

Evaluating Synthetic Aviation Fuel for Transport Decarbonisation: Techno-Economic and LCA Insights from the Portuguese Power System

Long-haul aviation is widely recognized as one of the most challenging transport sectors to decarbonize, as it will continue to rely on energy-dense liquid fuels well beyond 2030. This study presents a combined techno-economic assessment (TEA) and life cycle assessment (LCA) of a SAF PtL plant integrated with the Portuguese electricity system. The process configuration comprises water electrolysis, solid (S-DAC) or liquid (L-DAC) CO₂ direct air capture (DAC), and Fischer-Tropsch synthesis with downstream upgrading to SAF and co-products. The TEA estimates the levelized cost of fuel (LCOF), accounting for capital and operating costs of the main process units and electricity prices under a representative Portuguese grid mix. The LCA quantifies Well-to-Wake (WtWa) GHG emissions, using the average Portuguese mix as the energy supply for electricity-driven processes and comparing with onsite-generated renewable electricity supply. The economic assessment estimates an LCOF of 4.13 €/kg and 4.54 €/kg for S-DAC and L-DAC, respectively. The LCA reveals that the WtWa global warming potential (GWP) is 26.09 gCO₂eq/MJ for S-DAC with grid electricity, decreasing to 15.05 gCO₂eq/MJ when utilizing onsite-generated renewable electricity. In the L-DAC scenarios, the GWP amounts to 55.59 gCO₂eq/MJ with natural gas and 16.10 gCO₂eq/MJ when powered by onsite solar energy.

Keywords: Synthetic aviation fuels; Power-to-liquid (PtL); Techno-economic assessment (TEA); Life cycle assessment (LCA)

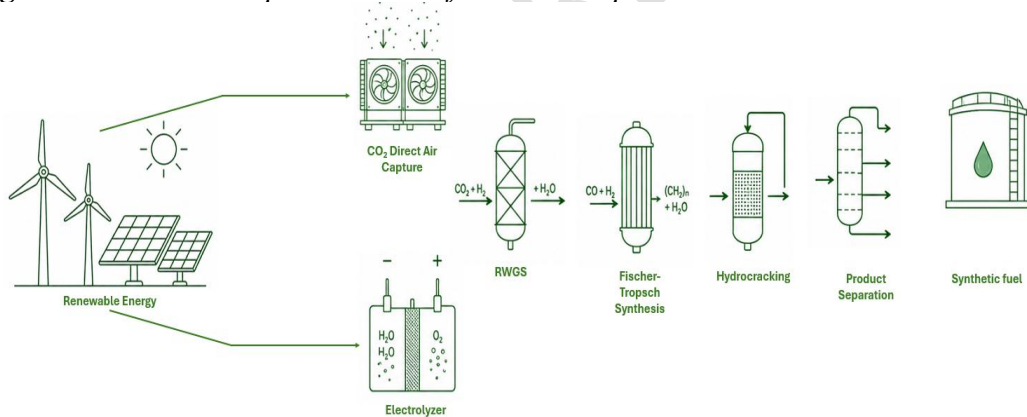
Introduction

Transitioning aviation from a highly emission-intensive sector to a net-zero pathway by 2050 is a central objective for both the aviation industry and transport policy frameworks [1]. As of 2021, jet fuel combustion accounted for 720 million tonnes of CO₂, corresponding to approximately 2% of global energy-related emissions [2]. It is projected that by 2050, Europe alone will see around 15.4 million flights, according to Eurocontrol [3]. The aviation sector is generally regarded as challenging to decarbonize, due to the complexities involved in replacing liquid fuels. As a result, numerous studies, reports, and proposals have been reinforcing the urgent need for effective mitigation strategies. Those strategies vary from airframe and engine efficiency improvements, operational measures, novel propulsion concepts such as liquid hydrogen, batteries, and the large-scale deployment of Sustainable Aviation Fuels (SAF) [4]. Hydrogen and battery systems, although often proposed as zero-emission pathways, are currently constrained by fundamental thermophysical limitations (low volumetric and gravimetric densities). These disparities lead to substantial system-integration challenges, demanding

1 complete redesigns of airframes and specialized cryogenic infrastructure at
 2 airports, a requirement that remains unrealistic for the transition timeline of 2030
 3 to 2050.

4 In contrast, SAFs are increasingly acknowledged as the most realistic near-
 5 to medium-term solution, given their compatibility with existing aircraft and fuel
 6 infrastructure, as well as their significant potential to reduce greenhouse gas
 7 (GHG) by 70-90% when produced from low-carbon feedstocks and renewable
 8 electricity [1][5]. As of 2025, the EU has implemented the ReFuelEU Aviation
 9 regulation, the world's first-ever blending obligation for SAF. Beginning in
 10 2025, this regulation mandates a 2% blend of SAFs, rising to 6% by 2030, which
 11 includes a targeted sub-mandate of 1.2% specifically for synthetic e-fuels[6].
 12 Among the various SAF pathways, synthetic fuels, such as e-kerosene, as
 13 illustrated in Figure 1, are particularly attractive as they do not rely on biomass
 14 feedstock but instead use captured CO₂, green hydrogen from electrolysis, and
 15 low-carbon electricity [7]. E-kerosene “drop-in” feature allows high blend ratios
 16 in conventional engines without major system modifications. Notably, multiple
 17 Airbus aircraft developed as part of the VOLCAN project have been conducting
 18 tests on 100% SAF for short flight segments, in line with the ambitious goal of
 19 achieving full operational capability with SAF by 2030 [8].
 20

21 **Figure 1.** Schematic representation of e-kerosene production



22
 23
 24 Despite the technical advantages of e-kerosene and the clear regulatory push
 25 from ReFuelEU, a significant 'implementation gap' persists. While over 45 large-
 26 scale e-kerosene projects have been announced in Europe, targeting a combined
 27 1.7 Mt capacity by 2030, as seen by some of the most prominent in Table 1, the
 28 majority of them have not yet reached a Final Investment Decision (FID). This
 29 stagnation is largely attributed to the techno-economic assessment (TEA)
 30 uncertainty surrounding sustainable CO₂ sourcing and the challenges of
 31 optimizing plant operations within volatile electricity markets.
 32
 33

1 **Table 1.** *Current e-kerosene production projects*

Project name	Project partners	Location	Commissioning Dates	Capacity (t/y)	CO2 Source	Ref
E-fuel 1 Accelerator	Nordic Electrofuel, BPT, Aker Solutions	Heroya, Norway	2026-2030	6,000-114,000	PS, Bio	[9]
Alpha Beta	Norsk e-Fuel, Sunfire, Climeworks	Mosjoen, Norway	2026-2030	32,000-64,000	Bio, DAC	[10]
Endor	Arcadia e-fuels, Technip Energies, Haldor Topsoe S/A, Sasol Ltd	Vordingborg, Denmark	2026	68,000	Bio	[11]
Hy X	Vattenfall, St1 P2X	West Coast, Sweden	2030	100,000	Bio	[12]
P2X-Portugal	Europe - The Navigator	Figueira da Foz, Portugal	2027	30,000	Bio	[13]

2
3 Currently, estimates place the cost of e-kerosene between 1320-4785 €/t,
4 which remains several times higher than fossil jet fuel prices, ranging from 500-
5 1125 €/t [14][15]. Nonetheless, life cycle impacts are highly sensitive to the CO2
6 source configuration, carbon intensity, and price of the electricity used in
7 production. This is particularly relevant in high renewable electricity systems
8 such as Portugal, where hydro, wind, and solar already account for a large share
9 of generation, but where the residual mix still contains fossil-based capacity
10 [16][17].

11 *Literature Review*

12
13
14 Recently, several system-level studies have begun to explore how e-fuels
15 can contribute to the deep decarbonization of transport and power systems. LCA-
16 TEA combinations as developed by Fasihi et al.[18], Rojas-Michaga et al.[19],
17 Schimdt et al.[1], Gray et al.[20], and Boilley et al.[5], focused on the sensitivity
18 of e-kerosene LCOF and GWP, conclude that e-kerosene produced via FT
19 synthesis can achieve substantially lower GWP than conventional jet fuel, but at
20 a significantly higher LCOF. LCA studies such as the one developed by Micheli

1 et al.[21] that have assessed the environmental assessment of various PtL SAF
2 process configurations via DAC and the FT process indicate that electricity with
3 an emission intensity below 139 gCO₂eq/kWh is required to provide a climate
4 benefit over conventional fossil fuels, achieving fuel emissions as low as 12
5 gCO₂eq/MJ. At the same time, Falter et al.[22] have evaluated the TEA and
6 environmental performance of solar thermochemical jet fuel, reporting a
7 baseline cost of 2.23 €/L and life cycle GHG emissions of 15.2 gCO₂eq/MJ.

8 From the prior studies, it has been observed that the Life Cycle Assessment
9 of e-fuels predominantly reports results in terms of Global Warming Potential
10 (GWP), with other environmental categories rarely evaluated. While climate
11 change remains a key indicator for evaluating the effectiveness of
12 decarbonization technologies, an exclusive focus on this metric can undermine
13 the assessment of other impact categories, leading to unintended burden shifting
14 and potential trade-offs not being fully identified. Relevant studies such as [23]
15 and [24] have identified that low-carbon technology is often metal-intensive.
16 Furthermore, the construction of dedicated solar and wind power plants and the
17 additional demand for electricity to support the SAF production could entail
18 urban land transformation and a higher capacity of the national electricity grid.
19 This study seeks to address that gap by integrating a TEA and LCA of e-kerosene
20 production, conducting a comparative analysis of S-DAC and L-DAC feedstocks
21 to determine the LCOF, and complementing the GWP assessment by
22 additionally examining selected environmental indicators, including water
23 footprint and land transformation. The implications of this study could serve as
24 a source of information to support future policy and investment decision-
25 making.

26 The organization of the paper is as follows: Section 2 provides an overview
27 of the TEA and the LCA methodology. Section 3 presents the results of the
28 LCOF, the environmental impacts, and a sensitivity analysis across various
29 scenarios. Section 4 concludes the study.

32 **Methodology**

34 *System Description*

36 The TEA evaluates the feasibility of a grid-connected PtL plant for
37 producing synthetic kerosene in Portugal, under a projected system that includes
38 all costs up to the delivery of fuel at the plant gate. The process examined
39 consists of four primary stages: (i) water electrolysis for hydrogen production,
40 (ii) CO₂ capture, (iii) syngas conditioning, and (iv) hydrocarbon synthesis,
41 followed by upgrading to e-kerosene. In this system configuration, hydrogen is
42 supplied by an alkaline electrolyser (AE) due to high technology readiness level
43 (TRL) and potential for industrial scalability [25]. It was sized to meet an annual
44 production target of 10,000 t e-kerosene at a specified operating hours fraction.
45 The plant capacity was selected as the lower end of the nominal plant capacity
46 range of 10 kt -100 kt reported by Bube et al., which exhibits the most significant

1 reduction in production costs [26]. CO₂ is supplied either by a solid-sorbent or a
 2 liquid-sorbent DAC configuration, depending on the scenario. The hydrogen
 3 produced is then combined with the captured CO₂ and converted into syngas via
 4 RWGS reaction, followed by FT synthesis that converts the syngas into syncrude
 5 molecules. And then, a hydrocracker breaks down the syncrude molecules,
 6 increasing lighter fraction yields, which are subsequently separated according to
 7 their boiling points, yielding, along with e-kerosene (C₉-C₁₅), added-value fuels
 8 such as e-naphtha (C₅-C₈) and e-diesel (C₁₆₋₁₈) [25]. In this study, FT liquid yield
 9 and product distribution are adopted from [27], and no economic credits are
 10 assigned to these co-products.

11

12 *Economic Evaluation and LCOF Formulation*

13

14 In order to evaluate the economic performance of the e-kerosene plant, it is
 15 necessary to determine the levelized cost of fuel (LCOF). The LCOF, expressed
 16 in Equation 1, is calculated by computing the capital (CAPEX) and operational
 17 (OPEX) expenditure, which incorporates costs associated with the operation of
 18 the CO₂ capture unit, green hydrogen production, and e-kerosene synthesis.

$$19 \quad \text{LCOF} = \frac{\sum_{t=0}^T \frac{C_t}{(1+r)^t}}{\sum_{t=0}^T \frac{F_t}{(1+r)^t}} \quad (\text{Eq.1})$$

20

21 where C_t represents total annual costs (CAPEX + OPEX), F_t is the annual e-kerosene
 22 production in tonnes, T is the economic lifetime, and r is the adopted WACC.

23 The CAPEX (I_{total}) corresponds to the sum of the installed cost of each sub-
 24 system investment component (electrolyser, DAC, synthesis and storage units)
 25 given by Equation 2, which is then annualized by multiplying the capital
 26 recovery factor (CRF) as seen in Equation 3.

27

$$28 \quad I_{\text{total}} = I_{\text{electrolyser}} + I_{\text{DAC}} + I_{\text{synthesis}} + I_{\text{storage}} \quad (\text{Eq.2})$$

29

$$30 \quad C_{\text{annual}}^{\text{CAPEX}} = I_{\text{total}} \cdot \text{CRF} \quad (\text{Eq.3})$$

31

32 The OPEX is the sum of the annual fixed OPEX ($C_{\text{total}}^{\text{fixO\&M}}$), which in this
 33 study corresponds to 4% of CAPEX, as utilized in [27] and the annual variable
 34 OPEX ($C_{\text{varO\&M}}$), which comprises expenses such as electricity costs, as
 35 expressed in Equations 4 and 5.

36

$$37 \quad C_{\text{total}}^{\text{fixO\&M}} = \% \cdot I_{\text{total}} \quad (\text{Eq.4})$$

38

$$39 \quad C_{\text{varO\&M}} = El_{\text{total}} \cdot \bar{p}_{\text{el}} + E_{\text{total}} \cdot \bar{p}_{\text{NG}} \quad (\text{Eq.5})$$

40

41 where El_{total} and E_{total} represent total electricity and energy
 42 required, respectively, while \bar{p}_{el} and \bar{p}_{NG} correspond to the price of
 electricity and natural gas, respectively.

All the techno-economic calculations are performed in euros (€) in 2026. A weighted average cost of capital (WACC) of 8% and an economic plant lifetime of 20 years are assumed, consistent with recent TEA studies for early commercial-scale plants, which assume WACCs and plant lifetimes of 6-12% and 20-30 years, respectively [5][19]. All core process units (electrolyzer, DAC, RWGS, FT), CAPEX, and OPEX are modelled using overall energy and carbon efficiencies taken from recent e-kerosene TEA-related studies, as presented in Table 2.

Table 2. *Technoeconomic parameters for e-kerosene synthesis, DAC, and electrolysis*

Parameter	Unit		
		Value	Reference
Electrolysis			
Electrolysis CAPEX	€/kW	790.5	[28][29]
Electrolysis capacity (MW)	MW	40	
Electrolysis electric efficiency	kWh _{el} /kgH ₂	55.1	[29]
H ₂ amount	kgH ₂ /kg _{fuel}	0.5	
OPEX	% CAPEX	2.5%	[28]
Project lifetime (years)	years	20	[28]
DAC			
Plant Capacity	tCO ₂ /year	40,000	
Plant Lifetime	years	20	[28]
DAC Capital Cost	€/tCO ₂	730-1133.6	[30]
CO ₂ amount	kgCO ₂ /kg	3.8	
OPEX	% CAPEX	4%	[28]
L-DAC Electrical Input	MJ/kgCO ₂	1.32	[31]
L-DAC Thermal Input	MJ/kgCO ₂	5.25	[31]
S-DAC Electrical Input	MJ/kgCO ₂	1.8	[32]
S-DAC Thermal Input	MJ/kgCO ₂	5.4	[32]
Fuel Synthesis			
Fuel Synthesis CAPEX	€/kW	1,099	[27]
Fuel Synthesis plant capacity	t/yr	10,000	[26]
OPEX	% CAPEX	3%	[27]
Project lifetime (years)	years	20	[27]
Fuel synthesis capacity factor	%	80%	

12

13

1 *Life Cycle Analysis*

2

3 Goal and Scope

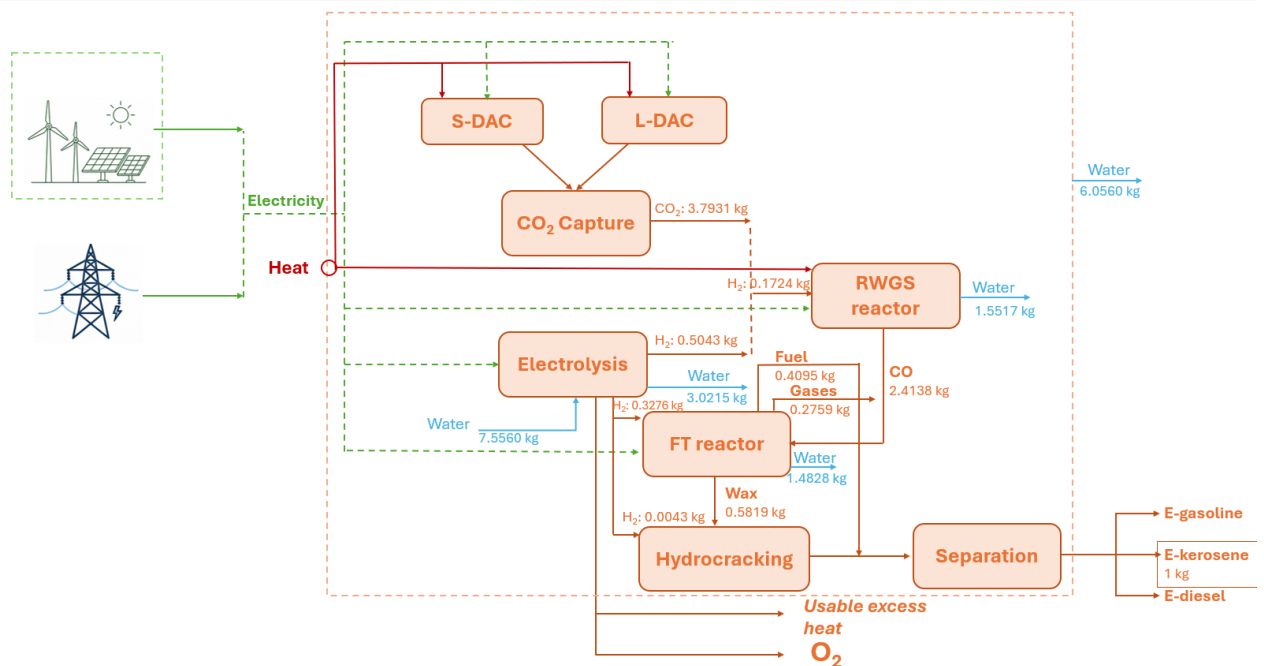
4 The present study follows the standards of ISO 14040 [ISO1 2006] and 1044
5 [ISO2 2006] to evaluate the lifecycle impact of e-kerosene production under
6 several environmental indicators. Foreground data, including material and
7 energy inventory balances of fuel and electricity production and plant
8 construction, were based on various sources from public literature and available
9 industry data. Background data, in particular life cycle inventory (LCI) data for
10 energy and material supply, were taken from Ecoinvent v.3. The same
11 methodology was applied, and the same data requirements were defined for both
12 the foreground and background data, ensuring their mutual consistency. Similar
13 to previous studies conducted in Portugal [33], the inventory is built in SimaPro
14 9.3.0.3 using time-dependent emission factors for the 2023/2024 Portuguese
15 generation mix.

16

17 Scenario definition

18 In this work, the e-kerosene production system is modelled in a Portuguese
19 scenario, with the facility projected in Sines, co-locating both electrolysis and
20 CO₂ capture units. The final product is then transported to the Humberto Delgado
21 Airport, a major international airport in Lisbon, to uplift e-kerosene into aircraft
22 on the flight segment Lisbon-Porto. Figure 2 outlines the pathways considered,
23 the mass flow through the system, and the energy requirements for each unit
24 process. The LCA is performed by comparing (i) a baseline scenario using
25 average grid electricity and natural gas, followed by scenarios using (ii) onsite
26 solar energy and (iii) hybrid renewable systems (50% wind and 50% solar PV).
27 Through this coupled approach, the study aims to show how aligning e-kerosene
28 pathway operation with low-cost, low-carbon hours can simultaneously reduce
29 LCOF and environmental impacts, and to guide DAC technology choice and
30 operational strategies for PtL deployment in high-renewables power systems.

31

1 **Figure 2.** *Process flow diagram and system boundaries of e-kerosene production*2
34 System boundaries

5 The life cycle of e-kerosene production covered in this study comprises a
6 well-to-wake (WtWa) system that spans from feedstock acquisition and fuel
7 synthesis to fuel combustion during aircraft operation. The system boundary of the
8 WtWa e-kerosene life cycle is presented in Figure 2. The system boundaries
9 considered in this study include all CO₂eq emissions associated with the material
10 and energy inputs required for the production, transportation, and utilization of
11 e-kerosene. The functional unit is selected on an energy basis, therefore equal to
12 1 MJ of e-kerosene. Both S-DAC and L-DAC technologies are modelled,
13 allowing for comparison of energy requirements and the gCO₂eq/MJ intensity of
14 the resulting e-kerosene production plant. Additionally, co-products (e-naphtha
15 and e-diesel) were not allocated environmental credits in this study, allowing the
16 analysis to focus conservatively on the primary aviation fuel output. Ecoinvent
17 databases for fossil jet fuel production were used to represent the transportation
18 of the fuel to the end consumer, as well as the end-use utilization. In terms of the
19 latter, the combustion emissions from e-kerosene are balanced by the CO₂
20 previously captured, as atmospheric CO₂ constitutes the main building block of
21 the e-kerosene. Thus, the emissions associated are counted as biogenic/recycled
22 atmospheric carbon, but non-CO₂ effects (NO_x, contrails) are excluded [19][34].

23

24 Impact assessment

25 In order to assess the LCA methodology impact, the SimaPro category
26 “Recipe 2016 midpoint (H)” was selected due to its popularity among LCA
27 practitioners, as well as its ability to estimate GWP for long time horizons. Out
28 of the 18 calculated environmental impacts, the GWP is discussed, along with
29 the water footprint and urban land transformation.

1 **Results**

2

3 In this work, a comprehensive TEA was carried out alongside an LCA study.

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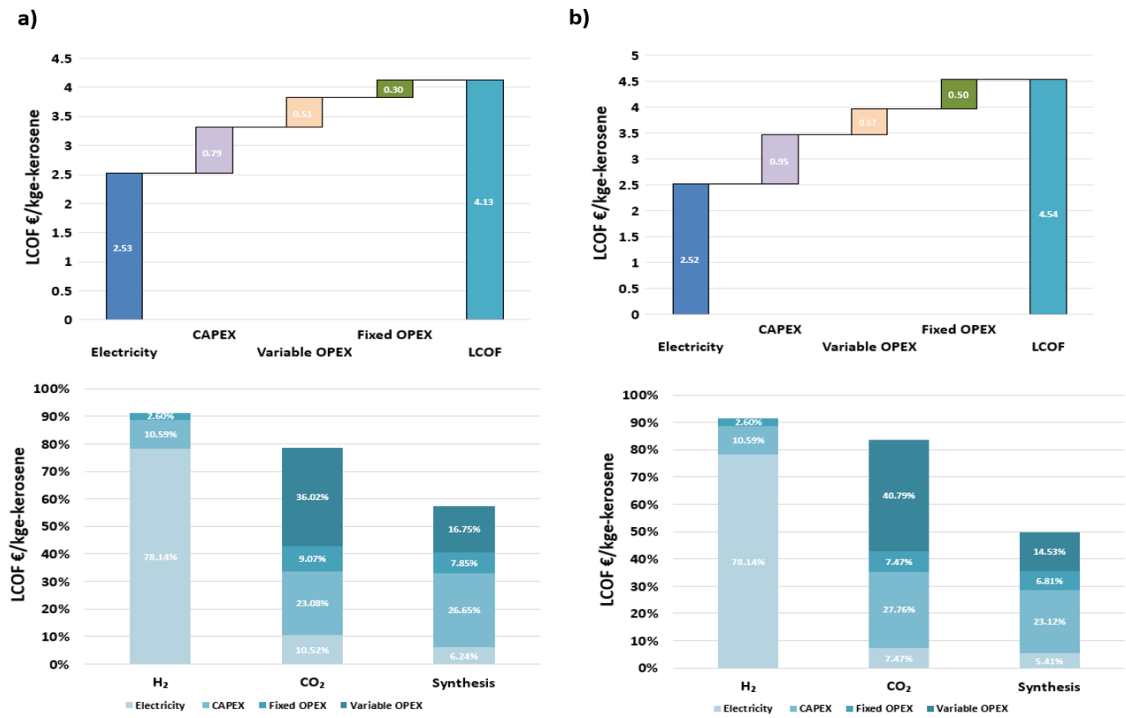
5 *Economic Performance*

6

7 To highlight the cost-driving steps of producing e-kerosene across the two
 8 DAC configurations investigated, the breakdown of the main constituents of the
 9 e-kerosene price is depicted in Figure 3. The cost of fuel over the analyzed period
 10 (20 years) is given by the LCOF, the most common economic indicator for e-
 11 fuel projects. The results obtained show an estimated LCOF of 4.13 €/kg for S-
 12 DAC and 4.54 €/kg for L-DAC. By analyzing the LCOF breakdown in Figure 3,
 13 it is noticeable that electricity costs are the largest contributor to the cost of e-
 14 kerosene production, followed by CAPEX and OPEX. Electricity costs, majorly
 15 associated with hydrogen production, dominate the total production costs,
 16 ranging from 60-80%. This finding is consistent with recent e-kerosene TEAs
 17 [5][27], which have found the same cost share distribution, with the electricity
 18 costs required to operate the electrolysis unit accounting for 50-70% of the total
 19 production cost. CO₂ capture associated costs represent the second largest cost
 20 contributor, depending on the sourcing method, with S-DAC accounting for
 21 23.3% while L-DAC accounting for 30.3%, relatively higher due to additional
 22 thermal heat requirement expenses.

23

24 **Figure 3.** Breakdown of the e-kerosene LCOF in absolute numbers for a
 25 capacity factor of 80%, an annual production of 10 kt/year, WACC of 8%, and
 26 a lifetime of 20 years for a) S-DAC and b) L-DAC

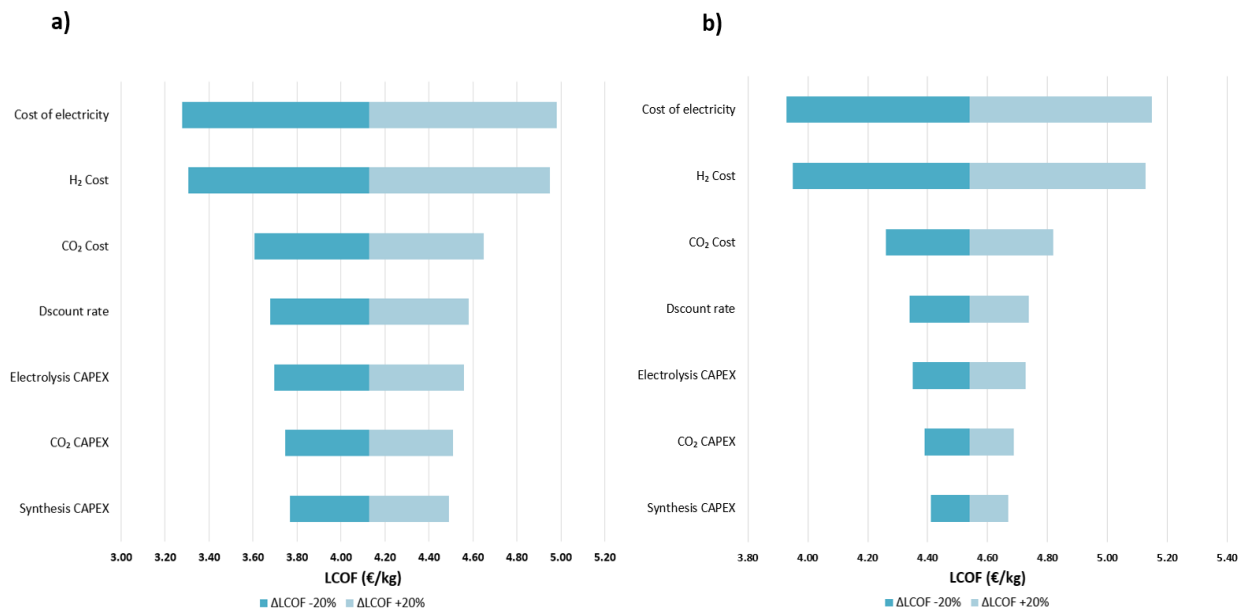


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28

1 As depicted in Figure 3, the S-DAC route was found to yield the lowest
 2 LCOF. Overall, when comparing the LCOF values obtained for e-kerosene
 3 produced via S-DAC or L-DAC, respectively, with the current price of jet fuel
 4 of around 0.73 €/kg, an increase of almost 6 times is observed. Even if acting as
 5 an additive, following ReFuelEU guidelines for 2035 of a minimum SAF blend
 6 of 20%, it would still configure a cost 2-2.5 times more expensive than the
 7 current jet fuel price in Europe. Therefore, accelerating the deployment of
 8 renewable energy sources, coupled with more efforts in enhancing capture
 9 technologies and hydrogen production, is essential to project e-fuels in the
 10 aviation sector. Figure 4 illustrates the sensitivity analysis conducted by varying
 11 each parameter by $\pm 20\%$ and observing the impact on the final e-kerosene
 12 LCOF.

13
 14 **Figure 4.** Sensitivity of cost parameters on the final overall levelized cost for e-
 15 kerosene



16
 17
 18 As depicted in Figure 4, for both DAC configurations, the variation in
 19 electricity ($\pm 20\%$) leads to a more pronounced effect on LCOF, followed by H₂
 20 and CO₂ costs, the discount rate, electrolysis, DAC, and synthesis CAPEX. The
 21 demonstration that these factors are the most sensitive reinforces those seen in
 22 Figure 3, which shows that PtL e-kerosene is much more sensitive to electricity
 23 prices than to capital costs, resulting in an increase of approximately 24-26% in
 24 the LCOF, compared to the 5-7% seen for the electrolyser CAPEX variation.
 25 The capital cost of the fuel synthesis facility, along with CO₂ and electrolysis
 26 CAPEX, and the discount rate, have minor impacts, accounting for increases of
 27 2-3%, 3-5%, 5%, and 5-8%, respectively. Nonetheless, it is important to note
 28 that the H₂ cost is the second most sensitive parameter, followed by the CO₂ cost,
 29 leading to variations in the order of 9% and 22%, respectively, indicating the
 30 significant influence of the capital expenditure associated with electrolysis units

1 and DAC plants on the final cost of e-kerosene. This observation emphasizes
2 that while direct capital costs related to the fuel synthesis plant may not have a
3 large impact on the final cost of fuel, downstream capital costs, such as
4 electrolysis and DAC, play a crucial role.

5 As denoted from the results obtained, the impact of energy sources is
6 noticeable from S-DAC to L-DAC. Although e-kerosene via the S-DAC route
7 resulted in the lowest LCOF and benefits from modularity and ease of operation,
8 real-scale feasibility is constrained by technology maturity. The current largest
9 S-DAC project, the Mammoth plant in Iceland, captures up to 36,000 tons of
10 CO₂ annually. Despite pronounced developments in low-temperature DAC
11 technology, if projected learning rates of 10-12.5% don't see an increase by
12 2050, the technology will not follow the growth expected to supply e-fuels, in
13 particular e-kerosene demands [35]. On the other hand, L-DAC configuration
14 leads to a higher LCOF, mainly associated with the system's high-temperature
15 operation requirement. Other implications are related to the system's reliance on
16 external thermal energy and water for circulation, as well as limitations in
17 installing more sustainable heat sourcing options, since relying on technologies
18 such as solar energy collectors could lead to additional costs related to the
19 installation of industrial-scale heat pumps. These current constraints make the
20 route less favorable for short-term e-kerosene production [36]. However, from a
21 long-term perspective, the greater operational flexibility offered by liquid
22 solvent systems, combined with their ability to integrate waste heat recovery,
23 can compensate for potentially higher capital requirements. Despite the cost
24 disparity, the trade-offs of each technology highlight the need for technology
25 selection to be guided by site-specific factors rather than inherent cost
26 advantages.

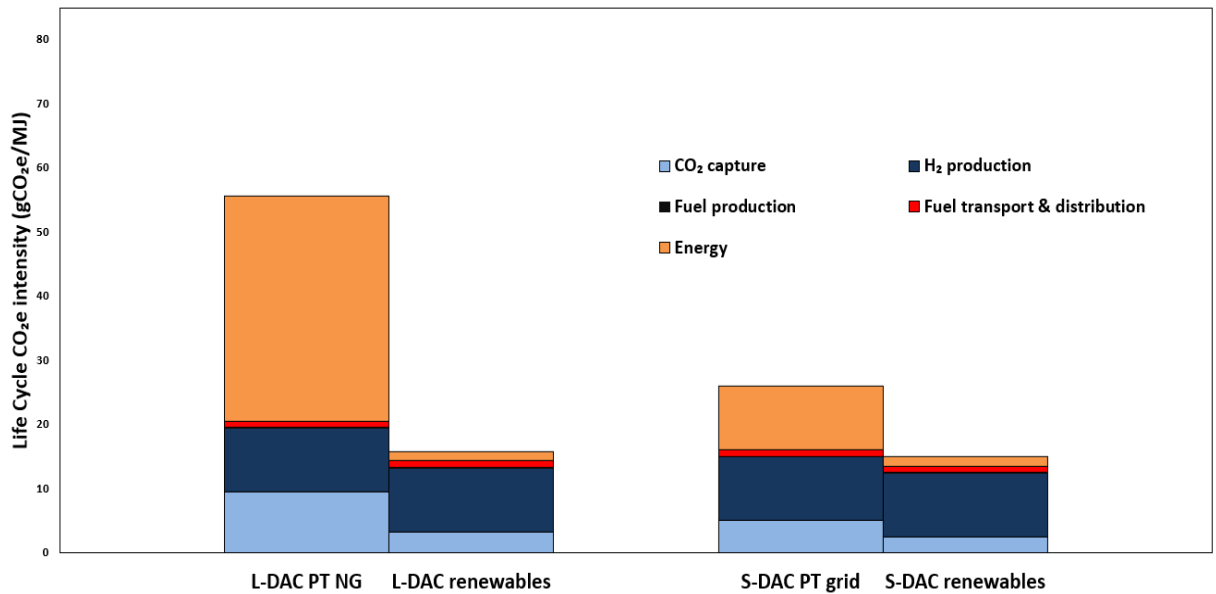
27 Overall, substantial uncertainty surrounds the future cost trajectories of both
28 technology families. The relatively early stage of commercial deployment for
29 both configurations implies significant learning potential, with cost reductions
30 possible through manufacturing scale economies, improved sorbent materials,
31 and process intensification [37]. Additionally, the potential e-kerosene cost
32 reduction under predictable seasonal electricity availability favors technologies
33 capable of sustained operation during periods of renewable abundance,
34 potentially benefiting liquid solvent systems in regions with pronounced
35 seasonal generation patterns.

36 *Environmental Performance*

37
38
39 LCA is an invaluable tool for understanding the environmental implications
40 of e-kerosene, from raw material acquisition through end-of-life considerations.
41 In this study, an LCA was performed to compare the life cycle GWP, as well as
42 water footprint, and land transformation of e-kerosene production from different
43 carbon capture pathways. Figure 5 illustrates the GWP emissions saving
44 potential by DAC technology configuration.

45
46

1 **Figure 5.** Life cycle CO₂eq emissions of PtL SAF under the different scenarios
 2 of CO₂ capture technology and electricity source



3
 4
 5 As depicted in Figure 5, the LCA revealed a GWP of 15.05 and 16.10
 6 gCO₂eq/MJ for S-DAC and L-DAC, respectively, when considering 50% solar-
 7 wind renewables and onsite solar energy contributions. There is a large range in
 8 results depending on the CO₂ capture technology and electricity scenario,
 9 ranging from 15.05-55.59 gCO₂eq/MJ. The L-DAC emissions breakdown
 10 compares technology's environmental performance when energy is sourced
 11 using both district heat and solar collectors. Since natural gas is used to provide
 12 heat to the L-DAC system, which requires high operating temperatures, the large
 13 contribution of CO₂ emissions is consistent with Prats-Salvado et al. [38], who
 14 reported GWP emissions for L-DAC using the EU heat source of 55.0-64.0
 15 gCO₂eq/gCO₂. A significant reduction can be observed when the L-DAC system
 16 transitions from a natural gas heat-supplier system to solar collectors, a decrease
 17 of around 71% in CO₂eq emissions. S-DAC, on the other hand, presents lower
 18 overall emissions, at around 15.05 gCO₂eq/MJ. The capture technology's
 19 reliance on electricity requirement per mass of CO₂ leads to higher emission
 20 impacts of around 26.09 gCO₂eq/MJ when grid electricity is used. When the
 21 high-temperature DAC plant is employed, over 90% is attributable to natural
 22 gas, while when the low-temperature DAC plant is used, up to 84% is caused by
 23 construction and End-of-life of the PtL and DAC plants.

24 Overall, being of synthetic origin, e-kerosene burns cleaner than
 25 conventional jet fuel, thereby reducing volatile and non-volatile particle
 26 emissions [21]. Just as seen from other studies, the GHG emissions potential
 27 reduction is significant during the utilization phase of synthetic aviation fuels,
 28 even potentially achieving negative values. Along with the GWP obtained for
 29 this study, similar studies as the one conducted in the UK [19], reported
 30 emissions significantly below the nation's emission reduction mandate. Despite

1 the emission reduction is directly linked to the e-kerosene's production process
 2 and feedstock acquisition, the findings achieved reaffirm the importance of e-
 3 fuels in achieving global neutrality goals, particularly in the aviation
 4 transportation sector.

5 In the context of aviation decarbonization, several regulatory frameworks
 6 have established minimum life cycle GHG emission reduction thresholds in
 7 sustainable aviation fuels. Table 3 summarizes the key mechanisms for life cycle
 8 GHG emission reduction.

9
 10 **Table 3.** *Comparison of aviation life cycle GHG emission thresholds*

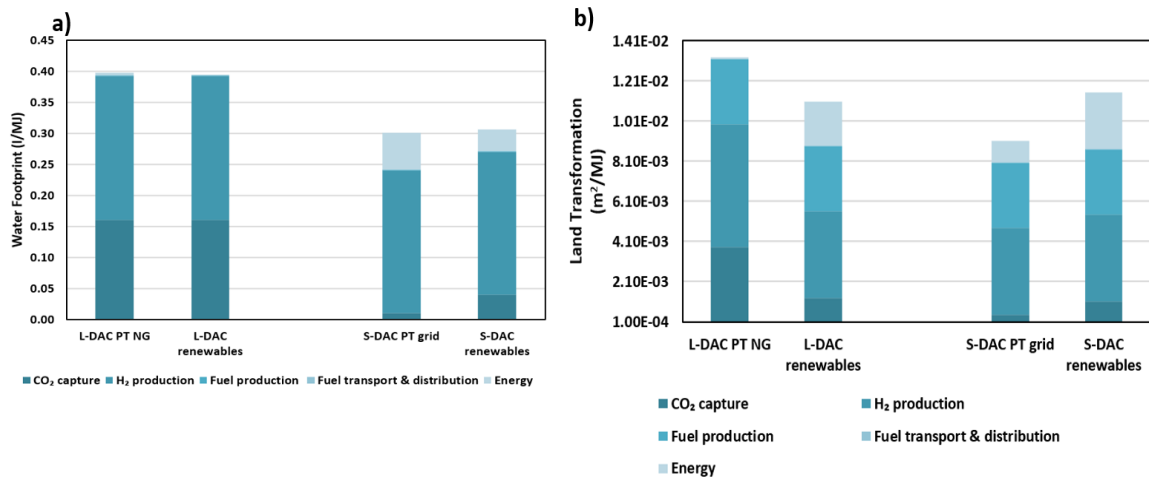
Framework	Required Reduction vs Fossil Jet Fuel	Equivalent Threshold (gCO ₂ eq/MJ)	Compliance in This Study
CORSIA	10%	84–85	All scenarios
UK SAF Mandate	40%	~53	All scenarios
US SAF Credit Benchmark	50%	~45	All scenarios except L-DAC + NG
EU ReFuelEU Aviation	70%	28.2	Renewable-powered S-DAC and L-DAC only

11
 12 As shown in Table 3, a key mechanism in this context is the Carbon
 13 Offsetting and Reduction Scheme for International Aviation (CORSIA), which
 14 mandates that SAF pathways achieve a minimum of 10% reduction in life cycle
 15 GHG emissions compared to the conventional jet fuel baseline of 89–94
 16 gCO₂eq/MJ [39]. In parallel, the UK, US, and EU have established more
 17 ambitious reduction targets of approximately 40%, 50%, and 70%, respectively
 18 [40]. Under the ReFuelEU Aviation framework, synthetic aviation fuels must
 19 also comply with the Renewable Fuels of Non-Biological Origin (RFNBO)
 20 criteria in order to meet the designated synthetic fuel sub-targets, projected to
 21 increase to 35% by 2050 [6]. As illustrated in Figure 5, all scenarios evaluated
 22 in this study satisfy the minimum GHG reduction thresholds established by
 23 CORSIA as well as the UK and US regulatory frameworks. However,
 24 compliance with the more stringent EU threshold of 28.2 gCO₂eq/MJ is only
 25 achieved under scenarios where renewable electricity is integrated into the PtL
 26 production pathway, particularly with the S-DAC configuration. These results
 27 underscore the significant reliance of PtL SAF environmental performance on
 28 electricity carbon intensity and thermal energy sourcing, while also
 29 demonstrating how regional regulatory frameworks can influence the
 30 deployment and technology selection of DAC-based e-kerosene systems.

31 Figure 6 illustrates the performance of water footprint and land
 32 transformation life cycle indicators.

33

1 **Figure 6.** *E-kerosene production climate indicators: a) water footprint and b)*
 2 *land use*



3

4

5

5 Water Footprint

6 Additionally, the water footprint indicator was evaluated, showcasing the
 7 environmental impact of water consumption associated with energy conversion
 8 processes. In e-fuel production, water is mainly needed as a hydrogen source in
 9 the water electrolysis step, where it is employed as feedstock in quantities that
 10 are defined by the reaction stoichiometry of the fuel synthesis. This fact is
 11 confirmed by the results depicted in Figure 6a), presenting the following
 12 distribution: hydrogen production on the top, accounting for almost 50% of the
 13 overall water footprint (WtWa analysis), followed by refinery plant necessities
 14 and CO₂ capture. Regarding the water footprint associated with the type of DAC
 15 configuration, it is reported that S-DAC extracts water from air at a rate of ~1
 16 t/tCO₂captured. L-DAC, on the other hand, uses water at a rate of 4.7
 17 t/tCO₂captured, although it doesn't consume any H₂O directly, since the water is
 18 kept in the production loop and later discharged, acting as a circulating fluid for
 19 cooling, generating steam, or heat transfer applications. For the S-DAC plant,
 20 the contribution of extraction from air ranges from 0.01-0.04 l/MJ, the direct
 21 consumption in fuel production up to 4.17×10^{-3} l/MJ, and indirect consumption
 22 (from the energy sources) up to 0.04 l/MJ. For the high-temperature DAC plant,
 23 extraction from air does not occur, and the hotspots are direct consumption in
 24 the DAC plant (0.16 l/MJ) and in fuel production (i.e., from water electrolysis).
 25 Therefore, the main drivers of freshwater consumption are either electrolysis or
 26 DAC when the high-temperature DAC plant is used.

27 When compared with biofuels, e-fuel's water consumption is by several
 28 orders of magnitude lower than that of first generation biomass alternatives.
 29 Biofuels footprint is expressive since they require water for inherent steps of
 30 feedstock acquisition, from agricultural practices to local climatic conditions and
 31 soil properties. According to the study conducted by [1], e-kerosene water
 32 footprint translates into a net water consumption of around 170,000 m³/year for
 33 a production of 100 kt/year. Even though it may be considered negligible
 34 compared to biofuel's water demands, local water availability and supply

1 options are relevant aspects that are typically addressed in local environmental
2 impact assessments. Water footprint, for instance, if reduced, could lead to an
3 overall benefit for SAF's environmental impact and improve the overall
4 sustainability of aviation.

5 6 Land Transformation

7 Land transformation represents another performance indicator of
8 environmental importance. Overall, the results highlight that the total land
9 transformation is mainly caused directly and indirectly by the wind and PV
10 power plants. For reference, from a gross area demand point of view, e-fuels
11 generally yield relatively higher area-specific fuel compared to biofuels. It is true
12 since biofuels require extensive land areas for agricultural biomass production,
13 which land coverage reaches near 100%, while dedicated renewable plants such
14 as PV and wind power typically occupy smaller land that can still serve for other
15 purposes. Along with the required land area, it is also important to evaluate the
16 type of land. Renewable power generation usually doesn't require arable land
17 for deployment, with desert regions being particularly suitable for PVs or solar-
18 thermal power generation. Therefore, e-fuels largely reduce the risk of
19 competition between energy and food production. Biofuels face direct
20 competition to keep supplying feedstock for e-fuels production. The pathway
21 typically relies on forest residues/forest logging residues, which are in direct
22 competition with paper and pulp, power and heat, and road transport sectors. It
23 is estimated that due to the limitation of forest residues, additional feedstock for
24 other applications will make SAF production competitive. As land
25 transformation linked to the installation of renewable power has proven to be a
26 polarizing topic in political discourse, it is pointed out that considering different
27 geographical locations could have a strong influence on land transformation.

28 29 30 **Conclusions**

31
32 In this study, a comparative techno-economic analysis of e-kerosene
33 production for different carbon capture configurations, along with an LCA that
34 has assessed environmental indicators beyond global warming potential. The
35 techno-economic analysis of e-kerosene production and utilization presents a
36 rapidly evolving landscape of opportunities, challenges, and implications. The
37 most significant expenses were associated with electricity requirements. The
38 impact of carbon capture configuration is showcased by the LCOFs obtained of
39 4.13 €/kg and 4.54 €/kg for S-DAC and L-DAC, respectively. Overall, these
40 alternative configurations are not only relevant in e-kerosene production cost,
41 but they also create a critical design trade-off between the plant's electrical
42 efficiency and its thermal synergy with the exothermic FT synthesis unit,
43 reinforcing the need to co-optimize CO₂ sourcing and power supply when
44 designing e-kerosene systems. The LCA results revealed that life cycle
45 emissions of 15.05 gCO₂eq/MJ and 16.10 gCO₂eq/MJ under S-DAC and L-DAC
46 scenarios, respectively, a substantial reduction of 71% and 42% compared with

1 operation under a Portuguese grid mix electricity source. The Lisbon-Porto
 2 segment chosen for this study is representative of the local baseline for
 3 volumetric and operational modelling within Portugal. Applying the study
 4 conclusions to long-haul international flights departing from Lisbon would lead
 5 to an escalation in fuel cost production and environmental performance. From a
 6 transportation systems perspective, the findings suggest that PtL SAF pathways
 7 could significantly contribute toward aviation decarbonisation targets in regions
 8 with high renewable electricity penetration, such as Portugal, although
 9 substantial cost gaps compared to fossil jet fuel still remain. As the transition
 10 from conventional fuels to sustainable alternatives accelerates, a thorough
 11 understanding of TEA and LCA provides valuable insights for stakeholders and
 12 policymakers.

13
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