GUIDE FOR FEASIBILITY STUDIES ON SUSTAINABLE AVIATION FUELS

Version 1.0 (July 2023)

FOREWORD

The ICAO Assistance, Capacity-building and Training for Sustainable Aviation Fuels (ACT-SAF) Programme was launched in June 2022. Its objective is to enable States to develop their full potential in SAF development and deployment, in line with the ICAO's *No Country Left Behind initiative*, the 2050 ICAO Vision for SAF, and the three main pillars of sustainable development – economic, social, and environmental, recognized by the United Nations.

A template has been developed in the context of the ICAO ACT-SAF Programme to facilitate the preparation of standardized feasibility studies on SAF. It can be used to assess the feasibility of SAF development and deployment both at the State and Regional (i.e. group of States) level.

In addition, ICAO has also developed this guide to complement the template. Being consistent with the structure defined in the template, it incorporates examples of outcomes from a selection of publicly available feasibility studies, as well as resources on SAF published by ICAO, to show in a practical manner varying approaches in support of the development of a feasibility study. This guide may also stimulate further discussions between the State and consultant performing these studies, to drive desired outcomes, and facilitate next steps in SAF development and deployment.

Depending on the varying context and objectives of each feasibility study, and the differing circumstances of States, the guide also explains why and how outcomes of one may be different from another.

For any questions, assistance, or suggestions, please contact the ICAO Secretariat by email (officeenv@icao.int) indicating "**ACT-SAF FS guide**" in the subject of the email message.

ICAO extends its appreciation to all our ACT-SAF Partners who have contributed to the preparation of this Guide.

EXECUTIVE SUMMARY

The Executive Summary provides a concise, high-level overview of the entire feasibility study, highlighting the most important and relevant findings and recommendations for decision-makers. It provides an overview of the background, the key findings of the study, policy implications and the opportunities mapped.

It summarizes the findings of the study such as the recommendations for feedstock and fuel conversion technologies prioritization, land use change and greenhouse gas life-cycle emissions reduction potential, and socio-economical and policy-related findings, including synergies with other (neighbouring) States.

It also highlights key aspects associated with the development, deployment and commercialization of SAF in the State under consideration, from multiple perspectives, such as from the government, fuel producers, feedstock producers, airlines, financing institutions and other key stakeholders.

The sections below detail various examples of the approach and design of an Executive Summary.

A. Background

This section in the executive summary generally provides a brief overview of the background of the feasibility study, including the reasons for conducting the study, and its main objectives.

In a number of feasibility studies, the development and deployment of SAF has been identified as a key mitigator of aviation emissions, contributing to a State's energy transition roadmap, and also to ICAO's aspirational goals for the international aviation sector. For example, the SAF feasibility studies for several States have been completed, as part of the ICAO-EU Assistance Project: Capacity building for CO2 mitigation from international aviation. In particular, for the project in Kenya, the study focused on examining the feasibility of various feedstock – taking into consideration conflicting uses, co-benefits, supply chain; and identifying an action plan to develop a viable SAF industry[1].

At times, a feasibility study may focus on specific feedstock and conversion pathways. This is evidenced in RSB's focus on Brassica Carinata (Ethiopian Mustard), having pre-identified it in a list of potential feedstocks whilst developing a SAF roadmap for Ethiopia, which subsequently commissioned a study to assess in further detail its SAF potential[2].

Also, a SAF feasibility study could be subsumed as part of a broader assessment of a State's energy transition, as GIZ's study on the opportunities of "Power-to-X" in Tunisia suggests[3]; or have its scope extend beyond SAF, evidenced in the ICAO-EU Assistance Project in Kenya, which also considered the supply of locally-sourced biodiesel for airport ground hander service equipment.

B. Key findings

[1] ICAO-European Union Assistance Project: Capacity building for CO_2 mitigation from international aviation. Feasibility study on the use of sustainable aviation fuels – Kenya. Page 4. https://www.icao.int/environmental-protection/Documents/FeasabilityStudy_Kenya_Report-Web.pdf#page=4

[2] Roundtable on Sustainable Biomaterials (RSB) – Pre-feasibility study for the production and processing of the Brassica Carinata (Ethiopian Mustard) crop for biofuels in Ethiopia. Page 22. https://rsb.org/wp-content/uploads/2023/05/RSB-Carinata-Report-D6.pdf#page=22

[3] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Study on the opportunities of "Power-to-X" in Tunisia. Page 12. https://www.giz.de/en/downloads_els/GIZ%20PtX%20Tunisia%20report-Web.pdf#page=12

This section summarizes the key findings of the feasibility study, highlighting the most important and relevant information for the State and its stakeholders. This should include an overview of the different types of feedstocks that were evaluated, the potential for expanding the use of different types of feedstock, and the critical success factors for the development, deployment and commercialization of SAF, including the key findings from the Action Plan developed.

Depending on the specific circumstances of each State (e.g. geography, demographics, climate, economics, etc.), the recommended feedstock/conversion pathways can be very different. For example, in the World Economic Forum Insight Report on Deploying SAF at scale in India, it noted four SAF feedstock/conversion pathways that would be the most feasible in the short term (Hydro-processed esters and fatty acids (HEFA), mostly from Used Cooking Oil (UCO), Alcohol-to-Jet (ATJ) using agricultural residues and surplus sugar streams, Gasification/Fischer-Tropsch using Municipal Solid Waste (MSW) and agricultural residues, and Power-to-liquid (PTL) based on hydrogen technology)[4], whereas in the ICAO-EU Assistance Project in Trinidad and Tobago, short term economic conditions (lack of level playing field in commercial markets) and lack of quantity and quality of locally sourced sustainable feedstock had made SAF deployment economically unviable[5]. Nonetheless, the recommendations would change if policy/economic condition were to evolve.

C. Policy implications

As in the case of many feasibility studies, this section should provide a snapshot view of the policy environment in the State impacting the development and deployment of SAF, and policy recommendations that could provide further support, in keeping with the objectives of the feasibility study. Any policy bottlenecks that risk hampering the emergence of a SAF market should be mentioned.

The ICAO Committee on Aviation Environmental Protection (CAEP) has developed a Guidance of potential policies and coordinated approaches for the deployment of SAF[6], which has been based on various studies performed since 2016. It provides an insight on the types of policy measures and their impacts, case studies from States, as well as links to additional helpful resources. Based on the Guidance, three key themes influence policy effectiveness:

1. Feasibility: Practicable and uncomplicated to implement
2. Effectiveness: Successful in producing a desired or intended result
3. Practicality: The policy targets the outcome rather than a theory or set of ideas.

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[4] World Economic Forum (WEF) Deploying Sustainable Aviation Fuels at Scale in India: A *Clean Skies for Tomorrow* Publication. Insight Report June 2021. Page 10 https://www3.weforum.org/docs/WEF_Clean_Skies_for_Tomorrow_India_Report_2021.pdf#page=10

[5] ICAO-European Union Assistance Project: Capacity building for CO_2 mitigation from international aviation. Feasibility study on the use of sustainable aviation fuels – Trinidad and Tobago. Page 4. https://www.icao.int/environmental-protection/Documents/FeasabilityStudies_TrinidadTobago_Report_Web.pdf#page=4

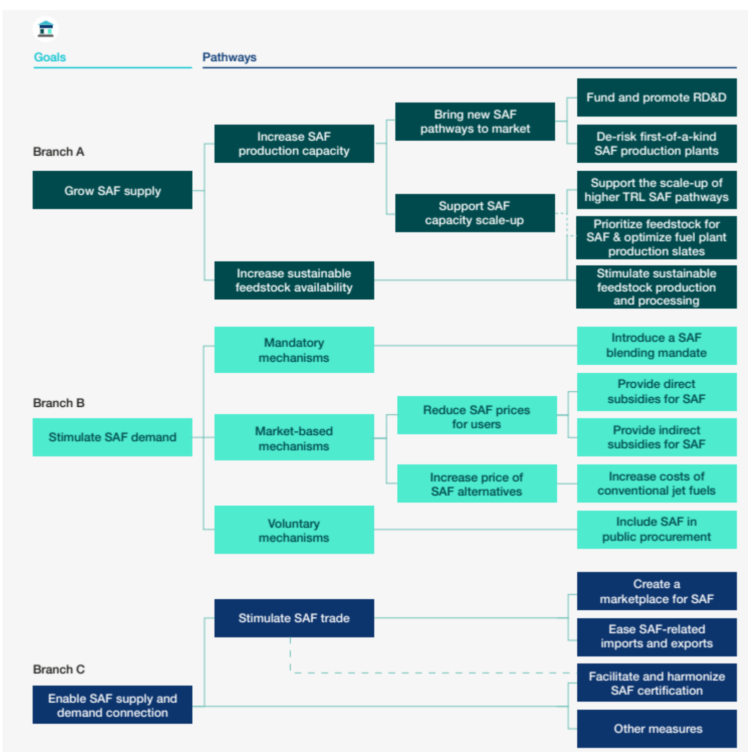
[6] ICAO Guidance on potential policies and coordinated approaches for the deployment of Sustainable Aviation Fuels. Page 27. https://www.icao.int/environmental-protection/Documents/SAF/Guidance%20on%20SAF%20policies%20-%20Version%201.pdf#page=27

The ICAO Guidance provides details on 28 policy options divided into three impact areas (Stimulating growth of SAF supply, Creating demand for SAF, and Enabling SAF markets), summarized below. Most of the analysis of a State's policy environment, as well as policy recommendations, would fall into either of these categories.

Impact area: Stimulating Growth of SAF Supply			
1 Government funding for RDD	**2 - Targeted incentives and tax relief to expand SAF supply infrastructure**	**3 - Targeted incentives and tax relief to assist SAF facility operation**	**4 - Recognition and valorization of SAF environmental benefits**
1.1 - Government R&D 1.2 - Government demonstration and deployment	2.1 - Capital grants ; 2.2 - Loan guarantee programs 2.3 - Eligibility of SAF projects for tax advantaged business status ; 2.4 - Accelerated depreciation/'bonus' depreciation 2.5 - Business Investment Tax Credit (ITC) for SAF investments 2.6 - Performance-based tax credit 2.7 – Bonds / Green Bonds	3.1 Blending incentives: Blender's Tax Credit 3.2 – Production incentives: Producer's Tax Credit 3.3 - Excise tax credit for SAF 3.4 - Support for feedstock supply establishment and production	4.1 – Recognize SAF benefits under carbon taxation 4.2 - Recognize SAF benefits under cap and-trade systems 4.3 - Recognize non-carbon SAF benefits: improvements to air quality 4.4 - Recognize non-carbon SAF benefits: reduction in contrails

Impact area: Creating Demand for SAF			Impact area: Enabling SAF Markets
5- Creation of SAF mandates	**6 - Update existing policies to incorporate SAF**	**7 – Demonstrate government leadership**	**8 - Market enabling activities**
5.1 - Mandate renewable energy volume requirements in the fuel supply 5.2 - Mandate reduction in carbon intensity of the fuel supply	6.1: Incorporating SAF into existing national policies 6.2: Incorporating SAF into existing subnational, regional or local policies	7.1 Policy statement to establish direction 7.2: Government commitment to SAF use, carbon neutral air travel	8.1 - Adopt clear and recognized sustainability standards and life cycle GHG emissions methods for certification of feedstock supply and fuel production 8.2 - Support development/recognition of systems for environmental attribute ownership and transfer 8.3 - Support SAF stakeholder initiatives

For example, the WEF Clean Skies for Tomorrow SAF Policy Toolkit takes a similar approach in policy recommendations, shown in the issue tree below, with further detail on implementation considerations, cost-benefit assessment, and case studies of its use[7].



[7] WEF Clean Skies for Tomorrow: Sustainable Aviation Fuel Policy Toolkit. Insight Report November 2021. Page 16. https://www3.weforum.org/docs/WEF_Clean_Skies_for_Tomorrow_Sustainable_Aviation_Fuel_Policy_Toolkit_2021.pdf#page=16

D. Opportunities and challenges

This section identifies and describe the opportunities for implementing SAF in an action plan, including the potential for feedstock expansion, the availability of financing, and the potential for reducing greenhouse gas emissions. It will also highlight any challenges and barriers that need to be addressed in order to realize these opportunities. This section may also include information on the market status in other States regarding the recommend SAF feedstock and conversion technologies. It could include information on the main industrial actors, investors, levels of production, and any opportunities and challenges faced in other States regarding the recommended SAF feedstock and conversion technologies.

SECTION 1. STATE-SPECIFIC INFORMATION

This section of a SAF feasibility study typically provides information on the specific circumstances of the State, explaining the unique characteristics and factors that could affect the development and deployment of SAF in the State under consideration.

This is typically done through a comprehensive literature review not limited to within the scope of aviation, and also interviews across various stakeholders in the aviation fuel supply chain (feedstock supplier, technology providers, fuel logistics, etc.), including government agencies responsible for aviation, environment, energy, etc.

1.1 Geography and Climate

A description of the State's geographical characteristics, climate zones, food and water availability, deforestation and land degradation issues should be included. Such aspects are typically more relevant towards agricultural (food/non-food) feedstocks, which can also include residues, as compared to wastes (municipal solid waste, used cooking oil, etc.). Some feasibility studies would provide analysis into which feedstock would be more suited towards a particular region/climate given the national geographic and climate aspects listed above, and a small selection (ICAO-EU Assistance Project in Burkina Faso and RSB's Development of SAF in Ethiopia: A Roadmap) have been detailed below[8,9].

Feedstock	Characteristics related to geography and climate
Jatropha	Tropical and sub-tropical climate, well adapted to arid regions, helps with soil erosion
Palm oil	Tropical and sub-tropical climate, with moderate to high rainfall
Sugarcane	Warm and tropical climate, high rainfall and irrigation needed
Castor seed	Medium tolerance to droughts
Brassica Carinata	Fertile and well-drained soil needed, tolerant to heat and drought, suitable for crop rotation and intercropping

At times, other resources not directly related to SAF feedstock, but covering broader agricultural aspects could be useful - with the interlinkages between sustainable food and bio-energy security. For example, resources such as the UN Food and Agriculture Organization (FAO) could potentially complement SAF feasibility studies through their analysis of similar themes of geography, climate, crop yields, and impact from climate change; as per the example below of the FAO's agro-economic zoning for major crops in Thailand on average annual precipitation[10], and crop suitability/potential production[11] (where some are known SAF feedstocks), and their potential impacts from climate change. The FAO also provides the Global Land Cover-SHARE (GLC-SHARE) land cover database, based on contributions from various institutions by a combination of "best available" high resolution national, regional and/or sub-national

[8] ICAO-European Union Assistance Project: Capacity building for CO_2 mitigation from international aviation. Feasibility study on the use of sustainable aviation fuels – Burkina Faso. Page 62. https://www.icao.int/environmental-protection/Documents/FeasabilityStudy_BurkinaFaso_Report-Web.pdf#page=62

[9] RSB – Development of Sustainable Aviation Fuel in Ethiopia: A Roadmap. Page 43. https://rsb.org/wp-content/uploads/2021/11/Development-of-Sustainable-Aviation-Fuel-in-Ethiopia-A-Roadmap-2021.pdf#page=43

[10] Food and Agriculture Organization of the United Nations (FAO) – Final Report – National Agro-Economic Zoning for Major Crops in Thailand (NAEZ). Page 16. https://www.fao.org/3/i7077e/i7077e.pdf#page=16

[11] FAO – Towards efficient and sustainable food and bio-energy security in Thailand. Page 2. https://www.fao.org/3/cb4766en/cb4766en.pdf#page=2

land cover databases[12].

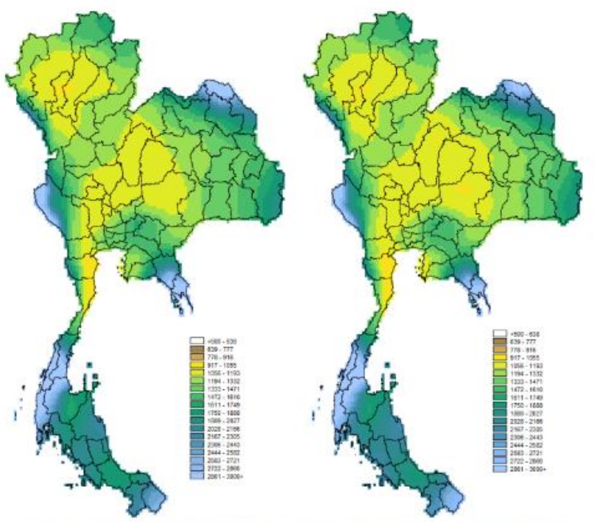


Figure 3 - Average annual precipitation (mm) in 1981 - 2010 and 2041 - 2070 (ensemble mean)

Impact of climate change on crop suitability and potential production

	Reference 1910–2010		Potential production (Δ %), 2050s
	VS+S Mill. Ha	VS+S+MS Mill. Ha	With
Rice	10.1	17.9	-10
Maize	8.9	15.6	8.1
Soybean	5.8	16.7	-1.1
Cassava	8.8	17.5	-19.9
Sugarcane	1.1	11.8	-32
Oil palm	2.6	3.2	-49
Rubber	1.7	2.9	-55
Coffee	0.5	2.4	-97.5
All eight crops*	16.9	19.9	-9.6

Note: VS=very suitable, S=suitable, MS=moderately suitable; * 'Umbrella' of crops giving highest net revenue in each grid cell and period

1.2 Trade and Governance

This section will provide information relating to trade and governance issues that pertain to the development and deployment of SAF in the State.

In addition, the institutional framework of stakeholders, public and private (including on financing), should be mapped out. In some States, there is already an existing structured network of vested stakeholders within the aviation sector, headed by a government agency, as the example of Trinidad and Tobago suggests[13], facilitating governance and enabling smoother implementation of environment initiatives.

In the design of roadmaps and its implementation, various government agencies (with mandates over energy, agriculture, trade, transport, environment, etc.) are often engaged, as the United States SAF Grand Challenge Roadmap shows[14].

	In Trinidad and Tobago, there is an Aviation Environmental Working Group headed by the Civil Aviation Authority, and works together with several other government entities and private agencies (airlines, ground handlers, etc) to implement environment initiatives.

[12] FAO: Global Land Cover – SHARE (GLC-SHARE) https://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1036355/

[13] ICAO-European Union Assistance Project: Capacity building for CO_2 mitigation from international aviation. Feasibility study on the use of sustainable aviation fuels – Trinidad and Tobago. Page 14. https://www.icao.int/environmental-protection/Documents/FeasabilityStudies_TrinidadTobago_Report_Web.pdf#page=14

[14] United States Office of Energy Efficiency & Renewable Energy: Sustainable Aviation Fuel Grand Challenge. https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuel-grand-challenge

	To achieve the SAF Grand Challenge Goals, the U.S. Department of Transportation, the U.S. Department of Agriculture, and other federal government agencies have partnered with the Department of Energy to develop a comprehensive strategy for scaling up new technologies to produce SAF on a commercial scale.

1.3 Demographics

This section provides information such as historical population, employment aspects relating to aviation fuels, and to the aviation sector globally. In doing so, it provides perspectives on the critical role of aviation/aviation fuels to the economy, and the need to ensure that it is maintained in the energy transition. This is more prevalent in States with a high ratio of aviation activity to economic footprint[15].

1.4 Vulnerability to Climate Change, and

1.5 Agriculture

These sections provide information relating to the vulnerability of the State to climate change, focusing on issues relating to SAF, as well as information on agricultural practices focusing on SAF feedstock, soil conditions, etc.

It is possible that the analysis in these sections be subsumed into Section 1.1: Geography and Climate, or as a standalone, depending on a State's engagement with the consultant performing the feasibility study.

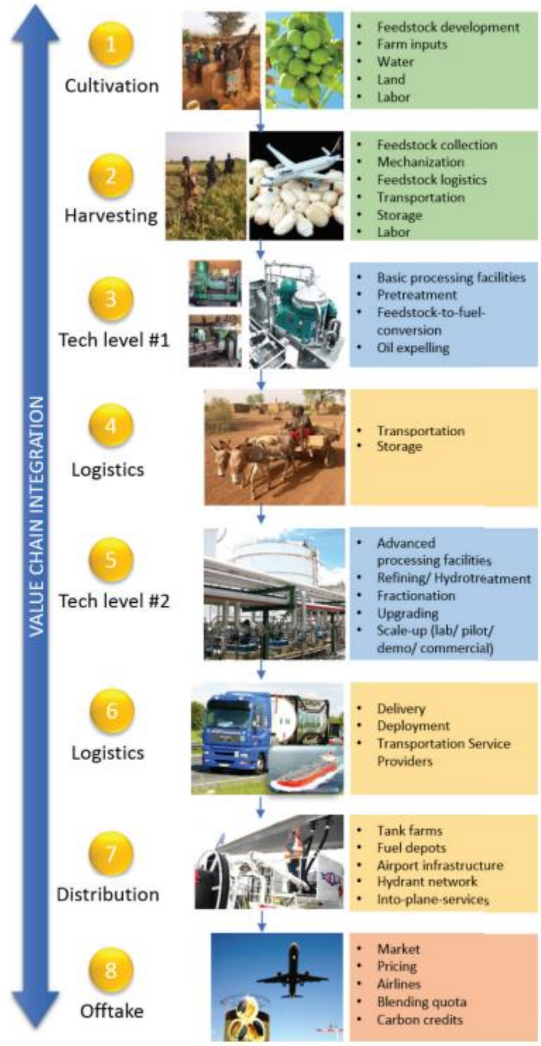
1.6 Energy

This section provides information on current and forecast energy demand, energy infrastructure, including refinery capacity, and historical production and use of aviation fuels (conventional and SAF), cleaner energy sources, energy transition plan(s), roadmaps and policies. It may include information on competing demand for sustainable liquid fuels from other sectors. On policies, it may also include existing supporting/inhibitory policies, stakeholders' interests and strategies (trajectories/targets) towards SAF, international/regional agreements towards environmental protection that may not necessarily be related to air transport.

[15] WEF Clean Skies for Tomorrow in collaboration with ICF International. Power-to-Liquids Roadmap: Fuelling the Aviation Energy Transition in the United Arab Emirates. White Paper July 2022. Page 6. https://www3.weforum.org/docs/WEF_UAE_Power_to_Liquid_Roadmap_2022.pdf#page=6

1.7 Aviation fuel supply chain

This section provides information on the supply chain that relate to aviation fuels (ground transport facilities, airports, etc.), as well as options for SAF integration into the aviation fuel supply chain (upstream/downstream blending, ASTM certification), as highlighted in the figure[16]



[16] ICAO-European Union Assistance Project: Capacity building for CO_2 mitigation from international aviation. Feasibility study on the use of sustainable aviation fuels – Burkina Faso. Page 97. https://www.icao.int/environmental-protection/Documents/FeasabilityStudy_BurkinaFaso_Report-Web.pdf#page=97

SECTION 2. EVALUATION OF FEEDSTOCKS AND PATHWAYS FOR SAF PRODUCTION

Section 2 should start with a brief definition of what are SAF. SAF is defined as renewable or waste-derived aviation fuels that meets sustainability criteria. A SAF pathway is defined as a specific combination of feedstock and conversion process used for SAF production. In many feasibility studies, assessments start with feedstock analyses, which will then move towards the potential conversion processes that could be used for SAF production for each of these feedstock. The assessments typically cover:

1. **Detailed information on each feedstock**
2. **Sustainability-related aspects, including greenhouse gas emissions**
3. **Economic/Market-related aspects**
4. **Overall Assessment.**

Consultation with the State and its stakeholders (fuel providers, energy/agricultural authorities, etc.) on each of these categories will result in a better understanding of the State's circumstances and priorities, facilitating its evaluation. For example, in a feasibility study done in Australia[17], while it covered the domestic production of natural oils comprising of existing food (canola, cottonseed) and non-food (tallow, brown grease, used cooked oil) feedstock, its study partners had preferred to maximize the use of non-food competing feedstock instead, and also in-keeping with the sustainability practices of its study partners. Depending on the complexity of the evaluation, the study may provide both qualitative and quantitative aspects (e.g. land and yields for particular feedstocks, minimum fuel selling prices).

An overall assessment (see section "Summary of evaluated feedstock") will provide a topline perspective of the most viable pathways, which a State may then focus its implementation support on.

2.1 Detailed information on Feedstock 1 (Repeated for other feedstock)

2.1.1 Feedstock-related Information

This section provides information of the feedstock in question – covering aspects such as:

1. Availability assessment
2. Main production/collection areas
3. Historical production/collection
4. Suitable conversion processes for SAF production
5. Possibility for production expansion and projections
    a. Potential for expansion of production on unused lands
    b. Potential of yield increase in existing production areas
6. Key stakeholders
7. Technological-readiness level
8. Use in other modes of transport, if applicable

A feasibility study would typically map the potential feedstock, with its strengths and weakness, yield and

[17] ARENA Public Report: Feasibility Study of Australian feedstock and production capacity to produce sustainable aviation fuel. June 2013. Page 16. https://arena.gov.au/assets/knowledge-bank/aviation-biofuel-report.pdf#page=16

requirements, as the comparison table of for the assessment done of Kenya shows[18] (ICAO-EU Assistance Project).

Feedstock	Strengths	Weaknesses	Yield	Alternate Fuel Yield L/Ha/year	Land Requirement	Notes on Viability
Cassava	*Non-Invasive *Hardy crop	*Potential food/fuel conflict *Can cause soil erosion *Would require large areas of broad-scale planting to ensure required feedstock quantity *Logistics framework non-existent	9.6 tonnes/ha/year 160-180 litres ethanol/tonne	1,000	50,000 Ha/ 100,000 Ha	Low – food competition issue. Commercialization hurdles to address before ethanol to aviation fuel becomes viable.
Sugarcane	*Industrial scale planting in place with required logistics *Non-Invasive *Hardy crop	*Food/fuel conflict relating to cane sugar and molasses *Bagasse availability uncertain due to alternative uses *Constrained by lack of irrigation	Cane: 71 v Sugar yield: 70 L/tonne Molasses : 10 L/tonne Bagasse yield: 32 tonnes/ha Sugarcane tops 15 tonnes/ha	- 440 2,400 (ATJ) 3,75 (ATJ)	- 1 10,000 Ha/ 220,000 Ha 21,000 Ha/42,000 Ha 130,000/ 260,000 Ha	Considered low viability for sugar/molasses due to competing uses. Financial hurdles before ethanol to aviation fuel becomes viable. Bagasse shows promise if supply can be secured. Cane,tops show good promise as a feedstock.
Sweet Sorghum	*Can produce both food and fuel	*Specialised harvesting equipment required *No current planting in the country *Would require broad-scale planting	30-40 tonnes/ha/ year (stalk sugar) 40 L/tonne ethanol yield	875 (stalk)	55,000 Ha/ 110,000 Ha	Low – food competition issue. Financial hurdles before ethanol to aviation fuel becomes viable.
Castor oil seed	*Suited to growing in agroforestry systems involving food crops and trees *Easy to cultivate *A high oil content and relatively low cost of production	*Invasive plant that has medium tolerance to drought *Castor does best on fertile, well- drained soils, therefore it may conflict with food uses on arable lands	0.23 (rainfed) tonnes/ha/year 448 litres oil/tonne	64	780,000 Ha/ 1,560,000 Ha	Low potential due to decentralized production and lack of mechanical harvesting. Would require significant area under cultivation.
Coconut	-Coconut is non-invasive, has medium tolerance to drought	-Very susceptible to pests	1.64 (kenya) tonnes/ ha/year 364 litres oil/tonne	300	170,000/ 340,000 Ha	Low – food competition issue. Low due to requirement of large monoculture and harvesting and logistic inefficiencies. Competition with food.
Croton	*Native to the region, widespread *Croton's deep tap-root can withstand drought *The tree produces well for many years and has many other uses and benefits on the farm	*Manual harvesting *Complicated logistics	2.5 tonnes/ha/year 336 litres oil/tonne	420	120,000/ 240,000 Ha	May prove viable in long term with development of harvester and large-scale monoculture.
Jatropha	*Jatropha is used to control soil erosion, especially in semi-arid areas, and its seedcake, which is high in nitrogen, can be used to improve soils	*Takes five to seven years to reach maturity and full production *Seeds contain a highly toxic substance called curcasin *Plantations cannot easily be mechanized *Jatropha is also considered invasive in many parts of the world *Susceptible to many pests and diseases	2.5 (rainfed) tonnes/ ha/year 336 litres oil/tonne	420	120,000/240,000 Ha	Considered unviable option for Kenya – see text.

2.1.2 Sustainability-related aspects, including greenhouse gas emissions

This section provides information on sustainability aspects associated with the feedstock in question, using as a basis the Sustainability Themes and related criteria for CORSIA Sustainable Aviation Fuels. Further details on CORSIA Sustainable Aviation Fuels, including default life cycle emissions values, methodology for calculating actual life cycle emissions values, and guidance for sustainability certification schemes is provided in the link[19].

CO_2 reduction themes	
1. Greenhouse gases 2. Carbon stock	SAF should generate lower carbon emissions on a life cycle basis – in CORSIA, a 10% reduction to the baseline life cycle emissions

[18] ICAO-European Union Assistance Project: Capacity building for CO_2 mitigation from international aviation. Feasibility study on the use of sustainable aviation fuels – Kenya. Page 41. https://www.icao.int/environmental-protection/Documents/FeasabilityStudy_Kenya_Report-Web.pdf#page=41

[19] ICAO Environment – CORSIA Eligible Fuels https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx

3. Greenhouse gas emissions reduction permanence	values for aviation fuel on a life cycle basis is applied[20]. The ICAO document – CORSIA default life cycle emissions values for CORSIA Eligible Fuels[21], and CORSIA methodology for calculating actual life cycle emissions values[22] provide further information on default values and methodology to calculate actual life cycle emissions values. Tools such as the GHG Regulated Emissions and Energy in Transport (GREET[23]) model are also useful references in performing life cycle assessment (LCA) of transportation fuels. FAO resources highlighted in Section 1.1 provide information on land cover, where together with access to satellite imagery, may provide indication on themes relating to carbon stock.
Environmental themes	
4. Water 5. Soil 6. Air 7. Conservation 8. Waste and chemicals 9. Seismic and vibrational impacts	The ICAO Document – CORSIA Sustainability Criteria for CORSIA Eligible Fuels provide guidance for these themes, where the production of CORSIA SAF should maintain or enhance water quality and availability, soil health, minimize negative effects on air quality, maintain biodiversity, conservation value, and ecosystem services, and promote responsible management of waste and use of chemicals. The ICAO document – Guidance on the application of CORSIA sustainability criteria, existing resources on established practices[24] provide further resources on evaluating these specific themes.
Socio-economic themes	
10. Human and labour rights 11. Land use rights and land use 12. Water use rights 13. Local and social development 14. Food security	The ICAO Document – CORSIA Sustainability Criteria for CORSIA Eligible Fuels provide guidance for these themes, where the production of CORSIA SAF should respect human and labour rights, respect land rights and land use rights including indigenous and/or customary rights, respect prior formal or customary water use rights, contribute to social and economic developments in regions of poverty and promote food security in food insecure regions.

2.1.3 Economic/Market-related aspects

[20] ICAO Document – CORSIA Sustainability Criteria for CORSIA Eligible Fuels. https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2005%20-%20Sustainability%20Criteria%20-%20November%202022.pdf

[21] ICAO Document – CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels. https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions%20-%20June%202022.pdf

[22] ICAO Document – CORSIA Methodology for Calculating Actual Life Cycle Emissions Values. https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2007%20-%20Methodology%20for%20Actual%20Life%20Cycle%20Emissions%20-%20June%202022.pdf

[23] Life Cycle Associates – GREET Model https://www.lifecycleassociates.com/lca-tools/greet-model/

[24] ICAO Guidance to Sustainability Certification Schemes (SCS) for application of CORSIA Sustainability Criteria, Themes 3 to 7, for CORSIA Sustainable Aviation Fuel produced on or after 1 January 2024. Version 1 – November 2021. Page 12 https://www.icao.int/environmental-protection/CORSIA/Documents/Guidance%20on%20Sustainability%20Themes%203-7.pdf#page=12

This section provides information relating to expanding the use of the feedstock, including strategic and financial considerations. This may also include assessments on economic value-add, jobs created, and/or other socio-economic benefits. In addition, if the feedstock is also used in the production of other types of biofuels that could impact the business case of SAF, the assessments may also be included in this section.

While the agencies performing the feasibility studies will be able to provide more State-specific assessments on local feedstock, costs and yield; ICAO, as part of work on SAF projections, CAEP experts from Washington State University, supported by experts from Hasselt University, have developed a set of heuristics or "Rules of Thumb" for SAF that could be utilized to make order of magnitude estimations related to SAF costs, investment needs, and production potential. While the values will change based on regional variables, The Rules of Thumb can be referenced with the local assessments, to support development of robust study outcomes.

With further information in the ICAO webpage[25], the summary tables below provide likely costs and facility scales based on Techno Economic Assessment (TEA) models, existing literature values and expert opinion.

Summary Table 1 - Feedstock Information

Technology, feedstock type and price, yield, total annual distillate scale, annual SAF production for both nth and pioneer facilities.

Processing Technology	Feedstock	Yield (ton distillate/ton feedstock)	Feedstock Price	Total Capacity (million L/year)		SAF production (million L/yearr)	
				nth	pioneer	nth	pioneer
FT*	MSW	0.31	$30/ton	500	100	200	40
FT*	forest residues	0.18	$125/ton	400	100	160	40
FT*	agricultural residues	0.14	$110/ton	300	100	120	40
ATJ	ethanol	0.60	$0.41/L	1000	100	700	70
ATJ	isobutanol-low	0.75	$0.89/L	1000	100	700	70
ATJ	isobutanol-high	0.75	$1.20/L	1000	100	700	70
HEFA	FOGs	0.83	$580/ton	1000	-	550	-
HEFA	soybean oil***	0.83	$809/ton	1000	-	550	-
FT	CO2 from Direct Air Capture (DAC) , H2	0.24	$300/t, $6/kg	1000	-	200	-
FT	waste CO_2, H_2	0.24	$300/t, $6/kg	1000	-	200	-
Pyrolysis**	forest residues	0.23	$125/ton	400	100	180	40
Pyrolysis**	agricultural residues	0.21	$110/ton	400	100	180	40

*feedstock price is for pre-processed feedstock
**pyrolysis ASTM approval is pending.
***2013-2019 average price of soybean and canola oils,

Summary Table 2 - SAF facilities information

Total capital investment (TCI), capital cost, and minimum selling price (MSP) for nth and pioneer facilities for each pathway.

Processing Technology	Feedstock	TCI (million $)		Capital Cost ($/L total distillate)		MSP ($/L)	
		nth	pioneer	nth	pioneer	nth	pioneer
FT*	MSW	1428	813	2.9	8.1	0.9	2.1
FT*	forest residues	1618	1088	4.0	10.9	1.7	3.3
FT*	agricultural residues	1509	1267	5.0	12.7	2.0	3.8
ATJ	ethanol**	328	117	0.3	1.2	0.9	1.1
ATJ	ethanol, agricultural residues	581	170	0.6	1.7	2.2	2.5
ATJ	isobutanol-low**	332	94	0.3	0.9	1.3	1.5
ATJ	isobutanol-high**	410	110	0.4	1.1	1.7	1.9
HEFA	FOGs	448	-	0.4	-	0.8	-
HEFA	vegetable oil	456	-	0.5	-	1.0	-
FT	DAC CO_2, H_2	3366	-	3.4	-	4.4	-
FT	waste CO_2, H_2	3209	-	3.2	-	3.5	-
Pyrolysis***	forest residues	1038	594	2.6	5.9	1.3	2.1
Pyrolysis***	agricultural residues	1084	619	2.7	6.2	1.3	2.2

*feedstock price is for pre-processed feedstock,
**alcohol feedstock is corn-based,
***pyrolysis ASTM approval is pending.

Other socio-economic assessments could factor in green job opportunities, evidenced in WEF's Clean Skies for Tomorrow publication on Deploying SAF at scale in India[26], highlighting that achieving 360,000 tons of SAF by 2030 could generate more than 120,000 jobs across the supply chain in collection, distribution, transportation, day-to-day operations, R&D and end-use distribution, spread across the viable various conversion pathways identified.

At times, assessments could also incorporate models to test sensitivities on the viability of a proposed SAF production plant. Assumptions on plant construction, lifespan of production, financials, cost of utilities,

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[25] ICAO Environment – SAF Rules of Thumb. https://www.icao.int/environmental-protection/Pages/SAF_RULESOFTHUMB.aspx

[26] WEF in partnership with McKinsey & Company: Deploying Sustainable Aviation Fuels in India: A *Clean Skies for Tomorrow* Publication. Insight Report June 2021. Page 20. https://www3.weforum.org/docs/WEF_Clean_Skies_for_Tomorrow_India_Report_2021.pdf#page=20

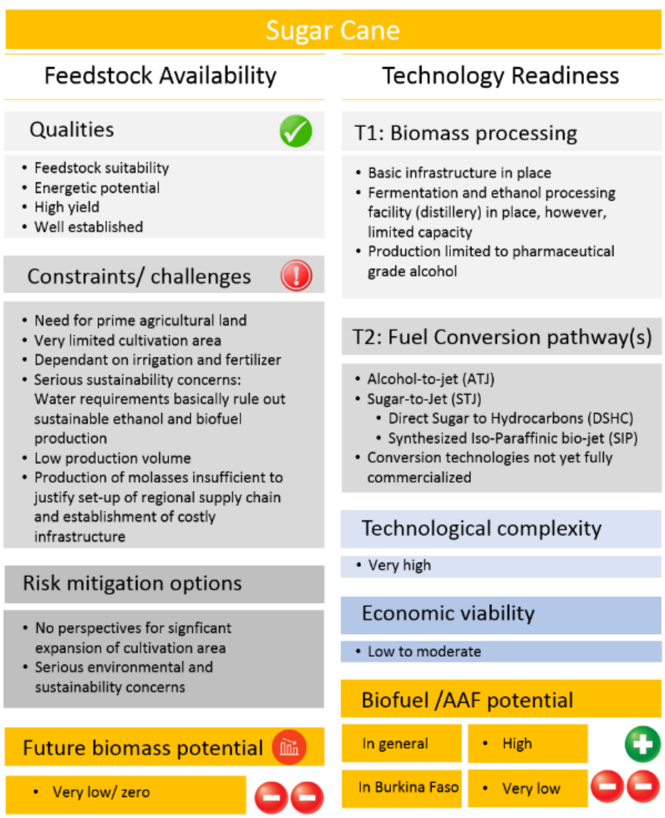
fossil prices as comparison, cashflow, incentives etc. will have to be made in discussion with the State recipient of the feasibility study. These inputs will then generate the minimum fuel selling prices and project net present values, which will be useful in justifying future project financing.

2.1.4 Overall assessment

This section incorporates a feasibility matrix to summarize the information in the previous three sections, comparing across, and then deriving an overall assessment to support recommendations on viable feedstock/conversion pathways.

Feedstock Considered	**Conversion pathway**	**Feedstock evaluation**	**Sustainability evaluation**	**Economic/markets evaluation**	**Overall**
Feedstock 1 (e.g. oils and fats)	HEFA				
	Co-processing				
Feedstock 2 (e.g. MSW)	AtJ				
…					

Another example of a feasibility matrix is shown in the ICAO-EU Assistance Project on the use of SAF in Burkina Faso[27], where more detail is provided for each of the shortlisted feedstock.



[27] ICAO-European Union Assistance Project: Capacity building for CO_2 mitigation from international aviation. Feasibility study on the use of sustainable aviation fuels – Burkina Faso. Page 38. https://www.icao.int/environmental-protection/Documents/FeasabilityStudy_BurkinaFaso_Report-Web.pdf#page=38

SECTION 3. IMPLEMENTATION SUPPORT AND FINANCING

This section provides information on implementation support and financing needed for the implementation of the priority pathways identified in the previous section. This will complement the ICAO State Action Plan to support anticipated LTAG monitoring processes.

3.1 and 3.2 Implementation Support and Financing

This section will provide information relating to capacity-building and assistance needs, which can range from technical/technological support, training, support to producers on SAF certification, integration of SAF into the aviation fuel supply chain. The consultant's engagement with local stakeholders as highlighted in Section 1 will be crucial to this process.

This section will also highlight different sources of financing for the identified SAF pathways according to the State possibilities. For example, in the ICAO-EU Assistance Project on the feasibility study of SAF in Kenya, potential funding sources were identified that could help advance the actions in the study, as shown in the table[28].

Where possible, the feasibility study can also map out the differentials/gaps based on estimated incremental costs in various stages of the SAF supply chain – this will support future analysis by the State if variables in Section 2.1.3 change, and also facilitate future discussions with financiers.

Policy / Strategy	Description
Green Climate Fund	Global fund created to support the efforts of developing countries to respond to the challenge of climate change. GCF helps developing countries limit or reduce their greenhouse gas (GHG) emissions and adapt to climate change. The National Environment Management Authority (NEMA) is the Adaptation Fund's (AF) accredited National Implementing Entity (NIE) for Kenya. NEMA commenced implementing AF funded programme titled, 'The integrated programme to build resilience to climate change & adaptive capacity of vulnerable communities in Kenya' in 2016.
Green Adaptation Fund	The Adaptation Fund finances projects and programmes that help vulnerable communities in developing countries adapt to climate change. Initiatives are based on country needs, views and priorities. The UNEP has oversight of a GAF project – "Adapting to Climate Change in Lake Victoria Basin (Burundi, Kenya, Rwanda, Tanzania, Uganda)". One of the project outcomes is "Regional resilience to climate change promoted through innovative, community-based projects". The proposed SAF studies in the Kisumu region may qualify under this outcome.
East African Community (EAC)	EAC oversees the Lake Victoria Basin Commission, a joint programme developed for the overall management and rational utilization of the shared resources of the Lake. The LVBC manages a number of projects that positive outcomes for the lake and member states with funding from a wide range of sources. LVBC staff have already show an interest in supporting the developing of pathways identified in this report.
African Development Bank Group	**Africa Climate Change Fund** Funding for a wide range of climate-resilience and low-carbon activities. **Sustainable Energy Fund for Africa.** Support for small and medium scale Renewable Energy (RE) and Energy Efficiency (EE) projects in Africa. SEFA is also aligned with the Sustainable Energy for All Initiative (SE4ALL) to support preparatory, sector planning and capacity-building activities arising out the AfDB-hosted SE4All Africa Hub. **Scaling Up Renewable Energy Program in Low Income Countries (SREP)** The Scaling Up Renewable Energy Program in Low Income Countries (SREP) is funded by the Strategic Climate Fund (SCF), one of the two Climate Investment Funds (CIF). SREP aims to scale up the deployment of renewable energy solutions and expand renewable markets in the world's poorest countries. It pilots and demonstrates the economic, social, and environmental viability of development pathways that do not exacerbate global warming.
Kenyan Government	**Climate Change Fund** The Climate Change Act 2016 establishes a Climate Change Fund as the financing mechanism for priority climate change actions and interventions approved by the Climate Council. **National Environment Trust Fund** NETFUND is a state corporation under the Ministry of Environment, Natural Resources and Regional Development Authorities. NETFUND was established within the provisions of the Environmental Management and Coordination Act (EMCA) 1999 to facilitate research intended to further the requirements of environmental management, capacity building, environmental awards, environmental publications, scholarships and grants. **Consolidated Energy Fund** Under the Energy Act 2015 the Government is establishing a Consolidated Energy Fund to cater for funding of the proposed National Energy Institute, infrastructure development; energy efficiency and conservation programmes as well as promotion of renewable energy initiatives.

[28] ICAO-European Union Assistance Project: Capacity building for CO_2 mitigation from international aviation. Feasibility study on the use of sustainable aviation fuels – Kenya. Page 57. https://www.icao.int/environmental-protection/Documents/FeasabilityStudy_Kenya_Report-Web.pdf#page=57

SECTION 4. ACTION PLAN

4.1 Policy and Regulatory Framework

This section will provide recommendations and options for enabling policies for an efficient and sustainable value chain for SAF, highlighting the policies necessary to promote SAF development, and to secure feedstock availability in the future. It will also identify obstacles and solutions to over the challenges related to policy and regulatory framework.

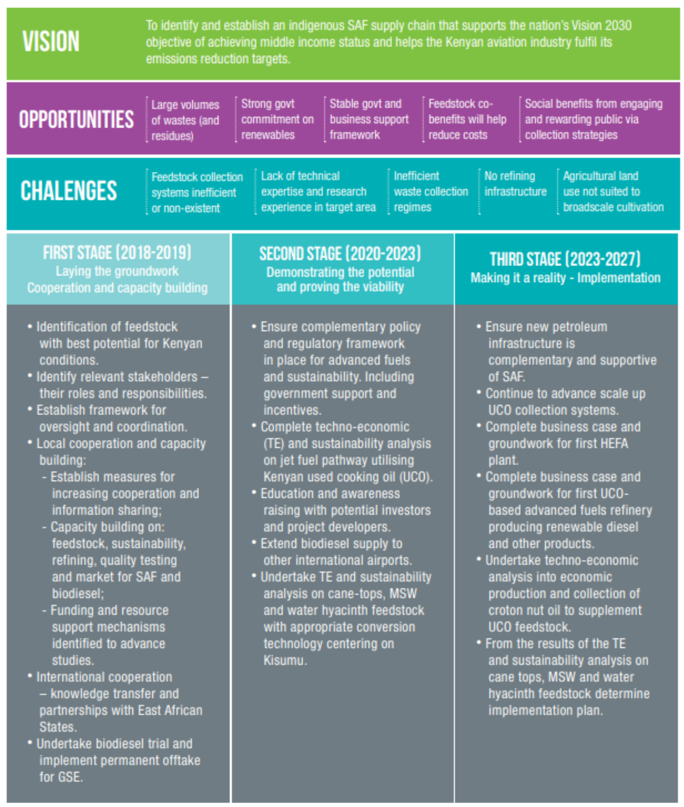
4.2 Critical Success Factors

This section identifies critical success factors for the implementation of SAF, including CO2 emissions reduction potential, access to funding, feedstock availability, processing and technology capacity, market structure and logistics, SAF certification, regulatory framework and support policies.

Economic measures leading to the success of SAF deployment, such as the emergence of SAF accounting and reporting systems (e.g. book and claim), potentially increasing the viability of SAF projects may also be highlighted.

4.3 Action Plan

An action plan could provide the description of the recommended actions, timeline of each action (e.g. stakeholder engagement, proof of concept, trials/pilots, scale-up, etc.), and the responsible entity for each action. It should be aligned with the State's existing and planned governmental policies related to the SAF development process, if any, and should focus on the most promising feedstock(s) and pathway(s) identified in Section 2.



This may also be drafted in a way to facilitate the creation/update to the State's ICAO State Action Plans, such as in cases where there is projected emissions reductions from the use of SAF, to support the anticipated LTAG monitoring process.

It should also include details dedicated to risk management: identification of risks, probability to occur, level of impact, and proposal for action. A SWOT-based analysis may be incorporated.

For example, this is exemplified in the ICAO-EU Assistance Project in Kenya, which provided a recommended action plan and roadmap (see above) with a medium term focus on Used Cooking Oil

(UCO)[29], and also provided insights into the challenges which could hamper its progress.

Other examples include more specific recommendations on particular feedstock/conversion pathways, as WEF's PtL Roadmap: Fuelling the aviation energy transition in the United Arab Emirates suggests (below), with targets for production in the immediate, short and medium term, with estimates on capacities, capex, and the policy instruments required to drive the energy transition[30].

	Immediate (2025)	Short term (2030)	Medium term (2040)
Production	Demonstration facility	0.2-0.4 Mt	1.5-3.0 Mt
Facilities		1-2	4-10
Power requirement	<0.01 TWh	7-15 TWh	45-105 TWh
DAC capacity	<0.01 Mt	0.2-1 Mt	1-14 Mt
Green H_2 capacity	<0.01 Mt	0.1-0.2 Mt	0.7-1.6 Mt
Total CapEx	<$5 million	$5-10 billion	$25-65 billion

Investment requirement	Small scale integrated facility
	Accessing capital markets to deploy large scale integrated PtL facilities
Estabilishing foundations	1 Establish a clear target
	2 Developing mechanisms to ensure market demand for low-carbon fuels
	3 Rapid deployment of renewable energy, hydrogen production and carbon capture
Policy instruments to scale industry	4 Government led funding
	5 R&D incentives
	6 Loan guarantees and capital grants
	7 Revenue support, e.g. contract for difference (CfD)/carbon value

Estimations are based on M-BT and H-RT scenarios

[29] ICAO-European Union Assistance Project: Capacity building for CO_2 mitigation from international aviation. Feasibility study on the use of sustainable aviation fuels – Kenya. Page 58. https://www.icao.int/environmental-protection/Documents/FeasabilityStudy_Kenya_Report-Web.pdf#page=58

[30] WEF Clean Skies for Tomorrow in collaboration with ICF International. Power-to-Liquids Roadmap: Fuelling the Aviation Energy Transition in the United Arab Emirates. White Paper July 2022. Page 46. https://www3.weforum.org/docs/WEF_UAE_Power_to_Liquid_Roadmap_2022.pdf

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