remained, which was hydrogenated and thus converted to farnesane (SIP).

2.2. SAF to Airport Supply Chains

For the environmental assessment presented in this article, two different supply chains for multiblend JET A-1 consisting of either two or three SAF with conventional JET A-1 were considered (hereafter referred to as case A and case B). The elements of these supply chains followed the planned and realized set up within the DEMO-SPK project. It is expected that with broader market implementation of SAFs in the future, the design of these supply chains will also be optimized. The following basic conditions applied to both the considered cases:

- Only ASTM-certified, biobased SAF was taken into consideration.
- JET A-1 was taken into account as the fossil component.
- A separate tank farm was used as a place for blending SAF and JET A-1. Due to safety regulations, blending could not be performed directly on the airport premises and was therefore done at an external tank farm. Composition and blending procedures had to comply with existing regulations.
- The place of multiblend use was defined as an airport whose tank farm is supplied exclusively via tank wagons using existing airport infrastructure.

In addition to these conditions, further case-specific assumptions are explained below together for the two cases.

Multiblend JET A-1, Case A: This case reflected the supply chain demonstrated within the DEMO-SPK project. The sustainable aviation fuels ATJ and HEFA were produced in the USA and hence had to be shipped to the port of Hamburg in ISO tank containers and then trucked to the blending site (partially via a container terminal) [6]. The individual types of kerosene were transported in different ways as they were manufactured at different locations. The fossil JET A-1 was produced in Germany and hence simply transported by rail tank car to the blending site. After mixing according to ASTM standard (stepwise JET A-1 with ATJ 6.03 vol.% and HEFA 32.23 vol.% [10]), the multiblend JET A-1 was transported to the airport.

Multiblend JET A-1, Case B: The supply chains of HEFA, ATJ, JET A-1, and the produced multiblend JET A-1 were congruent to case A, the supply chain demonstrated within the DEMO-SPK project. In order to evaluate a multiblend JETA-1 with three SAF, one more theoretical supply chain was introduced. In case B, only SIP was added to the other components for multiblend production. The SIP was filled into tank containers at the refinery site in Brazil and transported to Hamburg. Similar to ATJ, it was transported via Hamburg as an import hub to the blending site (JET A-1 with ATJ 3.32 vol.%, HEFA 16.61 vol.%, and SIP 4.98 vol.%).

2.3. Environmental Assessment

The life cycle assessment (LCA) methodology was used for environmental assessment. Requirements for conducting an LCA are defined in the international standards ISO 14040 and ISO 14044, which are recognized worldwide for the quantification of the environmental impact of products and services [25,26]. According to these standards, the analysis covers the complete product life cycle from the production of the raw material to the final disposal of the product after the use phase, including all the preproducts and energy carriers used. To that end, the life cycle of the product under investigation was analyzed, starting from raw material acquisition through to manufacturing, use of the product, and up to its disposal in order to fully apprehend all potential environmental impacts associated with this product. All auxiliary and operating materials used during the product's life cycle were taken into consideration as well. Emissions and expenditure associated with the production and use of the auxiliary and operating materials as well as other products and services were also taken into account. To properly carry out life cycle assessment in accordance with DIN ISO 14040/14044, the following conditions and parameters were defined.

To conduct the life cycle assessment, we used the Umberto software [27] as LCA tool and the internationally recognized ecoinvent database as the life cycle inventory database (ecoinvent version v3.3 was used) [28].

The impact assessment, which helps to understand and evaluate the environmental significance for a product system [25], was carried out using the ReCiPe (H) method v.1.13 [29]. This method allows the determined emissions to be established according to predefined factors and enables their expression within the scope of more easily understandable categories (e.g., greenhouse effect). The selected impact categories from ReCipe Midpoint v.1.13 that were used to compare the environmental performance of the considered SAF are as follows:

- Global warming potential (GWP 100) describes the potential to change global temperatures through greenhouse gas emissions. The main greenhouse gases relevant for GHG calculation are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The global warming potential of greenhouse gases is expressed in kg of carbon dioxide equivalents (CO_2-eq.). To convert a specific methane mass to kg CO_2-eq., the methane weight is multiplied by 25 and the nitrous oxide mass is multiplied by 298 (based on a period of 100 years according to IPCC 2007) [30].
- ALOP (agricultural land occupation potential) refers to the continuous use of the agricultural land.
- Fossil depletion potential (FDP) describes the consumption of fossil resources and indicates the decrease in availability of fossil resources. FDP is measured in kg oil-eq.
- Freshwater eutrophication potential (FEP) includes ammonia, nitrate, nitrogen oxide, and phosphorus emissions, which affect eutrophication. The FEP is expressed in kg P in water and soil.
- Marine ecotoxicity potential (METPinf) describes the effects of toxic substances, such as heavy metals, on the marine ecosystem.
- Terrestrial acidification potential (TAP) describes the acidification potential of water and soil through SO_2 and NOx emissions.
- Water depletion potential (WDP) states the water consumption.

The consideration of by-products is an important aspect in LCA [25,31]. In addition to the main product, the production process of ATJ also provides the by-products maize oil, feed, and isooctane. In this study, the by-products were taken into consideration by means of allocation based on the lower heating value. This allocation method allows the environmental impacts of different manufactured products to be divided into a product-based assessment of multiproduct systems. During the allocation, the determined environmental impacts are partitioned between the different manufactured products according to a predefined parameter (e.g., lower heating value, product prices, or mass). Because the by-products generated during the HEFA production process are used internally, they were not further considered methodologically. In the case of SIP production, the surplus electricity was taken into account using a credit system to replace the emission factor for the same type of fossil fuel power generation. For example, it was assumed that electricity from a biogas CHP replaced the same amount of electricity from a natural gas CHP. Accordingly, an emission factor for electricity from a natural gas CHP was used for the credit. The method of crediting is based on the assumption that by-products from the manufacturing process can replace other products, which therefore no longer require manufacturing. The emissions thus avoided are credited to the product system.

The LCA was conducted as a first step for the considered biobased sustainable aviation fuels (SAF), followed by an assessment of the two multiblend concepts within defined system boundaries.

Setting the system boundaries is one of the most important aspects of carrying out a life cycle assessment. The system boundaries define the framework in which the assessment takes place and determine which material and energy flows are taken into account in the assessment. The system boundaries of biobased SAF comprise the entire supply chain. This includes the process of biomass production, transport and conversion, and transport of SAF to the fuel depot where the multiblend is mixed (Figure 1). Biomass production comprises both the cultivation and the supply processes required for the use of cultivated biomass. If residues and waste are used for biofuel production, the analysis starts with transport of the feedstock to the conversion plant; upstream processes are not included.

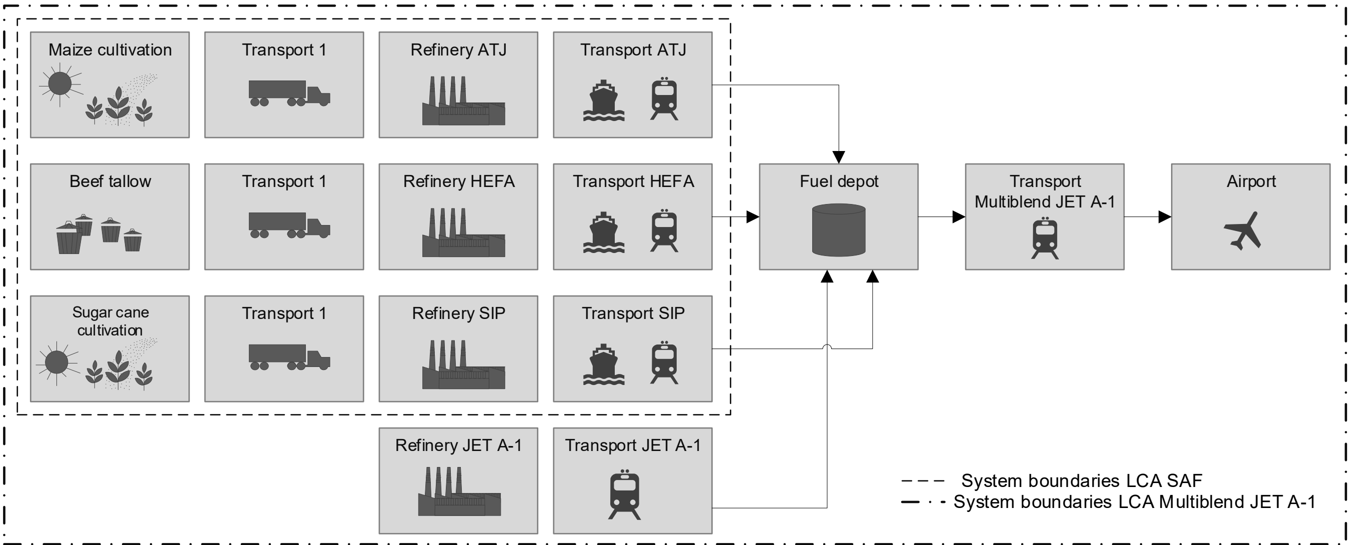

Figure 1. System boundaries for SAF and multiblend assessment. The figure shows case B supply chain. SIP is not included in case A.

The system boundaries of the investigated multiblend concepts included the supply chain of the SAF as well as the supply chain of the conventional JET A-1 fuel, transport of the multiblend from the fuel depot to the airport, and use of the multiblend in an aircraft (Figure 1). CO_2 emissions from biobased SAF use were not included in the calculation of GHG emissions; according to the IPCC, biogenic CO_2 emissions are considered to be offset by the CO_2 sequestration during plant growth [30].

The mass and energy flows for the SAF components and the JET A-1 fossil fuel were based on actual data and information from the literature.

The functional unit, which provided a reference to which all the inputs and outputs were related, was set for 1 MJ aviation fuel.

3. Results

The results of the LCA assessment allowed quantification of the resulting environmental effects from the production of the SAF and the production and use of the multiblend JET A-1 (as mentioned earlier, only GHG emissions from fossil fuel use were considered) as well as identification of the drivers and derivation of the optimization approaches.

3.1. LCA of SAF

Figure 2 shows the comparative life cycle environmental results of the considered sustainable aviation fuels. The results include all stages of biofuel supply from biomass production to supply and conversion and up to transport processes.

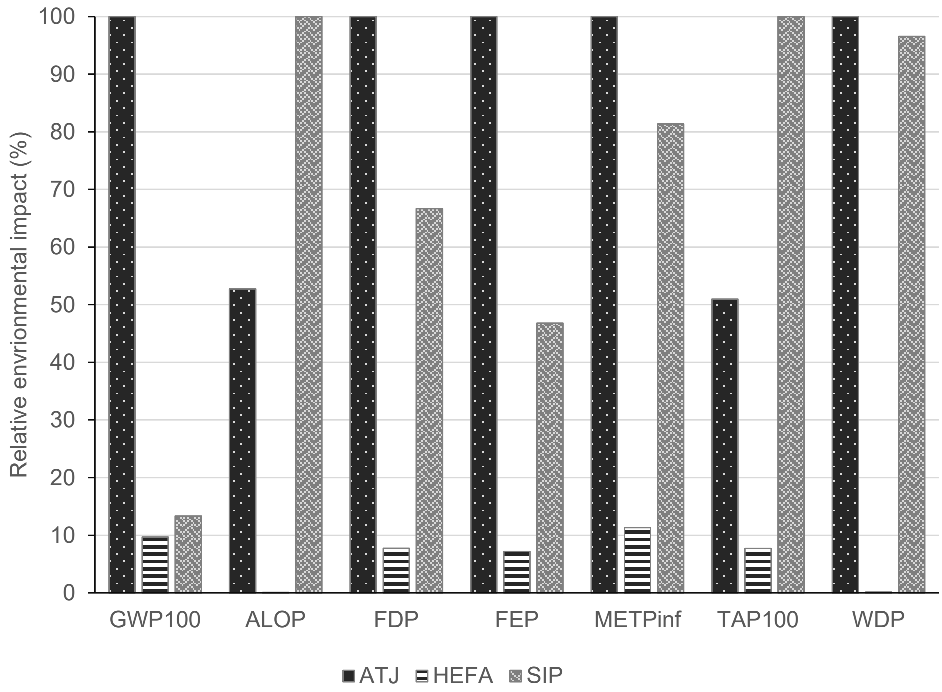

Figure 2. Relative environmental impacts of SAF production.

The results clearly show that under the assumptions made, the HEFA concept was associated with the lowest potential environmental impacts. The advantages compared to ATJ and SIP concepts were most evident in the categories of agricultural land occupation (ALOP) and water depletion (WDP).

As can be seen from the figures for ATJ (Figure 3a) and SIP (Figure 3c), ALOP and WDP were, for example, dominated by the biomass supply process. For both ATJ and SIP, this was mainly due to the use of arable land for maize and sugar cane cultivation, respectively, and the water requirements associated with the cultivation of these crops. While ATJ and SIP were based on the processing of cultivated biomass, tallow oil, a raw material declared as waste, was used for the HEFA concept. This meant that the assessment of the supply chain began with the transport of the tallow oil to the conversion plant, and upstream processes were not included.

The terrestrial acidification potential (TAP) of ATJ and SIP production were also driven by biomass cultivation processes. This was due to the ammonium and nitrogen dioxide air emissions associated with the cultivation processes.

The use of fossil fuels was the main factor for the impact categories of fossil depletion potential (FDP) and marine ecotoxicity potential (MEP) (primarily due to heavy metal emissions from the combustion of fossil fuels). In both FDP and MEPTinf, the ATJ concept showed the highest impacts, with the conversion process having the highest contribution. The reason for this was the use of fossil fuels to meet the process-specific demand for hydrogen, heat, and electricity. The contribution of biomass production process to both impact categories was primarily due to the use of fossil fuels for fertilizer production and the use of fossil fuels in agricultural machinery.

The phosphate and phosphorous emissions causing freshwater eutrophication (FEP) also originated from the conversion and the biomass supply processes. This was not only due to the use of fertilizers in the cultivation processes but also again due to combustion emissions from fossil fuels.

This type of illustration seen in Figures 2 and 3 was selected, on the one hand, to show the differences between the sustainable aviation fuels investigated here and, on the other hand, to show the shifting of the main drivers within the life cycle assessment of a process chain.

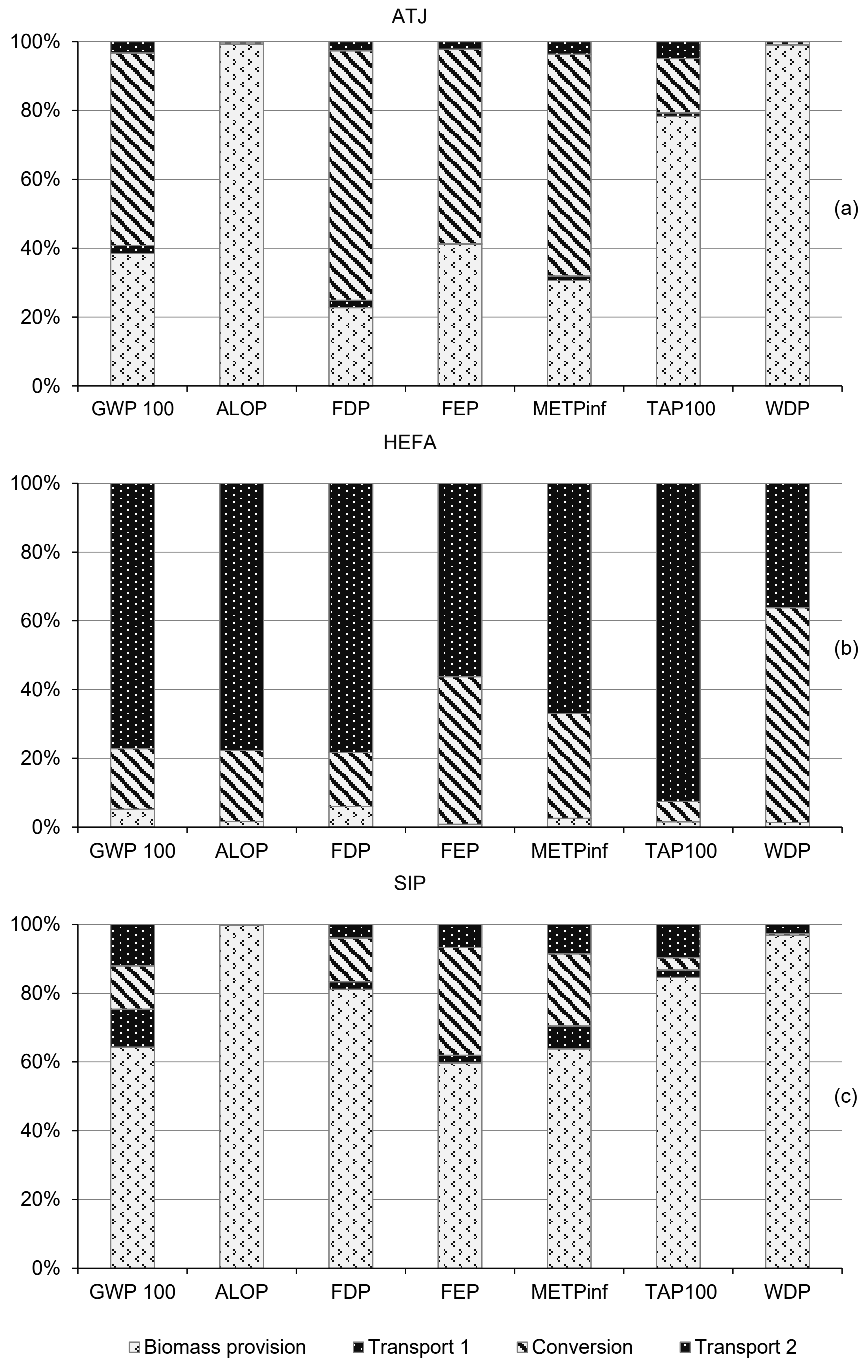

Figure 3. Environmental impacts of SAF production: (**a**) ATJ, (**b**) HEFA, and (**c**) SIP.

Figure 4 depicts the breakdown of climate change impacts for the assessed SAF. As can be seen, total GHG emissions of the considered SAF were between 3.1 (HEFA) and 35.8 gCO_2-eq./MJ (ATJ). These relatively large differences could be explained based on a number factors. The significant differences in assessment of emissions from biomass supply were due to, on the one hand, the raw materials used and, on the other hand, the selected system boundaries. While the ATJ concept is based on cultivated biomass, the HEFA concept uses tallow oil, a raw material considered as waste. This meant the assessment of the supply chain started with the transport of the tallow oil to the conversion plant. Upstream processes associated with the provision of tallow oil (for example, the availability in a rendering plant) were therefore not included as they were outside of the selected system boundaries. The specific emissions associated with tallow oil supply were thus significantly lower than the emissions associated with the supply of cultivated biomass, which was mainly due to the emissions from fertilizer production, direct emissions from N-fertilizer application, and emissions from the use of fossil fuels in agricultural machinery.

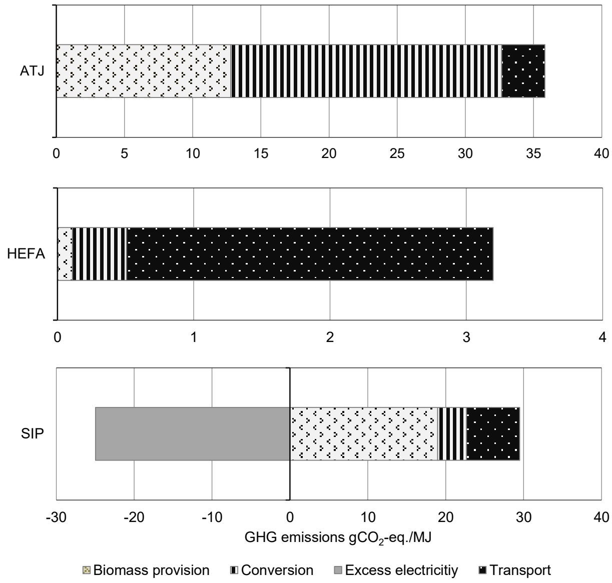

Figure 4. Specific GHG emissions of the investigated sustainable aviation fuels (SAF). For readability purposes, the *x*-axis displaying GHG emissions from HEFA production is enlarged by a factor of 10.

Emissions associated with conversion processes also differed widely across the considered concepts. Here too, the emissions were lowest for the HEFA concept. This was due to the use of by-products for generation of the necessary process energy. In this case, naphtha was used, on the one hand, to generate the hydrogen required by steam reforming and, on the other hand, as a source of the process stream.

Because the means of transport, fuel consumption, fuels, and kilometers driven were all subject to almost the same parameters for both concepts (Section 2.2), there were no significant differences in the levels of GHG emissions associated with the transport processes. As already described, the high proportion of transport emissions in total GHG emissions of HEFA was due to the very low GHG emissions associated with biomass supply and conversion.

The comparatively high GHG emissions caused by the conversion processes for ATJ primarily resulted from the use of fossil fuels to cover the process-related energy requirements. An increased share of regenerative energy in the process energy mix could reduce overall GHG emissions, as the following sensitivity analysis shows. As can be seen from Figure 5, if both heat and electricity are provided by renewable energy, the GHG emissions associated with ATJ can be reduced by up to 43% compared to the base case. In this case, the provision of heat via a wood chip boiler and the provision of electricity via a photovoltaic system were assumed.

3.2. GHG Emissions of Multiblend JET A-1

Based on the GHG emissions of the individual sustainable aviation fuels described in Section 3.1 and assessment of the provision of fossil JET A-1 (the LCA of JET A-1 resulted in a value of 90 gCO_2-eq./MJ), GHG balances were carried out for the multiblends produced, including transport from the blending site to the airport and the use of the multiblends in aircraft. The GHG reduction of the multiblends for different supply chains (Section 2.2) is described and discussed below.

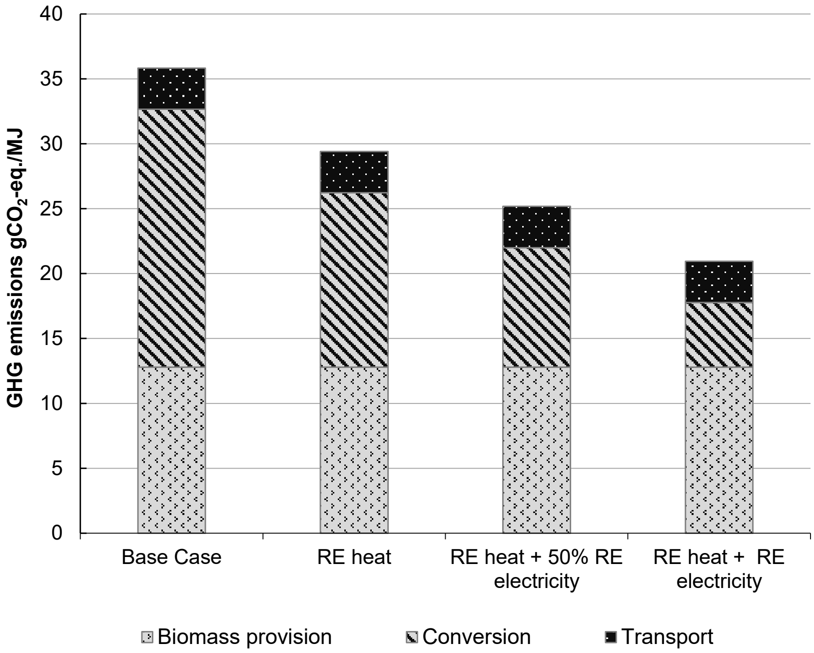

Figure 5. Sensitivity analysis of GHG accounting for ATJ production.

Figure 6 shows a clear GHG reduction of up to 35% for the multiblends compared to fossil JET A-1. The largest contribution to total GHG emissions was caused by engine combustion in aircraft. The GHG effect of emissions at high altitudes was not considered here; for the sake of simplicity, it was assumed that this effect would be the same for all of the SAF and multiblends considered here. As biogenic CO_2 emissions were not taken into account in the GHG balance, the proportion of fossil JET A-1 was decisive. This is shown by the higher GHG emissions in case B compared to case A. The reason for this was the low blending rate of SIP and the lower HEFA blending rate in line with the ASTM specification, which correspondingly led to higher proportion of fossil JET A-1 in the mix (Section 2.2). In this composition, the GHG emissions associated with the provision of sustainable aviation fuels had no significant impact on the total emissions.

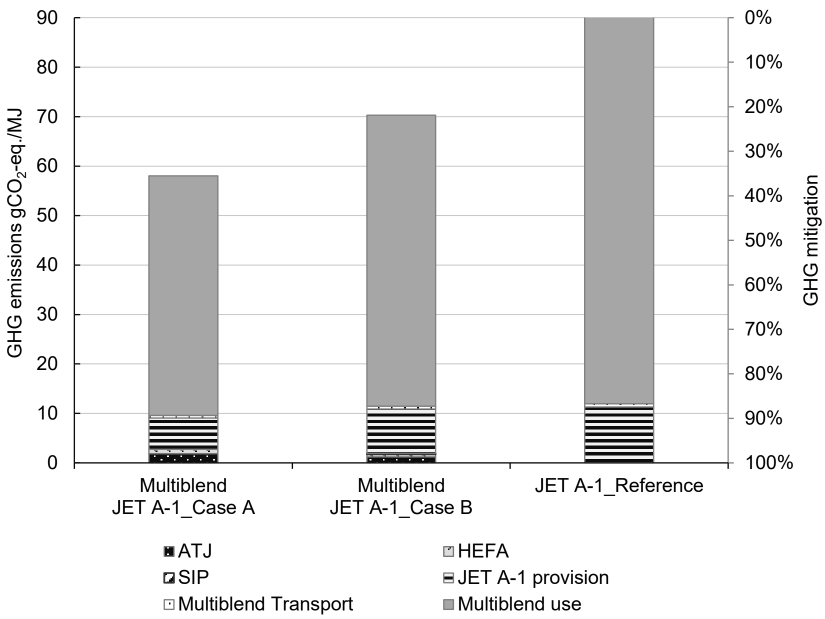

Figure 6. GHG emissions and GHG mitigation potential of the multiblends for the supply chains case A and case B compared to the JET A-1 reference.

4. Discussion

A detailed look at the GHG emissions of sustainable aviation fuels showed, on the one hand, the clear advantages of the use of residual and waste materials compared to the use of cultivated biomass and, on the other hand, the advantages of the use of renewable energy to meet process-specific energy requirements. Accordingly, the HEFA concept was found to be particularly advantageous because tallow oil, which is declared as waste, was used as a raw material. Due to the waste declaration (e.g., under RED II framework) and the resulting system boundaries, upstream processes associated with the provision of tallow oil (for example, the availability in a rendering plant) were not included. The specific emissions associated with tallow oil supply were thus significantly lower than the emissions associated with the supply of cultivated biomass, which was mainly due to the emissions from fertilizer production, direct emissions from N-fertilizer application, and emissions from the use of fossil fuels in agricultural machinery.

Meanwhile, the naphtha provided within the process was used for steam reforming to produce the required hydrogen and for the provision of process steam. The relatively high GHG emissions caused by the conversion processes for ATJ primarily resulted from the use of fossil fuels to cover the process-related energy demand. An increased share of regenerative energy in the process energy mix could lead to a significant reduction in total GHG emissions. This would also be advantageous in view of the corresponding certification in accordance with the Renewable Energy Directive 2018/2001 (RED II) and the associated proof of compliance with defined GHG reduction targets [4].

This study shows that the results strongly depend on the type of feedstock used in SAF production processes, the declaration of the biomass used, the greenhouse gas emissions associated with the supply of process energy, and the calculation method used.

The environmental assessment of the considered multiblends, and in particular the assessment of total GHG emissions, showed clear advantages of the multiblends compared to conventional JET A-1. With the mixtures considered here, up to 35% of GHG emissions could be avoided. As most GHG emissions are caused by the combustion of fossil kerosene and GHG emissions from biobased SAF combustion were not included, the fossil part in the multiblend JET A-1 could be identified as the main driver of the total GHG emissions. Multiblend JET A-1 case A thus had the lowest GHG emissions with the highest proportion of renewable kerosene and, at 35%, the highest GHG savings compared to fossil JET A-1.

Under the assumed conditions and in accordance with the ASTM requirements, biobased SAF as components of so-called multiblends is a potential option to mitigate GHG emissions in the aviation sector.

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Conflicts of Interest: The authors declare no conflict of interest.

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