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Could Biomass Derived Fuels Bridge the Emissions Gap between High Speed Rail and Aviation?

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Abstract: Aviation is a steadily growing sector, which largely contributes to transport greenhouse gas (GHG) emissions. When High Speed Rail (HSR) and aviation are considered as alternative options, HSR proves to be a more environmentally friendly mode of transport. Public available data have been used in order to calculate the emission profiles on two selected intra-European routes (London–Paris and Frankfurt–Amsterdam) by HSR and air. As expected, the air mode results in higher GHG emissions and solutions for mitigating its impact have been analyzed and suggested. Biomass Derived Fuels (BDF) has a limited, up to now, potential, to fill the existing gap in terms of emissions with rail. Moreover, BDF reduction in GHG emissions is accompanied with by an increase in fuel cost. Finally, the cost per tonne of avoided CO_{2e} by using BDF—which values 186 €/t—has been compared with the prices of the European Union (EU) Emission Trading System (ETS) allowances and, from a purely economic perspective, this market based measure still seems a preferable option to curb the GHG emissions of the air mode.

Keywords: Sustainable mobility; sustainable aviation; aviation emissions; High Speed Rail; Biofuels; biokerosene

1. Introduction

As the backbone of economic activities, it is widely recognized that the transport sector has a key role in countries' economic development; in 2015, the transport sector accounted for 33.1% of the total European Union-28 (EU-28) primary energy consumption, being equivalent to 359 Mtoe [1]. The European Commission (EC) has recently issued its "long-term vision for a prosperous, modern, competitive, and climate neutral economy", aiming at confirming the commitment to lead in global climate action towards net-zero greenhouse gas emissions by 2050 [2]. The above-mentioned document contains interesting information regarding the current and the expected relative importance of each mode of transport, with respect to primary energy consumption (Table 1).

Table 1. Relative share of transport modes on the total transport section energy consumption in European Union-28 (EU-28), 2015 (elaboration of data from baseline scenario of the European long-term strategy [2]).

	2015		2030	
	Mtoe	**%**	**Mtoe**	**%**
Total energy Consumption	360.7	-	318.5	-
Road	294.9	81.8	246.4	77.4
Rail	7.4	2.1	8.9	2.8
Aviation	53.3	14.8	57.3	18.0
Inland Navigation	5.1	1.4	5.9	1.9

In spite of the dominant role of the road sector, rail and aviation account for a significant share of the activities both for passenger as well as for freight. In 2015, rail accounted for 7.6% of the total EU passenger transport activity and for 12% of freight transport activity (Table 2), while aviation had a share of 10% on passengers with a negligible share of freight. Since 2014, the aviation sector has been showing a stable growth, after the 2009 contraction corresponding to the economic crisis [3]. The total number of passengers that were travelling by air in the EU in 2016 has been estimated in 973 million, with 17% of them moving within domestic airports (Table 3). The European Aviation Environmental Report (EAER) [4] presented an increase in passenger number of about 40% in 2017, as compared with 2005. In the same report, a base case future scenario forecasts that the total flights using EU and European Free Trade Area (EFTA) airports will increase from 9.5 million in 2017 to 13.6 million in 2040. The rail sector has been facing different trends when compared to aviation; passenger share in 2012 was 7.6% of the total passenger-km and, as previously shown, it remained stable in 2015 [5]. The High Speed Rail (HSR) segment shows a remarkable growth, accounting for 84% of the increment in passenger activity between 2005 and 2015, and for 29% of total passenger rail activity in 2015 [6].

Table 2. Passenger and freight relative activities in 2015 (source IEA [5,6]).

	Passenger	**Freight**
	pkm (%)	**tkm (%)**
Road	82.2	50.8
Rail	7.6	11.9
Aviation	9.9	0.1
Maritime and Waterways	0.3	37.2

Table 3. Disaggregated values for aviation in EU-28 (elaboration of EUROSTAT [7]).

Total Passengers (*in 1000*)	**Domestic (*in 1000*)**	**International Intra EU-28 Transport (*in 1000*)**	**International Extra EU-28 Transport (*in 1000*)**
972,693	168,676	457,422	346,596
%	17.3	47.0	35.6

Air and rail transport compete on EU domestic medium-haul trips (around 500 km) [8–10], but their specific energy consumption and, consequently, their emission profiles, strongly differ. Aviation specific passenger kilometer emissions are still typically higher than rails', even if rapid technological advances in the sector have been helping in mitigating the existing gap. In order to see the effects of these technological advances, all the sector players—from manufacturers to operators—must be early adopters of Best Available Technologies (BAT): the average age of the fleet is a key point. Despite the availability of new aircraft models, such as the A320neo and B737 MAX families, the European fleet—albeit young—is getting slightly older: the mean aircraft age has increased from 10.3 years old in 2014 to 10.8 years old in 2017 [4].

With no attempt to single out the contribution of EU domestic air traffic due to reporting systems, EU aviation has more than doubled its emissions since 1990 [4], totaling 13.3% of the EU28 greenhouse gas (GHG) transport emissions in 2017 [11]: this is the second most important source of transport GHG emissions after road. This happens despite the already occurred reduction in fuel burnt per passenger kilometer.

Two factors have contributed in the same period in lowering the environmental impact of the rail sector: enhanced energy efficiency in the rolling stock and a significant reduction in the use of oil products as energy source. According to International Energy Agency (IEA) and International Union of railways (UIC), the energy consumption per pkm decreased by 18.2% in the decade 2005 to 2015, and energy freight tkm decreased by 19.2% in the same period [5,6]. Due to the greening of the electrical

production system, the corresponding GHG emissions per decreased by 38.1% (per passenger-km) and the freight by the 31.2% (per tonne-km).

The paper estimates the emission profiles for aviation and HSR on two intra-EU selected routes; these case studies are proposed for comparing the GHG emissions of the two modes of transport. The value of measuring this differential impact deals with the growing concern regarding the forecast for aviation deployment in the near-medium term, which is being expected to worsen the current sector impact. As Biomass Derived Fuels (BDF) use is claimed to be able to mitigate aviation GHG emissions, consequently filling the existing gap with other modes of transport, this paper presents the current EU production state of play, with the proposal of estimating the actual mitigation potential. In the last section, the results of a cost/benefit analysis are presented, aiming to identify alternative strategies to BDF, for achieving the goal of mitigating aviation environmental impact.

2. Materials and Methods

In this section, the methodology that is used to define the specific GHG emissions for HSR and aviation, on two selected medium-haul routes, is presented. This analysis is a follow-up of a previous work [12].

2.1. Cities-Pairs Definition and Distances

In order to measure the potential for BDF to mitigate aviation emissions, a comparison with HSR is proposed by means of two case studies. Two intra-EU cities pairs have been selected as representative examples for the comparison of the two transport modes. Four specific airports have been chosen in order to connect the cities-pairs, mainly for their relative proximity, both in terms of distance and for flight duration: no more than one and a half hour:

- **LHE**: London Heathrow (UK): the busiest airport in the EU, with a total of 78.0 million passengers carried in 2017;
- **CDG**: Paris-Charles de Gaulle (France): the second busiest airport in Europe, with 69.5 million passengers moved in 2017;
- **FRA**: Frankfurt Main (Germany): 64.5 million passengers in 2017; and,
- **AMS**: Amsterdam Schiphol (The Netherlands): 68.5 million passengers in 2017 [12].

These two routes were already analyzed, among others, in a previous [13], but in this paper time for commuting has also been added to the comparison. Table 4 shows the results of the HSR versus aviation comparison in terms of trip duration. The time that is required for reaching the airport from downtown, plus the time from the arrival airport to the city center have been added for aviation to refine the quality of the comparison with HSR, for which stations are often in the very center of the cities. Data have been obtained by comparing the various tools [13–18].

Table 4. Journey description and duration comparison.

City Pair	Airport	Airport Code	Flight Average Distance (km)	Expected Gate-To-Gate Flight Time (h)	Additional Time for Downtown (h)	Total Journey (h)	Rail Distance (km)	Expected Trip Duration (h)
A	London Heathrow Paris-Charles de Gaulle	LHR CDG	348	01:15	02:15	03:30	480	03:10
B	Frankfurt/Main Amsterdam/Schiphol	FRA AMS	365	01:15	00:45	02:00	450	04:30

2.2. Emissions for Rail Transport

High Speed Rail is powered by electrical energy and the GHG emissions have been calculated on the basis of the carbon intensity of the electric power generation, which is a direct function of the primary energy mix of the country that is crossed by the train during its trip. The carbon intensity

of each country has been estimated using Moro et al. [19], in terms of gCO_{2e}/kWh for Medium Voltage infrastructure (Table 5). The specific energy consumption for HSR services can be calculated by defining an average occupancy rate for the specific journey. When considering the European case [20–22], a typical occupancy rate of 65% is deemed to be appropriate. According to available studies [23,24], a final specific energy consumption of HSR can be set in 0.057 kWh/pkm. With these assumptions as input, it is possible to calculate the specific emissions factor for the routes selected.

Table 5. Carbon intensity of Medium-voltage electricity, and percentage of the trip in each country.

Country	CI of Electricity Consumed at MV (with Upstream) [19]	Percentage of the Trip Length in Each Country (%)	
		CDG-LHR	AMS-FRA
DE	602	-	71
FR	101	57	-
NL	558	-	29
UK	599	43	-

The lower specific carbon intensity of the Paris–London route, with respect to the AmsterdamFrankfurt, is due to the lower carbon intensity of France, where nuclear power is still a relevant source in the current mix.

2.3. Emissions for Aviation

In order to estimate the air transport emissions on the identified routes, the aircraft type doing the service has to be taken into account. On the defined distance bands, all below 1000 km, regional Small Jet (SJ)—mostly turboprops—and Narrow Body (NB) aircrafts constitute the typical vectors; today, there is a general trend of reducing the small jets in favor of aircrafts with a higher load capability [25,26].

Based on the analyses that were reported in the previous study [12], in the present work flights among the reference airports have been segmented for the two aircraft types (SJ and NB), and fuel consumption has been calculated using the Corinair database [27]. The fuel consumption per aircraft type has been estimated for the standard LTO cycle (Take-Off, climb, approach, and taxi-in) adding the cruise phase. Two reference weeks of the yearly traffic have been analyzed: week 24 and week 37, which are typically recognized by airline operators as representative of the overall year [28,29]. The CO_{2e} emissions can be obtained by the fuel consumption—as expressed in kg of Jet A1—using a coefficient of 3.15 for the conversion (according to the EU Emission Trading System (EU ETS) Directive [30]).

2.4. Comparison over the Emissions Profiles

The comparison of the emission profiles from Tables 6 and 7 clearly highlights the higher impact of aviation as compared with HSR. The sector is fully aware of its impact, thus it has set an aspirational target for its international activities to achieve carbon neutral growth from 2020 onward and cut its overall carbon emissions by 50% by 2050 (as compared to 2005 levels [31]); no specific target is currently defined for EU. Among the tools that are available today for greening the sector, BDF are a technically available solution, and are here analyzed.

Table 6. High Speed Rail (HSR) route-specific CO_{2e} emission factor.

	gCO_{2e}/kWh	gCO_{2e}/pkm
CDG-LHR	315.8	18.0
AMS-FRA	589.6	33.6

Table 7. Aviation route-specific CO_{2e} emission factor.

Route	Distance	Average Fuel Consumption	Average CO_{2e} Emissions	
-	km	tonne	tonne	gCO_{2e}/pkm
CDG-LHE	348	1.75	5.51	143
AMS-FRA	365	1.50	4.72	116

2.5. Biomass Derived Fuel Carbon Intensity

Alternative fuels for aviation, independently from the feedstock that are utilized for their production, have to meet specific quality characteristics in order to be used in commercial flights. The American Society for Testing and Materials (ASTM) is the body that is in charge of issuing the technical norms regulating this aspect; today, the two reference norms are the ASTM D4054 and ASTM D7566 [32,33]. The procedures that are contained in the norms do not take into account only the final fuel quality, but the pathway that is used for its production. Currently, six production pathways are certified (see Table 8). These bio-derived jet fuels are drop-in: they can be directly blended with fossil derived Jet A1. For the time being, there are other pathways in the pipeline for ASTM certification.

Table 8. Alternative aviation fuel certified pathways [34–43].

Pathway		Potential Feedstocks	Maximum Allowed Blending Rate
HEFA	Hydroprocessed Fatty Acid Esters and Free Fatty Acid	Lipid feedstocks, such as vegetable oils, used cooking oils (UCO), tallow, etc.	50%
FT-SPK	Fischer-Tropsch Synthetic Paraffinic Kerosene	Woody, residual biomass, Municipal Solid Waste (MSW), etc.	50%
FT-SPK/A	variation of FT-SPK, where aromatics are included	Woody, residual biomass, Municipal Solid Waste (MSW), etc	50%
ATJ-SPK	Alcohol-to-Jet- Synthetic Paraffinic Kerosene	Sugar based feedstock, alcohols.	50%
HFS-SIP	Hydroprocessing of Fermented Sugars—Synthetic Iso-Paraffinic kerosene	Sugar based feedstocks.	10%
Co-Processing	Co-processing of mono-, di- and triglycerides with standard crud up to 50% by volume in input	fats, oils and other residues	5%

Defining the maturity level of the available production pathways, either from a technological or from a commercial point of view, is challenging and, despite the great dynamism of the sector, hardly any significant ASTM certified alternative fuels batches are today supplied at the commercial scale [41]. Among the already certified pathways, HEFA shows the highest maturity level [42], as a relevant amount of production capacity is already installed, being currently capable of supplying fuel for commercial flights. the maturity level for the Fischer–Tropsch conversion process is less clear, despite having been the first to get ASTM certification, today this technology has not yet reached a truly commercial scale. Alcohol to Jet pilot plants are today supplying, even at a very small scale, fuel for commercial flights [41], demonstrating an interesting maturity level. The production of alternative aviation fuels from sugars appears today as a promising technology and pilot plants are supporting pilot commercial initiatives [43].

In order to define an average GHG saving potential, from the use of BDF in aviation, the technologies and the production pathways that are used in EU-28 need to be assessed. Europe today relies on a significant number of commercial plants, which are currently in operation; the most common technology, in terms of installed nominal capacity, is the HEFA process. HEFA is obtained from Hydrogenated Vegetable Oils (HVO)—which is used in road transport as an alternative to

biodiesel—with an additional isomerization step. According to a recent work from Prussi et al. [44], the maximum aviation fuel technical potential ranges from 350 to 830 kt/yr, depending on the assumptions that are used for plants setting and market demand. A significant increase can be expected for the medium term, as co-processing and other new pathways may unlock larger potential.

In order to define a potential GHG saving by using BDF from EU production, a 2020 scenario has been defined. Based on the current status of the technological deployment—as shown in Table 9—it can be assumed that, in 2020, EU production will be mainly constituted by HEFA, with a minor share of ATJ and FT: we set a relative share of 80% for HEFA, 15% for ATJ and 5% for FT. This scenario results in an ideal EU average BDF blend. An average GHG saving can be associated to such a theoretical blend, on the basis of the technologies that are used for production but also as a function of the feedstocks that are used to supply the processes. When considering the current market values as well as the indications from RED-II, Table 9 reports the proposed shares of feedstocks considered per production pathway—based on the defined scenario, the average EU BDF GHG saving can be calculated.

Table 9. Assumed blend mix for Biomass Derived Fuels (BDF) production.

Conversion Process	Feedstock	Relative Feedstock Share
FT	Agricultural residues	30%
	Forestry residues	35%
	MSW, 0% NBC	5%
	Short-rotation woody crops	20%
	Herbaceous energy crops	10%
HEFA	Tallow	20%
	UCO	15%
	Palm fatty acid distillate	15%
	Soybean	15%
	Rapeseed/canola	30%
	Brassica carinata	5%
ATJ	Agricultural residues	100%

In spite of the high expectation for FT from lignocellulosic residues to significantly contribute in medium-term to EU production, HEFA is currently dominating the market. In the near term, the feedstocks for HEFA are expected to originate from waste or residual streams, namely UCO and tallow. While palm oil has gained a bad environmental reputation on the EU market, the Palm Fatty Acid Distillate (PFAD) could be widely used for biofuels production. PFAD is already widely used by industry, such as for feed production—an extensive use in aviation may lead to indirect effects, due to the displacement of this feedstock forcing, for instance, the feeding industry to use more vegetable oil to meet its demand. The real displacement effect is hard to be estimated and models that are proposed appear today unable to supply reliable results. For the time being, PFAD is still a suitable feedstock for companies producing biofuels, as Member States are able to classify this material as a waste.

3. Results

Based on the scenario and assumptions described, the theoretical EU production BDF—in 2020—would allow for a saving of 59 gCO_{2e}/MJ (Table 10): 66% as compared to the reference 89 gCO_{2e}/MJ of the fossil Jet A1.

Table 10. Average greenhouse gas (GHG) saving for European Union (EU) production.

Relative Share		Average Saving
	%	gCO_{2e}/MJ
HEFA	80	57.3
FT	5	80.0
ATJ	15	59.7
Average EU production	-	58.8

In order to calculate the potential for GHG saving per trip, a BDF blending rate with fossil kerosene has to be defined. All the pathways considered for the production of this EU typical BDF can be theoretically blended up to 50%; this is the maximum share allowed by ASTM certification and can be considered as a really high share, that is unlikely to be reached in real-world operations particularly with respect to its management at existing airport infrastructures.

At the airport level, a lower blending rate can be more easily and realistically managed. In spite of this practical consideration (mainly cost related), a blend of at least several perceptual points needs to be considered to have a measurable impact. For the purposes of this paper, and when considering the plans that were outlined by specific EU airport initiatives, a blending rate of 3% has been analyzed.

The 3% blend could be a viable solution for an airport willing to introduce BDF in its infrastructure; nevertheless, despite this ease of implementation, the environmental measurable benefits would be really limited. Conversely, for both the analyzed routes, when a 50% blend rate is used, the emissions drop significantly, to 94 and 77 gCO_{2e} per pkm, respectively. Despite this relevant reduction, as shown in Table 11, even a 50% blend of BDF does not allow to fill the gap between the emission profiles of flights on selected routes, as compared to the HSR emission profile.

Table 11. New aviation emission profiles with BDF use on the two selected routes.

Route	Blending Rate		
	0%	3%	50%
	gCO_{2e}/pkm		
CDG-LHE	142.6	139.7	93.6
AMS-FRA	116.5	114.2	76.4

4. Discussion

Cost-benefit Comparison for Mitigating GHG from Aviation

BDF has the potential to mitigate the GHG emissions of the aviation sector; however, the costs of this option constitute a barrier to real-market deployment [45]. To estimate the cost of saving CO_{2e} by using BDF, it is first necessary to define the differential cost with respect to commercial fossil derived Jet-A1; according to the International Air Transport Association [46], Jet-A1 fuel price today costs around 650 €/t. The variability of the costs for BDF, instead, is less certain, not only because most of the pathways are not fully commercial, but also because feedstocks are often subject to high price volatility. The SGAB group [47] reports HEFA production costs that range from 80–90 €/MWh (22–25 €/GJ), and aviation alternative fuel via FT in 110–140 €/MWh (31–39 €/GJ). A recent JRC study [48] presents the total production costs for conventional and advanced biofuel pathways for the road sector. The JRC values, which are in line with SGAB figures, can be used to calculate the cost of the average BDF for our scenario: according to the limited data available in literature [49], a 10% cost for upgrading to jet fuel has been added. Table 12 shows the costs for specific pathways and technologies; while considering the relative share of each pathway, as already presented in Table 9; the final production costs for an ideal EU BDF for aviation equals 1124 €/t.

Table 12. Biomass Derived Fuels production costs.

Conversion Process	Feedstock	Relative Feedstock Share (%)	Average Cost per Pathway (€/t)
FT	Agricultural residues	30	1768
	Forestry residues	35	
	MSW, 0% NBC	5	
	Short-rotation woody crops	20	
	Herbaceous energy crops	10	
HEFA	Tallow	20	902
	UCO	15	
	Palm fatty acid distillate	15	
	Soybean	15	
	Rapeseed/canola	30	
	Brassica carinata	5	
ATJ	Sugarcane Agricultural residues	100	2094

The emissions from Jet-A1 are equal to 3.8 tCO_{2e}/t_{JetA1}, while BDF value 1.3 tCO_{2e}/t_{BDF} (66% saving). Each tonne of Jet-A1 replaced by BDF allows for saving 2.5 tCO_{2e} and the cost of this saving is equal to the difference in fuels prices: the difference between Jet-A1 and BDF is around 470 €/t—and consequently, the cost saved results in 186 €/tCO_{2e}.

As alternatives to BDF, other options can be considered to mitigate the emissions from the aviation sector: for example, market-based measures, such as emission trading and carbon offsetting. Because of the above-mentioned enhanced cost of the use of BDF, market based measures are explored below as an economical way to reduce the emissions of aviation.

In 2005, the European Union launched the EU Emissions Trading System (EU-ETS) as a pilot of its strategy for cutting emissions of carbon dioxide (CO_2) and other greenhouse gases at least cost [50]. Emission allowances are 'currencies' in the EU ETS and the limit on their total number available should define their value. Companies have to balance part of their emissions (tonnes of CO_{2e} or the equivalent amount for nitrous oxide, N_2O, or perfluorocarbon emissions, PFCs), by acquiring allowances that are auctioned within the EU ETS [50]. Aviation activities have been included in the EU ETS since 2012 but until 31 December 2023 the EU ETS will only apply to flights between airports that are located in the European Economic Area (EEA) with a cap for the total allowances. The cap for the whole 2013–2020 period has been set at 210 million aviation allowances per year [4]; this is equivalent to 95% of the aviation emissions for the reference period 2004–2006. For the time being, 82% of the aviation allowances are granted for free to aircraft operators, 15% of aviation allowances are auctioned, while the remaining 3% of aviation allowances are held in a special reserve for later attribution to new market entrants and fast-growing operators. Firms are incentivized to become more energy efficient because they can then sell their emissions permits on the secondary market. Figure 1 summarizes the aviation CO_{2e} emissions under EU ETS. The EU ETS allowances price varied between 4–6 €/tCO_{2e} during the 2013–2017 period, while in the course of 2018, their value rose above 20 €/tCO_{2e} [51].

In addition to the EU ETS, the EU Member States can participate, on voluntary basis, in the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA): an attempt to address international aviation emissions. CORSIA was launched in 2016, with the aim of offsetting international aviation CO_{2e} emissions—above the 2020 levels, by means of credits acknowledged at global level. CORSIA operates on a route-based approach: a route is covered by CORSIA offsetting obligations if the state of departure and the state of destination are participating in the scheme. Offsetting credits represent the certification that a tonne of CO_{2e} has been reduced, in comparison with a scenario without CORSIA.

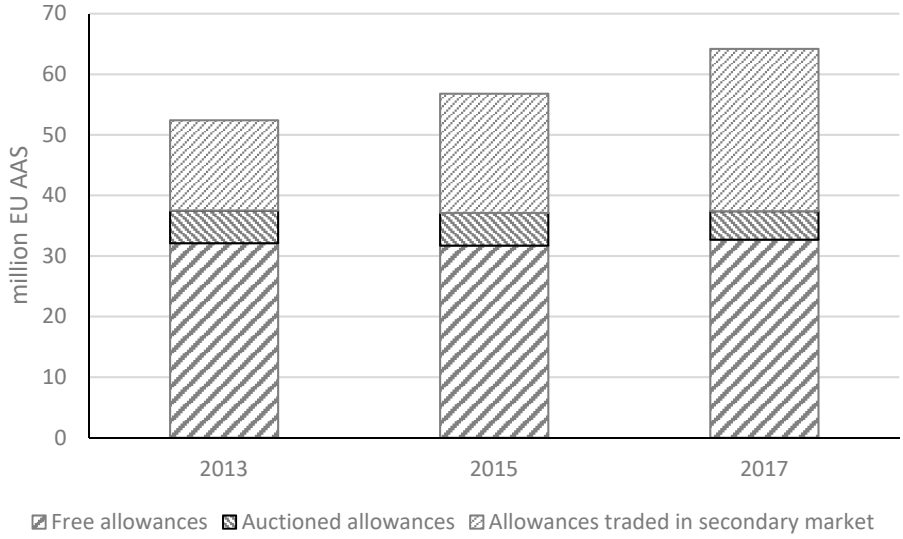

Figure 1. Aviation CO_{2e} emissions under EU Emission Trading System (EU ETS) (elaboration from European Aviation Environmental Report (EAER) [4]).

In order to give EU Member States the possibility to participate in ETS and CORSIA, in December 2017, the Parliament and the Council agreed to prolong the derogation at ETS for extra-EEA flights—until 31 December 2023. Emissions trading systems (ETS) and offsetting schemes (CORSIA) aim to address the need of reducing aviation emissions but they differ in the way that they operate. CORSIA has a larger geographical scope when compared to EU ETS. Concerns and criticisms have been moved for this kind of tools, as they may tend to divert the focus from reducing emissions to trading on emissions. On the other hand, BDF are a direct way to try to reduce emissions, but their costs—per tonne of saved CO_{2e}—are today still significantly higher than the ETS allowances.

5. Conclusions

In this paper, the emission profiles of aviation and HSR on two intra-EU selected routes (London–Paris and Frankfurt–Amsterdam) have been compared. The aviation mode of transport shows higher GHG emissions when compared with rail. For the route London-Paris the GHG emissions resulted in 18.0 and 143 gCO_{2e}/pkm for HRS and aviation, respectively. The corresponding figures for the route Frankfurt-Amsterdam were 33.6 and 116 gCO_{2e}/pkm.

Biomass Derived Fuels could be considered as a direct way to reduce aviation GHG emissions, and the potential impact of their use has been analyzed. A theoretical EU BDF blend has been defined on the basis of EU production capacity in 2020. For both of the routes analyzed, when a 50% BDF and fossil jet-A1 blend is used, the emissions drop significantly, to 94 and 77 gCO_{2e}/pkm, respectively. Despite this relevant reduction, even a 50% blend of BDF does not allow for fill the aviation gap, as compared to the HSR emission profile.

Moreover, the final production cost for an ideal EU BDF for aviation is expected to be higher than 1100 €/t, making this option unattractive in economic terms. The cost per tonne of saved CO_{2e} has been estimated at 186 €/tCO_{2e}.

In near future, the limitation of the number of the allowances, with the consequent expected rise in their price will act as an incentive for the aviation companies to consider BDF as an alternative means to reduce emissions. Nevertheless, for the time being, while taking into account the current price per tonne of CO_{2e} in the EU-ETS (around 20 €/tCO_{2e}), it could be concluded that EU ETS is still a more viable option for the sector.

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Abbreviations

ASTM	American Society for Testing and Material
ATJ-SPK	Alcohol-to-Jet- Synthetic Paraffinic Kerosene
BAT	Best Available Technologies
BDF	Biomass Derived Fuel
CO_{2e}	Carbon Dioxide equivalent
EAER	European Aviation Environmental Report
EC	European Commission
EEA	European Economic Area
EFTA	European Free Trade Area
ETS	Emissions Trading Scheme
FT-SPK	Fischer-Tropsch Synthetic Paraffinic Kerosene
HEFA	Hydrotreated Esters of Fatty Acids
HFS-SIP	Hydroprocessing of Fermented Sugars - Synthetic Iso-Paraffinic kerosene
HSR	High Speed Rail
HVO	Hydrogenated Vegetable Oil
MSW	Municipal Solid Waste
Mt	Million metric Tonne (10^6 kg)
NB	Narrow Body
PFAD	Palm Fatty Acid Distilled
pkm	Passenger Kilometers
SJ	Small Jet
tkm	Tonne-Kilometers
UCO	Used Cooking Oil

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