Report of the Feasibility of SAF Production to Power the Entire UK Aviation Fleet

ADVANCED TOPICS IN MECHANICAL ENGINEERING (MENGM0059)

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Executive Summary

A mandate for achieving net-zero carbon emissions for international air travel by 2050 has been set out by the UK Government. Given the challenges and opportunities presented by Sustainable Aviation Fuels (SAFs), a nuanced analysis to support informed decision-making is aimed to be provided by this report. The key objective is to contribute to the efforts of the UK aviation industry to decarbonise, in alignment with national and international climate goals, through the potential adoption of SAFs.

Understanding of the various feedstocks available, as well as processing pathways, is essential. These feedstocks and pathways each come with various Green House Gas (GHG) emissions, where lower results are achieved by secondary (waste biomass) sources than that of primary (crops grown for fuel). The improvements in GHG emissions from SAFs are primarily due to the carbon absorption that occurs during crop growth, alongside carbon saving that occurs during recycling of secondary feedstock sources.

A range of statistical and academic sources were consulted, and databases were constructed to provide GHG emissions for feedstocks and pathways, as well as to provide data for calculating the land-use required to power the entire UK aviation fleet from primary sources. This calculation was made by combining data on yearly yield and energy content of crops to find a Ha/MJ value. By performing a regression analysis on fuel consumption data provided by the UK government between 1970 and 2019, an estimated 2050 fuel requirement projection is determined. This fuel requirement is used in conjunction with energy content data on jet fuel to estimate the required energy to power the entire UK aviation fleet each year.

Assuming current blend % values of SAFs, it is found that Palm is best to be grown internationally with, x; however, if the crops are to be grown domestically, corn is identified as the best option with, x. Under the possibility that the blend reaches 100%, the values for palm and corn are x and x, respectively. Validation was performed by using a methodology that combined 3 external statistical sources to calculate the estimated SAF consumption for the UK, which resulted in a value out by a factor of 4. Nonetheless, this value does fit within the range of best- and worst-case scenarios, hence providing adequate validation for the results; however, due to this, error must be considered.

Recommendations for the company going forward comprise a dual-headed approach, consisting of using the lower GHG emitting secondary sources up to their predictive allowance in conjunction with primary sources with low land-use requirements. This approach will ensure sustainable production of SAFs, as well as improving reliability on feedstock, due to the use of multiple sources.

1 Introduction

Decarbonisation within the UK aviation industry is led by the commitment of the UK Government to achieving net-zero carbon emissions for domestic travel by 2040 and international aviation by 2050 [1]. The commitment to 2050 aligns with the objective outlined in the Paris agreement, which details that global warming should aim to be limited to well below 2, preferably to 1.5 degrees Celsius [2].

Baseline scenarios for aviation emissions are outlined by the Department for Transport (DfT), setting a trajectory that necessitates substantial reductions to meet the UK's net-zero targets [3]. This imperative is further underscored by the Transport Decarbonisation Strategy (TDS), which details a roadmap for the sector's transition to sustainable practices [4]. Aircraft modifications, air traffic management, airspace modernisation, and ground operations at airports are detailed as potential changes to conventional aviation to improve fuel efficiency [5]. However, Sustainable Aviation Fuel (SAF) has been identified by the TDS as the critical component, offering reductions in carbon emissions compared to Traditional Jet Fuel (TJF) [4].

SAFs are represented as a potential drop-in replacement for TJFs, compatible with existing aviation engines without modifications, thus providing a pathway that is economically viable and realistic. However, while the combustion of SAFs is less carbon-intensive, it still results in CO2 emissions, presenting a complex challenge in the evaluation of their overall lifecycle impact [1].

Dedicated support for the integration of SAFs into the aviation industry is shown, with the UK government being backed up by 72 written evidence submissions, 5 public evidence sessions, and 32 witness hearings from various industry representatives, supporting the advancements of SAFs [1]. UK SAF production, which began in 2022, and various SAF blends that have already been used on over 450,000 flights globally, are noted [4]. The International Air Transport Association has over 290 committed airlines aiming to achieve net-zero emissions by 2050 [6]. In addition to industry and organisational backing, combinations of market-based measures have been introduced, such as the United Nations CORSIA program, EU Emissions Trading System, and the UK ETS [5].

The aim of this report is to assess the feasibility of SAFs as a substitute for TJFs in the decarbonisation of the UK aviation industry. The focus is placed on evaluating the lifecycle impacts and land-use considerations of primary SAFs, and to provide recommendations regarding the adoption of SAFs as an alternative to TJF [7].

In the report, considerations of error are to include predictive analysis for the increase in airline passenger numbers, which are expected to rise by 65% between 2018 and 2050 [5]. Moreover, the Functional Unit (FU) for assessing the environmental impact of SAFs will be limited to CO2 emissions, as the DfT currently excludes non-CO2 emissions in modelling [3], and CO2 is the only emission modelled in the Sustainable Aviation roadmap [4]. Instead, other emissions are compiled into CO2 equivalent by the sources. The entire UK aviation fleet will also be considered as comprising all commercial airlines commencing domestic and international travel for ease of data access.

In addressing these considerations, the report will not perform a lifecycle assessment but will instead rely on a synthesis of relevant studies and data that shed light on the key impacts of SAF use in aviation. The analysis will focus on aspects directly relevant to the question of SAF feasibility, particularly environmental factors.

In this report, primary biomass sources are categorised as any feedstock that can be grown to produce biofuel. Secondary biomass sources are categorised as any feedstock that comes from waste, and thus cannot be grown, as requested by the company.

2 SAFs vs. TJFs: Lifecycle Impacts

To understand the key differences between SAFs and TJFs, an overview of the production process is required. This overview will provide context on results later in the report as well as describe the impacts of feedstocks under different generations and pathways.

2.1 Production Pathways and Feedstocks of SAFs

Various pathways are available for the production of SAFs. The most common include Hydrotreated Esters and Fatty Acids (HEFA), Fischer-Tropsch (FT), Alcohol to Jet (ATJ), Ethanol to Jet (ETJ), Hydro-processing of Fermented Sugars (HFS), and pyrolysis [8]. Each of these pathways allows for the conversion of various feedstocks into SAFs. Namely, these feedstocks are split into categorisations of first-generation (G1), second-generation (G2), third-generation (G3), and fourth-generation (G4) [9].

HEFA is a process in which renewable oil-based feedstocks are processed using hydrogen treatment, after which the fuel is mixed with TJF, up to a blend ratio of 50% [10]. Currently, HEFA is the only process that can sustain production on a large scale, owing to rigorous testing [8]. Reviews indicate that the HEFA route is the best performer for GHG emissions when using oil-based crops [11].

FT is a chemical process based on gas synthesis, where the fuel can be blended with TJF up to 50% [8]. FT represents another pathway that is commercially viable and has been certified for SAF production, leading to cleaner and higher quality jet fuel [11].

The ATJ pathway is identified as a biochemical conversion process that involves processing alcohol to form a fuel mixture, which can then be blended with TJF up to 30%. The primary feedstock for this pathway consists of edible plant sugars [8]. This pathway is considered less commercially viable due to its research being in a more nascent stage in comparison to FT and HEFA [11]. The ETJ pathway follows a process similar to ATJ, with similar statistics, including a blend ratio of 30%. In this report, ETJ will be assumed to perform identically to ATJ unless included data varies.

HFS and pyrolysis are identified as newer techniques where further research is required for the pathways to become commercially viable in the future and hence will not be considered in this report [11].

G1 feedstocks are primarily composed of oil-seed and starchy crops, examples of which can be found in Table 1. Sugar, starch, fat, and oil contents are extracted from these crops, where they commonly follow the industry standard HEFA process [9]. ATJ is emerging as a preferred pathway due to the abundance of sugarcane, which is economically viable and is already produced on an industrial scale. The use of G1 feedstock is a subject of large debate due to the use of arable land, risking an increase in price to the food chain economy [12], and the fact that cultivation can also strain a country's water resource. Academic claims also suggest that employing G1 feedstocks for biodiesel leads to a significant amount of GHG emissions [13].

G2 differs from G1 as the feedstocks are comprised of sugars that are trapped in a tough lignocellulosic matrix of plant cell walls that require pre-treatment [9]. The main categories of G2 feedstock are Oil-seed energy crops, agricultural waste, and municipal waste, examples of which can be found in Table 1. The primary advantages of G2 are that the food vs fuel issue of G1 feedstock can be solved by the non-edible biomass resources [12], alongside their high abundance and low use [9]. Excessive costs and technical limitations, however, are the key issues for G2 stock utilisation [9], though advanced technology is still under development to reduce the cost of conversion [14].

Algae and microalgae are the sole contributors to G3 feedstocks, where they are both of high interest due to having no food value and low land quality requirements [9]. The cost to produce G3 feedstock is also low due to the growth requirements only being sunlight, simple nutrients, CO2, and less water than most G1 feedstocks [9]. Algae is also capable of growing in polluted water, using redundant land mass [9]. In comparison to other feedstocks, G3 is produced at a higher rate and contains more fatty acids than G1 and G2 biofuels [13]. HEFA is the most promising industrial pathway, from which G3 biofuels can be produced. Issues surrounding G3 feedstocks are issues in harvesting and oil extraction technologies [9]. G3 biofuel consists of low productivity, and even though the land-use is primarily redundant, substantial amounts of land-use are required.

Feed.	Pet. Jet Fuel*	Algae	Waste gases	Used Cooking Oil	Palm acid*	Municipal*	Lignocellulose	Fore. Residues	Agri. Residues*	Switchgrass	Sorghum	Poplar	Miscanthus	Jatropha Oil	Flax Shives	Wheat	Sugarcane*	Sugar beet	Palm Oil	Corn Oil	Corn Grain	Corn Grain
Gen	JF	G3	G2	G2	G2	G2	G2	G2	G2	G2	G2	G2	G2	G2	G2	G1	G1	G1	G1	G1	G1	G1
P/S	TJF	P	S	S	S	S	S	S	S	P	P	P	P	P	P	P	P	P	P	P	P	P
Low	83	14	29	14	19	3.2	2	25	27	18	28	7	-14	-1.3	-23	-50	42	44	23	17	91	7.9
High	87	193	42	17	23	7.2	28	40	31	49	55	46	24	45	260	150	46	53	99	32	101	86
[ref]	[17]	[16]	[15]	[15]	[15]	[15]	[12]	[15]	[15]	[15]	[12]	[12][15]	[15]	[15] [16]	[12]	[12]	[15]	[15]	[15] [16]	[15] [17]	[15]	[15]

Table 1: Examples of Feedstock Categorisation into Pathways, Generation, and Primary/Secondary Biomass Source. Low and High Yields, Measured in kgCO2e/MJ, are Displayed, Feedstocks with an Asterisk Hold Yield Data Without a Range. Full Table: see Appendix A.

2.2 Emission differences

Using the emissions and categorisation values from the large GHG database, Appendix A, where example elements are shown in Table 1, is constructed from sources [12], [15], [16], [17], and [18]. The sources primarily comprise a low and high value and occasionally a baseline value. To keep the data consistent, Figure 1 only shows the data that has a low and high range where the baseline is not included. The data is not suitable for showing the median GHG emissions of feedstocks; however, it can give a general range for how they perform in comparison to others. Where there are overlapping sources for the same feedstock under the same pathway, the low and high values are combined to form a combined data point.

Miscanthus, considered the best option for primary biomass feedstocks, is shown to have the lowest emission rates over a variety of pathways with low variability. Municipal Waste, identified as the best option for secondary biomass feedstocks, under the LT pathway exhibits low variability with a low emissions range and could be seen as the best option for reliability. While wheat clearly shows a possibility of low emissions, the range of data available suggests that using this as a recommended result would be a fault. It can be seen that primary biomass sources have higher variability than secondary, and their average GHG emission is higher. While there are fewer feedstocks for secondary biomass, they exhibit low variance and achieve good GHG emission values. Primary and secondary biomass significantly outweigh the GHG emissions of a variety of TJFs. This is due to SAFs emitting less GHGs than TJF due to the method of fuel production and the actual burning of SAFs. This is also attributed to the CO2 absorbed by plants during the growth of biomass. When waste resources are used, CO2 entering the atmosphere is reduced, and the resource is recycled [19].

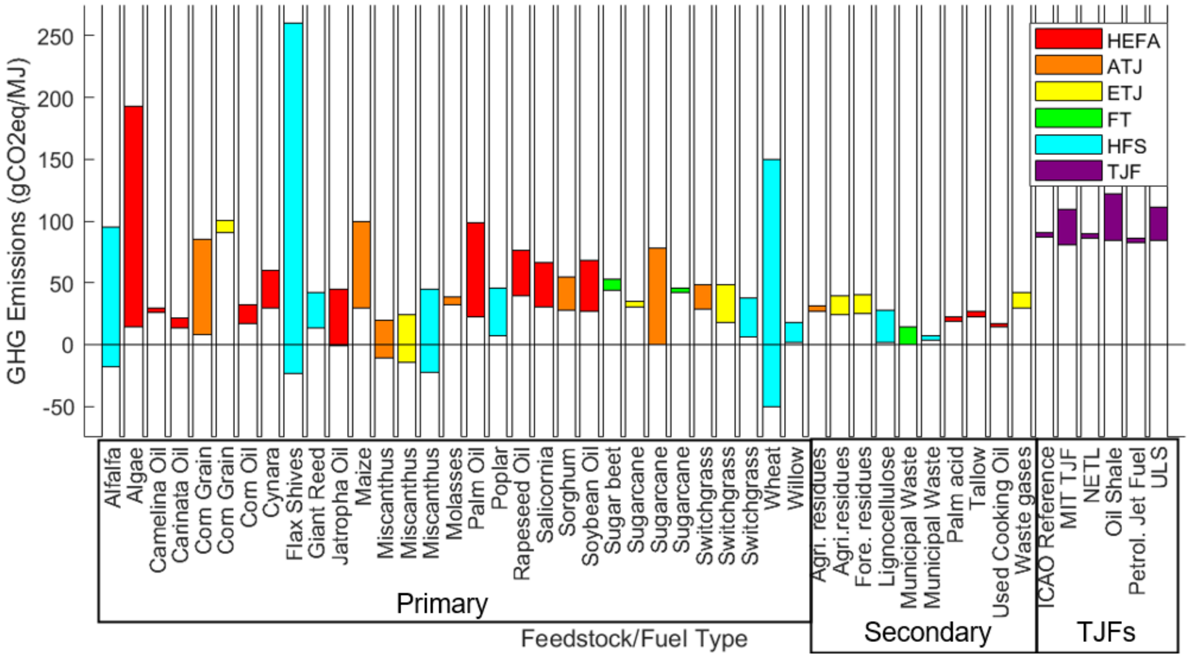

Figure 1: GHG Emissions for Various Feedstocks

3 Land-Use Requirements for SAF Production

3.1 Land-Use for SAFs

The yield (kg/Ha) and the varying internal energy density (MJ/kg) of different crops necessitate different amounts of land to produce the same amount of fuel.

With the UK average long-term air traffic growth rate expected to increase at a rate of around 4%, fuel demands will continue to increase. With the possibility of blend ratios reaching 100%, the demand for SAFs will be extremely high by 2050 [20].

3.2 Assumptions for Calculation

Table 2 presents a selection of examples taken from the land-use database, Appendix B. Yield, energy contents and energy per hectare information columns are included. In biomass statistics, mass is commonly referred to instead of liquid volume as shown by the extent of sources available providing statistics with mass units.

The yield columns are constructed from sources [18], [21], [22], [23], [24], and [25]. The number of sources required to populate information about the top primary feedstocks. [24] provided large ranges of yield due to data being extracted from a large number of countries. Low and high values are used to create a worst- and best-case scenario shown in the results. A functional baseline value is created by taking the average of all the countries' yields. Data taken from [18], [22], [21], and [23] provide only 1 data value (no low or high); this value is taken as the baseline for the relevant crop. [26] is a dedicated source to populate switchgrass as the previously highlighted sources did not include it, and it was seen to be relevant to results. The low, high, and baseline yield alongside the relevant source reference can be shown in columns 2-5 respectively in Table 2.

The energy content of each feedstock was sourced from [27], excluding camelina, sunflower, palm, sugarcane, and jatropha, which were all specifically sourced from their own based studies due to [27] not containing data, [26], [28], [29], [30], and [31] respectively. Energy coefficient was commonly given in a singular value without a range and hence does not have a high or low value. An error will not be introduced to not overcomplicate the data; however, in the results discussion, it should be noted that this will be a source of error. The energy coefficients for each feedstock alongside corresponding references are shown in columns 6-7 respectively in Table 2.

To produce the adjusted values in Column 9 of Table 2, the efficiencies of various pathways had to be consulted. Due to the limited research available on HFS, a concrete efficiency was not obtained, resulting in the removal of sugarcane HFS from the analysis. Source [32] provided efficiency values for HEFA, ATJ, and FT. ETJ is assumed to have the same efficiency as ATJ due to a lack of data to suggest otherwise.

It is unassumed whether the company is seeking land-use estimations for 2050 or any specific year before it. Thus, a regression analysis was performed on data provided by [33]. Data stretching from 1970 to 2019 (Appendix C) was analysed with the omission of 2020 and 2021 due to COVID-19 skewing the data. Figure 2a. displays the results.

Feedstock	L. Yield	H. Yield	B. Yield	[ref]	EC	[ref]	EPH	EPH Adj.	UK	[ref]
Camelina Oil	3.37	3.37	3.37	[23]	36.2	[26]	121994	90275.56	Y	[35]
Sunflower Oil	1.8	2.4	1.228	[18][24]	20	[27]	24560	18174.4	Y	[35]
Corn Oil	0.53	28.6	14.565	[24]	17	[27]	247605	183227.7	Y	[35]
Maize	3.9	5.8	4.85	[18]	18	[27]	87300	34308.9	Y	[35]
Miscanthus	17.3	17.3	17.3	[21]	19	[27]	328700	129179.1	Y	[35]
Miscanthus	17.3	17.3	17.3	[21]	19	[27]	328700	129179.1	Y	[35]
Poplar	11	27	19	[18]	19	[27]	361000	157396	Y	[35]
Sorghum	0.17	36.37	1.8652	[24]	17	[27]	31708.4	12461.4	Y	[35]
Wheat	0.4	10.08	5.24	[24]	18	[27]	94320	41123.52	Y	[35]
Willow	8	8	8	[21]	19	[27]	152000	66272	Y	[35]
Jatropha Oil	2.5	2.5	2.5	[22]	37.83	[31]	94575	69985.5	N	[35]
Palm Oil	1.99	18.16	10.987	[24]	23.6	[29]	259293.2	191877	N	[35]
Sugarcane	6.31	115.82	57.953	[24]	6.625	[30]	383938.6	150887.9	N	[35]
Switchgrass	8.7	12.9	10.8	[25]	18	[27]	194400	76399.2	N	[35]

Table 2: Database of Yield, Energy Content, Calculated Energy per Hectare (and Adjusted) Values, with UK Growth Eligibility Discretion, Alongside Respective References. Red: HEFA, Orange: ATJ, Yellow: ETJ, Cyan: FT

3.3 Calculation Methodology

Following the inclusion of baseline yield (Y_f) and energy contents of each feedstock (EC_f), an energy produced per hectare of farmland (EPH_f) is calculated for low high and baseline cases, populating Col. 8. Table 1, using Equation 1:

$$EPH_f = Y_f * EC_f. \tag{1}$$

The adjusted energy per hectare per feedstock ($EPH_{f.a}$) is further modified by Equation 2,

$$EEPH_{f.a} = EPH_f * P_{eff}, \tag{2}$$

with the efficiency values of each pathway (P_{eff}) sourced as: 74% for HEFA, 39.3% for ATJ, 39.3% for ETJ and 43.6% for FT [32]. Predicted energy required per year (E_{req}) can be calculated by extrapolating data from Figure 2a in conjunction with Equation 3:

$$E_{req} = M_p * EC_p. \tag{3}$$

The mass of petroleum oil (M_p) value taken is multiplied by the energy content of petroleum (EC_p), which is found to be 43100 MJ/kg [34]. To further find the land-use for each feedstock (LU_f) required to power the entire aviation fleet, Equation 4 is used:

$$LU_f = \frac{E_{req}}{EPH_{f.a}} \tag{4}$$

Lack of supporting data for yields and energy content of Algae renders its inclusion within land-use estimations obsolete. However, a study, [12], suggests that the land-use required for algae can be as low as 0.1 to 2.87 $\mathrm{dm}^2.\frac{\mathrm{a}}{\mathrm{MJ}}$. Converted to Ha/MJ, this value is 0.1 to 2.87 μHa/MJ. Since this value is already low, the higher side of the range is taken for a more realistic outcome. The land-use required for Algae (LU_a) is further calculated using Equation 5:

$$LU_a = 2.87 * 10^{-6} * E_{req} \tag{5}$$

3.4 Estimation Results

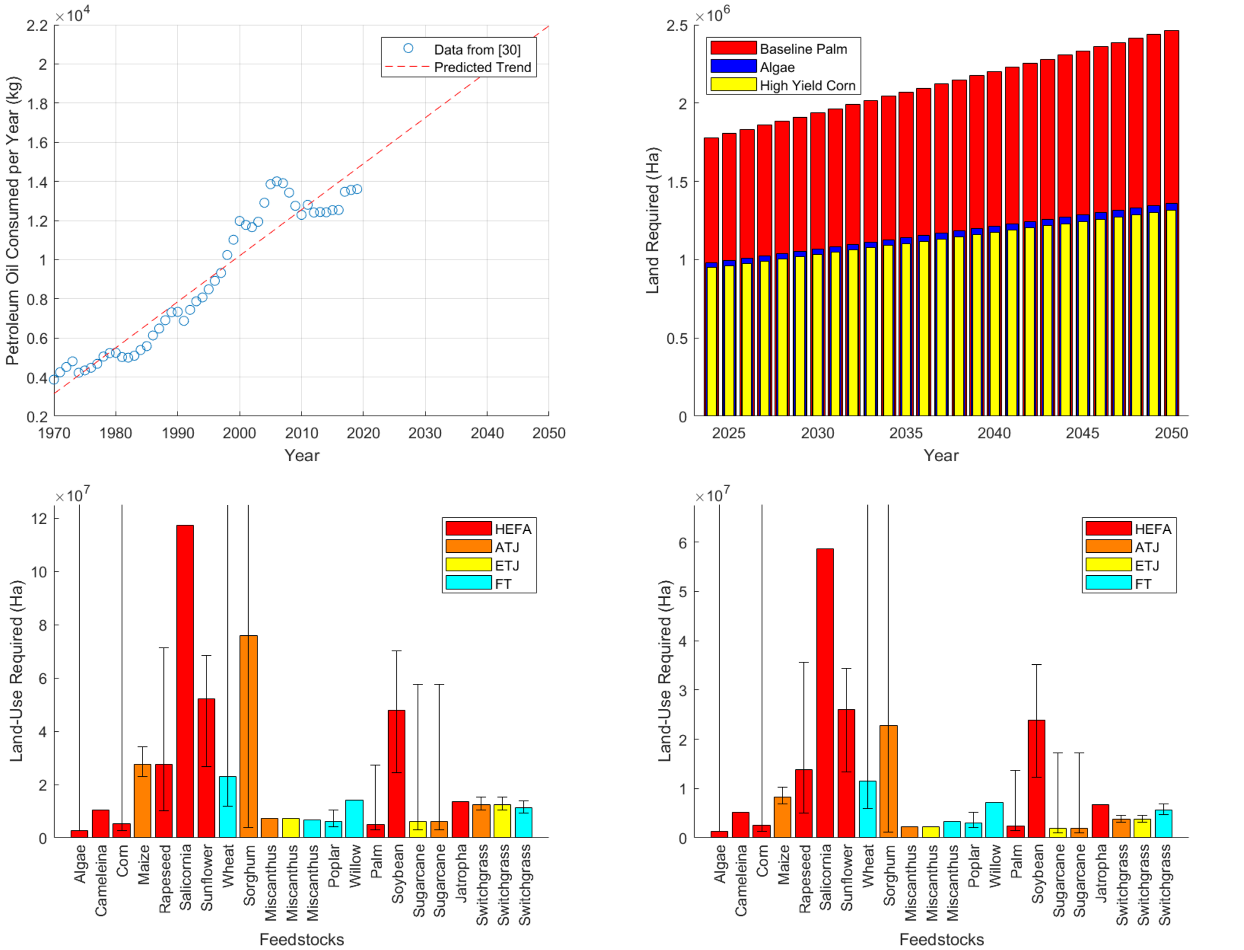

Figure 2: a) Expected Petroleum Oil Use by the UK Aviation Fleet b) Land-use Required for Feedstock Each Year c) Land-use for 100% SAF Blend to Meet Current Fuel Requirements d) Land-use for 2023 SAF Blend to meet 2050 Fuel Requirements

The land-use for 100% SAF blend can be seen in Figure 2b, with high and low yields shown in error bars, where applicable. As shown in Table 2, Camelina, Miscanthus, Willow, and Jatropha do not have high and low yields due to lack of data suggesting a range. Under the conditions that the blend ratio remains at the 2023 standard, detailed in Section 2.1, the land-use requirement can be seen in Figure 2c.

3.5 Discussion of Findings

If the company is seeking to achieve 100% SAF integration by 2050, with a 100% blend being ideal, Algae would be the best option by using 2,715,780 Ha of land. If only values taken from the calculation methodology, the optimal land-use would be using 4,931,600 Ha of palm farmland. This is using the baseline yield adjusted value for the feedstock as the reliability of the high yield is uncertain. This is the most comfortable prediction I can make. For the company to grow all of their produce in the UK [35], and to avoid major transport emissions, the best-performing crop is corn, as shown in Figure 2b, resulting in a land-use of 5,164,400 Ha. This is equivalent to 2.5 times the size of Wales [36].

3.6 Validation

To validate the results, a method to estimate the land-use required in the UK had to be implemented due to reliable UK statistics not existing. [37] details the projected SAF use for 2050 globally; thus, we need to convert the projected worldwide use to a UK predicted use. To do this, the worldwide jet fuel consumption for 2019, 95 billion gallons, is taken from [38] and compared to the 2019 fuel consumption of the UK, 14.65 million metric tons, sourced from [39]. Gallons are converted to litres by multiplying by 3.785 and further converted to kg by multiplying by 0.8 [40], resulting in a worldwide consumption of 0.288 billion metric tonnes. Comparing the two consumption values, a ratio can be seen, where the worldwide consumption is approximately 21,100 times larger than the UK's airline consumption. This scale is assumed to hold with time. To calculate the SAF required by the UK, the global amount required in 2050, 0.359 billion metric tonnes (converted from 445 billion litres) [37], is divided by the ratio to obtain an SAF consumption for the UK, 0.109 billion metric tonnes. To convert this to Ha of palm farmland, we must divide by the value of the baseline yield used in previous calculations, 10987 kg/Ha [24]. This results in 9,920,816 Ha of farmland required. It is assumed that in the 2050 predictions, the fuel blend ratio is still capped at 50% for the HEFA process as this is what we know is currently feasible. Figure 2d shows the baseline palm yield land required for 2050 under a 50% blend, which is around 2,500,000 Ha of land. The validation is out by a factor of 4; however, this is comparing to the best-case scenario. Figure 2c displays the land-use required per feedstock for the current blend in 2050; the validation results are more consistent with a feedstock such as salicornia, where the yield is lower, at a value of 20,000. However, the resulting required farmland from the validating method is 55,000,000 Ha, which has significantly less error when compared to the land-use predicted 58,700,000 Ha. This suggests that there is a sensitivity to the yield data used, which could also be present in the energy content for each feedstock. The validation is within an acceptable region to suggest the resulting calculations have backing; however, the existing error here should be taken forwards in recommendations.

4 Critical Analysis of Studies

4.1 Evaluation Criteria

The sources evaluated within this report are split into 4 categories: statistical sources, governmental and organisational sources, and academic sources. The statistical sources are primarily used to form the bases of the databases used to produce figures and tables, whereas the governmental, organisational, and academic sources form the body of the report. Verbal inclusions of sources can be shown in Appendix D.

Table 3 shows each source is determined as a primary (black) or secondary (white) source based on whether the source has been interpreted or evaluated by a secondary party. Secondary sources primarily consist of review papers as well as accumulations of data input into reports. Each source is further categorised into the type of source it is, which is between a government or domestic/internal organisation (yellow), reports made by companies (orange), academic research/review papers (cyan), and statistical databases (red). Gray represents the report brief. Due to the volume of sources, grouping and key appraisals will occur.

Source	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]	[20]
P/S																				
CAT.																				
Source	[21]	[22]	[23]	[24]	[25]	[26]	[27]	[28]	[29]	[30]	[31]	[32]	[33]	[34]	[35]	[36]	[37]	[38]	[39]	[40]
P/S																				
CAT.																				

Table 3: Primary/Secondary Determination and Categorisation of Sources

4.2 Governmental and Organisational Sources

Sources categorised into this section are primarily used within the introduction of the report to set the precedence of developing SAFs. Sources [1], [5], [6], [33], [35], and [36] are all UK organisation or government-led sources, with direct relevance to the UK aviation sector. All of the governmental websites are trusted sources of information due to their regulation and accountability. The Paris Agreement, [2], is a very public and regulated document, certifying credibility.

4.3 Company Reports

Company reports are considered less trustworthy compared to others due to conflicts of interest and selective disclosure. Company reports [4], [15], [19], and [34] are primary sources, increasing their reliability due to public interest. However, in particular, the lack of supporting structure around the information given in [34] proves the report to be uncertain on its reliability. [15] also includes a footnote commenting on the uncertainty of the data being harvested annually, decreasing reliability and introducing error. Since the value for the EC_p is referenced here, an error on energy demands is predicted. [3] and [16] are extensive review papers, however they are released under companies elementenergy and PARTNER respectively. Due to the extensive literature involved, as well as the company accountability being at stake, these sources are seen as trustworthy. This is notably more important in [16] as this provides most of the emissions database. [23] and [27] both compile data from various databases and are seen as dependable due to their resources being primary data from national databases. [25], however, is assumed to be unreliable due to it not being academic. The values have not been referenced or validated. Thus there should be potential error in switchgrass results. These values were used due to the scarcity of data available about switchgrass.

4.4 Academic Papers

The main body of the report is comprised in the form of a review paper, providing insight into the key features of SAFs, as well as their differences to TJF, sourced by [8] - [13]. Many papers have common references and have been built themselves from many review papers. There is a clear possibility of biased interpretation through articles. To solve this issue, a large number of papers were used to build this section of the report to provide validation. Sources [12], [14], [17], are academic papers contributing data to perform calculations for emissions and land-use within the report. [12] is used extensively to populate the emission database, where its alignment with various other sources in the review section found to improve credibility. This source is used in conjunction with [15], [16], and [17] to validate database values fell in the correct region. Sources [18], [22], [26], [28], [29], [30], and [31] are used to populate the database to calculate land-use. In contrast to the emission database, acquiring data was more fragmented and to achieve a validated and populated database, more sources were required. Larger error is involved under consultation, the energy content and yield data may not be consistent due to sources measuring feedstocks in various. These sources were primarily not focused on SAFs and instead on general biofuel, which would also introduce a potential error in data due to technical differences between the data values of SAF in comparison to general biofuel. [32] Provides efficiency values of different pathways, which could not be validated due to limited amounts of data. This source was chosen as it contained efficiency information about the most pathways, however, these values are further extracted from other sources. This source exhibits errors in results.

4.5 Statistical Sources

Sources [15] and [40] provide data in factsheets and reports. CORSIA is a world-known initiative, with high accountability. Waypoint 2050 is backed by government and energy institutions, providing credibility for the sources. Source [24] is used to populate yield statistics, which were validated using academic sources. [24] is backed by the University of Oxford and has extensive amounts of statistics stored, proving credibility. Sources [37]-[39] are all published by the Statista Research Department. Whilst each of these sources is technically secondary, they are all extracting data from 1 source each from credible organisations, hence they are treated as primary. Statista is one of the most widely used statistical sources and provides high reliability.

5 Recommendations

Evidenced in Figure 1, it is shown that secondary biomass sources have lower GHG emissions than primary with less variability. The issue with secondary biomass sources is the unpredictability of access of feedstock due to the amount relying directly on agricultural or municipal waste. Hence, it is suggested that the availability of secondary biomass should be assessed each year and primarily used, specifically feedstocks that can undergo FT and HEFA processes, due to established processing techniques, as well as high blend potential. To supplement the remaining biofuel requirement, it is suggested that algae should be grown. If the data surrounding algae found in [12] is seen to be unreliable, an international recommendation for palm and a domestic use of corn is advised. With G1 feedstocks, the issue of fuel vs food still remains. This is where, if the data is dependable, the G3 feedstock of Algae will prove to be the best option. However, if the issue proves to be detrimental, alongside unreliable Algae data, the use of G2 primary feedstocks is recommended, such as camelina oil or jatropha oil, which see low contest and no contest, respectively, against edible crop land. Both exhibit low GHG emissions, suggesting they are viable options in the described scenario.

To further extend on the work performed in this report, further research into Algae must be completed. Inability to validate the land-use result deems a failure on behalf of this report; however, the suggested data is very promising. In light of the findings on Algae in this report, this should be the most focused on feedstock in future work. Next, pre-treatment techniques should be analysed and applied to each feedstock to monitor the GHG improvements as well as land yield and energy content improvements. Further inquiry into the use of multiple crops should be conducted; this would remove possibilities of the feedstock running out as the fuel as multiple sources. The emissions caused due to land-use change have not been considered in this report and will increase the emissions of any primary crop. This must be carefully analysed before making an executive decision. Inclusions of both of these factors are not considered in this report due to the allowable volume of content within this report. The technology determining blend % should be consistently monitored to assess the applicability of higher blends in SAF, meaning more feedstock is required.

This report should be used as a building block to implement more in-depth database modifications to improve the accuracy of data provided within this report; however, the results detailed provide insight into predictive land-use, as well as well-supported feedstock suggestions.

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