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European Union's biomass availability for Sustainable Aviation Fuel production and potential GHG emissions reduction in the aviation sector: An analysis using GIS tools for 2030

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Abstract

To be the first carbon-neutral continent by 2050, the European Union (EU) should decarbonize the aviation sector. According to the ReFuel initiative, sustainable aviation fuels (SAFs) are crucial in reducing carbon emissions from the sector. The Clean Sky 2 program by the EU commission, shortlisted four promising technologies - hydro-processed esters and fatty acids (HEFA), Fischer–Tropsch (FT), fast pyrolysis (FP), and alcohol-to-jet (ATJ) for the production of SAFs from bio-based sources. This study addresses the potential of these four technologies to reduce net and total greenhouse gas (GHG) emissions in the aviation sector. With a focus on mapping feedstock availability in 33 European countries for meeting the national demand in 2030. The investigation identified the best pathway combinations for each country, having the highest GHG emissions reduction while satisfying fuel demand when considering different degrees of biomass competition. Without any political and economic barriers to SAF production and biomass competition, we estimated a sufficient biomass supply exists to support the European SAF demand across all forecasted scenarios in 2030.

Keywords: Sustainable aviation fuels, GIS tools, Greenhouse gases emission, biomass conversion

1. Introduction

Nowadays, there is greater accessibility to air travel, with the majority of flights being used for passenger transport rather than freight. Accordingly, aviation contributes significantly to greenhouse gas (GHG) emissions. By 2050, the GHG emissions from the aviation sector are predicted to be 3.1 billion tons globally. Which is a sharp rise from 0.78 billion tons in 2015 (Doliente et al. 2020). To reduce the impact of these emissions on climate change and also to become the first carbon-neutral continent in the world, the European Union (EU) is taking different initiatives such as the EU Green deal and ReFuelEU aviation initiatives (Soone 2022; Zachmann, Tagliapietra, and Claeys 2019). Aligning with the same goals, CleanSky2 initiated TRANSCEND (Technology Review of Alternative and Novel Sources of Clean Energy with Next-generation Drivetrains). TRANSCEND investigated the potential of drop-in sustainable aviation fuels (SAFs), as a possible means of reducing aviation's influence on the environment. Drop-in SAFs are a new class of aviation fuel blended with regular fossil jet fuel and used in existing aircraft engines without significant changes. It is believed that bio-based drop-in fuels can significantly mitigate the GHG impacts on the aviation sector. TRANSCEND identified four promising technologies for the production of SAFs from bio-based sources. These include the hydro processed esters and fatty acids (HEFA), Fischer–Tropsch (FT), fast pyrolysis (FP), and alcohol-to-jet (ATJ) technologies. This study contributes to this field by addressing the potential of these technologies to reduce net and total GHG emissions in the aviation sector based on biomass availability (type and amount) in different European countries while considering local demand for different forecasted scenarios (Muijden et al. 2021).

The objective of this study is to estimate the total supply of residual biomass available in Europe in 2030. Further, to evaluate potential SAF availability and related net reductions in GHG emission for various SAF conversion pathways. Finally, the results are shown in a comprehensive map indicating the suitable conversion pathway that produces the maximal net GHG emission reduction for each country. The research questions focused in this study are

- Is there enough biomass available to meet European SAF demand in 2030?
- What is the best combination of biomass type and conversion technology leading to the maximum net GHG emission reduction for each country?

2. Scope and Boundary

This study uses a mixed-method approach to address the mentioned research questions, where quantitative findings are validated and expanded using data gathered from peer-reviewed articles.

2.1. Spatial and temporal Boundary

The geographical scope of this study is limited to 33 European countries. The 33 European countries consist of EU27 + Serbia, Ukraine, Bosnia, Albania, Moldova, and Macedonia. With respect to the temporal scale, this study is limited to the medium-term year of 2030. This was chosen to align with the policy targets in the sector and the maturity of various conversion pathways. “Conversion pathway” refers to a technology and feedstock combination for analysis purposes.

2.2. Conversion Pathways

In terms of conversion pathways, technologies considered in this investigation are hydro-processed esters and fatty acids (HEFA), Fischer–Tropsch (FT), fast pyrolysis (FP), and alcohol-to-jet (ATJ) technologies. Likewise, this study focuses on residual biomass as a SAF source because it requires no additional land, consumes lower water and has less commercial value than energy crops. Also, this conform with EU’s commitment to using non-food feedstock as biomass sources for SAF. The three types of residual biomass considered in this report are agricultural residues (AR), forestry residues (FR) and municipal solid waste (MSW).

Agriculture residues consists of lignocellulosic by-products, harvesting, logging, and post-harvest operations (e.g. wood processing, crushing, and milling). Examples of agricultural residues include cereal straw, rice straw and corn stover. Similarly, forest residues are by-products of timber-harvesting activities. Examples of forestry leftovers include unprocessed fragments of cut trees (such as stumps and branches), wood pulp, and sawdust and cutter shavings. Lastly, municipal solid waste is defined as waste collected from a municipality and commonly referred to as trash or garbage (e.g. food processing waste and industry and commercial processing waste). In this study, we assesses the biomass availability (in tonnes) of 36 feedstock types in 33 European countries. Of the 36 feedstock types, 18 can be categorised as forest residue, 15 as agricultural residue, and 3 as municipal solid waste.

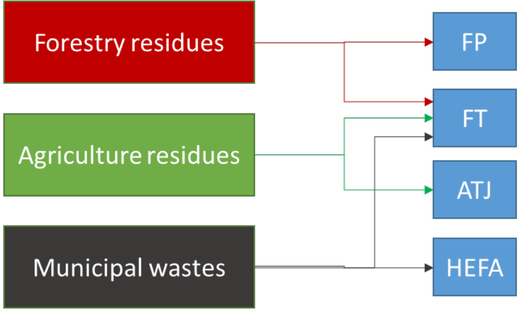

Figure 1: Schematic overview of the combinations of feedstock categories and conversion technologies considered.

The possible conversion pathways are shown in Figure 1. The selection is based on two criteria. The primary criterion is the compatibility between feedstock type and conversion technology. This compatibility depends on the type of biomass sources the technologies can process. The compatibility of feedstock type with certain technologies is obtained from the literature. For example, FT can process almost any carbon-rich material; therefore, it matches all three feedstock categories. The second criterion is whether literature data is readily available on process performance and GHG emissions intensity specific to the aviation sector. For example, the combination of FP and MSW shows promising results for the road sector but was excluded from this study due to missing data on process performance for SAF quality. Thus, only conversion pathways analyzed in previous studies in terms of SAF yield and associated GHG emissions specific to the aviation sector are included. In total, this study examined 85 conversion pathways for the 2030 scenario.

2.3. Geographic Information System

Biomass and GHG reduction potentials are mapped using ArcGIS Pro. ArcGIS is a geographic information system (GIS) that captures, stores and displays data related to spatial coordinates. It aids the user in understanding spatial patterns and relationships using layered maps. A demographic feature layer containing all EU countries provided by the ArcGIS database was used as a base map. Data was then added to the base map to illustrate its spatial distribution at a national level. Since this study uses a country-specific approach, the NUTS0 level is the most suitable to illustrate the results.

3. Scenario Evaluation

3.1. Estimation of potential SAF production

3.1.1. Biomass availability and SAF demand

The data on biomass availability for 2030 by type and country is collected using the S2BIOM tool (Dees et al. 2017). With specification of regional level, year and feedstock type, this tool generate data for the amount of biomass available (in kilo tonnes dry mass) per year and potential type combination as a map. For this study, the technical potential is considered. According to the S2BIOM tool, this potential illustrates the maximum lignocellulosic biomass volume available, without any competing uses and with sustainable constraints. For the SAF demand in 2030, data for each country was provided by the Royal Netherlands Aerospace Centre (NLR). Figure 2 illustrates the spatial distribution of biomass and national SAF demand.

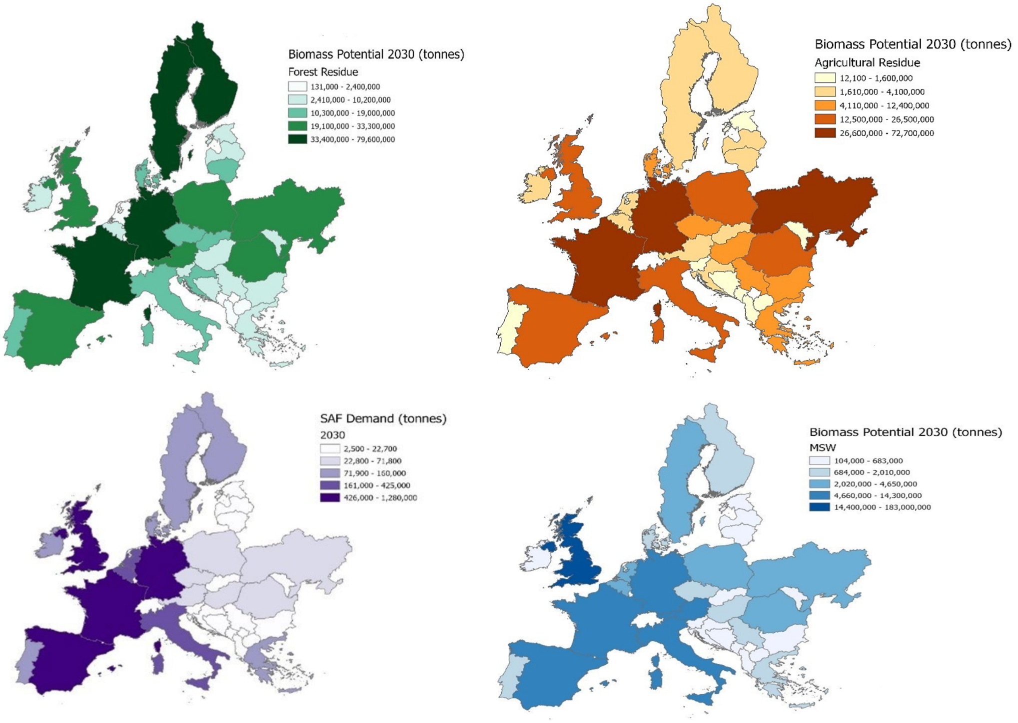

Figure 2: Spatial distribution of forestry residues (top left), Agriculture residues (top right), municipal solid waste (bottom right), and national SAF demand (bottom left).

3.1.2. Potential fuel output (PFO)

Potential fuel output can be calculated based on the potential SAF supply and national SAF demand. In order to estimate SAF supply, quantitative conversion yields for certain conversion pathways and biomass availability were taken into account. The conversion yields were obtained from literature data (Capaz et al. 2021; Santos et al. 2018). Due to data limitation for European context, some conversion pathway yields were obtained for the United States and assumed to be the same for the EU. Table 1 shows, example PFO of the most promising conversion pathways for UK in 2030 with 10% SAF blending policy.

$$PFO = \frac{Potential\ SAF\ supply}{National\ SAF\ demand} * 100\% \quad (1)$$

Table 1: PFO for some representative conversion pathways for UK in 2030 with 10% SAF blending

Technology	Feedstock	Biomass availability (in million tons)	SAF supply (in kilotonnes)	Demand (in kilotonnes)	PFO (in %)
FT	Thinnings from nonconifer trees	2,1	471	1283	37
FT	Thinnings from conifer trees	1,1	250	1283	19
FT	Oil seed rape straw	2,5	508	1283	40
FT	Sunflower straw	0,0	1	1283	0
ATJ	Oil seed rape straw	2,5	661	1283	51
ATJ	Sunflower straw	0,0	2	1283	0
FP	Thinnings from nonconifer trees	2,1	578	1283	45
FP	Thinnings from conifer trees	1,1	306	1283	24
HEFA	UCO	171,6	142445	1283	11102

3.2. Net GHG emissions and biomass competing uses

Based on environmental life cycle analysis, net, and total GHG emissions were calculated for each conversion pathway. A well-to-wake (WtWa) approach was followed in this investigation. We relied on studies that utilized the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to assess SAF conversion pathways' medium- and long-term GHG emission performance (Jong 2018). However, GREET uses the US as its geographic coverage of the input data. Therefore, the actual values for GHG emissions in Europe could be different. For the WtWa analysis, the CO_2 emissions from SAF combustion are considered part of the biogenic carbon cycle. The average WtWa emission intensity for typical jet fuel used in the United States (87.5 g CO_2 eq MJ^{-1}) is utilized as the fossil fuel baseline.

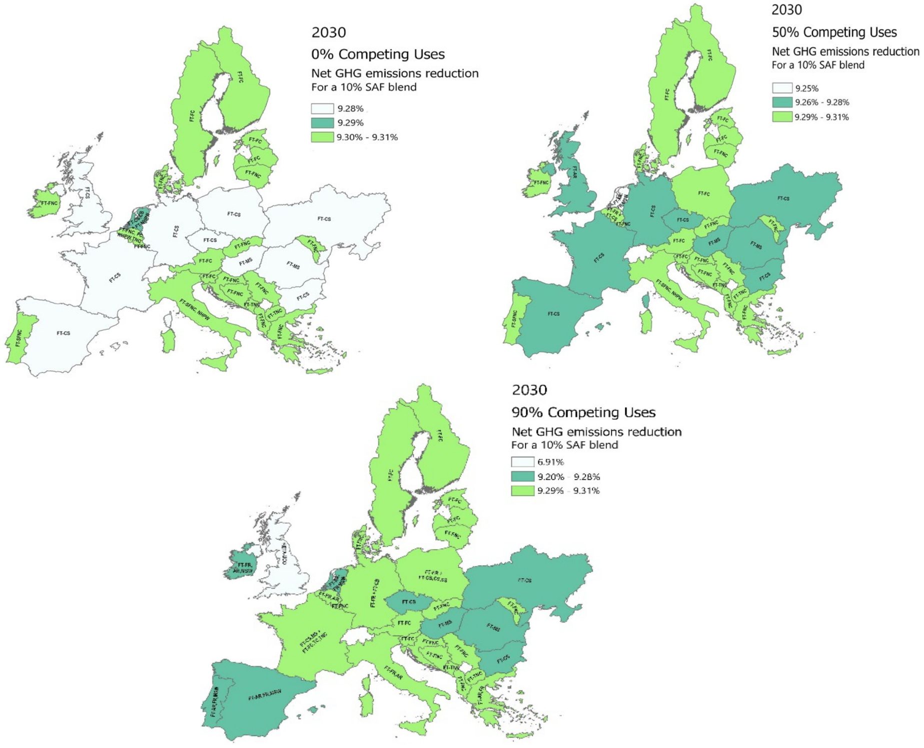

Figure 3: The net GHG emissions reduction potential (in %) based on 10% SAF blend for each European country in 2030 for different biomass availabilities.

Effect of biomass competing sources (0%, 50%, and 90%) was also analyzed as feedstock competition is expected in the future. Figure 3 illustrates the net GHG emissions reduction potential for the considered 33 European countries while accounting for biomass competition. The potential net GHG emissions reduction ranges between 9.25% and 9.31% across all biomass availability levels for most countries. The maximum total GHG emissions reduction potentials collectively for Europe in the 2030 scenario was found to be 21 Mt (0% competing uses), 19 Mt (50% competing uses), 15 Mt (90% competing uses). The difference in values is attributed to the selected feedstock category. For example, FT-AR pathway has slightly higher net GHG emissions (6.3g CO_2/MJ SAF) than FT-FR (6g CO_2/MJ SAF). The UK is the only country where biomass supply limits potential net GHG emissions reduction. From Figure 3, to cover the UK's SAF demand for 90% competing uses, the conversion pathway is changed to HEFA-UCO, with a significantly lower net GHG emissions reduction potential (6.91%). Overall, the results indicate at least a 9% net reduction in GHG can be achieved for the 33 European countries, even when 90% competing uses are considered.

4. Conclusions

In this research, we initially assessed if there is sufficient biomass to supply the SAF demand of Europe; and secondly, identified the best conversion pathways that lead to the highest GHG emissions reductions for each country. For a scenario in 2030 with a 10% blending of SAF with fossil jet fuel, we also investigated the impact of biomass competition with biomass uses varying from 0%, 50%, and 90%. Collectively, the 33 European countries can produce sufficient SAF to meet the total demand in 2030. This was the case for all the competing percentages. One key learning from this study was that conversion pathways with maximum yield need not always perform best in terms of GHG reduction. For example, in the UK, HEFA-UCO offers the highest PFO indicating higher yield, however, FT-FR had the highest GHG emission reduction while satisfying the demand. The conversion pathway that leads to the highest GHG emissions reduction across the EU for 2030 is FT – FR/AR/FR+AR, based on biomass availability. The maximum total GHG emissions reduction potentials collectively for Europe in the 2030 scenario is 21 Mt (0% competing uses), 19 Mt (50% competing uses), and 15 Mt (90% competing uses). Based on the analysis conveyed, it can be concluded that bio-based drop-in fuels can go a long way towards mitigating the impact of the aviation sector. However, there is a lot of room for refinement as a follow-up. Expanding the temporal scale to 2050 and assuming different blending percentages can spotlight some key areas of concern. Therefore, it is believed that the future SAF supply and the associated GHG emission reductions will be strongly impacted by policy incentives, the pace of technology development, and exact biomass supply and demand.

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